Opportunity Assessment

Industry 4.0 for energy productivity

Final report

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Industry 4.0 for energy productivity

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What is RACE for 2030?

RACE for 2030 CRC is a 10-year co-operative research program with AUD350 million of resources to fund research towards a reliable, affordable, and clean energy future.
https://www.racefor2030.com.au

Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

Executive Summary

Industry 4.0 technologies and terminology

The International Energy Agency (IEA) (*Digitalization and Energy – Analysis - IEA*, 2017) explained the concept of Digitalisation (Industry 4.0) as "the increasing interaction and convergence between the digital and physical worlds", where "the digital world has three fundamental elements:

- **Data**: digital information
- **Analytics**: the use of data to produce useful information and insights
- **Connectivity**: exchange of data between humans, devices, and machines (including machine-to-machine), through digital communications networks."

Utilising these elements, smart autonomous systems can 'reason with data' and implement optimal decisions (in real-time) to streamline business processes – leading to improved energy productivity. Digital connectivity, and the creation and sharing of information, delivers the true power of Industry 4.0.

Utilising Industry 4.0 technology, the IEA found that digitalisation could cut energy use across various sectors by about 10% by using real-time data to improve operational efficiency, and that "smart demand response" could provide 185 gigawatts (GW) of system flexibility in IEA countries[1], roughly equivalent to the currently installed electricity supply capacity of Australia and Italy combined (*Digitalization and Energy – Analysis - IEA*, 2017).

Some emerging digital technologies and concepts that combine under the general topic of Industry 4.0 are listed below. These terms are explained in this report.

Function	Emerging Technologies
Data Collection	• Internet of Things (IoT) / Industrial IoT (IIoT) • Cyber physical systems (CPS) • Natural language processing • 5G and other communications standards
Data Management	• Cloud data management • Geospatial mapping • Semantic modelling • Data access controls and privacy management • Blockchain
Data Analysis	• Data mining • Digital twin / Digital thread • Machine learning • Artificial intelligence
Decision and Action	• Information Technology (IT)/Operational Technology (OT) convergence • Information sharing over mobile devices

[1] IEA member countries are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Korea, Lithuania, Luxemburg, Mexico, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, The Netherlands, Türkiye, United Kingdom, United States.

	• E-commerce/ sharing platforms • Digital assistants (chatbots) • Automated dispatch and robotic actuation

Industry 4.0 is typically implemented on shared 'platforms' that operate on the cloud to connect relevant industry participants. These may be called 'IoT-platforms', 'data-platforms', 'sharing platforms' or other sector specific names.

If energy users are to interact with electricity markets (i.e., provide flexible demand) then platform connectivity will need to be provided as a service for consumers (flexible demand providers).

Ideally, software can be rapidly developed and deployed on these platforms to implement use-cases as 'Apps' (analogous to downloadable Apps on a smart phone). This will enable scalability through self-service (rather than manually assisted) software implementation.

In the non-residential buildings sector: the relevant 'platform' for Industry 4.0 is called an Energy Management Information System (EMIS).

Once the EMIS platform (common data infrastructure) is installed, then the building owner is able to access many smart 'Apps'. Specific energy productivity Apps include:

- *Monthly data analytics*: This provides high level information transparency to track the aggregate impact of business sustainability initiatives at monthly or annual intervals. Tracking, with National Australian Built Environment Rating System (NABERS) (*NABERS*, 2019) ratings as the core Key Performance Indicator (KPI), has been particularly successful in driving ambition and behaviour change in the sector.

- *Energy analytics*: Real-time energy (and sub) meter data collection allows computer analysis of energy trends, energy baselining and financial settlement of energy savings measures. Kramer et al. (Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, 2020) found that the median annual energy savings across a cohort of buildings was 3%.

- *Equipment fault detection and diagnosis* (FDD): By combining sensor data, Heating, Ventilation, and Air Conditioning (HVAC) equipment data and energy meter data, it is possible to get a more detailed understanding and correlation of why energy consumption is higher than necessary and get insights into how to reduce energy consumption. Across 1,500 buildings in North America, Kramer et al. (Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, 2020) and Crowe et al. (Crowe et al., 2020) found median annual energy savings of 9% and a median simple payback time of 1.7 years, respectively, when insights were manually implemented.

- *Building controls optimization*: A number of advanced HVAC control strategies are described by the NSW Office of Environment and Heritage (*I Am Your Optimisation Guide: Heating, Ventilation and Air Conditioning Systems*, 2015), each with the potential for significant savings. These automated control strategies override static control strategies with more dynamic seasonal strategies, or strategies that take advantage of dynamic price and weather forecasts. Unfortunately, this technology has not yet been widely adopted, at least partly due to fears of automated controls creating unintended and unsupervised consequences. A meta review by Serale et al. found that implementations of model predictive control (MPC) gave savings ranging from 0% to 40% (Serale et al., 2018).

- *Flexible demand*: Beyond energy efficiency actions in single buildings, the connectivity obtained from an EMIS enables a building-portfolio level response to electricity system market signals. The US Department of Energy (*National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021) identifies the need for 'Grid-Interactive Efficient Buildings' (GEBs) to simultaneously take advantages of both energy efficiency and demand flexibility. Over the next two decades, GEBs could save the US power system USD 100-200 billion and help reduce CO_2 emissions by 80 million tonnes per year (*National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021). Similarly, IEA scenario modelling in assumed that around 50% of required flexible demand capacity would come from buildings.

It should be noted that EMIS 'Apps' are not limited to energy productivity use-cases. Accessing the full breadth of platform use cases (e.g., maintenance, safety, staff productivity) can be a valuable tool for obtaining wide internal stakeholder enthusiasm. It is also a strong opportunity for innovation and business growth.

In the industrial sector, Industry 4.0 can yield extensive industry-spanning opportunities, e.g., increases in equipment effectiveness, labour effectiveness, quality, flexibility, and resource efficiency. In sum, Industry 4.0 can maintain companies' competitiveness whilst ensuring future competitiveness. Industry 4.0 technical features (e.g., AI, sensors, big data & analytics, IoT) enable multiple services to improve the industrial productivity, which are not limited to the followings:

- **Energy efficiency:** Ensuring energy efficiency through energy management is one of the main pillars of Industry 4.0. The motivation comes from a combination of environmental aspects, cost pressure, and regulation as well as the pro-activeness of organizations when it comes to efficient consumption of energy and utilities.

- **Real time monitoring (RTM):** RTM gives businesses a full view of every detail of their production process, allowing them to see precisely when, where and why problems arise – in real-time. Armed with this actionable data, organisations have the power to optimise processes immediately to make business safer, more efficient and more profitable.

- **Resource management:** Efficient resource management, throughout its lifecycle, is key to every organisation. Understanding the connections between production resources, knowing their dependencies and relationships will give visibility of the impact of downtime, delays on spares and power outages.

- **Industry 4.0 virtualisation:** The virtualised view (creating a **digital replica of industrial plant**) helps warehouse operators and managers to better manage growing complexity, reduce equipment downtime and optimize processes. The role of Virtual Reality (VR) technology in creating a smart, connected factory is undeniable in today's era of digitalisation.

- **Interoperability:** Today, improving manufacturing requires more than simply finding ways to operate faster and reduce expenses. This is where the importance of interoperability, the capability for components in a system to share and exchange information with each other, a core concept to Industry 4.0, and the exchange of data throughout a connected factory becomes key to improving manufacturing operation.

- **Autonomisation:** Industry 4.0 is based on asynchronous manufacturing, with components in the production flow using auto identification technology to inform each machine and operator what needs to be done to produce the customized end product at each step of the production process.

- **Flexibility:** The emerging technologies in Industry 4.0 allow for new flexible production systems. Through Industry 4.0 connectivity, automation, fast information exchange and analytics, a new dimension of flexibility can be reached and novel approaches to planning & controlling production systems.

Barriers to Industry 4.0 for energy productivity

Adoption of radically transformative technologies, such as Industry 4.0 technologies – and the realisation of the attendant benefits - requires supportive technological, legal, and social infrastructures. In the absence of these supports, the barriers to technological adoption and diffusion identified in this report will result in less-than-optimal levels of investment in technology adoption and use.

There is broad agreement – in both the published literature and stakeholder feedback - concerning technological, economic, regulatory, and social (or behavioural) barriers to technology adoption for energy productivity. There are, however, complex, and subtle interactions between the identified barriers, and differences of emphasis in different industry sectors. The number, range and complexity of the barriers means that identifying solutions is far from straightforward. However, progress can be made by identifying and further understanding some of the more important barriers.

Firstly, difficulties can flow from industry perceptions, and entrenched practices, which may not mesh well with the commercial and social potential of the technologies. Investment decisions commonly fail to consider the full range of potential benefits that can arise from transformative technologies and business practices. For example, many investment decisions are based on achieving a short-term return on investment. This can overlook the potential system-wide benefits, as well as benefits that may accrue over a longer term.

Perceptions, which may be based on imperfect information, can cloud investment decisions. This points to the importance of social barriers to technology adoption. There are difficulties arising from significant trust deficits. While 'trust' is a complex, multi-faceted concept, there is a need to build trust in technologies, people, and institutions.

Trust deficits can arise from:

- uncertainties relating to inadequate information about technologies and potential economic returns.
- personal and collective experiences of failed implementations of technologies, including the costs of past flawed IT projects.

- the complexity of the current wave of technological innovations, which this project has grouped together as Industry 4.0 technologies, and the complexities of successfully implementing the technologies, especially in the context of legacy systems.
- fears of complex technological ecosystems, such as data ecosystems, which entail sharing of costs and benefits across parties with different interests and agendas.
- the sharing of data, including real-time data, between different organisations which can pose considerable risks, including security and privacy risks.

The complex and decentralised nature of Industry 4.0 technologies create imperatives for interoperability between systems. In this sense, interoperability must be interpreted as incorporating both interoperability between technologies and interoperability between business and organisational systems. While establishing appropriate standards can promote interoperability between technologies, this alone is insufficient.

Standardisation of data, including standardised data labelling, is necessary to facilitate data accessibility, portability and use. But measures are also needed to address the coordination problems associated with the diverse range of parties involved with Industry 4.0 systems and processes. As the problem of split incentives illustrates, the different interests of parties, and a failure to align costs with benefits, can skew investments. Moreover, the complexity of Industry 4.0 infrastructures, and the parties participating in the infrastructures, results in legal complexity. This includes the complex nests of contracts that characterise Industry 4.0 supply chains, as well as difficulties in allocating and establishing legal liability.

The complexity of the barriers to technology adoption identified in this report, as well as the interactions between the barriers, suggest the need for holistic approaches to be taken to technology adoption and implementation. A key factor in this Industry 4.0 is the need for appropriate training in relation to both technologies and processes. This need is associated with the inadequate level of appreciation of the potential benefits of Industry 4.0 technologies and how they can best be implemented.

Successful technology adoption is not simply a matter of investing in technological systems, as successful implementation necessarily involves organisational and institutional change. For example, Industry 4.0 technologies, such as Industrial IoT, facilitate the collection and analysis of data at scale, including much data that is relevant to improving energy productivity. But this potential cannot be realised unless a business has systems and staff that are able to make intelligent decisions based upon the data. A comprehensive analysis of the full range of barriers to Industry 4.0 adoption assists understanding of how implementation within a firm necessarily requires an integrated, whole-of-business approach.

Productivity benefits from Industry 4.0

The energy productivity benefits from the application of Industry 4.0 are likely to be large. While there is an urgent need for more detail analysis of these potential benefits, this project has estimated cumulative figures that the possible impacts of Industry 4.0 technologies include:

Gross energy savings of $1.1B by 2030-31 and $2.4B by 2034-35 (see Table 16),

Emissions reductions of 5.9 Mt CO2e by 2030-31 and 12.9 Mt CO2e by 2034-35 (see Table 16).

Beyond the usual focus on energy demand reduction, evidence suggests that energy-efficient technologies can bring value through a broad range of economic and social impacts. The term "multiple benefits" refers to a wide range of positive implications across several industries. The extent of the multiple benefits can be significant; some impacts of enhanced energy efficiency produced up to 2.5 times the value of the energy demand decrease (Multiple Benefits of Energy Efficiency – Analysis - IEA, 2019). Broadly, energy efficiency can boost economic and social development, improve energy system sustainability, contribute to environmental sustainability, and boost wealth in general.

While discussing the KPIs and indicators, two distinct categories (e.g., technical, and economical) have been considered in this report. Capacity utilisation, production volume, and throughput are the commonly practised KPIs in the technical sector, whereas, Return on Investment (ROI), payback time, Net Present Value (NPV), Internal Rate of Return (IRR) are commonly considered KPIs for economic/ financial issues.

The impacts of energy productivity highlight the implementation of Industry 4.0 technologies at various stages of the supply chain. Industry 4.0 technologies are involved in most impacts along the supply chain. The dimensions on which the technologies have impacts are macroeconomic, industrial, public budget, health & well-being, and energy delivery. In fact, in these areas, we can observe that energy-efficient technologies can bring the major changes, both at operational and strategical levels.

The adoption of Industry 4.0 technologies can bring superior competitive advantage for adopting firms as drivers of energy productivity, differentiation, and support to innovation. However, despite the growing attention to multiple benefits of energy productivity, there are few industries that have captured how investments in energy-efficient technologies affect firm performances and disentangled the role of specific technologies. Industrial stakeholders in this project have argued that Industry 4.0 is an extremely broad topic which is still little understood among the industries. In this regard, a specific focus on technologies or projects targeting a specific sector within Australian business context might be helpful.

Regulatory framework for Industry 4.0 for energy productivity

Large-scale data practices – including the collection, analysis and use of data – form the core of Industry 4.0 technologies. Given that these technologies and business practices are both recent and continuously evolving, it is unsurprising that there is an ongoing need for legal and regulatory frameworks to adjust. Consequently, there are completely new regulatory regimes – such as the Consumer Data Right (CDR) and critical infrastructure regimes – that have been specifically developed to achieve policy objectives, such as promoting data use and sharing, and securing data. Moreover, existing legal regimes, such as data privacy laws, are being challenged by evolving data practices, contributing to current proposals for fundamental law reforms. In addition, there is increased use of less formal (and more flexible) rules, often known as 'soft law', such as voluntary codes and standards.

This report summarises the diverse, and complex, set of regulatory frameworks that may apply to Industry 4.0 data practices in the energy sector. As explained in this report, the regimes that apply depend upon: the type of the data; the ways in which the data are collected and used; and the nature of the entities that are responsible for the relevant data practices. Beyond this, the difficulties experienced with access to, and use of, smart meter data in the energy sector, illustrate the need for coherent regulatory frameworks to promote responsible data access and sharing. The extent to which the regulatory initiatives forming part of the Australian Data Strategy (ADS) – such as the CDR regime – can transform Australia into a data-driven society, is unclear.

Business models for Industry 4.0 and energy productivity

Advancements in both Industry 4.0 and energy productivity have generated new and potentially lucrative means for organisations to create, capture and deliver value; the underlying logic of which underpins the term "business model". The internal configurations of these business models for Industry 4.0 and energy productivity considered in this report present three overarching business model patterns i.e., integration, servitisation and expertisation. Here, integration business models attempt to broaden (or integrate) the number of activities considered in a particular firm's value chain (e.g., open innovation and social manufacturing). Servitisation business models, on the other hand, focus on the pursuit of additional value from the sale of products through the inclusion of services (e.g., product-based services and the sharing economy). Meanwhile expertisation business models rely on and leverage in-house expertise and knowledge to provide new products and services (e.g., product-based platforms).

These Industry 4.0 business models are all designed to leverage the mass of data that stems from the adoption of Industry 4.0 technologies – from the digital design of a product, through digital monitoring and control of production, to digitally enabled after sales service, maintenance and finally disposal or recycling. This so-called "digital thread" acts as an enabler for improved communication, monitoring and ultimately decision-making. However, business model patterns (the interplay of data across different aspects within Industry 4.0) such as these are rarely found in isolation. Typically there are multiple patterns being leveraged within a single business model e.g., the X-as-a-service suite and pay-per-X business models. There is also the possibility to observe redundancy in the patterns with closely linked characteristics.

Whilst these business models hold great market potential, some are yet to secure a strong foothold in extant markets. The flexibility of the "servitisation" approach, for example, has often been met with challenges in terms of the ambiguity customers may experience whilst trying to decipher the value proposition of some service offerings, as Langley (2022) mentions "many new servitization solutions result in a worse customer experience as new ways of working have not yet been optimally designed".

Combined with the associated operational and managerial nuances, the shift to a servitisation strategy can confront considerable barriers to uptake, particularly in the case of manufacturing organisations and the steel industry. Collaborative activities in leveraging Industry 4.0 enabled business models, and the formation of collaborative networks in particular, are still being treated as a burden on organisations.

Other challenges to the implementation of Industry 4.0 enabled technologies include:

- conflicting business models with traditional modes of operation,
- potential for significant impact on entire value chains,
- impact on prices and regulatory concerns, and
- the intellectual property rights and patent considerations stemming from the democratisation of production that may be a core existing activity.

Nonetheless, the adoption of these technologies hold significant potential benefit for participating stakeholders. Digital platforms, for instance, are already well-established in many industrial contexts and are a pillar of effective Industry 4.0 application, having changed how both organisations and society operates. Blockchain (and similar emerging models), has opened up the potential for greater transparency in supply chains, decreased operational costs and better monitoring and performance control – helping to enable social manufacturing and the sharing economy. Thus, whilst some kinks remain in the adoption and impact of Industry 4.0 enhanced business models, there are many more opportunities to explore and exploit in this space.

Research Roadmap

A critical success factor for the adoption of Industry 4.0 solutions for energy productivity is the cooperation between stakeholders operating in the energy efficiency market. Indeed, investors, utilities, governmental agencies, financial institutions, local authorities, research and development organizations, equipment manufacturers, market institutions, ESCOs, and international institutions can all play vital roles. It is thus important to enlarge the perspective, identifying which stakeholders may be in the best position to develop and stimulate effective drivers to promote Industry 4.0 solutions for energy productivity.

This research roadmap is structured according to six strategic focus areas indicated by the International Energy Agency, that are highly integrated, as follows:

1. Cybersecurity frameworks and guidelines
2. Methodologies for valorising energy efficiency/productivity
3. Removal of interoperability barriers
4. Stakeholders' awareness and capacity building
5. Institutional arrangements and platform for data sharing and data management
6. Pilot and Demonstration projects

Each pillar serves the RACE for 2030 CRC's work of preparing for and accelerating the deployment of Industry 4.0 solutions for energy productivity in industry and non-residential buildings, for market transformation, energy productivity, and sustainability of all Australian businesses.

The proposed research roadmap provides an overview of initiatives to be implemented from now to 2030 to support and facilitate the market transformation. Most of the activities are designed to be seeding actions that will induce, stimulate, and nurture market transformation towards improved energy productivity and sustainability of businesses. Such initiatives are briefly summarised in the following table.

The proposed roadmap spans across the major IEA suggestions as outlined in the figure below. Particular attention has been given to identifying and involving key agents or taking actions with significant impact on business performance, as well as developing clear methodologies, criteria and KPIs to point out the major impacts stemming from the adoption of Industry 4.0 solutions for energy productivity. Further, the documentation and promotion of outcomes of pilot and demonstration projects, through several potential avenues (either networks, or media, or seminars, round tables etc.) represent another crucial pathway to drive the transition to an economy with more sustainable Industry 4.0 for energy productivity. However, such actions would have a limited impact without the development of clear guidelines, frameworks and platforms for data protection, sharing and data management.

Table 1. Proposed projects and their focused dimensions

Project Number	Criteria					
	A. Pilot	B. Arrangements	C. Stakeholders	D. Barriers	E. Methods	F. Cyber
1	✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓	✓ ✓ ✓ ✓		✓ ✓ ✓
2	✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓ ✓		✓ ✓ ✓ ✓
3		✓ ✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓		✓ ✓ ✓ ✓ ✓
4	✓	✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓	✓ ✓ ✓
5	✓ ✓ ✓ ✓	✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓	
6	✓ ✓ ✓ ✓ ✓	✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓	
7	✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	
8	✓ ✓ ✓ ✓ ✓		✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓	
9	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓ ✓	✓ ✓ ✓	
10	✓ ✓ ✓ ✓ ✓	✓ ✓	✓ ✓ ✓ ✓ ✓	✓ ✓ ✓	✓ ✓ ✓ ✓	
11	✓ ✓ ✓ ✓ ✓	✓	✓ ✓ ✓ ✓	✓	✓ ✓ ✓	

Within the scoring matrix of Table 28, the metric is from 1-5. Detailed description of each criteria is:

A. Pilot & Demonstration projects
B. Institutional arrangements and platforms for data sharing and data management
C. Stakeholders’ awareness raising and capability building
D. Removal of interoperability barriers
E. Methodologies for valorising Energy Productivity/Efficiency
F. Cyber security framework and guidelines

RACE for 2030: Industry 4.0 for energy productivity - Prioritised list of projects

Project no.	Title	Focus/target sector	Key beneficiaries	Main challenge	Timeframe	Project budget
Project 1	Institutions for Data Custodianship: Data Trusts	Businesses that generate and use energy data	All businesses that generate or use energy data	Social and regulatory barriers. Establishing legally binding obligations on data custodians builds trust in data sharing.	Short-medium-long term	< $500,000
Project 2	Reference architecture models for Industry 4.0 interoperability in the energy sector	Businesses that may benefit from Industry 4.0 technologies for improved energy productivity	Businesses implementing Industry 4.0 technologies for energy productivity	Barriers to interoperability of Industry 4.0 technologies. A reference architecture can assist in overcoming these barriers by developing 'rules of the road' to allow better integration of Industry 4.0 technologies and systems.	Short-medium term	< $500,000
Project 3	Cybersecurity frameworks & guidelines	Businesses that share energy data	Businesses that share energy data an energy users	Inadequate cybersecurity in the energy sector which contributes to a lack of trust	Medium-term	< $500,000
Project 4	Defining Digital Ready for Non-Residential Buildings	Non-residential buildings	Building owners who want to de-risk investment in digitalisation technology. Electricity retailers who need to know if its cost effective to procure flexible demand services. Digitalisation technology providers who would like endorsement of their technologies	Perceived complexity, risk and cost of establishing the requisite IT infrastructure and connectivity for implementing Industry 4.0	Short-medium-long term	> $1 million for the overall research, testing and industry utilization support journey. (staged investment)
Project 5	Industry 4.0 Energy Productivity Networks – sharing knowledge to improve competitiveness	Manufacturing sector	Key decision-makers of companies operating in various manufacturing sectors	Awareness and lack of skills	Medium-long term	$500,000 -$1million or above (depending on number of companies involved)
Project 6	Smart metering and Artificial Intelligence for industry decarbonisation	Manufacturing sector	Key decision-makers of companies operating in various manufacturing sectors	Lack of awareness	Short-medium term	$500,000 -$1million or above (depending on number of companies involved)
Project 7	Australian Smart Energy SMEs – from Industry 4.0	Manufacturing sector	Key decision-makers of companies operating in various manufacturing sectors	Lack of awareness / Energy auditors	Medium-long term	$500,000 -$1million or above (depending on

	energy audits to an integrated approach					number of companies involved)
Project 8	Optimising energy productivity and consumable lifetime in machining processes	Manufacturing sector	Manufacturers, Consumers (lower cost)	Inadequate Infrastructure, Uncertainty about ROI, Resistance to Change	Short-Medium term	$100,000 -$300,000 or above
Project 9	Optimising energy productivity of HVAC Systems – Energy Consumption, Air Quality, and Comfort	Building management	Building Managers, HVAC Plant Operators, Occupants	Inadequate Infrastructure, Uncertainty about ROI, Resistance to Change, Inadequate Information	Short-Medium term	$100,000 -$300,000 or above
Project 10	Overcome or bypass barriers to real time smart data collection due to limited meter capability, reduce M&V cost	Manufacturing and non-residential buildings with potential, based on outcomes, to expand to other sectors. Government operators and delivery agents of M&V for white certificate programs	Industry 4.0, EP businesses and their clients, white certificate program operators, Third party energy service providers, energy auditors, water authorities, energy retailers and network operators	Limited numbers of smart meters (for electricity, gas and water) and high up-front Monitoring & Verification costs are major barriers to adoption of Industry 4.0 and Energy Productivity measures	Short-Medium term	$500,000 -$1million
Project 11	Develop strategies to assist early-stage adoption of basic Industry 4.0/ EP measures and trial in Compressed Air across selected sites	Businesses using existing inflexible equipment and inefficient technologies that are unable to respond to real time data to optimise performance, have high standby losses, etc,	Accelerate adoption of Industry 4.0/EP across business; help i4.0/EP service providers to identify ways of overcoming major barriers identified in this project	Compressed air is used widely throughout industry and uses 10-15% of site electricity with high (80+%) losses and impacting on business productivity	Short term	500,000 -$1million

For more information on these projects, please refer to Section 7.5.

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Foreword

Energy sustainability is arguably among the most pressing socio-environmental concerns of modern times. Consequently, the Australian energy sector must transition so that it can provide consumers with reliable affordability and clean energy into the future.

Worldwide, the industrial sector accounts for 54% of total delivered energy and more than 30% of greenhouse gas (GHG) emissions. Non-residential buildings account for around 25% of overall electricity use and 10% of total carbon emissions in Australia.

Amongst other things, industrial and non-residential consumers can support the energy transition by improving energy productivity and by increasing demand flexibility.

Utilising Industry 4.0 technologies, which will be thoroughly reviewed in the following Chapter, IEA found that digitalization could cut energy use by about 10% by using real-time data to improve operational efficiency, and that "smart demand response" could provide 185 gigawatts (GW) of system flexibility, roughly equivalent to the currently installed electricity supply capacity of Australia and Italy combined (*Digitalization and Energy – Analysis - IEA*, 2017).

Thus, the sustainable energy transition and Industry 4.0 share important characteristics that can be interconnected to attain both economic benefit and socio-environmental benefit. Industry 4.0 technologies offer consumers a means to use energy to greater effect and to improve energy productivity. That is, capturing greater value by identifying waste (resources, energy, labour, etc), understanding energy and resource flows and impacts (e.g., CO_2 emissions), and then optimising operations, technology application, investment and asset utilisation.

This RACE for 2030 B2 "Industry 4.0" Opportunity Assessment Project report provides an initial overview of Industry 4.0 and how it is applicable to energy productivity. It outlines the major services and benefits that these technologies offer, with specific focus on industrial and non-residential services sectors, together with the analysis of the most relevant barriers hindering their widespread deployment, the major regulatory and governance issues as well as the current and emerging business models. The analysis includes reference to case studies of industrial and non-residential use cases. The report concludes with a research roadmap for RACE for 2030 in this stream, outlining prioritised potential research initiatives.

2 Industry 4.0 technologies and their applications in manufacturing and building management

The IEA explained the concept of Industry 4.0, also known as Digital Transformation or Digitalization as "the increasing interaction and convergence between the digital and physical worlds", where "the digital world has three fundamental elements:

- Data: digital information
- Analytics: the use of data to produce useful information and insights
- Connectivity: exchange of data between humans, devices and machines (including machine-to-machine), through digital communications networks.

The trend toward greater digitalisation is enabled by advances in all three of these areas: increasing volumes of data thanks to the declining costs of sensors and data storage, rapid progress in advanced analytics and computing capabilities, and greater connectivity with faster and cheaper data transmission."(*Digitalization and Energy – Analysis - IEA*, 2017).

This concept is almost identical to the idea of Industry 4.0. Forbes (*What Is Industry 4.0? Here's A Super Easy Explanation For Anyone*, 2018) describes Industry 4.0 as "the adoption of computers and automation and enhancing it with smart and autonomous systems fuelled by data and machine learning", and "as Industry 4.0 unfolds, computers are connected and communicate with one another to ultimately make decisions without human involvement. A combination of cyber-physical systems (CPS), the Internet of Things (IoT) and the Internet of Systems make Industry 4.0 possible and the smart factory a reality. Ultimately, it's the network of these machines that are digitally connected with one another and create and share information that results in the true power of Industry 4.0".

TechRadar suggests that "fundamental shifts are taking place in how the global production and supply networks operate - through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large-scale machine-to-machine communication (M2M), and the internet of things (IoT). This integration is increasing automation, improving communication and self-monitoring, and the use of smart machines that can analyse and diagnose issues without the need for human intervention" (*What Is Industry 4.0? Everything You Need to Know | TechRadar*, 2020).

Similarly, Ghobakhloo and Fathi (Ghobakhloo & Fathi, 2021) suggest that Industry 4.0 is inherently enabling "informed yet autonomous decisions" for flexibility and agility. AlphaBeta (*Australia's $315bn Opportunity in Digital Innovation - CSIRO*, 2018) casts Industry 4.0 in a similar fashion as an automated process from data to decisions. This process includes steps of (i) data collection, (ii) data management (ii) data analysis and (iv) decision and action (Figure 1).

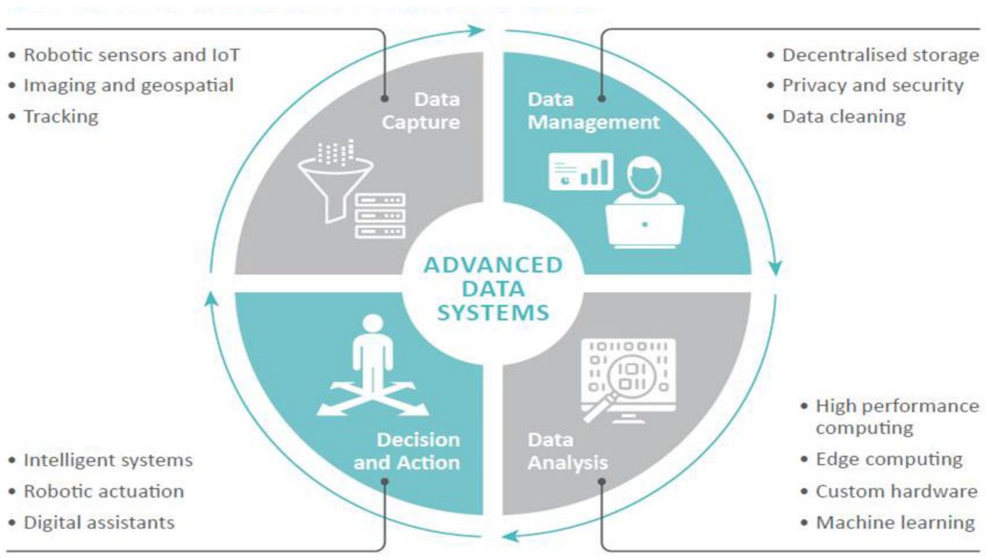


Figure 1. Data Innovation Relies on Specialised Systems for Data Capture, Management, Analysis and Action (*Australia's $315bn Opportunity in Digital Innovation - CSIRO*, 2018)

Some generic Industry 4.0 applications include:

- Analysing data in real time, to identify patterns and insights that can inform maintenance, process-performance improvements, and other business KPIs
- Sharing information and dispatching orders, in order to optimize logistics and supply chains, creating a connected supply chain that can interact and adapt when requirements/conditions change
- Automating equipment and processes to reduce human intervention and labour costs

Industry 4.0 and Digitalisation are concepts that can apply equally across industrial manufacturing, buildings, transport, and other sectors. However, each sector may use different terminology to explain the interaction between data, connectivity and analytics.

Some relevant terminology in the buildings sector include 'Proptech' and 'Smart Buildings'. Proptech, short for Property Technology, aims to reshape the real estate market, using digitalisation to overcome inefficiencies (*What Is Proptech?*, 2020). This includes streamlining and automating traditional processes within the research, planning and construction phases, renting or purchasing real estate phase, and the on-going management and maintenance of buildings. New processes aim to cut out middle-parties where appropriate.

Proptech (while less concerned with automating the operation of physical assets) and Industry 4.0 are similarly concerned with utilising data to automate otherwise onerous administrative processes. They can apply tools such as blockchain, machine learning, artificial intelligence, predictive analytics, IoT, and social media to derive value from data and to link market actors.

Huge pools of real estate data are already being used by artificial intelligence (AI) programs to improve the customer experience through personalisation and predictive tools. AI can help accurately predict which locations will be the most beneficial for developers to invest in, optimising market-level profitability and revenue, as well as helping to identify optimised spatial layouts of new developments (including for energy efficient orientation).

The Urban Developer notes that "access to data is probably still the single biggest struggle many technology providers in the Proptech space face, and data sharing principles are sorely needed especially in areas where the private and public realm intersect" (*What Is Proptech?*, 2020).

"Smart Buildings" is another frequently used but poorly defined term. Zhou and Yang (Zhou & Yang, 2018) refer a smart building as 'a type of building with reasonable investment, efficient energy management, and comfortable and convenient environment, designed by considering the optimized relationship among structure, system, service, and management. It has intelligent control systems and smart and interconnected devices beyond the traditional building structure and function' and that IoT 'is one of the major technologies of smart buildings … supported by web-enabled hardware, automation devices, and sensor networks'. They suggest that smart buildings should be "equipped with some renewable sources of power generation such as solar panels mounted on the rooftop', and 'provide a better air ventilation system to improve the environmental quality [where] the temperature, humidity, and ventilation rates are controlled by the intelligent devices.'

Similarly, the Buildings Performance Institute Europe (BPIE) provides the following as an illustration of a 'smart built environment':

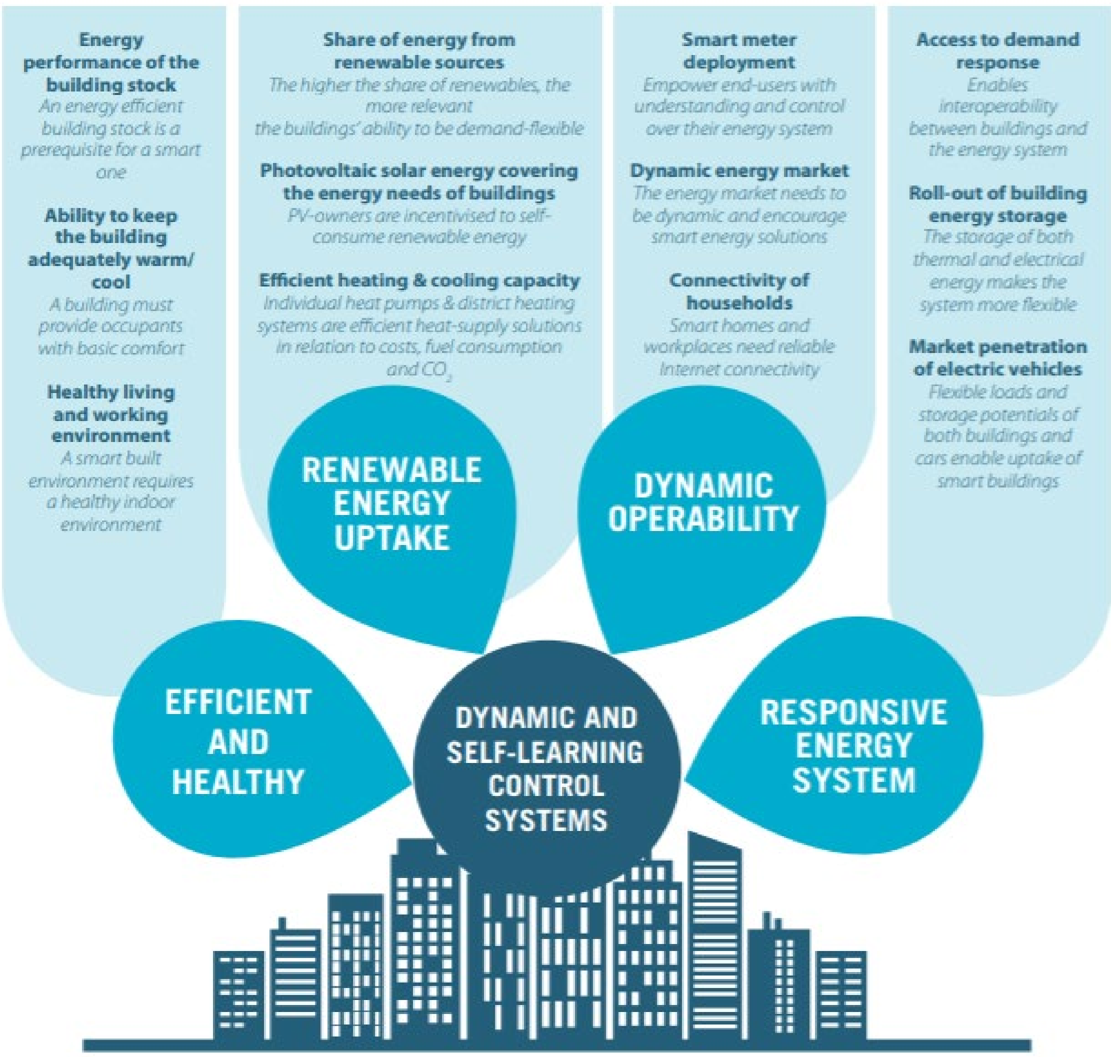


Figure 2. Characteristics of a smart built environment (*Is Europe Ready for the Smart Buildings Revolution?,* 2017); credit BPIE as the copyright owner. All rights reserved.

These descriptions combine aspects of Industry 4.0 style advanced automation, with a range of other considerations such as (i) improved design and hardware selection, (ii) superior performance through integrated/systems thinking and (iii) cost effectiveness. This diversity of thought is also reflected in the variety of certification schemes aiming to identify those buildings which can be considered 'smart'.

For the purposes of energy productivity and grid interactivity (at least), a smart building must be able to drive physical processes than can change the quantity and pattern of energy consumption. So, in summary, while Smart Buildings could have a range of definitions in different application contexts, we are more focusing on a smart energy-productive building. To this end, the International Energy Annex 81 https://annex81.iea-ebc.org/ describes a smart energy-productive building as follows:

> 'A Data-Driven Smart Building is a building that uses digitalization technologies to dynamically optimize its operation. Optimization objectives will typically relate to site energy use, IEQ, and occupant experience.
>
> Ideally, it is sufficiently connected and integrated with markets and processes, that it can adaptively respond to externalities and changing conditions (e.g. weather, electricity prices, energy supply constraints, equipment maintenance, etc). Ideally, it has sufficient memory of past events, and ability to anticipate future impacts, that it can select an informed course of action for achieving higher-level objectives – reminiscent of human intelligence.
>
> To achieve this vision, a Data-Driven Smart Building utilizes live and historical data from relevant sensors, IoT equipment, mobile devices, and other sources to provide situational awareness for informed decision-making. Enabling the desired physical optimization objectives will often require advanced supervisory-level automation, driven by computational analysis using available information.
>
> Sourcing, managing, analyzing and dispatching input/output data - from measurement through to equipment automation and control - can be streamlined with emerging digital technologies, protocols and methods. To this end, the functions and technical attributes that underpin the infrastructure of a Data-Driven Smart Building may include some combination of (a) continuous data quality monitoring and assurance; (b) communication interfaces that support interoperability between heterogeneous devices; (c) time-series data storage with meta-data descriptions that capture the context of the data, and facilitate data discovery and re-use by various software applications; (d) AI/machine-learning and rule-based analytics that inform maintenance and/or control processes in the building; and (e) automated dispatch of commands to orchestrate equipment operation at supervisory level.
>
> Open standards (communication protocols, data schemas, interfaces etc) should be used, where possible, to avoid vendor lock-in and maximize interoperability.
>
> While many of these digitalization functions can and will be performed onsite (at the 'edge'), new applications and business models can also take advantage of cloud-based data platforms. Data platforms provide a Smart Building with means for exchanging data with a wider variety of sources and users (cloud-hosted databases, IoT, mobile devices etc) and a means for utilizing powerful software tools and workforce skills available from the IT industry.' (*IEA EBC || Annex 81 || Data-Driven Smart Buildings || IEA EBC || Annex 81, 2022*)

This is a slightly longer, more technically prescriptive version of that of Verbeke et al. (*Technical Support to the Development of a Smart Readiness Indicator for Buildings*, 2020) aims to point toward a set of functions ('product') that can be purchased rather than just an aspirational concept

> 'Smartness of a building refers to the ability of a building or its systems to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems or the external environment (including energy grids) and to demands from building occupants' (*Technical Support to the Development of a Smart Readiness Indicator for Buildings*, 2020).

Ideally a definition will point toward key features and functions, in order to point toward a 'product' that can be purchased rather than just an aspirational concept. In this way, a Smart Building definition is useful for identifying required enabling technology for some energy productivity applications (e.g. flexible demand), and preferred enabling technology for many other applications (e.g. fault detection and diagnosis). However, by itself, 'smartness' does not necessarily directly result in a low energy building compared with one that is 'dumb'.

2.1 Some underpinning technology concepts

Various emerging technologies and technology concepts underpin Industry 4.0. They are illustrated below, followed by their detailed descriptions.

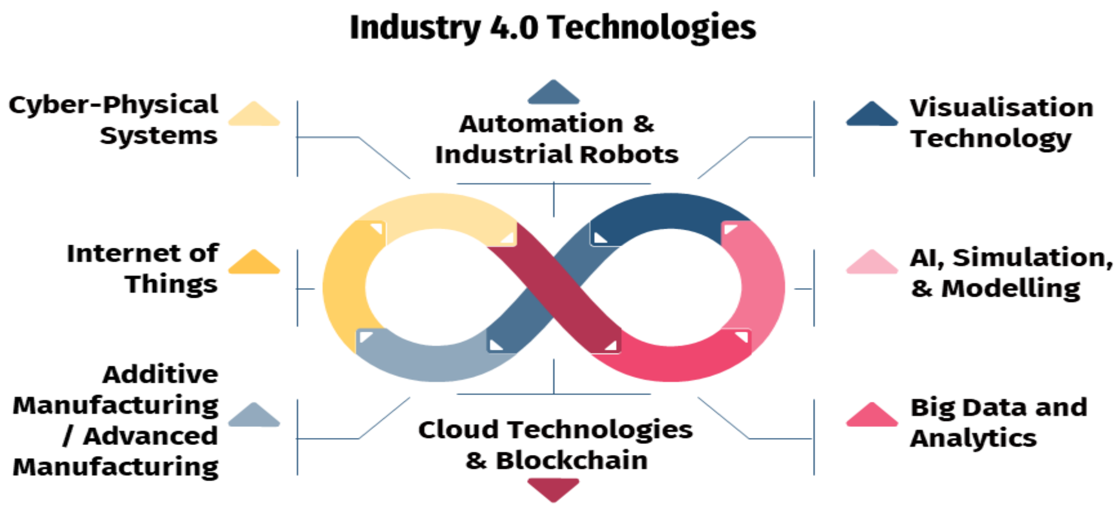


Figure 3. Industry 4.0 technologies along the data stream in common manufacturing processes (an original graphic)

Table 2. Brief description of the Industry 4.0 technologies

Technologies	Brief description
Cyber-physical systems	Cyber physical system is a collection of transformative technologies that connects the operations of physical assets and computational capabilities. The main aim is to monitor physical systems while creating a virtual copy

Internet of things (IoT)	Information network of physical objects (sensors, machines, cars, buildings, and other items) that enables the collection and exchange of data, allowing interaction and cooperation of these objects
Big data and analytics	Collection and analysis of large amount of available data using a series of techniques to filter, capture and report insights, where data are processed in higher volumes, with higher velocities and in greater variety
Cloud technology	System for the provision of online storage services for all applications, programmes and data in a virtual server, without requiring any installation
Artificial intelligence (AI)	System that thinks humanly and rationally according to six main disciplines, including natural language processing, knowledge representation, automated reasoning, machine learning, computer vision and robotics
Blockchain	A database that creates a distributed and tamperproof digital ledger of transactions, including timestamps of blocks maintained by every participating node
Simulation and modelling	Technologies that mirror the physical world data such as machines, products and humans in a virtual world, aiming for simplification and affordability of the design, creation, testing and live operation of the systems
Visualisation technology	Augmented Reality: a set of innovative Human Computer Interaction (HCI) techniques that can embed virtual objects to coexist and interact in the real environment; Virtual Reality: application of computer technology to create an interactive world, allowing the user to control the virtual object and whole virtual scene in real time
Automation & Industrial Robots	Machinery and equipment that automate operational processes, containing also Collaborative Robotics, which allows humans and machines to operate in a shared learning environment
Additive Manufacturing	Process of joining materials in successive layers to make objects from 3D model data to 'unlock' design options and achieve great potential for mass-customisation
Digital Twin	A virtual representation of a physical object, emulating the object in real time, underpinned by mathematical model that gives the ability to predict the objects behaviour under different conditions.
IT/OT Convergence	Connecting on-site industrial control equipment (operations technology (OT)) with enterprise business processes/systems (information technology (IT)) to open up the potential to discover new insights, improve business coordination and drive innovative new value-adding services

Cyber Physical Systems

Physical systems, including a supply chain, a production plant, or buildings, are the foundation for developing and deploying Industry 4.0 technologies, including digital twin models. Nevertheless, other entities existing inside the systems, such as manufactured products and occupants, are generally considered as part of the systems that interact among each other and with the environment and generate dynamics. Cyber physical systems, comprise sensing systems, communication infrastructure, and databases, aggregate data from their physical counterparts to form the data-rich representations of the physical objects, entities, and environment in a virtual space. The data collected via cyber physical systems allow one to have a better understanding on the properties and status of the physical systems, and thus be able to predict their performance, perform optimisation dynamically, and make well-informed decisions.

Internet of Things (IoT)

IoT comprise massive volumes of smart devices equipped with sensors and actuators (e.g., robot arms and conveyor belts). They not only are able to collect and report data to a central hub, but also able to aggregate and process data locally for decision making. Through exchanges of information, smart objects are capable of reasoning about their physical world and generate higher level of intelligence (Wu et al., 2014). With the data provided by the IoT, smart applications such as situation assessment and Big data analysis can be realized which can add-value to manufacturing processes and building management applications.

Big data analytics

Big data is generated and analysed at different stages of a product lifecycle (Tao et al., 2018) and at different sub-systems in asset management. Large datasets can come from various sources such as sensors, programmable logic controllers, mobile devices, and other information and/or operational systems (Taylor et al., 2020). The high dimension and volume of data imposes computational challenges, which often requires to harness the high processing the analytical power of Cloud computing technologies. Via Big data analytics, non-trivial correlations and patterns in the data can be revealed to provide decision makers with greater insights for making more well-informed decisions (Zimmerman et al., 2017). In manufacturing, all relevant production data including machines status and their energy consumption are collected via cyber physical systems under the digital twin models and become part of the Big data. Via analytics, scheduling plans and control parameters can be obtained to yield higher energy productivity.

Cloud technology

Cloud computing technology enables users to access, store, manipulate data, and deploy applications on an online platform over networks without requiring upfront investments in computing hardware and software. It is a system that centralises the management of both hardware and software resources of the networked elements at the provider side instead of the users. This resources management approach is beneficial to increase users' flexibility with re-provisioning and expanding technological infrastructure resources meanwhile lowering the overall maintenance and hosting cost since local data centres and physical servers are no longer needed at users' premise. It offers elasticity to users to control the scale of resources up or down to seamlessly grow and shrink capacity to any need. Cloud technology provides services in three major forms, they are respectively software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS) for leveraging different operational needs (Mell & Grance, 2011). It can support, optimise energy consumption, and facilitate smart manufacturing requirements to increase business productivity, and thus improve energy productivity in companies of any scale. As indicated in RACE for 2030 B1 Opportunity Assessment (2021), via adopting cloud-connected smart meters, water supply and demand can be adjusted adaptively to yield a higher energy productivity in water system.

Artificial intelligence

Artificial intelligence (AI) in general refers to intelligence demonstrated by machines. It is capable of not only mimicking human's mind or nature systems to achieve learning and problem-solving skills, but also being applied for making automated decision, revealing reasoning and metalogic, offering knowledge representation, and automated planning and scheduling (Stuart J. Russell and Peter Norvig, 2021). In manufacturing sector, data collected from the factory floor are correlated with product quality, productivity, utilisation, and the health of the machines. However, those relations are often hidden and highly nonlinear, which are best to be revealed via AI incorporating with machine learning algorithms. Using learning-based AI for data analytics in business makes numbers of complex tasks potentially automatable and streamlines the manufacturing production. Defects in the manufacturing production processes can be identified at their early stages using AI-based methods and thus increase yield rates. Predictive maintenance can be carried out to reduce machine downtime. In marketing aspect, AI-based business strategic planning helps businesses better understand their customers to make better business decisions. AI-driven solutions and its automation induce opportunity to deliver benefits by lifting companies' competitive capabilities, fostering healthy local manufacturing transformation, as well as unlocking local jobs and economic development.

Blockchain

Blockchain is the enabling technology behind many popular cryptocurrencies, including Bitcoin and Ethereum. The abstract ideas of blockchain and its first application, Bitcoin, were introduced in Nakamoto's white paper in 2014 (Nakamoto, 2014). Blockchain is a distributed database with an irreversible nature that new data can only be appended to the end of the chain. As each block contains a hashed version of its previous block, modifying the data in a single block will require the modification of all the blocks built on top of that. The chain is replicated and stored on multiple nodes on the blockchain network which makes the database immunes to single point of failure and virtually impossible to shut down. Transactions among individuals are broadcasted and verified by blockchain nodes on the network in a fully distributed manner such that a central authority is not necessary. Cryptocurrency and IoT networks share a lot of similarities including a large number of data exchanges among individuals are happening in an environment that lacks trust. By integrating IoT with blockchains, machine-to-machine (M2M) communications can be executed freely and securely without being coordinated by a centralized system.

Simulation and modelling

Data, including control, internal, and output parameters collected from machines and processes in a production line allow one to have a better understanding on their behaviours, characteristics, and limitations. Those data can be used to formulated equations that describe the relationships among the parameters, which formed the foundations of the digital twins of the corresponding physical entities. In general, a more complete data set would allow a more accurate mathematical model to be built which can capture the reactions of a system to different intrinsic and extrinsic stimuluses better. Simulation can then be executed with the model to study different "what-if" scenarios and thus generate the optimum operation strategies based on the given criteria. Simulations are often time-consuming processes as they may involve executing an extensive number of modelling equations iteratively with massive volume of data. With the help of AI and Big data analytics, the cost, both time and computational effort, can be greatly reduced which allow industry to use simulation and modelling to verify their strategies and predict the market trend in a timely manner.

Visualisation technology

Visualisation technology helps to present high-dimensional data in intuitive and interactive manners. With specific hardware, like Augmented Reality (AR) goggles, Big data aggregated using cyber-physical systems can be populated back into the physical world using visualization technologies. Visualisation and analytics tools, like Grafana (*Grafana Cloud | Grafana Labs*, 2022), provide visual tools for plotting different time series data, generating heatmaps for geographical data, and produce histograms for statistical data on interactive dashboards to ease their understandings and to facilitate comparisons and analyses. Visualization tools normally are equipped with a set of data access mechanisms for it to communicate with different common databases, such that up-to-date data can be retrieved and presented timely and accurately. Most modern visualization technology can also perform basic analysis on its data and trigger warning or inform external routines when anomaly has been detected.

Automation & Industrial Robots

Automation had been the focus in the last industrial revolution. Manufacturing productivity has been greatly increased by largely employ embedded computing systems, sensing technologies, and industrial actuators to shorten cycle time and thus lead time. In contrast, the 4th industrial revolution emphasises on utilising real-time data collected from the supply chain to minimise waste while maintaining a high productivity such that to yield a higher energy productivity and increase the competitiveness of a business. For processes that are costly to be fully automated or redesigned for manufacturing, collaborative robots (cobots) have been designed to work with human workers to speed up processes like pick and place, packaging, and quality inspection. To work with human, cobots are not only designed with safety features, including limitations on their force, speed, and momentum, some advanced models are also equipped with situation assessment capabilities to make decisions based on contextual information, such as adjusting its speed when they are human or obstacle nearby, and dynamically adjust their routines based on the actions and behaviours of their human co-workers.

Additive Manufacturing

Additive manufacturing (AM), also known as 3D printing technology, is a catalyst in the current digital transformation. 3D printing has many advantages over conventional injection moulding, including rapid prototyping, lower overheads for small volumes manufacturing, supporting complicated and/or hollow structures fabrications, etc. This technology can be applied in many different industries, including automobile and medical. Among the techniques in AM, Fused Deposition Modelling (FDM) is widely adopted due to its low manufacturing cost and robust performance. Nevertheless, Stereolithography (SLA), Digital Light Projector (DLP), and Selective Laser Sintering (SLS) are gaining their popularity in recent years. A FDM printer heats plastics, ABS or PLA, to close to their melting points. The filament, in their glass transition temperatures, are then extruded onto a printing platform via a nozzle. To print an object, its 3D computer-aided design model is first broken down into separated layers using a slicer software. The internal volume of the printed object is then filled with different infill patterns and densities depending on the required strength and stiffness. Objects are then built in a layer-by-layer and segment-by-segment fashion.

Digital Twin

IBM defines a digital twin as "a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making" (*Cheat Sheet: What Is Digital Twin?*, 2020). They further suggest that this means "creating a highly complex virtual model that is the exact counterpart (or twin) of a physical thing. The 'thing' could be a car, a building, a bridge, or a jet engine. Connected sensors on the physical asset, collect data that can be mapped onto the virtual model. Anyone looking at the digital twin can now see crucial information about how the physical thing is doing out there in the real world."

In this way, a digital twin could be viewed as an assembly of visual and functional information, with predictive modelling of a physical object, that provides the user with the ability to understand how the object will behave under different conditions. This detailed knowledge of the object can be used, as a subcomponent, to inform the operation of a production system. By itself, a digital twin is not Industry 4.0 or Digitalization, because it is not a business process.

The literature review of Ardebili et al. in (Ardebili et al., 2021) identifies monitoring, forecasting and anomaly detection as key use-cases for digital twins. They suggest that digital twins play the role of 'brain of an [Industry 4.0] system'.

Building Information Modelling (BIM) is one segment of the Proptech sector, which is sometimes referred to as a Digital Twin. BIM tools are used to develop searchable 3D models of the physical attributes of a building. These digital models can be shared between architects, engineers, product suppliers and construction professionals to efficiently plan, design, construct and manage buildings and infrastructure. In this way BIM enables the smooth flow of information between stakeholders and reduces systemic operational inefficiency caused by paper-based workflows.

Utilising appropriate naming and relational tags, construction data from BIM models can potentially be accessed by different service providers and supplemented with application-specific data, through into the operational phase of the building. This lifecycle view of the building has not been widely adopted but is the aspiration of, for example, the Digital Built Britain initiative (*What Is a Digital Built Britain? | Centre for Digital Built Britain*, 2022).

IT/OT Convergence

The operations technology (OT) world involves industrial programmable logic controllers (PLCs) that implement automation on rugged industrial quality hardware. The PLC operates largely on-premises, with input from local hard-wired sensors, serviced by specialised staff.

Conversely, the information technology (IT) ecosystem consists of large numbers of low-cost consumer grade products interconnected through wireless communications and cloud connectivity. To the extent possible, the IT products ecosystem gains robustness through redundancy (large numbers of devices) and serviceability through the ubiquitous availability of IT support teams.

For example, the traditional Building Management System (BMS) is a PLC (OT device) working on-premises to manage building services. This contrasts with IT systems, where company business processes and facilities management tasks are typically managed using cloud-based enterprise software tools. Connecting the BMS to the cloud (and hence to the enterprise's business processes) opens up the potential to discover new insights, improve business coordination and drive innovative new value-adding services.

Of course, IT/OT is not a binary choice, with hybrid solutions available. An OT approach to connecting a building to the cloud could involve installing a hardware gateway device to manage the IT/OT interface. Alternatively, software solutions can be installed on a generic onsite server to achieve the IT/OT interface.

Core to IT/OT convergence is the ability to enable data exchange and device discoverability, through open protocols and generalised software tools. In the IT/cloud environment 'semantic web technology' uses formal semantics to give meaning and context to (and build relationships between) disparate data sources. This enables machines to process long strings of characters and index data, so that machines can store, manage and retrieve information based on meaning and logical relationships. In this way, machines can "understand", share and reason with data.

2.2 Services offered by Industry 4.0 to improve energy productivity

Energy efficiency

Energy efficiency is the proportion of total energy input to machine or system that is consumed in useful work and not wasted as useless heat or otherwise. Improving energy efficiency through energy management is one key application Industry 4.0. The motivation comes from a combination of environmental aspects, cost pressure, and regulation as well as the pro-activeness of organizations when it comes to efficient consumption of energy and resources. In addition, the integration of different sources of energy generation in a dynamic market will require management technologies capable of recognizing, predicting, and acting in a way to guarantee quality, sustainability, and efficiency, including costs, in energy consumption. Modern energy and utilities management systems should be able to exploit a large volume of data collected by various types of meters on a number of variables of interest, such as energy consumption and water usage etc., for a certain industrial operation and guide it toward a more energy efficient and sustainable production plan without sacrificing productivity.

Real time monitoring (RTM)

Refers to the feature that allows users to observe and monitor current state of the machine and production streams continuously with updated information streaming close to real-time. RTM gives businesses a full view of every detail of their production process, allowing them to see precisely when, where and why problems arise – in real-time. Armed with this actionable data, organisations have the power to optimise processes immediately to make business safer, more efficient, and more profitable. By knowing essentially "what is where" in real-time, it is possible to digitise the physical world; that is, to create a dynamic digital model of the real-world environment. It can be used to automatically identify and track the location of staff and workpieces in production lines or in the factory hall, as well as mobile inventory in facility management. Introducing measures for ensuring advanced workers safety, analysing how equipment is being used, and assessing the efficiency of the supply chain lets businesses identify opportunities for improved workflow, increased safety and security, and improved customer satisfaction levels. The survey from indicates that Boston Consulting Group (BCG) "72% of manufacturing executives said that they considered advanced analytics to be important" (*BCG-WEF Project: Unlocking Value in Manufacturing Through Data | BCG*, 2022). Real-time monitoring has helped many businesses tackle traditional problems such as dealing with downtime, increasing equipment efficiency, and logistics management.

Resource management

Resource management refers to the management of production resources, including but not limited to energy, and how effectively the resources are been utilized during various phase of industrial operation. Efficient resource management, throughout its lifecycle, is key to every organisation. Understanding the connections between production resources, knowing their dependencies and relationships will give visibility of the impact of downtime, delays on spares and power outages. This will mean that plans and contingencies can be made with more complete knowledge of their consequences. With the advent of Industry 4.0 technologies, it is possible to do much more than understand the resources' structure and relationships. The production resources will, in essence, be able to communicate each other in the form of data. This means that industrial engineers can understand cause, effects, faults and performance on a much wider and more detailed scale of the production resources.

Industry 4.0 Virtualisation

Industry 4.0 virtualisation (different from Cloud Virtualisation) allows a digital replica of the industrial plant/warehouse by merging sensor data acquired from monitoring physical processes and equipment. The virtualised view helps warehouse operators and managers to better manage growing complexity, reduce equipment downtime and optimize processes. The role of Virtual Reality (VR) technology in creating a smart, connected factory is undeniable in today's era of digitalisation and Industry 4.0. With innovations picking up pace, more industries are leaning towards identifying ways to use VR tools. The technological advancements in Virtual Reality have given rise to innovative industry solutions, including virtual manufacturing, virtual prototyping, virtual designing and staying connected with customers through this technology. In addition, VR opens a whole new way of visualising the Big Data and thus, enables more informed decision-making.

Interoperability

The term interoperability refers to the capability of manufacturing units/ enterprises to exchange information in a coherent manner within and between each other. In fact, interoperability is not just about connecting machines, rather a method of supporting better decision making that improves how manufacturers operate. It allows accessing real-time data that leads the way to a new approach for how companies can improve their production operations. Today, improving manufacturing requires more than simply finding ways to operate faster and reduce expenses. Efficient ways for exchange of data throughout a connected factory becomes key to improving manufacturing operations as it has a significant impact on whether the data can be used for making informed business decisions in a timely manner.

Interoperability between devices and assets is being used by increasingly more factories. Seeing the benefits, many are modernizing their plants and facilities to have a standardized methods of communication, data, analysis, and security. The drive for true connectivity has even become a common denominator for cloud-based industrial equipment, with machine learning capabilities across connected devices now a reality. Manufacturing companies who have established the infrastructure for enabling data interoperability can better serve their customers and optimize their operations – with the added benefit of a broader visibility across their entire business.

Autonomisation

Autonomisation refers to the concept that enables machines to make decisions and perform activities autonomously. However, the autonomous process is based on human designed algorithms. Traditional assembly manufacturing lines are synchronous, with predefined workflows based on production work orders running in enterprise business systems. In contrast, Industry 4.0 is based on asynchronous manufacturing, with components in the production flow using auto identification technology to inform each machine and operator what needs to be done to produce the customized end product at each step of the production process. The use of new flexible machines that adapt to the requirements for the part being produced is another dimension of Industry 4.0. This achieves a highly flexible, lean, and agile production process enabling a variety of different products to be produced in the same production facility.

Flexibility

Flexibility addresses the operational strategy that shows the quickness in response towards any variation in production system. In particular, in this project, we refer flexibility that points how operation responds to any external issues (e.g. change in supply demand, disruption in machine). The emerging technologies in Industry 4.0, such as cloud operations or industrial Artificial Intelligence, allow for new flexible production systems. Through Industry 4.0 connectivity, automation, fast information exchange and analytics, a new dimension of flexibility can be reached and new approaches to planning & controlling production systems. Profitable mass customization allows the production of small lots (even as small as single unique items) due to the ability to rapidly configure machines to adapt to customer-supplied specifications and additive manufacturing.

2.3 Data issues/concerns ("the importance of data")

The IEA Annex #81 "Data-Driven Smart Buildings" (*IEA EBC || Annex 81 || Data-Driven Smart Buildings || IEA EBC || Annex 81*, 2022) conducted an online Mentimeter survey where participants were asked to suggest the key attributes of a smart building. The results (which have parallels in other sectors) are illustrated in Figure 4 below

Figure 4. Attributes that Characterise a Smart Building (*IEA EBC || Annex 81 || Data-Driven Smart Buildings || IEA EBC || Annex 81*, 2022)

This word cloud hints at a vision of a smart building as one that has understated automation, working in the background, to anticipate and responsively (i) service the needs of occupants and (ii) optimise the operation of equipment parts as an integrated system. This outcomes-based vision aligns well with the concepts of 'digitalization' and Industry 4.0.

Working in small groups, IEA Annex #81 participants further explored the technology features that underpin this vision. The discussions identified key technology attributes, being

- *Hardware and software interact in near real time to deliver value*. This requires two-way data-communication between sensors, devices, and servers. It further anticipates that the result of applying 'smart' analytics will lead to automated machine-to-machine dispatch of requests for action (e.g. adjustments to control settings) to deliver a value-adding result (rather than just providing information for subsequent ad-hoc human consideration). Furthermore, the central processor is assumed to be continuously learning from the streaming of sensor data and from ad-hoc human intervention, giving it predictive capability for the relevant objective functions of interest (e.g. energy minimisation, equipment performance etc).
- *IT infrastructure has "data-pipes", and related processes and tools to ensure data quality*. It is understood that 'garbage in leads to garbage out'. Consequently, there is strong emphasis on the need for technical functionality that can deliver high quality data. Data quality relates not just to data cleaning and gap filling, but to a range of other factors including
  - Labelling and context
    - *Data richness*: A simple unlabelled stream of data is generally of limited value. Additional information (meta-data) on the source of the data, the physical meaning of the data, the units of measure, how the source of the data relates to other objects in its ecosystem, etc - all add context that can be used to infer causation of events and achieve desired outcomes. By way of example, address-matching is often a means for linking records, utilising analytics to discover new correlations, and enabling administrative processes. In many Industry 4.0

use-cases, time stamping is also required to ensure that diverse data sets can be validly compared.

  - *Ground truth*: Machine learning algorithms will often 'train' using 'ground-truth' data where the target event or condition is known to occur. After training, the algorithm is then able to detect the event/condition from other confounding factors. In this way, access to ground truth meta-data can greatly improve the value of data.
  - *Provenance*: The validity of data can be compromised in a range of ways. For example, sensors can go offline due to connectivity issues, sensors can fail to update leading to a static signal, technicians can alter some hardware or software configuration (and possibly fail to log changes) etc. A secure digital identity is required for assets to enable them to be coordinated. Some form of data health, traceability and data provenance tools could help to ensure that decisions are being made based on correctly identified and operational information.
- Structure and discoverability: Rich data sources, that incorporate relevant meta-data, can be stored in a suitably structured database. Such databases can be queried by machines based on logical relationships (see IT/OT convergence). Cloud-hosted Industry 4.0 processes (software Applications) can then discover and orchestrate the operation of devices. The extent to which database structures can be aligned with industry-wide open data schemas, will influence the efficacy of industry collaboration. Web Ontology Language (OWL) data schemas further support seamless integration with diverse cloud-based data sources, supporting the potential for innovative Industry 4.0 use-case applications and Proptech business opportunities. While not directly developed for Industry 4.0, the so-called FAIR Data Principles (Findable, Accessible, Interoperable, Reusable) can help inform data management approaches for streamlining data exchange and avoiding expensive bespoke solutions (Wilkinson et al., 2016).
- Consent, privacy and cyber-security: Just because data is available does not mean that it can be ethically used. It is particularly important to note that relevant Industry 4.0 use-cases may involve interaction with occupants and perhaps inadvertent collection of occupant personal data. While data ethics and data security issues are discussed separately, it is noted here that a Smart Buildings should provide technical functionality to overcome many of these concerns (including streamlined consent processes).

While data doesn't need to be perfect, any deviations from perfect should be documented to avoid inappropriate use of the data.

2.3.1 Infrastructure Requirements for Industry 4.0

Industry 4.0 systems, including IoT Devices, communication infrastructure, and Cloud platforms, have become the invisible backbone supporting much of our daily lives. Cloud computing is the delivery of computing services—including servers, storage, databases, networking, software, analytics and intelligence—over the Internet. The rising popularity of the cloud has gone hand-in-hand with that of 4G (and the soon-to-be-rolled-out 5G) broadband technology and of mobile devices such as smartphones and tablets.

Thanks to cloud computing, stakeholders are able to access extensive databases on-the-go, all through streamlined user interfaces. Great attention is given to iterative human-centred software design processes, to ensure that an excellent "user-experience" is achieved for people who must interact with the service.

End to end operation of Industry 4.0 cyber-physical systems is achieved using an "IoT platform", a middleware platform hosted in the cloud. Objects and functionalities of the IoT platform architecture are illustrated in Figure 5. The IoT platforms is, for Industry 4.0 at least, partly analogous to what a computer operating-system is for a personal computer; guiding computational workflows and accessing data from storage.

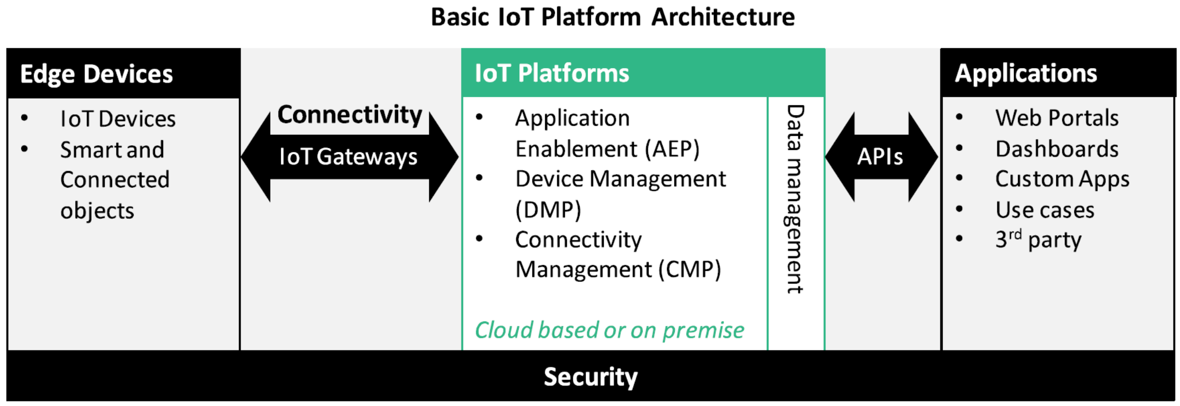


Figure 5. Basic IoT Platform Architecture, credit CSIRO as the copyright owner. All rights reserved.

Various alternative industry-specific names can be given to an IoT platform. For energy-productivity applications in the property industry, the data platform could be called an Energy Management Information System (EMIS). Alternatively, when an energy-utility attempts to manage loads from multiple buildings (and other grid resources), it does so through what is often called a Distributed Energy Resource Management System (DERMS).

The role of the IoT platform is generally much greater than simply gathering and storing engineering measurements from field sensors and devices. Roles include both

- *Integrated collection of information*: While energy metering by itself can identify changing energy consumption, it has quite limited ability to explain why the rate of energy consumption has changed. Answering the 'why question', may require information and/or data on the changing conditions in the manufacturing process or building. This could include (i) monitoring the operating status of equipment, (ii) collecting weather data and sensor data on conditions in the occupied space and (iii) incorporating information on changes to how the plant is being used. Comparing the available variables with energy meter data allows cause and effect to be correlated.
- *Integrated management of information*: While analytics can identify the cause of high energy consumption, the task of taking action to rectify issues and reduce consumption requires a business process for engaging stakeholders to deliver a solution. Delivering such a business process requires a range of market and information exchange functionalities to be performed - beyond the basic technical measurement, monitoring, and analytics functions. These functionalities are expected to be delivered over an IoT platform.
  For example, Ofgem in (*Ofgem's Future Insights Series Flexibility Platforms in Electricity Markets*, 2019) considered the software functionalities required to deliver a twenty first century electricity

system that is more decentralised, more flexible, more responsive to changing demand and more accommodating of variable renewable generation. Relevant functionalities they identified include (i) coordination of data and information flows, (ii) operating a market for procuring services (iii) automating the dispatch of assets, (iv) verification of service provision and subsequent financial settlement (v) asset registration and characterisation and (vi) analytics and governance

While not all of these functionalities will always be required from a platform, they give a good flavour of what's potentially involved in integrated management of information.

Coordination	Coordinating platform tasks Facilitating data flows Harmonisation of standards and principles Alignment with external platforms and markets Conflict avoidance
Flexibility Procurement	Attracting flexibility providers and purchasers to the market Communicating requirements and availability Matching providers and purchasers
Dispatch and Control	Sending signals to dispatch assets Notification of asset dispatch Verification of asset dispatch
Platform Transaction Settlement	Verification of service against transaction Settlement of transactions
Platforms Market Services	Credit checking Asset pre-qualification
Analytics and Feedback	Network analytics, response times etc. Counterparty scoring and review Identification of market faults

Figure 6. Six tasks envisaged of Flexibility Platforms, for providing grid services (Ofgem's Future Insights Series Flexibility Platforms in Electricity Markets, 2019)

2.3.2 The digital last mile

Manufacturers, especially those which have been established for decades, may find it challenging to capture real-time production data as they often still own legacy machines or equipment that have limited to no network connectivity, and are operating with proprietary data and communication formats. The same issue may also apply to the building services industry as buildings are often with a mix of modern and legacy mechanical, electrical, and plumbing systems. In some cases, data are still collected manually that can only processed offline. The manual data enter process is also prone to error. A poorly designed data collection mechanism can jeopardise the accuracy and integrity of the data collected, which could seriously affect the analysis and decisions made based on them. The lack of the “digital last mile” makes it impractical for data to be aggregated and conveyed to the relevant decision makers in close to real time. To overcome such hurdles, IoT gateways can be deployed for bridging OT with, IT, including time-series database, interactive dashboard, and data analytic platforms. The gateway is responsible for translating across heterogenous data storage and communication standards, and provide an access mechanism, in form of Application Programming Interfaces (APIs) to enable system interoperability. Once a connection has been established, data collection can be automated with the help of manufacturing execution system (MES) and enterprise resource planning (ERP).

For legacy machines that have no interface for data aggregation, like boilers and HVAC systems, their stoppage events can be detected by monitoring their change in power consumption using a power meter. Alternatively, limit switches can be set up to be triggered when some parameters have exceeded their pre-defined thresholds. For manufacturing machines with built-in signal tower lights, machine status can also be tapped from the light indicators with simply circuitry or replace them with intelligent signal tower lights with production data monitoring capability. Part counters or sensors could be installed onto legacy machines for capturing production quantity in a close-to-real-time and low-cost manner. It is common for companies, especially for small and medium-sized enterprises, in the manufacturing sectors to attach the job paperwork (i.e., a traveller) along an order’s lifespan. The traveller contains information including drawings, quantity, due date, etc. and it keeps updating when it migrates across different workstations on the shop floor. By adding a bar code or QR code onto the document, and populating scanners across stations, it will not only allow more rapid access to the job information via connecting to a centralised database, but the scanning processes can also serve as a check in/out system for providing traceability to each individual order.

2.3.3 IoT Gateway

A wrapper is a software routine designed to be executed on IoT gateways, a device for connecting IoT devices to the Internet, to perform bi-directional translating between proprietary and open/standard protocol(s). Multiple wrappers can be running on the same IoT gateway to perform translations simultaneously in real-time. The wrapper can also be executed on modern OT equipment with programming and communication capabilities. The case study in (Benedick et al., 2019) found that even when adopting the same communication protocol (e.g., OPC-UA (*Unified Architecture - OPC Foundation*, 2022)), different implementation approaches (open62541 (*Open62541 Documentation*, 2021) and Eclipse Milo (*Eclipse Milo | Projects.Eclipse.Org*, 2020)) can introduce compatibility issues which require extract effort in software customizations. From their study, the throughput of the gateway and concurrent traffic on the network can introduce bottlenecks to an information system, which can be evaluated using the duration for collecting and updating a data entry, known as the Service Response Time (SRT). Unlike ordinary IoT applications that with SRT within seconds, industrial applications often require their SRT to be around the 100 milli-second range or even lower in order to machines, conveyers, and actuators to synchronise, which imposes extra requirements on the effectiveness of wrappers and communication protocols.

2.3.4 Data governance arrangements

Beyond the IT hardware and software infrastructure, a core component of the infrastructure is the data governance arrangements. This requires implementation of controls to manage, amongst other things, privacy (e.g. General Data Protection Regulation (*GDPR - User-Friendly Guide to General Data Protection Regulation*, 2022)) and relevant commercial rules.

For example, while much is made of data ownership, data has a practical tendency to find its way to the service provider and be inaccessible to the client (the nominal/legal data owner). Consumer Data Right (CDR) protections are being introduced by the Australian government Consumer Data Right (*Homepage | Consumer Data Right*, 2022) to overcome this issue in the fields of finance and energy. These protections give consumers more control over their data, enabling them to access and share their own data with accredited third parties to access better deals on products and services. This enables more choice of providers, more access and control over one's own data, simpler setup of transactions, more competition and diversity of product offerings.

However, in many cases, such governance rules need to be instantiated in software infrastructure to translate the theory (and legal rights) into reality. Various IoT/data-platforms have been established to provide this infrastructure. Data management functionalities are typically incorporated into a broader IoT platform targeted at specific industry needs.

The International Energy Agency Annex #81 "Data Driven Smart Buildings" (*IEA EBC || Annex 81 || Data-Driven Smart Buildings || IEA EBC || Annex 81*, 2022) has surveyed a number of data platforms for the buildings industry. The surveyed platforms are intended for Industry 4.0 applications relating to the management of Heating Ventilating and Air Conditioning (HVAC) services including Fault Detection and Diagnosis (FDD), Model Predictive Control (MPC) and Grid Integrated Efficient Buildings (GIEBs). They share a common feature of benefitting from cloud connectivity, with concomitant need to collect, manage and share data.

In reviewing the various data platforms, a range of desirable features and functionalities are presented in Table 2.

Where a data platform gains sufficient traction, it can play a powerful role to help enforce standardized data structures and communication protocols, resulting in industry wide efficiency gains. The building HVAC industry Project Haystack (*Home – Project Haystack*, 2022) provides naming conventions (tags) for relevant data streams, and Brick (*Home - BrickSchema*, 2022) provides a metadata schema for describing the relationships between data streams. These data standards for HVAC equipment, in the operational phase of a building, sit inside a wider set of data standards relating to building architecture (see discussion on BIM) and asset classifications such as Virtual Buildings Information System (*VBIS – Virtual Buildings Information System*, 2022).

Table 3. Some Desirable Features and Functionalities for Industry 4.0 Data-Platform Infrastructure (White, 2019)

Feature/Functionality	Comments/ Purpose
Open-source code	If the data-platform software code is open source (e.g., available on GitHub under some form of creative commons licence) then the platform user may be able to find an alternative provider if necessary, and thereby avoid becoming captive to a single service provider.

Data access controls	Analogous to valves in a water-supply system, 'data-pipes' need to be routed, and flow controlled, to users of the data. It is important for the data-owner (e.g. building owner) to have the self-service ability to manage the data-pipes for their own data, rather than relying on service providers to manage the data flows (see discussion on CDR above). Encryption and authentication functionalities further provide security against leakage of data to unintended parties.
Data connectors/drivers	A wide range of data and communications protocols are used across industry (e.g., BACNet, Modbus, MQTT etc). A data platform should recognise and accept data transmitted using relevant protocols. The platform should be able to export structured data and import data using an uniform interface, such as representational state transfer (RESTfu)l APIs
Data health monitoring	A data platform should have functionality for cleaning the raw data and detecting anomalies. This would include identifying missing data and loss of connectivity to the data source.
Data storage and data structure	Data should be stored in a time series data base that can be queried with standard industry query language supported by a structured meta-data schema/ontology (see discussion on semantic web technologies, and machine to machine reasoning).
Work-flow management	A real time data platform should manage the allocation and prioritisation of storage and CPU for ingesting data and processing analytics workflows
Cyber security	A data platform should be capable of avoiding malicious attack.
User interface	Authorised people should be able to manually interact with the data platform to extract data samples that they have permission to see, obtain visualisations of key metrics and conduct basic correlation analysis of variables.

2.3.5 Energy management information systems (EMIS) platforms and 'Applications'

As discussed in Section 2.3.1, data-driven applications in the property industry are enacted using an Energy Management Information System (EMIS) (IoT platform). Some of the energy productivity Application options that proceed from this EMIS infrastructure are illustrated in Figure 7.

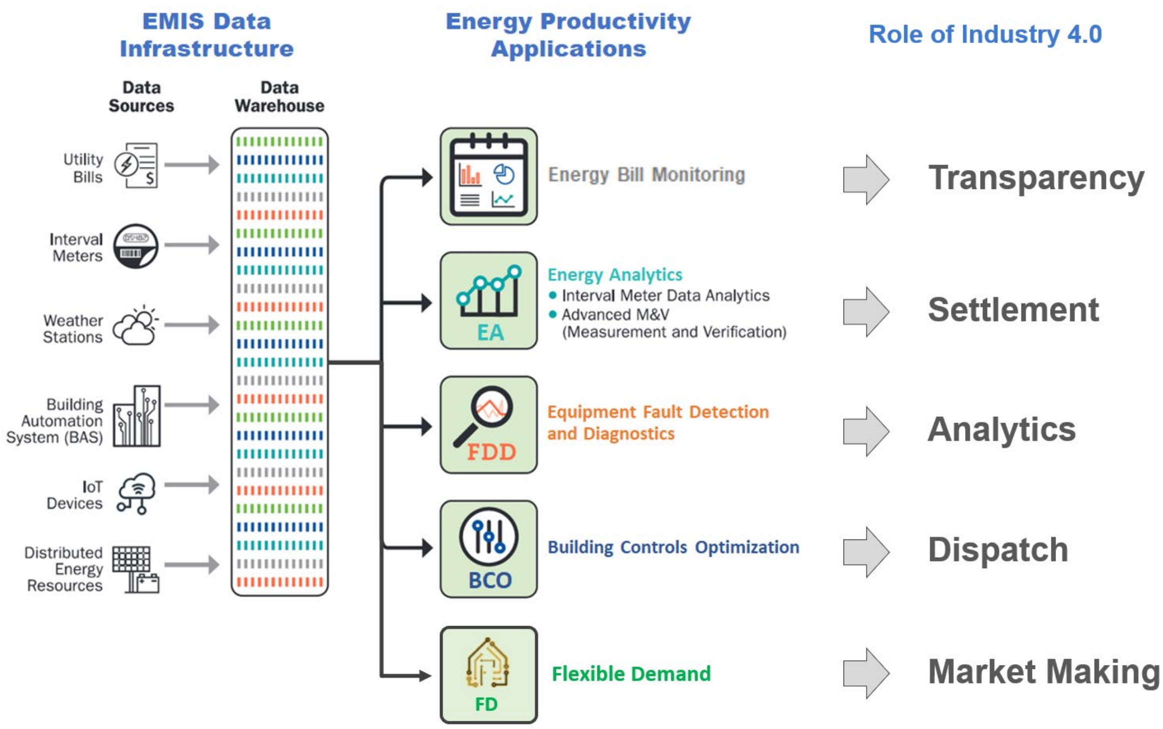


Figure 7. Energy productivity Applications hosted on an integrated EMIS infrastructure (adapted from Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, 2020)

The Applications, illustrated in Figure 7, are described below and case studies are provided in Section 2.4.2

- Energy bill monitoring: Site meter data and retailer bills are used for tracking energy bills and for reporting on sustainability metrics such as NABERS ratings. By presenting information in visually appealing formats, senior managers can track the aggregate impact of strategic business initiatives.
- Energy analytics: More frequent time-stamped energy meter (and sub meter) data collection allows computer analysis of energy consumption data. Weather and time-of-day normalised baseline energy consumption can be determined using machine learning algorithms trained on historic data. This can provide a coarse level understanding of cause and effect and an ability to perform IPMVP Option C measurement and verification (M&V). Option C M&V can be used for financial settlement of energy performance contracts and subsidy schemes (e.g. white certificates). In demand response settlement Applications, Hoch (2019) identifies that alternative baselining approaches (than CAISO 10 of 10) are required for baselining weather sensitive loads. To achieve energy savings from energy analytics alone, improvement measures must be identified manually (off platform) due to a lack of data on building operation. Median annual energy savings was 3% across the US DoE Energy Analytics Campaign buildings (Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, 2020).
- Equipment fault detection and diagnosis (FDD): By adding time-stamped sensor data and HVAC equipment data (sourced from the building management system (BMS)), to the data from energy meters, it is possible to get a more detailed understanding and correlation of why energy consumption is higher than necessary and get insights into how to reduce energy consumption.

FDD analytics can imbed expert knowledge using rules-based algorithms (if/then diagnosis of poor operating practices). Alternatively, the algorithms can apply data-driven approaches (machine learning, reinforcement learning) to identify both degradation of equipment operation and alternative operating conditions that lead to better performance. Energy saving improvements are identified on-platform but must be manually implemented by procurement of rectification services from a contractor. Across 1,500 buildings/373 million ft^2 of floor area in North America, Crowe et al. (Crowe et al., 2020) found that the task of conducting rectification works was achieved with median simple payback time of 1.7 years. Kramer et al. found that, after two years of using fault detection and diagnosis, the median annual energy savings was 9% across the US DoE Energy Analytics Campaign buildings (Kramer, Hannah, Claire Curtin, Guanjing Lin, Eliot Crowe, 2020).

- Building controls optimization: Traditional building controls make decisions based on immediately available sensor readings and one-off target setpoints selected at time of commissioning. There is substantial opportunity to optimise controls by making control decisions that incorporate day-ahead forecasts of relevant variables (e.g., future electricity prices, weather forecasts etc.). Similarly, target setpoints that may be appropriate for one season or occupancy scenario, may not be suitable at a later point in the life of the building. Utilising an Industry 4.0 platform with read/write capability, energy consumption can be reduced by applying supervisory controls based on more sophisticated control algorithms. Continuous recommissioning can also be applied to regularly update control setpoints based on changing circumstances in the building. Building controls optimization is a promising opportunity because manual intervention is not required to achieve savings. However, this technology has not yet been widely adopted, at least partly due to fears of automated controls creating unintended and unsupervised consequences. Granderson et. al. (Granderson Guanjing Lin Rupam Singla Samuel Fernandes Samir Touzani et al., 2018) conducted a field validation and verification study of the BuildingIQ Predictive Energy Optimization (PEO) technology, at five-sites, with mixed results ranging from 0% to 9% energy savings. Serale et al. (Serale et al., 2018) reviewed the state of the art in Model Predictive Control and found that implementations of model predictive control (MPC) gave savings ranging from 0% to 40% (Figure 8).

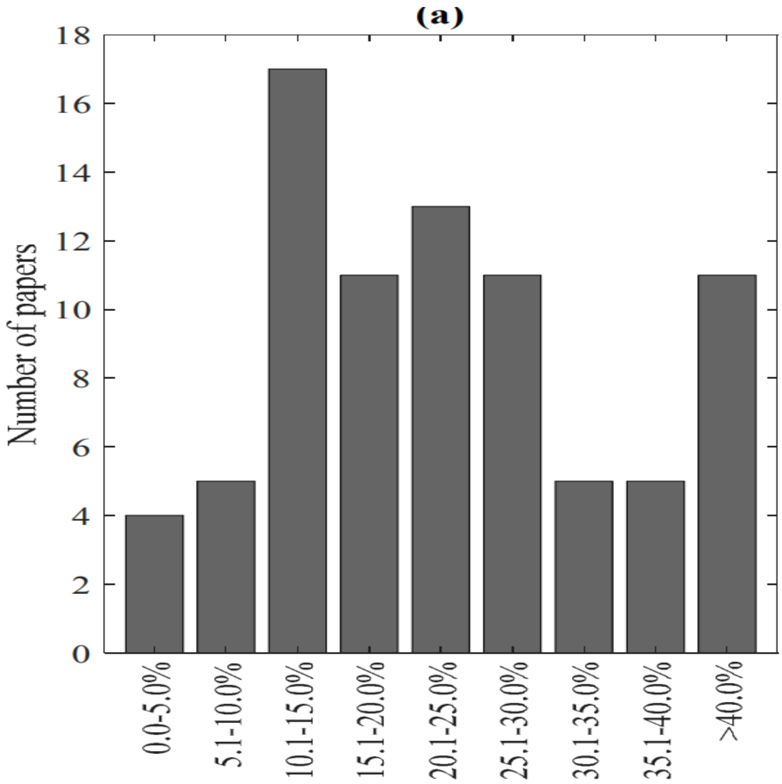
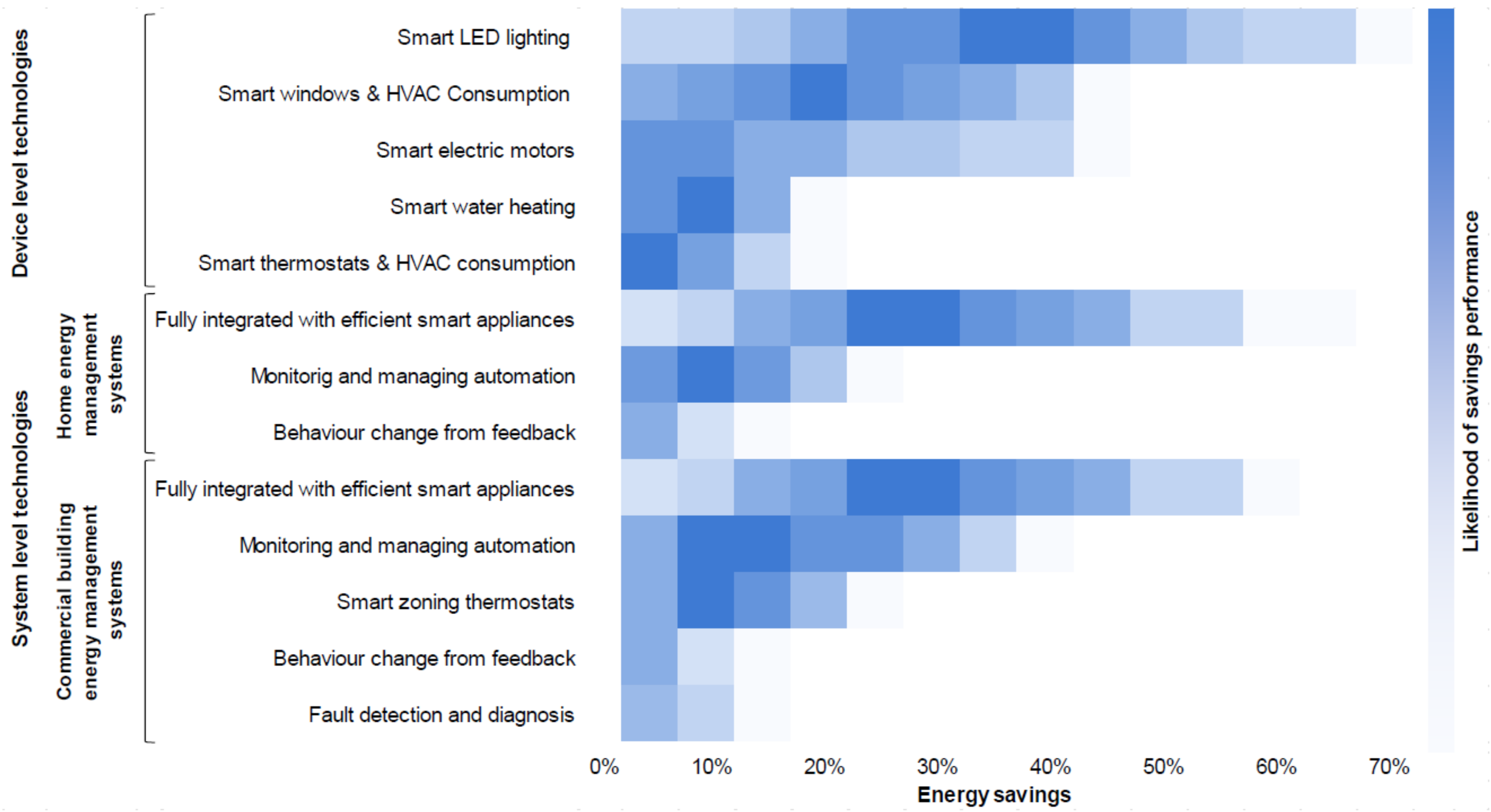


Figure 8. Number of papers claiming various levels of energy savings, when implementing model predictive control (MPC) in buildings (Serale et al., 2018)

Maddalena et al. (Maddalena et al., 2020) reviewed available literature on data-driven methods for building control and identify a list of attributes that an ideal high-level supervisory controller should exhibit, to achieve widespread commercial adoption.

The International Energy Agency (Figure 9) also provides the indicative energy savings range and likelihood of achieving these energy savings (*World Energy Outlook 2021 – Analysis - IEA*, 2021).

Expanding the scale of energy efficiency with digital devices



Note: HVAC = heating, ventilation and air conditioning.
Source: IEA analysis based on case studies.

Figure 9. Range of energy savings and likelihood of savings for different digitally enabled technologies (*World Energy Outlook 2021 – Analysis - IEA*, 2021).

Beyond energy efficiency actions in single buildings, the connectivity obtained from an EMIS enables a building-portfolio level response to electricity system market signals.

Combining concepts of both energy efficiency and flexibility, the US Department of Energy identifies the need for 'Grid-Interactive Efficient Buildings' (GEBs) (*Grid-Interactive Efficient Buildings | Department of Energy*, 2022; *National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021). GEBs are energy efficient buildings with smart technologies characterized by the active use of distributed energy resources (DERs) to optimize energy use for grid services, occupant needs and preferences, and cost reductions – in a continuous and integrated way. GEBs take advantage of energy-efficient materials and equipment to help minimize energy use. They also contain DERs, such as energy storage, rooftop solar photovoltaics (PVs), and grid-connected water heaters. Smart controls (activated through an EMIS) enable GEBs to play a key role in achieving greater affordability, resilience, environmental performance, and reliability across the U.S. electric power system (Figure 10).

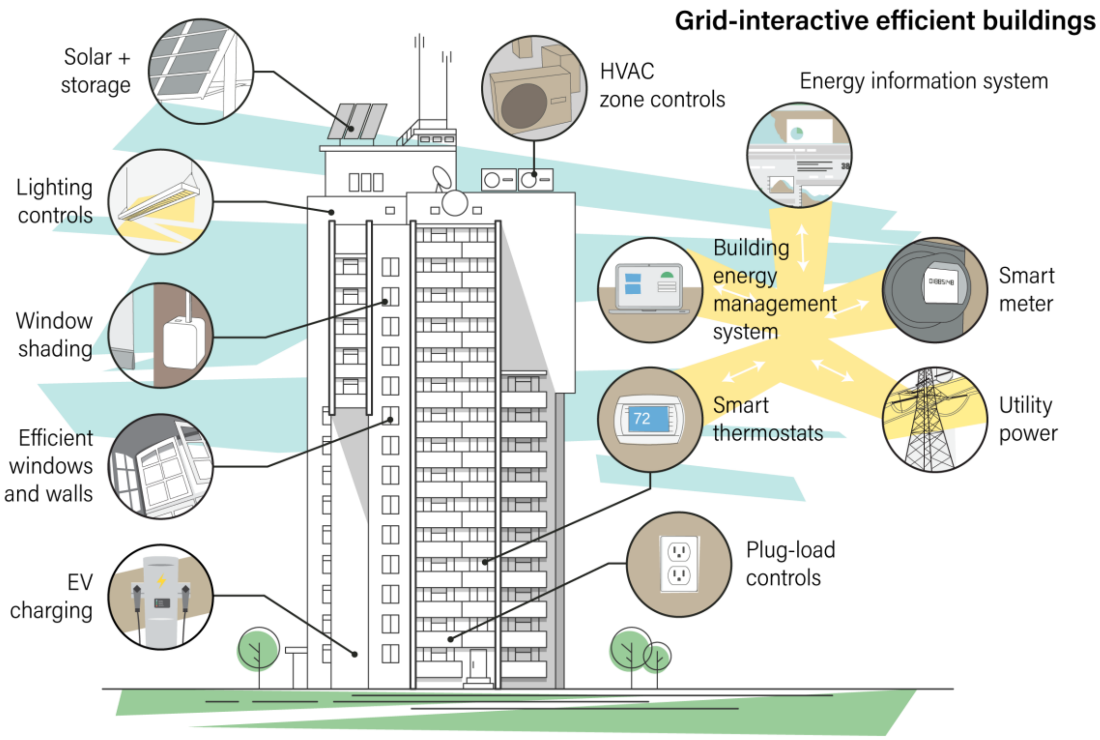


Figure 10. Example of a commercial GEB (*National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021).

Over the next two decades, GEBs could save the US power system USD 100-200 billion and help reduce CO_2 emissions by 80 million tonnes per year (*National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021). These savings arise from both reduced energy consumption (energy efficiency) and shifting demand away from periods of extreme peak or towards periods of minimum demand (demand flexibility).

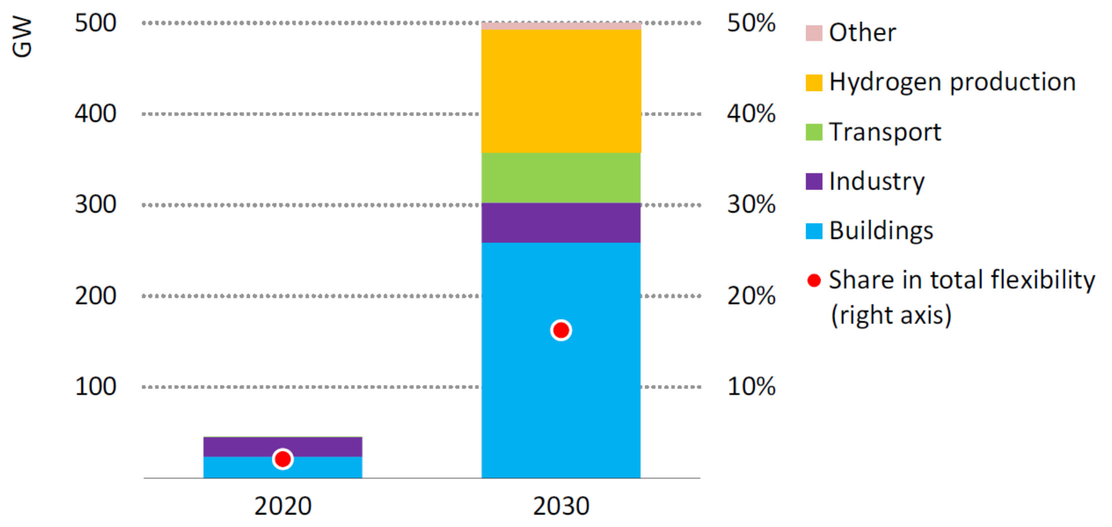
Digitalization can help to achieve these energy efficiency and demand flexibility outcomes. A minimum level of digitalization is a pre-requisite if buildings are to provide flexible demand at scale.

The US Grid-Interactive Efficient Buildings Roadmap is consistent with the IEA's Net Zero Emissions by 2050 Scenario, where more than 500 GW of demand response is brought to market by 2030 to support the power system. In the IEA scenario modelling (*National Roadmap for Grid-Interactive Efficient*

Buildings | Department of Energy, 2021), around 50% of this flexible demand capacity comes from buildings (Figure 11). By 2030 all new buildings become flexible resources for the energy system, using connectivity and automation to manage electricity demand and the operation of energy storage devices, including electric vehicles.

In their scenario, 20% of existing buildings are retrofitted by 2030 and 85% by 2050 with efficient and grid-interactive appliances. This highlights the importance of broadening energy efficiency policies to focus on demand flexibility and intelligent efficiency.

Demand response availability at times of highest flexibility needs and share in total flexibility provision in the Net Zero Emissions by 2050 Scenario, 2020 and 2030



Note: DSR availability in 2020 is estimated based on a review of DSR capacity contracted for deployment in 2020 across capacity, balancing, frequency response and other markets.
Source: IEA (2021), World Energy Outlook.

Figure 11. Flexible demand capacity growth to 2030 in the IEA Net Zero Emissions by 2050 Scenario (*National Roadmap for Grid-Interactive Efficient Buildings | Department of Energy*, 2021)

Targeting building managers in the US General Services Administration (GSA), the Rocky Mountains Institute characterised the technological differences between traditional demand response approaches and those of future GEB buildings (Figure 12) (Cara Carmichael, 2021). Across the US Federal Governments building portfolio, they suggest that the GSA could save USD50 million in annual cost savings while simultaneously achieving a societal reduction in grid-level T&D and generation costs worth up to USD70 million/yr.

Key Differentiators of Grid-Interactive Efficient Buildings

Attribute	Optimized GEB Scenario	Demand Response Today
Two-way communication between building and grid	Ability to receive utility signals (price or carbon) and to communicate load flex potential to grid	Manual, widget-based demand response programs
Interoperability and intelligence across building systems	Single, overarching integrator to monitor and control all loads, including plug and storage loads; ability to optimize for cost, carbon, resilience, etc.	Limited building automation system controls; isolated lighting, storage controls
Load flexibility and demand-focused building optimization	Building-level intelligence to track and map demand, and shift or shed rapidly based on inputs such as price, weather, carbon, peak grid demand, etc.	Isolated applications of thermal energy storage; battery storage

Basic Control System

- Piecemeal monitoring and management of building systems through building automation system (BAS)
- Pneumatic or other non-digital control
- Monitoring points that are not energy related (e.g., fan status rather than electric draw in kWh)
- Little ability to optimize energy consumption
- Little visibility into how tenants are consuming energy

Advanced Control System

- Holistic management across all building energy end uses through energy management information system (EMIS)
- Direct digital control
- Monitoring that provides granular (hourly to 15 min) energy consumption data
- Two-way communication between building and the grid
- Tenant energy use submetering

Buildings to the left of the spectrum should be targeted for controls upgrades and will require more manual control by a building manager to dispatch load flexibility.

Figure 12. Changing technology for demand response (Cara Carmichael, 2021)

2.4 Case studies

Case studies, representative of some of these key market segments, are provided in this section.

2.4.1 Industrial case studies:

Table 4. Industrial case studies of Industry 4.0 incorporating energy benefits.

(IoT Case Study Database - Page 1 of 62 | IoT ONE Digital Transformation Advisors, 2022), (Industry 4.0, connected revolution - Renault Group, 2022), (IoT Case Studies and IoT Applications: Manx Technology Group, 2022), (Digital Bulletin | Case Studies | Unilever, 2022), (Industry 4.0 case studies - KPMG Global, 2022), (ABB digital solutions to improve energy efficiency for China's industrial giant, 2022), (System 800xA at Indian Cement Plants by ABB | IoT ONE Digital Transformation Advisors, 2022)

Sector	Energy intensity	Industry type	Technologies involved	Service provided	Location/ Country	Benefit reported	Benefited stakeholders in the value chain
Fast-moving consumer goods (FMCG)	High	Large	AI, Robot/Automation, Sensors	Real time monitoring and management of equipment	Italy	Improved overall labour effectiveness (OLE), improved overall equipment effectiveness (OEE), flexibility, safety	Customers
Cement industry	High	Large	Smart sensors, AI	Automation; Remote monitoring; Data management	India	Energy consumption was reduced by 10%; reduction of production cost.	Tech manufacturer; Tech distributor; Customer, Energy supplier
Agriculture	Low	SME	Smart sensors	Real time monitoring & management	Spain	Resource utilization	Tech manufacturer; Tech distributor; Customer
Pharmaceutical	High	Large	Simulation, Smart sensors, AI, IoT	Simulation; real time monitoring	USA	Resource utilization; efficiency	Tech manufacturer; Tech distributor; Customer, energy service companies (ESCO), Energy supplier
Agriculture	Low	SME	Smart sensors	Real time monitoring & management	Australia	Resource utilization	Tech manufacturer; Tech distributor; Customer
Food & beverage	Low	SME	Sensors, data management, cloud server	Energy management	Australia	Cost reduction; resource utilization	Tech distributor; Customer
Battery manufacturer	High	Large	Digital Twin / Simulation	Production planning and resource management	Austria	Resource utilization; efficiency	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier
Fast-moving consumer goods (FMCG)	High	Large	AI, Robot/Automation, Sensors	Real time monitoring and management of equipment	Multiple	Improved OLE, improved OEE, flexibility, safety	Tech manufacturers; Tech distributors, customer

Sector	Energy intensity	Industry type	Technologies involved	Service provided	Location/ Country	Benefit reported	Benefited stakeholders in the value chain
Agriculture	Medium	SME	Sensors, data management, cloud server	Real time monitoring, energy management	Australia	Cost reduction; better control	Tech distributor; Customer
Manufacturing industry	High	Large	Sensors, AI	Real time monitoring, energy management	USA	Improved productivity and efficiency	Tech distributor; Customer, ESCO, Energy supplier
Fertilizer	High	Large	AI, IoT	Decision support tool; asset management	USA	Reduced cost; improved asset management;	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier
Automotive	High	Large	IoT, sensors, AI	Real time monitoring & management, connectivity	Not disclosed	Resource utilization; improved performance of labour	Tech manufacturer; Tech distributor; Customer
Steel, pipe	High	Large	Autonomous robots, Big data, Cloud computing	Decision support tool; asset management	Sweden, Norway, Poland	Improved efficiency, competitiveness, improved resource utilization, cost reduction, operation speed	Customers
Agriculture	Low	SME	Smart sensors	Data collection; Real time monitoring	Italy	Resource utilization	Tech manufacturer; Tech distributor; Customer
Retail	Medium	SME	Smart sensors, IoT, SCADA	Real time monitoring & management, connectivity	France	Labour cost reduced by 13 %; equipment effectiveness increased by 8%	Tech manufacturer; Tech distributor; Customer
Metal	High	Large	Sensors, AI	Real time monitoring; Data analysis	Belgium	Better equipment effectiveness, labour effectiveness; costs reduction; less maintenance	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier
Automotive	High	Large	Sensors, AI, IoT	Real time monitoring & management; Data analysis,	Multiple	Improved OEE, OLE, production speed, resource utilization	Tech manufacturer, Customer
Paper & pulp	High	Large	Sensors; AI, IoT	Real time monitoring, data analysis, simulation	Colombia	Resource utilization; reduced down time; reduced operation cost	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier
Petroleum	High	Large	Sensors, AI, IoT	Real time monitoring	China	Resource utilization, OLE, OEE	Tech manufacturer, Customer
Food & beverage	Medium	SME	Sensors; AI, IoT	Real time monitoring & management	United Kingdom	Improved reliability; resource utilization; reduction of cost	Tech manufacturer; Tech distributor; Customer
Mining	High	Large	AI, IoT	Remote monitoring; control system	USA	Improved labour safety; improved communication	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier
Apparel	High	Large	Sensors, AI	Real time tracking	Taiwan	Resource utilization	Tech manufacturer; Tech distributor; Customer, ESCO, Energy supplier

Sector	Energy intensity	Industry type	Technologies involved	Service provided	Location/ Country	Benefit reported	Benefited stakeholders in the value chain
Automotive	High	Large	Sensors, Robots	Real time monitoring, data analysis, reporting	Italy	Resource utilization, OLE, OEE	Tech manufacturer, Customer
Automotive	High	Large	Sensors, Robots	Real time monitoring, data analysis	Multiple	Resource utilization, OLE, OEE	Tech manufacturer, Customer

2.4.2 Non-residential case studies and applications

There are numerous providers of Industry 4.0 solutions for the buildings sector. Harbor Research provides a sample of global companies in the various Industry 4.0 market segments (Figure 13) (*Intelligent Building Energy Management Systems*, 2020). Two of the listed companies (Switch Automation and BuildingIQ) were founded in Australia.

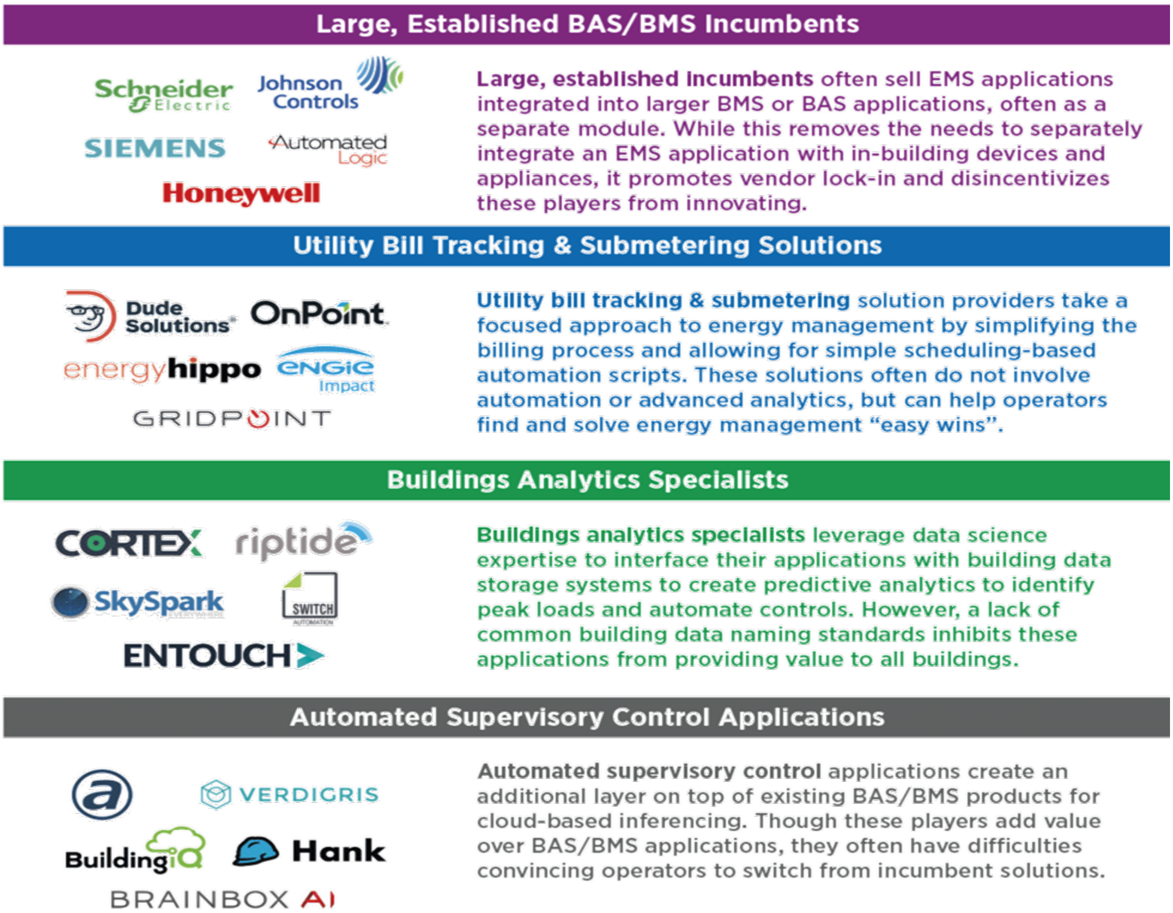


Figure 13. Examples of companies offering Industry 4.0 energy productivity services in the non-residential buildings sector (*Intelligent Building Energy Management Systems*, 2020)

Monthly data analytics case studies

Basic utility data capture and energy consumption visualisation is common practice in the non-residential buildings sector. These services are utilized for tracking business performance leading to energy saving mandates and investment. Much of this data capture and visualisation work is for reporting on NABERS ratings.

- NABERS Ratings Data Platform Case Study

NABERS - the National Australian Built Environment Rating System - is one of the most effective sustainability initiatives in Australia, bringing an unprecedented level of transparency to energy performance in buildings. Buildings that regularly certify under NABERS have reduced energy use at one of the fastest rates in the world. The average building participating in NABERS reduced energy use by more than 30% over the past decade (Figure 14).

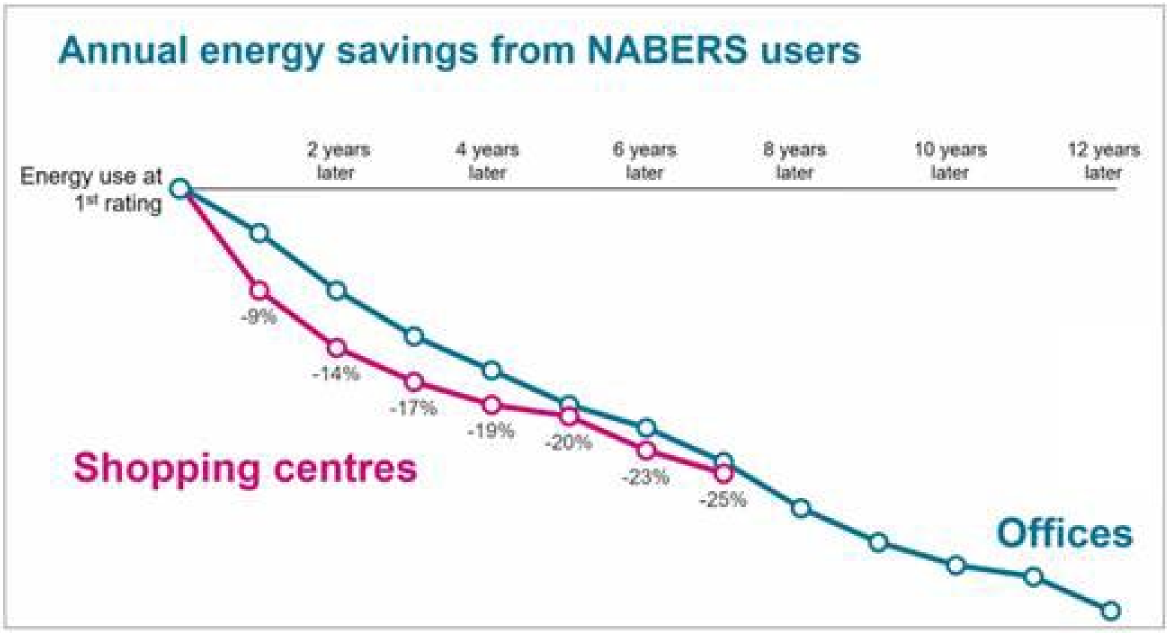


Figure 14. Progressive energy savings from continued use of NABERS tools (*NABERS*, 2019)

NABERS vision is to scale up its role in driving sustainable change to a larger part of the Australian economy. NABERS goals are that every major building type can be rated by NABERS and to double the number of NABERS ratings.

To enable this vision, NABERS is building a new data platform ('NABERS Perform') that underpins their operations. NABERS Perform underpins the rating system, from submitting a rating, to getting a certificate, managing Assessor accreditations, to paying for a rating, storing data on all of the ratings, and communicating with NABERS customers. Customers can access the data platform through any device. Using the platform, it is faster and easier to submit ratings and make payments, it is simpler to collaborate with colleagues, and clearer to communicate with auditors.

In September 2021, NABERS launched NABERS for 2 new sectors – residential aged care and retirement living. The new platform reduced the time it took NABERS to expand to these sectors and immediately presented a simple, clear and fast interface to rate with NABERS. Quotes from assessors included

> "Much easier than before. You have addressed the key things. If you can save me a couple of hours each rating that saves me a lot over time."

> "You listen to everyone's feedback, I can see it's designed with assessor's feedback, designed to save time, flexible and intuitive."

> "The fact that you can pre-fill from last year is good because the electricity meters don't change much, and it helps me cross-check with the history of the building."

> "Autosave, that would have been very handy many times during my life using Rate [NABERS existing platform]. I think that's the best thing that happened during 2020."

"The new L1 [audit] process is a lot better; this is a much easier way to do it."

Current development projects include (i) adding more sectors, (ii) creating and publishing APIs to help calculate NABERS ratings and access ratings data, (iii) investigating how one might compare demand management in buildings, (iv) investigating simple comparisons for any building to use, (v) designing a benchmark for embodied emissions, and (vi) adding a renewable energy indicator.

- CSIRO Data Platform Case Study

Building portfolio owners also look to data platforms to consolidate Environmental, Social, and Governance (ESG) data across the organisation and use digitalization as a tool to help manage maintenance.

CSIRO is one building portfolio owner that has recently adopted an IoT data platform (the Data Clearing House (DCH)) for managing sustainability related data. The DCH has also been used for deeper data integration in a sample of CSIRO's buildings.

Prior to implementing the DCH, CSIRO had a central submetering system in place, which collected meter readings automatically and stored the data on an external cloud. However, other than supporting its billing and reporting processes, the system struggled to achieve any improvement in energy efficiency. Issues with the original system related to both data and system integration. Because the facilities are old, there is limited documentation which makes it difficult to develop and record the context of the data collected. In addition, because the system was solely a submetering system, it was difficult to consider energy efficiency alongside other data points (such as BMS points) without significant additional labour resource from the facilities team. Moreover, real-time data was not available. As a result, it was difficult to identify data-driven opportunities for energy efficiency, and even more difficult to communicate between stakeholders.

The motivation and vision, then, for rolling out the DCH was to deliver a system that enables integration of data from multiple sources, and with the goal of using this to increase flexibility in CSIRO's operations and to open the doors for future improvements. The DCH was a good fit for this as it alleviated most of CSIRO's technical concerns because it:

- allows contextual relationships to be mapped between data points.
- supports the collection of live data.
- functions as a central repository for all building data points to be considered in tandem.

Full utilisation of the DCH platform is a journey. CSIRO has progressed with on-boarding existing energy and water metering points across most of its operations (e.g., Figure 15), and it has fully onboarded BMS data from 4 large buildings, complete with semantic models. In this way, CSIRO is able to capture how meters interact with the buildings, in context, while providing access to live data. With this availability of data, CSIRO is in a better position to increase energy productivity through flexible demand and industry 4.0 technologies. This has manifested itself in a number of internal efforts, such as applications developed by data scientists, as well as external collaborations.

In one example, CSIRO was able to quickly provide data access to a building, to an external provider (Exergenics), which has been used to identify new settings for staging the chillers in CSIROs Synergy building. Previously this would have been an arduous task to work through different stakeholders to find and compile the necessary data.

Overall, the journey towards digitalisation is an exciting one, but it has its challenges. The CSIRO facilities team found that the biggest challenge is to articulate the end goal and what that means for CSIRO, as it can be open to interpretation. What does a fully efficient and smart building look like? What do we have to do to get there?

Communicating the vision with stakeholders can be challenging. For example, the facilities management team was primarily interested in action and minimising risk of equipment failure (rather than energy efficiency). It is important to articulate, in a way that is tailored to each stakeholder, what digitalisation and smart buildings look like, and how it impacts their work.

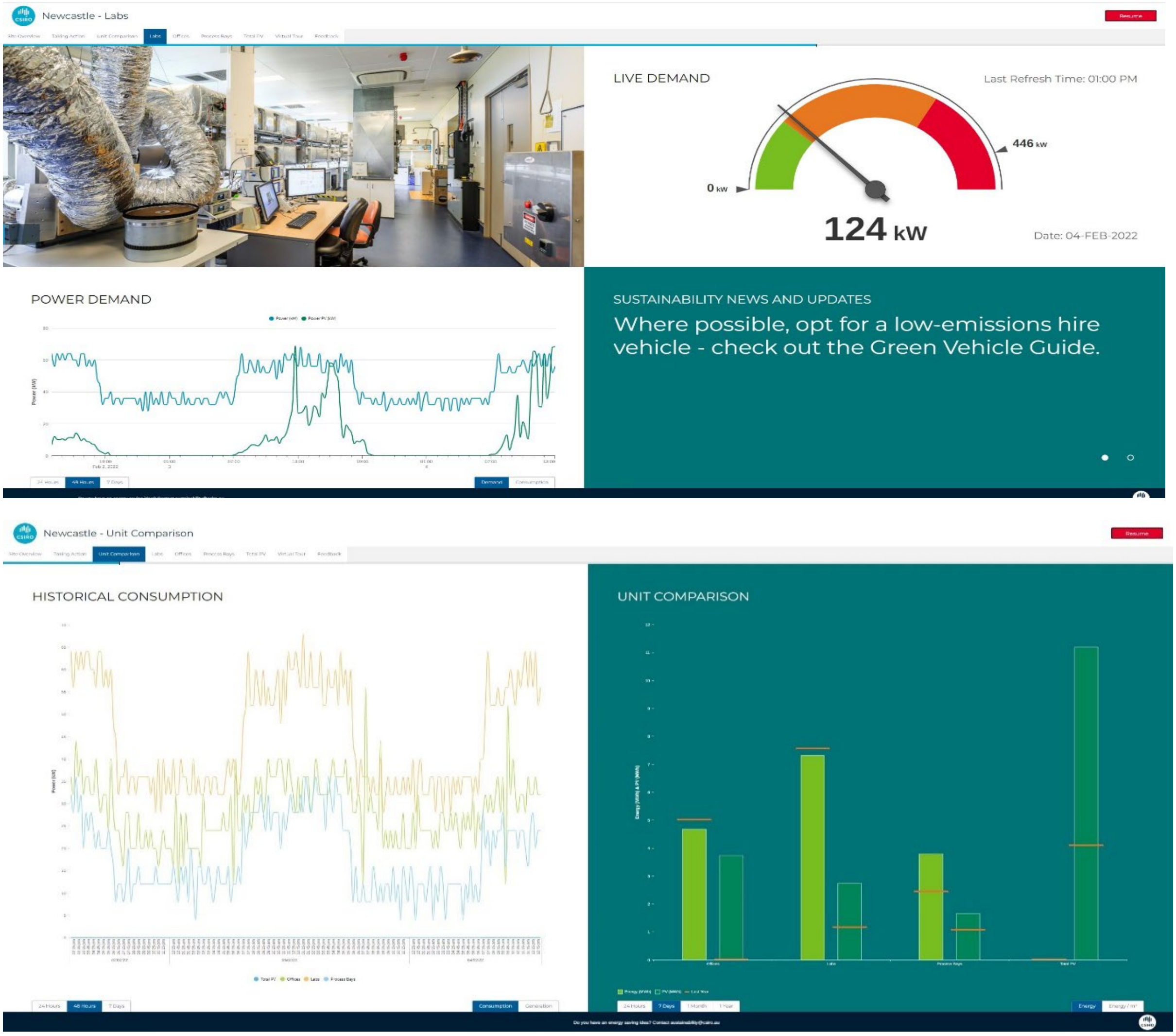


Figure 15. Live dashboards at CSIRO Newcastle Site

Equipment fault detection and diagnosis (FDD) case studies

Fault Detection and Diagnosis (FDD) involves automating the process of detecting faults in the operation of physical services in a building (particularly HVAC systems) and diagnosing the causes of these faults. In this context, faults may include, for example (i) stuck or leaking dampers and valves, (ii) sensors reading incorrectly or not at all, (iii) heat exchanger fouling, (iv) equipment (e.g., chillers, pumps etc.) switched off or electronically locked out, etc. These faults may be triggers for maintenance or for changes to be made to equipment control strategies. Rectifying these faults will typically lead to energy savings, improved occupant comfort and reduced complaints. FDD is analogous to visiting a medical doctor with symptoms, from which the diagnosis of an illness can be deduced. Similarly, FDD could be compared with using computer diagnostics to perform a tune-up on a car.

Automating FDD, in buildings, involves continuously streaming data from the building management system (BMS) relating to the status and operation of equipment, and running analytics on the data to identify abnormal operation of equipment. Incorporating energy meter data, along with the BMS data, provides additional evidence for anomaly detection.

Rule-based analysis uses hierarchical logic rulesets with inherent knowledge of inter-system dependencies (if/then dependencies between different equipment classes) to detect system and equipment faults. These expert-systems typically have a library of rules and thresholds based on expert knowledge. These can be refined for relevant climate zones, building types, HVAC systems or pieces of equipment. In contrast, data-driven analysis learns the behaviour of the building based on historical data and then diagnoses when the building is departing from how it would normally operate. Learning and diagnosis can be unsupervised (black box). Black box approaches can be constrained by physical parameters, models or benchmark limits (grey box), to prevent unintentional outcomes. Data-driven methods can be used to enhance rule-based analysis.

The challenge for FDD technology is to ensure that the analytics solutions are not too sensitive so as to create an overwhelming number of results or false alarms but are still sensitive enough to not miss critical issues. Another challenge is ensuring that identified faults and operational issues are prioritised and presented in a way that facilitates actual remedial actions for best practise O&M, without causing information overload.

A commercial challenge for FDD providers is to minimise the labour cost of engineers and domain experts, both for installing IT infrastructure and for analysing data. Standardised automated reports help to create delivery-cost efficiencies, but risk missing some of the more detailed energy saving opportunities.

Addressing these challenges, Navigant suggests that "by assembling an unprecedented amount of data from one or multiple buildings, IoT and business intelligence (BI) solutions will open up data-rich environments creating opportunities for new smart building applications and actionable insights … These include increased energy savings from more efficient devices that provide intelligence at the edge of subsystems; cloud-based processing that enables enhanced data analysis of device or system functionality; enhanced operational efficiency through two-way connectivity and greater insights from more granular operational performance data; and preventive maintenance capabilities from devices that can sense anomalies before they become costly problems" (*Navigant Research Analyzes IoT Market for Intelligent Buildings*, 2017). Wall and Guo, 2018 present 6 case studies of FDD deployments in Australia. The case studies and the overall outcomes from these sites is summarised in Table 4.

Table 5. Six case studies of FDD in Australia (Wall and Guo, 2018)

Case study Project	Description	Key FDD Outcomes
Melbourne Museum, Melbourne VIC, 70,000m² floor area	In 2016, the museum invested in a new BMS. The museum employed CIM, an independent platform provider, to continuously monitor and validate the real-time commissioning of their new BMS through the Defects Liability Period. CIM's ACE platform identified 117 BMS and mechanical-asset faults across the estate, which would have otherwise gone unnoticed. Rectifying these faults has delivered significant energy savings. This was achieved for a 4½ month payback.	Yearly savings of 20% in electricity and 28% in gas
Commercial Office Tower, Sydney NSW A-grade commercial offices	The Kyko Group (landlord) set CBRE (operator) a target of achieving a 4.0 NABERS star rating on one of their A-grade commercial offices. Using CIM's ACE platform, 69 building performance faults were identified and resolved, 52 BMS faults and 17 relating to large equipment lifecycle issue. In addition to energy savings, tenant comfort complaints were reduced from 60% to less than 5% of all tenant complaints.	8.3% electricity savings and 13% gas savings Increased NABERS rating from 1.5 Star to 5 Star in 24 months
Commercial Office Tower, Canberra ACT 40,000m² floor area	CopperTree's Kaizen analytics platform was implemented in a commercial office tower in October 2015, to help drive maintenance outcomes and tuning activities. The Kaizan platform includes • Continuous monitoring and reporting • Public API for 3rd party integration • Community FDD Library of Algorithms After 18 months of data driven maintenance and tuning the building is gone from 5.7 star to 5.96 star NABERS rating	Improved thermal comfort conditions while achieving 15% total electricity reduction and 19% total gas reduction
Melbourne Airport, Melbourne VIC	The Schneider Electric EcoStruxure Building Advisor platform was deployed at Melbourne Airport to drive maintenance activity. Objectives included: • A proactive response to occupant comfort, equipment uptime and energy efficiency • Transition from traditional labour intensive BMS and HVAC problem finding and maintenance, to a software assisted FDD advisory service • Improve labour efficiency by reducing inspection and test tasks • Availability of information for capital planning	Reduction in the avoidable energy cost, number of comfort anomalies, and number of maintenance anomalies
Public Hospital, Brisbane QLD	Synengco's SentientSystem platform was used to build a digital twin of the hospital's site energy supply plant (diesel gensets, gas fired trigeneration) and energy consuming plant (steam, water heating, space heating and cooling). The digital twin was used to optimize life-cycle operation and maintenance costs.	Decisions-support to reduce the life cycle cost of operation, and aided electricity, gas and facility management contract negotiations
Research Laboratory Facility, Canberra ACT Two storey, 3,120 m² floor area built in 1962	Although the HVAC system was meeting occupant comfort requirements, FDD was chosen for its ability to identify equipment inefficiencies and potential energy savings. A near real time data connection was configured to the Siemens APOGEE Building Management System (BMS) and 27 fault detection rules selected by the BMS contractor team (Control and Electric) were applied. The FDD algorithms look for any patterns or outliers that would indicate faults such as simultaneous heating and cooling, excessive cycling and rapid rates of change as well as temperature and humidity instability.	20% decrease in monthly energy consumption and 744MJ/m² decrease in site energy intensity

Building controls optimization case studies

Building HVAC control strategies must be able to maintain comfortable conditions inside a building across a wide range of weather conditions and must be implementable in buildings with varying HVAC equipment layouts. Control strategies must be sufficiently simple and packaged to enable technicians to implement with limited customisation. Consequently, building control strategies are typically chosen for wide applicability and ruggedness, rather than for energy optimization.

Various rule-of-thumb setpoints/constraints are often baked into the control strategy during initial commissioning (e.g. chilled water supply temperature, condenser water temperature, supply air temperature and/or fan pressure) to ensure that conditions can be met during the small number of hours of peak demand. This reduces the flexibility (degrees of freedom) for the control system to optimise performance over the vast majority of the year, where conditions are not requiring peak cooling capacity.

A number of more advanced control strategies are described by the NSW Office of Environment and Heritage, each claimed to have the potential for significant savings (5% to 30% but not additive – this would lead to more than 100% energy savings) (*I Am Your Optimisation Guide: Heating, Ventilation and Air Conditioning Systems*, 2015). A challenge is to automate these control processes, using Industry 4.0 technology, to avoid the labour costs of skilled engineers and technicians.

- Exergenics Case-Study

Exergenics uses its API to connect securely to the building owners existing system (BMS, Data Warehouse or Analytics Provider), in order to automatically generate a digital twin of the chilled water plant and simulate how it will operate under different conditions. It then produces actionable controls strategy recommendations for optimal performance. At this stage, Exergenics does not perform this optimisation in real time and push control setpoints to live buildings.

The simulated savings of Exergenics digital twin algorithms, in a Queensland Children's Hospital case study, are elucidated in Table 5.

Table 6. Summary of control recommendations and simulated savings potential (*LLHC4: Queensland Children's Hospital - i-Hub*, 2020)

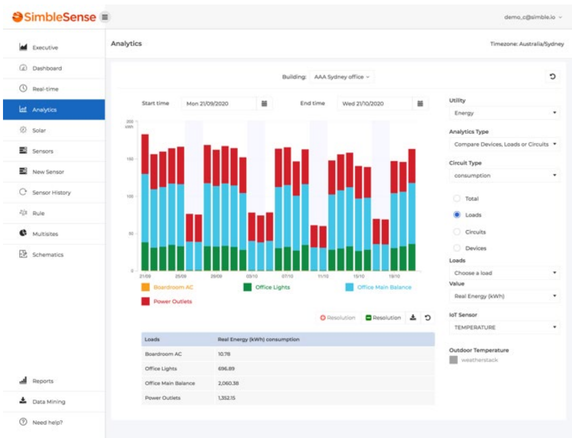
Simulated savings potential (%)			
No.	**Recommendations**	**Energy - kWh**	**Peak Demand - kVA**
1	Chiller staging	2.8%	2.6%
2	Dynamic condenser water temperature algorithm	1.8%	1.5%
3	Chiller load balancing	2.5%	1.3%
	Total	7.1%	5.4%

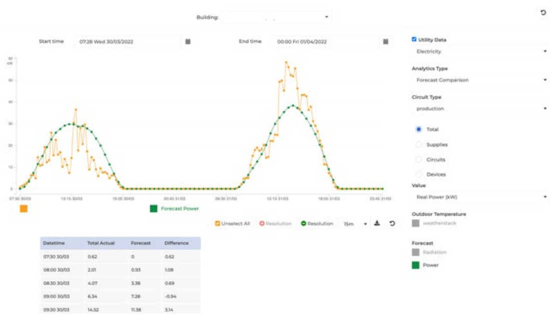
Model-based predictive HVAC control (MPC) is another data-driven technology for optimising building controls. It works by generating a predictive model of building operations, and then optimizing heating, ventilation, and air conditioning (HVAC) setpoints and equipment schedules, to meet these predicted loads. In this way, it is possible to prevent (for example) the control system switching between heating mode at the beginning of the day and cooling mode later in the morning. It can further be used to schedule demand response events.

- Best and Less DC (Western Sydney) with SimbleSense

SimbleSense is an Energy management and IoT platform developed by Simble with several key functionalities, from energy monitoring to performance tracking and automated reporting. Simble Solutions, in partnership with Wattwatchers and MTA Energy, have investigated the impact of energy efficiency on the operations within a major warehouse in Sydney. A number of IoT devices have been installed to help control electricity in the site.

Interestingly, prior to analysis, the assumption in the site was that the biggest user would've been the automatic sorter. Therefore, using actual data dispelled preconceived ideas on the biggest energy-consuming devices. The dominant load was actually Metal Halide high bay lights, the data convinced management to upgrade to LED. Also, the deployment of specific devices also led to the capability of control so to be able to reduce peak load. In particular, the peak load of forklift charging systems has been reduced. Shifting the forklift charging from peak to off-peak tariffs which reduced kVA charges and direct energy cost using the IoT functionality in the SimbleSense platform (below an exemplary screenshot from the platform). The two combined actions led to a 35% savings on electricity in the first year.





- SDG&E MPC Case-Study

San Diego Gas & Electric performed a case-study evaluation on the service of one commercial provider of model predictive control, an advanced method of process control. The controller provides a real-time prediction of a building's power profile for the subsequent 24-hour period, and updates this model every 4 hours. This predictive model then informs how to most efficiently control HVAC system start-up and shut down times, and optimize heating, cooling, and airflow set points (*M&V Report - Model-Based Predictive HVAC Control Enhancement Software*, 2016).

Starting with a generic grey-box model representation of the building, the platform continuously monitors building power consumption and compares the results to the expected power consumption from the model. Parameters of the grey-box model are adjusted based on the difference between the predicted building power consumption and the actual measured power consumption. Using this approach, the model 'learns' how the specific building operates and tunes the model parameters until an acceptable fit is achieved. This learning process typically takes 4-6 weeks depending on the variation in outdoor air temperature and occupancy observed during the learning period. After the 'learning mode' is complete, the model will predict future building power consumption 24 hours in advance, based on expected occupancy and weather profiles.

Once the model has completed the learning phase, the predictive controls are slowly transitioned into effect over a 4-6 week period. Based on the predictive model, the system optimizes air-side HVAC schedules and set points to achieve the most efficient operating point. The most efficient operating point is defined by minimizing overall energy cost. The system considers factors including peak pricing, HVAC system part-load efficiency, and demand response capabilities in order to define the HVAC optimization sequence in a way that minimizes overall cost – not just overall energy consumption.

The system also uses the model to intelligently reduce HVAC demand in response to an automated demand response (DR) signal from the utility. The demand response algorithms include the following general sequence:

1. The HVAC system is driven in a "pre-cool" mode prior to the DR timeframe, in order to move the spaces toward the minimum acceptable zone temperatures.
2. At the start of the DR event, the HVAC system is set to supply air temp maximum, and supply air pressure minimum. There will be a gradual ramping of these parameters per standard system operations.
3. The optimization software will then dynamically pulse the units in a staggered manner to eliminate coincident cooling peaks from the air handlers. The term pulsing means resetting the unit to lower the supply air temperature and increase the supply air pressure to provide a calculated amount of cooling for a predetermined period of time. The software will then reset the natural drift of that space, so that the maximum acceptable space temperature is not breached within the DR period.
4. If at any time a zone approaches the maximum acceptable comfort temperature, that unit is removed from the DR algorithms and returned to full cooling.
5. At the end of the DR event, all HVAC equipment is returned to normal operation in a staggered fashion to minimize any demand spikes at the end of the DR event.

The case study evaluation was performed in a large office building in SDG&E's service territory (Table 6). Whole-building HVAC power consumption was measured every 15 minutes using the utility interval meter for a period of 9 months prior to retrofit and 7 months after the retrofit. Space temperature, humidity, and light levels was also measured in a sample of offices on each floor in order to confirm that occupant comfort was maintained before and after the software installation. Finally, interviews with facilities staff and building owners were conducted in order to identify, track, and address any changes to the building operations or occupancy that occurred during the baseline and post-installation monitoring periods. This data was used, along with weather data from local weather stations, to develop a regression model of the baseline building operation and the building operation after the software was installed. Two demand response event tests were held lasting 2 and 4 hours. The 10-in-10 Baseline methodology was used with "Morning-of Adjustment" to determine the demand response potential of the MPC system.

Table 7. Case study building characteristics (*M&V Report - Model-Based Predictive HVAC Control Enhancement Software*, 2016)

Building Type	Large Office Building			
# of Floors	6			
Conditioned Area	144,000 Square Feet			
Vintage	2001			
HVAC Systems	The HVAC systems include three 65-ton and three 72-ton Trane Intellipak packaged air handling units – one serving each floor. Each unit is equipped with a VFD-controlled supply fan, water-side economizers, water-cooled DX compressors, and hot water coils. The DX compressors are on a common condenser water loop which is served by a rooftop cooling tower that operates with a VFD-controlled fan. Heating is provided by rooftop boilers that supply hot water to coils in each air handling unit and to some of the zone-level air distribution boxes. Hot water is distributed using two VFD-controlled pumps in a lead/lag configuration. Fresh air is circulated through the building using one VFD-controlled supply fan and two constant-speed exhaust fans. Fresh air is supplied to a common plenum that each air handling unit pulls from.			
Air Distribution	Conditioned air is distributed through the building using VAV boxes with hot water re-heat coils. The one exception is the lobby area, which is served by a constant-volume box with hot water reheat.			
HVAC Control	HVAC operations are controlled by a Johnson Metasys control system. The system sets and monitors space temperatures and controls the HVAC operating schedule, supply air temperature, duct static pressure, condenser water temperature, and hot water supply temperature. Fresh air is provided to the building using a variable speed outdoor air fan which supplies air to a common plenum for each air handling unit. The following observations of the baseline HVAC control capabilities were made: - HVAC units are set to turn on and off based on a programmed operating schedule. There are no optimal start/stop controls. - The supply fans operate using VFDs to maintain a constant duct static pressure (DSP). The DSP set point is different for each floor, and varies from 1.2 to 1.8 IWC. - There is a supply air temperature reset in place, which varies the supply air temperature set point based on the measured return air temperature. - Compressors are cycled on and off to maintain the supply air temperature set point. - Each unit has a water-side economizer that uses condenser water to directly cool the air stream when the building load does not require the compressors to operate. This typically happens early in the morning, and when outside air temperatures are mild. While in water-side economizer mode, the cooling tower provides 59 °F water. - Whenever any compressors are operational, the cooling tower operates to maintain a constant condenser water supply temperature of 80 °F.			
Hours of Operation	Weekdays: Saturdays:	5 AM – 6 PM 8 AM – 1 PM	Sundays: Holidays:	OFF OFF

The cloud-based software platform was installed on top of existing EMS controls and did not utilize any new/independent sensors or equipment. The software remotely managed building HVAC operations with the primary goal of reducing energy consumption and peak demand. In order to manage the systems, the software monitored EMS sensor readings and adjusted set points based on the algorithm's prediction of the most efficient control approach for that day. Data points collected by the platform included zone temperature and humidity, supply air temperature and temperature setpoint, duct static pressure and pressure setpoint, power metering, compressor staging, fan speed, outside air damper position, outside air temperature and humidity. External weather data was captured from a local weather station.

The software includes a graphical front-end that provides building operators with an at-a-glance look at the current set points and system operations. Should building operators identify any problematic set points, or if they begin receiving comfort complaints from occupants, they can contact the software provider to investigate the issue and modify set points if appropriate. This is a key difference compared to the approach that facilities staff may have taken using only their standalone EMS. Frequently, the issue would be 'solved' by manually overriding a set point and leaving that set point in place until another occupant comfort complaint arose. With the model-based predictive HVAC control enhancement software in place, the software provider's staff, who are specialists in HVAC optimization, are in control of the set points and can more effectively adjust operations to meet occupant comfort needs while not eliminating the energy-savings components of the EMS. Additionally, if on-site staff do override systems, the software can detect this remotely and generate an alert if the override isn't removed in a timely fashion.

Savings achieved from the case study building are detailed in Table 7. The energy savings were 10.7% and peak demand savings of 4.1%. IT software/hardware installation costs represented half of the total 5-year cost for the service. The service provided a 6.5-year payback and when a utility incentive was included, this dropped to 4.8 years.

Table 8. Summary of energy and demand savings in the case study building (*M&V Report - Model-Based Predictive HVAC Control Enhancement Software*, 2016)

	Annual Energy Consumption (kWh/yr)	Average Maximum Peak Demand (kW)	Annual Energy Savings (kWh/yr)	Peak Demand Savings (kW)	Average DR Event Savings (kW)	Simple Payback Without Incentive (Years)
Baseline	779,983	241	-		-	
Predictive HVAC Control	696,706	231	83,277	10	14	6.5

There were significant difficulties and uncertainties associated with baselining for the demand response events, with the software provider and the independent M&V expert coming up with quite different results.

Temperatures on each of the floors of the building, during the four-hour event, are illustrated in Figure 16 (the 5th floor is not included as that was unoccupied). It is evident that the normal variation in temperature across floors was much larger than any variation caused by the demand response event. SDG&E suggest that the demand response opportunity could have been driven much harder.

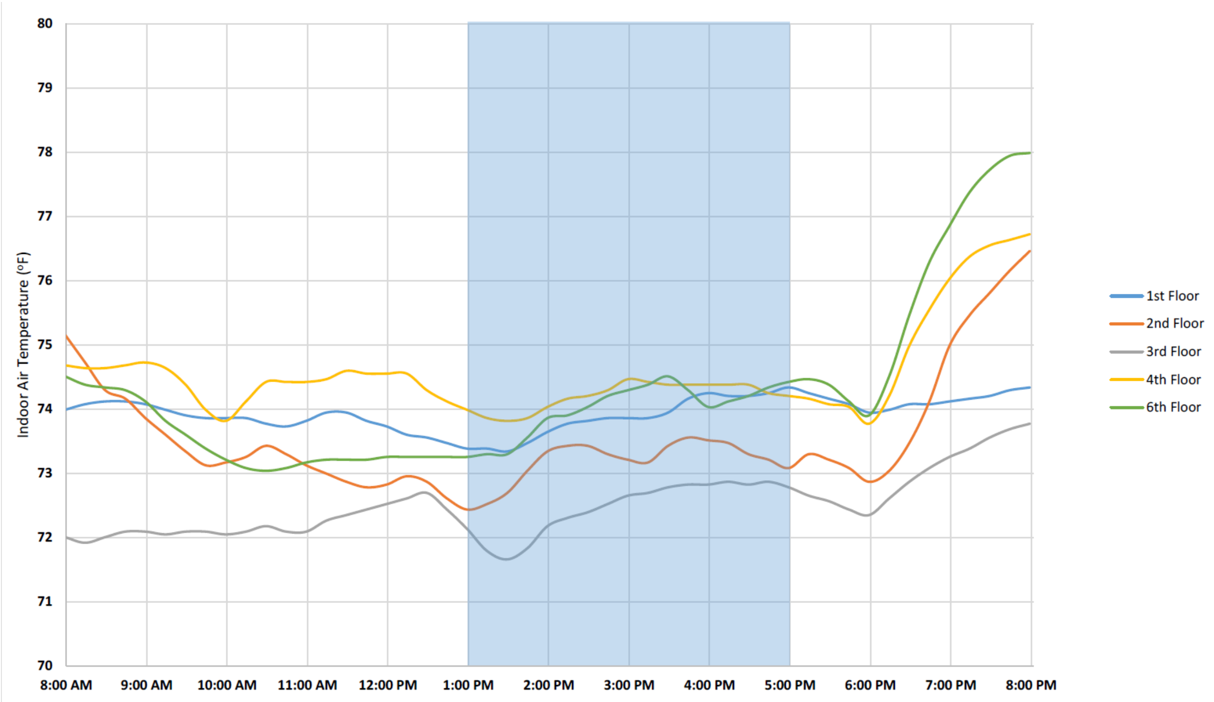


Figure 16. Temperatures across floors during a demand response event (*M&V Report - Model-Based Predictive HVAC Control Enhancement Software*, 2016)

Integrated energy productivity platforms

Perry et al. surveyed utility programs in the US that are relevant for Grid Interactive Efficient Buildings. Programs relevant to the non-residential building sector are listed in Table 8.

Table 9. US utility programs with GEB elements (Perry et al., 2019)

Program Type	Description	Example Programs
Energy efficiency programs that cross-promote separate demand-response programs	Programs that offer a range of smart devices such as energy management hubs, connected thermostats, and smart lighting. The utility cross-promotes demand response programs for eligible devices.	• National Grid New York's Electric C&I Retrofit program
Streamlined energy efficiency and demand response programs	Programs designed to promote energy efficiency and demand response simultaneously in a single streamlined program	• NV Energy's Power Shift Commercial Energy Services program
Smart energy management programs	Programs that promote smart technologies and services that enable smart energy use	• NYSERDA's RTEM program, • BC Hydro's Continuous Optimization program, • Efficiency Nova Scotia's EMIS program
Automated demand response (ADR) programs	The utility provides incentives and installs communication equipment at customer facilities. The utility can then send signals to equipment to conduct load-curtailment strategies. Energy efficiency is not included in these programs.	• Duke Energy's EnergyWise Business program • Austin Energy's Load Co-op pilot

ADR programs that also promote energy efficiency measures	Programs that promote energy efficiency measures and offerings to ADR program participants. Programs may provide additional rebates or incentives for energy efficiency measures installed at the same site. If the program requires a facility audit, the utility recommends an efficiency measures audit report. It can also provide energy-saving behavioural tips and feedback to participants.	• PG&E's ADR program • Dominion's Smart Thermostat program
DER aggregation pilots	Utility pilots that integrate multiple separate DERs into fleets for greater demand flexibility.	No non-residential programs identified

Technology providers offer platform solutions for these programs and for internal utility data management. These platforms can aggregate distributed energy resources and load flexibility to create 'virtual power plants' (VPP), utilising Industry 4.0 platforms. The functionality of these technology platforms must cover the perspectives of numerous stakeholders (*Building to Grid-Industry Transformation for Flexible Integrated Value-Generated Resources*, 2020).

- Advanced distribution management systems (ADMSs) typically encompass a suite of application software and information management services that supports electric distribution system operations (DSOs). These may consist of metering and network monitoring data, real-time simulation and static engineering applications, potentially integrated with outage management and SCADA systems. They could be used for signalling flexible demand limits on elements of the network.
- Demand response management systems (DRMSs) are used by electricity utilities to manage participants in DR programs, including some level/combination of (i) DR program enrolment, (ii) device tracking, (iii) forecasting, (iv) dispatch, (v) data communications, and (vi) settlement capabilities. Some vendors offer comprehensive DRMS solutions while others have systems that focus on specific parts of the value chain e.g. specific customer segments (residential or C&I) or specific loads. DER management systems (DERMS) also include distributed generation and energy storage, to allow grid operators to reliably operate systems with high penetrations of renewable energy, storage, EVs and flexible loads.

Bringing together (i) system-level IT informatics and situation-awareness of the electricity grid with (ii) local hardware automation and physical device performance management, is challenging and would likely require partnerships between relevant industries and skillsets.

- SwitchIn DERMS Technology Case-Study

SwitchedIn has developed a DERMS platform. Their mission "is to enable that two-sided marketplace and to fast-track the shift towards a decentralised energy service. And the key problem that we focus on is removing the complexity - making it possible to manage at scale all these small assets owned by different people and coordinating the way they work to deliver value to their owners and to enable smooth interaction with the grid." They say "At the moment we provide a gateway device and we build into that all the communication protocols - proprietary and other protocols out there - which enables us to pretty well connect & control all the solar and battery systems that are in the market. This is great if you're trying to build a fleet of connected systems because you don't have to lock into a single vendor solution and also you've got fine-grained control over things like cyber security and communications pathways and all these sorts of things which are important once these things become significant in the electricity system."

SwitchDin has been working with Lake Macquarie City Council (LMCC) since 2017 to provide distributed energy asset monitoring and management for 29 council-owned sites across the local government area. Each site is equipped with a SwitchDin Droplet controller to connect a mix of SMA and SolarEdge PV inverters (about 60 devices in total), providing the council with data visibility and management through a single portal.

In addition to the monitoring and analytics dashboard for the fleet and individual sites, SwitchDin's platform enables customisable alerts and the ability for the LMCC to operate its asset fleet as a virtual power plant to take advantage of new energy opportunities using both current assets as well as those connected in the future. SwitchDin is also advising the council on bolstering energy self-reliance and resilience across its sites.

- EnergyOS DERMS Technology Case-Study

EnergyOS has developed a DERMS platform. EnergyOS uses a cloud-based software called eOS. eOS is an operating system for energy. It's a multi-tasking, multi-user platform that orchestrates data, software and devices. It includes advanced metering infrastructure to ingest, analyse and display smart meter data. It also supports real time switching services with appliance level monitoring and control.

The eOS platform is used to provide consumers with

- Understanding – real time interfaces, monthly reports, alerts and alarms.
- Bill management – budgets, spending alerts and tariff recommendations.
- Personalised advice – energy insights, savings tips, technology assessments.
- Control services – remote switching, 'set & forget' efficiency and load matching services

3. Barriers to the Adoption of Industry 4.0 Technologies for Energy Productivity

This chapter of the report identifies and analyses barriers to the adoption of Industry 4.0 technologies and services for energy productivity. The chapter has three main sections: the first section deals with general barriers to the adoption of Industry 4.0 technologies; the second section deals with specific barriers to the adoption of Industry 4.0 technologies for improving energy productivity; the third section presents a case study that applies the framework for analysing barriers to adopting Industry 4.0 technologies for energy productivity to the specific context of non-residential buildings.

This report places considerable emphasis on analysing barriers as overcoming barriers is essential to identifying pathways for promoting Industry 4.0 technologies for energy productivity. The three sections of the chapter introduce and explain the barriers in a logical order. First, it is impossible to understand the specific barriers to Industry 4.0 technologies for energy productivity without first identifying the general barriers to adopting Industry 4.0 technologies. Drawing on an extensive literature review, the first section of the chapter sets out a framework for understanding general barriers to the adoption of Industry 4.0 technologies. As the particular impacts of barriers depends upon industry sectors, the second section of the chapter concentrates on explaining the operation of the barriers identified in this first section in the specific context of energy productivity. Finally, the operation of barriers to Industry 4.0 technology adoption, and how this ultimately depends upon context, is further illustrated by the case study of barriers to the adoption of Industry 4.0 for energy productivity in non-residential buildings, which are set out in the third section of this chapter. This case study was chosen as it provides detailed practical insights on the operation of barriers in a particular context.

In this report, the barriers to technology adoption are considered predominantly from the point of view of energy users (and enablers of energy use, such as third-party intermediaries) rather than energy suppliers or, indeed, technology developers. Thus, for example, the focus of this report is on barriers to technology adoption in the 'behind-the-meter' context – that is, on the customer side of the energy system. The focus is therefore not predominantly on productivity gains that may be possible for energy suppliers and distributors. Moreover, while it is always important to consider barriers to the development of new technologies, they are outside the scope of this report, which focusses on barriers to technology adoption. In addition, the report assumes that energy users do not face specific barriers to enhancing energy productivity that may arise from particular agreements with energy suppliers, such as minimum energy supply requirements in energy contracts or other agreements to purchase an agreed amount of energy for a predetermined period.

3.1 General Barriers to the Adoption of Industry 4.0Industry 4.0 Technologies

This first section of the chapter – dealing with general barriers to the adoption of Industry 4.0 technologies - is based on a literature review, which includes academic articles and grey literature, such as industry reports and official government reports. There is an extensive literature on general barriers to innovative technologies, and a growing literature on barriers to adopting Industry 4.0 technologies. Where appropriate, this section of the chapter places the relatively recent literature on barriers to adopting Industry 4.0 technologies within the context of the broader long-standing literature on barriers to technology adoption and to the diffusion of new technologies.

The academic literature on 'barriers' has developed many frameworks or taxonomies for categorising barriers in specific contexts, such as barriers to energy efficiency (Sorrell et al, 2004; Grein & Pehnt, 2011; Dunstan et al, 2011; Cagno et al, 2013). Acknowledging the scope for debate about the precise categorisation of barriers, this chapter applies a typology that is based on the consensus of the literature on barriers to Industry 4.0 technology adoption. This typology is applied to identify and promote understanding of the main barriers to Industry 4.0 technology adoption for the purpose of this report. It is not intended to contribute to debates about typologies of barriers. That said, there is a very high level of agreement in the published literature about the following four broad categories of barriers to the adoption of Industry 4.0 technologies:

3.1.1 Introduction

The academic literature on 'barriers' has developed many frameworks or taxonomies for categorising barriers (Green & Pehnt, 2011; Dunstan et al, 2011). This report does not attempt to progress debates about how to categorise barriers. Acknowledging the scope for debate about the precise categorisation of barriers, and that there is no universally accepted framework, this chapter applies a typology that draws on the consensus of the literature *specifically* on barriers to Industry 4.0 technology adoption. For example, while it would have been possible to apply a PESTLE (Political, Economic, Social, Technological, Legal and Environmental) analysis of barriers (Mlecnik et al, 2020), this approach is far from generally applied and does not add substantially to the categories of barriers identified in the literature on Industry 4.0 adoption. There is a very high level of agreement in the literature about the following four broad categories of barriers to the adoption of Industry 4.0 technologies:

1. Technological
2. Economic
3. Legal and regulatory
4. Social

There are more specific sub-categories of barriers falling within each of these four general categories of barriers. The general categories of barriers and the specific sub-categories are introduced and set out in Figure 17; and subsequently expanded upon in this section of the chapter.

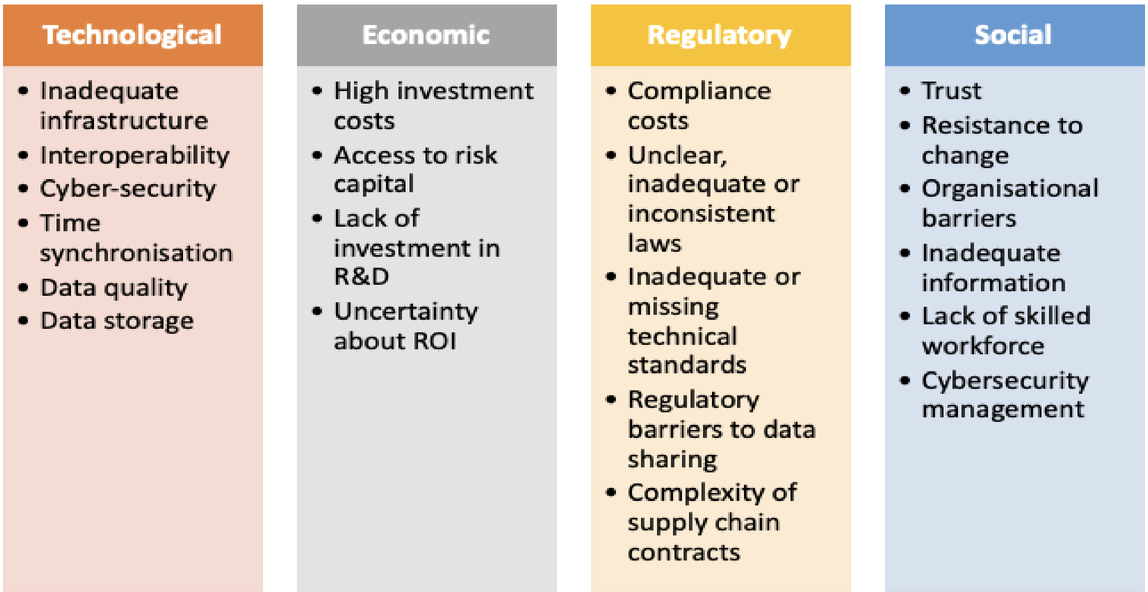


Figure 17. Barriers to Industry 4.0

There is some artificiality in separating out the barriers to technology adoption in this way, especially as there are important interactions between the identified barriers. For example, adopting state-of-the-art technological solutions may be costly, meaning that technological barriers cannot be considered separately from economic barriers. Moreover, the adoption of the most appropriate technologies for particular applications depends on an understanding of the technologies, namely technological literacy, meaning that social barriers must also be taken into account. In reading the material under each of the categories of barriers, it is therefore important to consider the barriers holistically; and this is emphasised in the discussion that follows.

3.1.1.1 Technological barriers

Technological barriers are barriers that 'hinder the adoption of Industry 4.0 as a consequence of the limitations of key technologies' (Obiso et al, 2019, p. 237). The key enabling technologies for Industry 4.0 systems include cyber-physical systems (CPS), cloud computing, industrial Internet of Things (IoT) and AI systems. Technological barriers may consist of limited access to appropriate hardware or software or where 'the use of the technology is perceived as not being sufficient to perform the tasks or accomplish the objectives for which the technology was initially utilized' (O'Connor et al, 2016). This illustrates the extent to which barriers may arise not only from inadequate access to technologies, but from perceptions about the adequacy of technological solutions.

Technological barriers may arise from either the supply-side or the demand-side (Weigelt & Sarkar, 2009). For example, technology suppliers may design technologies that fail to adequately take into account the needs or preferences of users (Glass et al, 2018). Furthermore, a barrier to adoption might arise where suppliers are not able to effectively communicate the performance characteristics of particular technologies to potential adopters. On the other hand, as further explained in the section of the report on social barriers, adopters of technology need to implement training and other institutional systems to ensure that technologies, such as cyber-security technologies, are effectively implemented. It is therefore important to appreciate that failure to effectively understand or implement a technology, which are more properly social barriers, are as much or more of a barrier to technology adoption as the limitations of the technologies themselves. Supply chains including advisers, product retailers and installers must also support technologies. These barriers may have disproportionate impacts on firms with limited resources, such as start-ups and SMEs (Glass et al, 2018).

The main general technological barriers to the adoption of Industry 4.0 technologies include: (*i*) lack of adequate infrastructure (especially in supply chains); (*ii*) insufficient integration/interoperability across technologies; (*iii*) cyber-security; (*iv*) barriers to real time communications (time synchronisation); (*v*) data quality; and (*vi*) the challenges of distributed data storage.

Lack of adequate infrastructure

Many of the advantages of Industry 4.0 technologies arise from their potential to achieve greater integration and optimisation within firms, between enterprises and along supply chains. These advantages, however, are achievable only if there is sufficient connectivity, and the associated capabilities for sharing and processing data.

At the most general level, adequate communications, IT and energy infrastructures are fundamental pre-requisites for the adoption of Industry 4.0 technologies. As Kumar et al (2021, p. 89) state:

> To implement industry 4.0 successfully, the manufacturing organizations must have sufficient and capable technological infrastructure like reliable high-speed connectivity, uninterrupted energy supply, and IoT architecture for cyber-physical systems in their manufacturing environment. It is the most significant factor which plays [a] vital role in successful implementation of industry 4.0 technologies. Unless this barrier is mitigated, the focus on mitigating other barriers may not be effective.

At a minimum, implementing Industry 4.0 technologies depends upon access to affordable and reliable broadband technologies. As Andrews et al (2018, p. 7) highlight, high quality broadband infrastructure is essential to the adoption of more sophisticated technologies, and 'constitutes the backbone of a digital economy'. Given that Industry 4.0 technologies are really a 'constellation of innovations' (Perez, 2010), broadband represents only one part of the picture. For industry to take full advantage of Industry 4.0, it is also necessary for affordable access to other relevant enabling technologies, including cloud computing, IoT, cyber-physical systems and AI systems (Martinelli et al, 2019; Sauer et al, 2021). Affordable access is clearly especially important for firms, such as SMEs, suffering from resource constraints. If access to enabling infrastructure is confined to large firms or industry incumbents, this may well skew innovation and prevent some of the broader potential benefits of Industry 4.0 technologies. On the other hand, large established businesses could be slow movers because of their 'sunk capital', while innovative SMEs may face fewer obstacles to adoption of new business models.

Poor integration/interoperability across technologies

Industry 4.0 technologies promise to deliver efficiencies through cost-effective integration of processes across supply chains and businesses. Liao et al (2017, p. 3621; see also Zeid et al, 2019) have identified the following three forms of integration of IT systems:

- *Horizontal Integration:* integration of IT systems used in stages of manufacturing and business planning both within a firm (inbound logistics, production, outbound logistics, marketing) and between firms (value networks).
- *Vertical Integration:* integration of IT systems at different hierarchical levels (for example, actuator and sensor level, manufacturing and execution level, production management level and corporate planning level).
- *End-to-end Integration:* integration across the entire value chain and across different firms.

Integration of processes at each of these three levels can be impeded by systems that are insufficiently interoperable. There are multiple technical definitions of 'interoperability' (Zeid et al, 2019), but the IEEE Standard Computer Dictionary defines it as 'the ability of two or more systems or components to exchange information and to use the information that has been exchanged' (IEEE, 1991).

Barriers to interoperability may be technological, but they can also include barriers arising from organisational structures or barriers relating to different data formats (Venâncio et al, 2018; Staples et al, 2017). The latter is raised later in this report in the section dealing with 'data quality'. Technological barriers to interoperability include problems relating to incompatible standards, with different suppliers of technologies, such as industrial IoT or cloud computing, promoting different proprietary standards (Martinelli, 2019), and overlapping standards inhibiting adoption (Kemmerer, 2009). Moreover, new technologies often may not be fully compatible with existing legacy systems (Choi et al, 2020). As Burns et al (2019) put it, establishing a sufficient level of interoperability for Industry 4.0 technologies requires 'arranging complex and partially competing standards on a multitude of communication levels such as device integration, event processing, data management integration and cloud operations' (p. 647). In the absence of such measures, data and information systems may be confined to silos, unable to be accessed or used across value chains.

The Manufacturing Interoperability Program at the U.S. National Institute of Standards and Technology (NIST) has identified the following factors as being particularly important in affecting interoperability (Kemmerer, 2019, p. 7; see also Zeid et al, 2019):

- Attempting data exchange between commercially similar or dissimilar systems.
- Attempting data exchange between same-vendor software but with different versions on each machine.
- Upward and downward compatibility between software versions.
- Misinterpreting definitions or the meaning of terms used to structure data exchange or interpret the meaning of that which is exchanged.
- Not using a recognized normative documentary standard upon which exchange data are formatted and based.
- No means of consistently testing self-declared conformant applications to ensure correct communication, one system to the other.

A key issue in overcoming technological barriers to interoperability is the establishment of standardised service interfaces (Boss et al, 2020). As the *German Standardization Roadmap Industrie 4.0* (Standardization Council Industrie 4.0, v. 4, 2020, p. 44) puts it:

> There should be an open IT backbone with standardized interfaces for the versatile automation of the factory of the future as the basis for an ecosystem, including data-driven services for artificial intelligence.

Standardised interfaces can be promoted within the context of a reference architecture model. Consequently, the roadmap set out in Chapter 7 of this report includes a project for overcoming barriers to interoperability by progressing reference architecture models for Industry 4.0 technologies in the energy sector.

Reference architecture models are guidelines for the development of system, solution and application architectures, with the purpose of providing a roadmap for the use of standards (Burns et al, 2019). One prominent model, developed in Germany, is RAMI 4.0 (Reference Architect Model Industry 4.0), which has subsequently become an international standard, published as IEC PAS 63088. RAMI 4.0 is a three-dimensional layered model that represents a basic architecture for Industry 4.0 using a coordinate system. In essence, RAMI is a sort of 3D map of Industry 4.0 solutions, which allows the requirements of sectors to be plotted together with national and international standards (Gotz, 2016). RAMI is, however, not the only reference architecture model. For example, the Industrial Internet Reference Architecture (IIRA), developed by the Industrial Internet Consortium Architecture Task Group, sets out a layered common framework for system engineering. Unlike RAMI, however, the IIRA is aimed at supporting design and not implementation, meaning that standards are not given the same importance (Burns et al, 2019).

Cyber security

Industry 4.0 technologies are premised on interconnectivity, interoperability and data sharing (often real-time) at scale. The highly interconnected nature of Industry 4.0 systems renders them vulnerable to security breaches, including malicious exploits, cyber-espionage, ransomware, spear phishing and unintended data breaches. Moreover, security breaches in one part of a supply chain can have implications for all parties involved with integrated systems, including remote third parties. In addition, as attacks on cyber-physical systems may obviously have physical consequences, the potential harms can be of a different order to cybersecurity threats in the virtual world. These risks become more pronounced with the implementation of machine-to-machine communications and automated decisions based on AI and machine learning algorithms (Dhirani et al, 2021).

As a 2017 report on *Industry 4.0 and cybersecurity* by Waslo et al states (Waslo et al, 2017, p. 3):

> As threat vectors radically expand with the advent of Industry 4.0, new risks should be considered and addressed. Put simply, the challenge of implementing a *secure*, *vigilant*, and *resilient* cyber risk strategy is different in the age of Industry 4.0. When supply chains, factories, customers, and operations are connected, the risks posed by cyber threats become all the greater and potentially farther reaching.

General surveys of barriers to the adoption of Industry 4.0 technologies invariably nominate concerns about cybersecurity risks as an important barrier (Obiso et al, 2019; Raj et al, 2019).

There are many ways of categorising cybersecurity risks for Industry 4.0 technologies. For example, Pandey et al (2019) group cyber security risks for Industry 4.0 in the following three categories.

- *Supply risk* – refers to 'the probability of an event associated with the inbound supply that might cause failures from supplier(s) or the supply market' (p. 115).
- *Operational risk* – refers to 'the possibility of an event that affects the firm's internal ability to produce goods and services; quality and timeliness of production; and profitability of the company' (p. 115).
- *Demand risk* – refers to 'the probability of an event related to outward flows that might affect ... customers' (p. 116).

Dhirani et al (2021) identify a range of specific security issues associated with Industrial IoT (IIoT) technologies, including:

- Lack of convergence between IT and Operational Technology (OT). While the IT sector has focused on the security of applications, services and supporting technologies, OT has traditionally focused on the availability and integrity of Industrial Control Systems (ICS). Yet, Industry 4.0 technologies are aimed at integrating IT and OT systems. A lack of convergence between these two approaches and systems may give rise to security vulnerabilities.
- Industry 4.0 technologies, such as IoT and machine-to-machine (M2M) communications are characterised by the use of new technologies, such as Time Sensitive Networking (TSN), which may be accompanied by new vulnerabilities.
- Industry 4.0 systems involve multiple parties, such as vendors, software service providers and cloud service providers. It may be difficult to coordinate security between these parties which, in the event of problems, can result in 'finger pointing'.
- The complexity and potential overlapping of technology standards that apply to the security of Industry 4.0 technologies, which can create uncertainty and security vulnerabilities.
- Incompatibilities between systems, such as incompatibilities between new technologies and legacy systems, can create security weaknesses.

Comprehensive systems have been developed for categorising cybersecurity threats, such as the European Union Agency for Cybersecurity's (ENISA's) taxonomy of security threats for 5G networks (ENISA, 1st ed, 2019). For the purposes of this report, however, ENISA's 2019 analysis of the cybersecurity challenges facing Industry 4.0 technologies is of more immediate relevance (Malatras et al, 2019). In that report, ENISA identified security challenges relating to people, processes and technologies, which can be summarised as follows:

People

- Need to foster and align IT/OT security expertise and awareness
- Incomplete organisational policies and reluctance to fund security

Processes

- Liability over Industry 4.0 products' lifecycle is poorly defined
- Fragmentation of Industry 4.0 security technical standards
- Supply chain management complexity

Technology

- Interoperability of Industry 4.0 devices, platforms and frameworks
- Technical constraints hampering security in Industry 4.0 and smart manufacturing

Real-time communications (time synchronisation)

Industry 4.0 technologies depend upon high throughput and low latency, and usually incorporate real-time communications (Alcácer & Cruz-Machado, 2019; Dhirani et al, 2021; Liagkou et al, 2021). A key advantage of these systems is that they enable large scale data collection and processing, which can be leveraged to make critical real-time or near-real-time decisions (Waslo et al, 2017).

The extent to which Industry 4.0 technologies are based on real-time communications and decision-making creates challenges that were not faced by previous generations of technologies. For example, communications using Time Sensitive Network (TSN) standards must address the following requirements:

1. Time synchronisation: All devices that are participating in real-time communication need to have a common understanding of time;
2. Scheduling and traffic shaping: All devices that are participating in real-time communication must adhere to the same rules in processing and forwarding communication packets;
3. Selection of communication paths, path reservations and fault-tolerance: All devices that are participating in real-time communication must adhere to the same rules in selecting communication paths and in reserving bandwidth and time slots, possibly utilising more than one simultaneous path to achieve fault-tolerance.

The dependence of Industry 4.0 systems on real-time processes creates the potential for critical failures if systems are not properly integrated and synchronised. Real-time systems add complexity, meaning that integration may be more difficult. For example, as Al Amri et al (2021) point out in relation to construction sites, some sectors are characterised by high variability and unpredictability, making time synchronisation of supply chains especially challenging. Furthermore, there are trade-offs between performance and safety: safe systems are conventionally built on multiple redundancies, whereas time-sensitive networks must in general be as simple as possible. Additional complexities arise from the need for real-time monitoring of the performance of real-time systems. For example, with real-time communications it becomes more difficult for timely detection of security breaches. In this sense, the move to real-time processes can exacerbate existing technological challenges.

Overall, the security challenge posed by real-time systems makes it more important to establish effective security safeguards, which may mean establishing different levels of protection for different categories of data. As Waslo et al (2017, p. 5) explain this difficult challenge:

> As the DSN [digital supply network] evolves, one expected outcome is the creation of a network that allows real-time, dynamic pricing of materials or goods based upon the demand of purchasers relative to the supply available. But a responsive, agile network of this nature is made possible only by open data sharing from all participants in the supply network, which creates a significant hurdle; it will likely be difficult to strike a balance between allowing transparency for some data and maintaining security for other information.

Data quality

Industry 4.0 technologies, such as the IoT and machine learning, are based on the collection and processing of often heterogeneous data sets at scale. Moreover, as Raptis et al (2019, p. 3) point out, in the context of Industry 4.0:

> Data is what enables the integration of the two worlds (physical and cyber), what enables digital twins to interact, what enables digital twins to represent their physical counterparts, what enables knowledge extraction.

The usability of a data set – how it can be collected, transformed and used to achieve certain goals - depends upon data quality. While data held in databases will be structured, a lot of data used in Industry 4.0 implementations will be unstructured and may, for example, include sensor data, textual data, digital signal data, or visual data. The ABS (ABS, 2009) *Data Quality Framework* lists the following seven dimensions of data quality, each of which is important in assessing the quality of a data set: institutional environment, relevance, timeliness, accuracy, coherence, interpretability and accessibility.

For almost all data sets, including structured data sets, some pre-processing of data, sometimes known as 'data wrangling', is commonly required before it can be usable (Torres et al, 2019). In other words, the efficient representation, access, and analysis of data sets, especially of unstructured or semi-structured data, presents significant challenges. In the context of AI systems, Torres et al (2019, p. 19) have identified the following pre-processing techniques:

- *Data cleaning* – which is needed to deal with duplicated or missing data, outliers or noisy data (i.e., data containing random values).
- *Data transformation and data reduction* – which are methods applied to statistical data to ensure that the data are compatible ('normalisation') or removing redundant or unnecessary data ('data reduction').
- *Conflation* – which involves merging the components of two or more data sets.

Each of these processes presents different challenges for effectively managing data-driven applications.

Poor quality data sets, and the costs required to ensure that data quality is sufficient to make it usable, can present real barriers to adopting Industry 4.0 technologies. There are a variety of factors relevant to assessing the barriers posed by poor or inadequate data quality, namely:

- Data contained in legacy systems present particular challenges, such as: inability to link data; standardisation issues between data systems; gaps in metadata; and inconsistent storage formats (Productivity Commission, 2017b, p. 165).
- There are overarching difficulties in standardising data and metadata, with poor metadata reducing discoverability and usability of data sets. As the Productivity Commission (2017b, p. 386) emphasised, standardising data sets and metadata is a key to supporting availability and use of data.
- As the Productivity Commission (2017b, p. 388) also emphasised, a lack of skills in data management and use can be a critical factor in inhibiting improvements to data quality, and the effective and appropriate use of data sets.

- There are issues in separating out different kinds of data, such as separating personal or confidential data from other, less sensitive, data.
- Given the important security challenges facing Industry 4.0 technologies, it is important for data to be appropriately encrypted. The vast amounts of data being collected and used creates challenges for encryption, such as the suitability of existing hashing schemes for large data sets; as does the need to apply different encryption algorithms to heterogeneous data sets.
- Once data is collected and stored, there are challenges in ensuring ongoing data integrity. For example, there may be difficulties in maintaining the integrity of data stored remotely in the cloud which can arise, for example, from inadequate technical information about how the data are stored.

Distributed data storage systems

The sheer scale of data that are collected and used by Industry 4.0 technologies poses particular infrastructure challenges that were not explained previously in this report. The efficient collection, storage and use of large data sets requires significant storage capacity, which will commonly involve distributed storage systems, with data stored on different servers. The more servers that are used, however, the more likelihood there is of server failure. To ensure continued availability of data in the event of server failure, data should be replicated and stored on parallel servers. Yet this, in turn, raises the risk of inconsistencies between data sets. Moreover, the storage of data on distributed systems means that data processes are vulnerable to network failures.

The costs, and challenges, of establishing distributed data storage for Industry 4.0 technologies are therefore of a different kind and order of magnitude than data storage for legacy systems. Distributed storage requires different technologies, management processes and skill sets, to those required for more traditional data processing, and this can present barriers to adoption.

3.1.1.2 Economic barriers

This report defines economic barriers as 'those that discourage the adoption [of Industry 4.0 technologies] as a consequence of perceived high economic risk' (Obiso et al, 2019, p. 237). This definition emphasises the extent to which, for investors, it is perceptions of risk that often present the main economic barrier.

The main economic barriers to the adoption of Industry 4.0 technologies may be generally classified as: (*i*) high (perceived) investment costs; (*ii*) lack of access to risk capital; (*iii*) lack of investment in R&D; and (*iv*) uncertainty about economic returns, including a failure to recognise the full economic benefits of Industry 4.0 technologies.

There are complex interdependencies between these barriers; but to aid clarity of understanding, they are dealt with separately in what follows. Before turning to these sub-categories of barriers, it is important to first understand the particular challenges facing investment decisions in transformative technologies, which are commonly known as 'deep tech' or 'tough tech'. These challenges establish the context for understanding the sub-categories of economic barriers and are explained in the section immediately following.

The Challenges of Investing in 'Deep Tech' and 'Tough Tech'

There are particular challenges confronting investing in what has become known as 'deep tech' and 'tough tech'. According to the Boston Consulting Group (BCG) (de la Tour & Portincaso, 2020), 'deep tech' ventures are characterised by the following four features:

- They are problem-oriented, often working on solving large fundamental problems, such as those falling within the UN Sustainable Development Goals.
- They look at using the best existing or emerging technologies to solve the relevant problem, which commonly involves a combination of at least two new or emerging technologies.
- They build upon transformative digital technologies, often involving advanced data analytics, commonly to produce physical products.
- They are part of a deep inter-connected R&D ecosystem, which can involve links among private sector firms, universities, research labs and government.

They also often involve redefining of the nature of the services provided, or challenging deeply ingrained assumptions about 'how things are done'. They may therefore be disruptive and put returns on 'sunk' intellectual and physical infrastructure investments at risk.

'Deep tech' ventures are sometimes referred to as 'tough tech' which, strictly speaking, refers to ventures, commonly involving breakthroughs in science or nascent technologies, that share characteristics that make them a 'poor fit' for venture capital investment (Nanda, 2020). In particular, 'deep tech' and 'tough tech' ventures involve investments with both long lead times for returns and substantial technology risk.

As a 2020 report from the BCG (de la Tour & Portincaso, 2020) explains, a number of paradoxes have been identified arising from investment decisions involving 'deep tech' and 'tough tech'. For example, while these technologies are commonly characterised as being risky, failure to invest may be riskier as the technologies may disrupt whole industries. Moreover, barriers to raising funds for 'deep tech' ventures appear to be increasing at the very time that barriers to technological innovation may be falling.

According to the BCG report, the investment challenges faced by 'deep tech' or 'tough tech' ventures suggests the need for reframing investment strategies, including:

- Growing in-house knowledge and building an inter-connected ecosystem to support innovation.
- Favouring risk mitigation over risk minimisation.
- Embracing new investment models and financing tools, including taking into account longer timelines for returns on investments.
- Emphasising the society-wide benefits of investments directed towards achieving the Sustainable Development Goals and mitigating climate concerns, and recognising the reputational value for businesses as well as the new networks and potentially higher value markets that can be accessed.

Unless and until traditional investment strategies are modified to take into account the very different context for investing in 'deep tech' or 'tough tech' ventures when compared with traditional investments, the specific economic barriers identified in this section of the report will continue to present obstacles to the adoption of Industry 4.0 technologies.

High (Perceived) Costs of Investment

The perception of high costs of investment in new technologies can be one of the most significant barriers to technology adoption (Marchi & Zagnoni, 2017). For example, in a 2021 study of Industry 4.0 technology adoption by Italian businesses, Cugno et al found that financial and economic barriers could outweigh incentives, including government incentives, for the adoption of Industry 4.0 technologies (Cugno et al, 2021). While there are government programs aimed at supporting energy efficiency, there are problems in accessing government support: the time and effort involved in qualifying for government incentives often outweighs the likely benefits and there is a lack of awareness of relevant programs.

Perceived costs of investment may lead to adoption of technologies being delayed or rejected due to factors including (Obiso et al, 2019; Kleijnen et al, 2009):

1. the perception that innovative technologies have higher investment costs than established technologies and, accordingly, longer periods for achieving returns on investment (ROI);
2. the perception that the costs of new technologies will become lower in the future, meaning that it is perceived to be better to defer investment decisions; and
3. a lack of confidence in new technologies, meaning that investment decisions are commonly deferred until technologies are perceived to have matured.

In a 2019 study based on interviews with Australian executives, Cheng et al found that many businesses, especially SMEs, did not invest in Industry 4.0 technologies because of the perception that the technologies were too costly, with a low or slow ROI (Cheng et al, 2020). As the authors argue, however, this perception overlooks the extent to which it is possible for businesses, including SMEs, to adopt particular cost-effective Industry 4.0 solutions. This emphasises how analysis of economic barriers must take a nuanced approach to the context, including the nature of the business and the specific technologies. Moreover, there is often a failure to understand or take into account the full economic benefits that may arise from Industry 4.0 technologies, such as improved reliability, optimisation of capital investment and staff engagement.

SMEs face greater economic hurdles to technology investment than larger businesses due to resource constraints coupled with perceptions that Industry 4.0 are designed predominantly for larger enterprises (Raj et al, 2019; Machado et al, 2021). Schröder (2017) concludes that this results in senior management of SMEs being more cautious about the adoption of Industry 4.0 technologies than management of larger businesses. Moreover, due to the complexity of Industry 4.0 technologies, SMEs may have more doubts about financial returns on technological investments than larger firms (Matt et al (eds), 2020).

The perceived costs of investment are only part of a much larger picture. In making investment decisions in rapidly evolving technologies it is always necessary to take into account not only the ROI but also the Cost of Inaction (COI). For example, investment in a technology may offer a modest short-term ROI but if the COI are significant the investment should still be made. However, as a 2020 study by ABI Research points out, much depends upon the particular use case and the manufacturing site.

Perceptions that Industry 4.0 technologies involve high investment costs relative to ROI therefore may or may not match reality. In the end, however, it is perceptions that may matter more than the actual costs or returns. Without a good understanding of relevant technologies, potential cost savings and benefits, and the potential costs of inaction, it is difficult for business to know whether to invest and, if so, when to invest and what to invest in. Good, accurate information about available technologies and potential cost-savings is therefore essential to address barriers arising from potential misconceptions about investment costs.

Access to Risk Capital

Even where a firm perceives the potential ROI from adopting new technologies as justifying investment, there may be difficulties in attracting risk capital in venture capital markets. In particular, early adopters of new technologies, which are often start-ups or SMEs, may encounter difficulties due to a lack of internal funds and/or insufficient track record to attract investors (Hall & Lerner, 2009). Therefore, inadequate risk capital markets or viable alternatives, such as government seed financing, may present a barrier to investment in new technologies (Andrews et al, 2018). As previously referred to, there are obstacles to accessing existing government programs.

There are significant differences in the availability of risk capital, and the depth of venture capital markets, between countries (Saia et al, 2015; Andrews et al, 2015). This can lead to a gap in the adoption of technologies between firms that depend upon access to national capital markets and global firms, which may have more ready access to global capital markets (Andrews et al, 2015). Further, as Andrews et al (2015) found:

> … in more entrepreneurial industries (i.e. where there is likely to be a greater demand for risk capital), a larger pool of venture capital (relative to GDP) is associated with a smaller productivity gap, relative to less dynamic industries … (Andrews et al, 2015, p. 21).

As explained previously, particular difficulties may arise in relation to 'tough tech' or 'deep tech', which essentially means technologies that have difficulties in attracting venture capital due to relatively long timelines for recovering a ROI (Nanda, 2020). Risk capital is more readily available for technologies where the risk of failure can be managed by either short term returns on investments or mechanisms such as 'staged financing', with financing tied to particular milestones. This can lead to skewed investment incentives, as some technologies ('tough tech') may involve fundamental breakthroughs in science and/or nascent technologies, with substantial risk and long timelines for returns, and therefore have difficulty in attracting risk capital.

In these circumstances, where access to venture capital may pose a barrier to investment, the existence of an effective innovation eco-system - involving industry, government and universities – may be critical to overcoming failures in private capital markets. For example, the U.S. Department of Energy's SBIR grant program has been instrumental in financing start-ups to prototype new technologies, leading to an increased likelihood of attracting private capital for commercialising technologies (Howell, 2017).

As this section of the report has illustrated, access to risk capital is not an absolute barrier to the adoption of Industry 4.0 technologies, as some technologies and applications may always attract investments. There are, however, barriers where venture capital markets fail. There may, in particular, be barriers where there is insufficient depth in national risk capital markets or where investment decisions are skewed in favour of technologies that promise short term returns. This may have particular impacts on innovative start-ups or SMEs seeking to develop or adopt unproven technologies. In these circumstances, measures may need to be considered to establish an investment infrastructure to supplement access to private capital markets. That said, the widespread adoption of new technologies can depend upon take up by early adopters, who may be prepared to pay a premium, which can then result in cost reductions, such as from economies of scale, which can then lead to broader adoption.

Inadequate Investment in R&D

R&D is the driver for Industry 4.0 technologies and, just as the technologies are continually evolving, there is a need for ongoing R&D investment. R&D investment is needed to develop new technologies but, in addition, firms need to invest in R&D in order to adopt and apply Industry 4.0 technologies.

R&D costs are largely sunk costs which produce knowledge. As such, it may be difficult to recover investment costs as, with the exception of patented inventions, it may be impossible to sell 'knowledge', or to achieve a return from the positive externalities arising from knowledge generation that is 'leaked' (Arnold et al, 2014). The presence of substantial spillovers, however, means that the generation of knowledge by a firm may result in benefits for others while the firm may, in turn, benefit from significant externalities from knowledge produced by others (Smith, 2000). This suggests that the social rates of return are likely to exceed private rates, meaning that there are often insufficient private incentives for R&D investment (Martin & Tang, 2007).

The presence of knowledge spillovers and externalities means that collaborative strategies for implementing R&D are important for successful innovation (Cugno et al, 2021). Moreover, the complexity of Industry 4.0 technologies increases the importance of collaboration, especially for SMEs, which may extend to partnerships with universities and research centres (Mittal et al, 2018; Müller et al, 2018). There are, however, obstacles to coordination between potential partners, which can be addressed by the establishment of networks that enable sharing of mutually produced value (Dellerman et al, 2017; Ghanbari et al, 2017).

Uncertainty about economic returns

There have always been uncertainties about the productivity gains of investment in information technologies (Raj et al, 2019). One version of this is known as the 'productivity paradox' (or the 'Solow paradox'), which refers to the historical slowdown in productivity growth in the U.S. in the 1970s and 1980s despite the rapid uptake of information technologies (Brynjolfsson, 1993). A similar gap (or paradox) has been observed between the rapid contemporary uptake of Industry 4.0 technologies, such as AI systems, and continued sluggish productivity growth in the U.S. (Brynjolfsson et al, 2020). Obermaier and Schweikl (2019), investigating the relevance of the 'productivity paradox' for Germany's Industry 4.0 initiative, found that elements of the fourth industrial revolution appear to track the same pattern as the earlier 'computer revolution' (Dold and Speck, 2021). There are several possible explanations of the 'productivity paradox' but, as Brynjolfsson et al (2020) contend, the most compelling appears to be the time it takes for new technologies to be implemented in ways that allow their full economic potential to be realised. As previously pointed out, there are also problems with understanding and evaluating the full economic benefits of Industry 4.0 technologies.

Dold and Speck (2021) link the 'productivity paradox' with the extent to which firms are required to evaluate the potential for digital technologies while profitability remains unclear, thereby complicating investment decisions. As they explain, there are important differences between decisions to invest in Industry 4.0 technologies and other, more conventional, investment decisions. In short, decisions to invest in Industry 4.0 technologies are more complex due to insufficient knowledge of the technologies and higher risk levels. Moreover, the complexity of Industry 4.0 value chains – which require integrated systems and advanced data collection and analysis, as also the RACE for 2030 B1 OA revealed – demand new processes and criteria to evaluate ROI. In other words, the complexity of digital transformation means that it may be difficult to directly link tangible economic benefits to investments, leading to a decoupling of cost and perceived value. A number of other studies have shown that investment in Industry 4.0 technologies may be avoided or deferred due to uncertain amortization schedules and/or uncertain future uses (Geissbauer et al, 2014; Müller et al, 2018; Birkel et al, 2019).

There are therefore considerable uncertainties about the assessment of the economic benefits of investment in Industry 4.0 technologies which may pose barriers to adoption, unless firms adopt a longer term and more holistic view of ROI, and adapt criteria for investment decisions accordingly. Moreover, firms investing in Industry 4.0 technologies must take into account the extent to which, in order to maximise the returns on economic investments, it may be necessary to invest in changes to human resource capabilities and processes (Kache & Seuring, 2017).

3.1.1.3 Legal & Regulatory Barriers

For the purposes of this report, regulatory and legal barriers are defined simply as 'legal (or regulatory) preconditions that discourage adoption of Industry 4.0 technologies' (Obiso et al, 2019, p. 237).

Laws and regulations have a complex relationship with technological innovation (Pelkmans & Renda, 2014). Laws and regulations are necessary to promote responsible innovation by, for example, preventing anti-competitive, unfair and/or unethical practices, protecting consumers, and promoting other social objectives. A well-established literature recognises that regulation can be a significant stimulus to socially beneficial innovation and entrepreneurship (Ashford & Heaton, 1983; Ashford, 2000). For example, the 'Porter hypothesis' posits that cutting-edge firms can benefit economically by being first-movers to comply with new regulations (Porter, 1990; Porter & van den Linde, 1995).

On the other hand, laws and regulations can create barriers to the development and diffusion of new technologies and business practices. For example, laws can present barriers to new and improved products and production processes; discourage research efforts; distort technology choices; or increase uncertainty and the costs of beneficial innovation (OECD, 1997). At the most general level, complying with regulation will increase costs and restrict a firm's freedom to act (Palmer et al, 1995). That said, the impact of regulation on innovation can be quite different depending, for instance, on the form and timing of regulation, and how the costs of compliance are structured and shared. For example, innovators may need to fund expensive testing for compliance with regulations relating to fire safety, electrical safety or noise abatement. While existing firms may already have systems in place to comply with these regulations, the costs of establishing compliance systems may deter new entrants.

Particular difficulties arise in ensuring that laws and regulations are 'fit for purpose' in the context of rapidly changing technologies, such as Industry 4.0 technologies. The difficulties of adapting laws and regulations to rapid technological change are sometimes referred to as the 'Collingridge dilemma' (Hagemann et al, 2018). The Collingridge dilemma (also known as 'too fast or too slow') essentially refers to the trade-off between knowing the impact of a particular technology and regulating it: a technology can either be regulated in the early stages of development which, due to insufficient information about the technology can result in inappropriate regulation, or a 'wait-and-see' approach can be taken, in which case the technology may already have developed to the extent that it becomes impossible to successfully regulate (Collingridge, 1980). This highlights the difficulties of ensuring that laws and regulations are adequately adapted and appropriate to promote socially beneficial innovation while preventing individual and societal harms.

The main general regulatory and legal barriers to the adoption of Industry 4.0 technologies can be grouped into the following categories: (*i*) compliance costs (including for product or process approvals or accreditation, and approvals for operating; (*ii*) unclear, inadequate or inconsistent laws and regulations; (*iii*) inadequate technical standards; (*iv*) barriers to data sharing; and (*v*) complexity of supply chain contracts.

Compliance costs

In a 2020 Information Paper on *Regulatory Technology,* the Productivity Commission identified the following regulatory compliance costs potentially incurred by individuals and businesses (Productivity Commission, 2020, p. 8):

- assessments, approvals, authorisations or accreditation for particular products, processes, occupations, business operations or activities (for example, permits, certifications, development approvals, registrations, licensing or other permissions);
- reporting and conduct obligations, including to a regulator and to the public or customers;
- industry code of conduct requirements; and
- inspections, audits and investigations.

As the Information Paper went on to state (Productivity Commission, 2020, p. 8), there are considerable resources tied-up with regulatory compliance activities, though precise magnitudes are hard to estimate, especially as some compliance activities replicate processes that a business would need to undertake anyway.

Nevertheless, citing the 2015 Australian Chamber of Commerce & Industry *National Red Tape Survey,* the Paper reported that about a quarter of SMEs spent 11 hours or more a week on compliance, and over 20% of businesses spent between $10,000 and $50,000 annually as compliance costs (ACCI, 2015).

At the extreme, compliance may pose an absolute barrier to technology adoption or use as regulations may restrict technologies to licensed users, or over-regulation may stifle innovation. For example, road transport in the UK in the late nineteenth century was notoriously inhibited by 'red flag' laws that required all 'self-propelled vehicles' to be preceded by a person carrying a red flag to warn pedestrians and other vehicles (Eggers & Turley, 2020). The potential compliance costs for investors in Industry 4.0 technologies are vast, and depend upon particular investments, but include complying with data privacy laws and obtaining relevant approvals, such as licences and planning permissions. Otherwise, the potential costs of compliance may act as a financial disincentive for development or use of a technology. Moreover, uncertainty about how a law or regulation can apply to an emerging technology or business practice can increase compliance costs and therefore deter investment in developing and using new technologies. On the other hand, businesses commonly underestimate the extent to which regulatory compliance can assist the business, such as enhancing reputation and consumer trust, and avoiding reputational harm.

Unclear, inadequate or inconsistent laws

With new and emerging technologies, it is not uncommon for there to be uncertainties about how existing laws or regulations apply to the technologies and associated business practices. In the worst case, the laws may prohibit beneficial innovation. For example, laws that create regulated monopolies may present an absolute barrier to entry. Otherwise, a lack of clarity about how laws or regulations apply can inhibit investment and innovation. Furthermore, as implied by the 'Collingridge dilemma', new laws or regulations may not be adequate or well-adapted to technologies, imposing considerable uncertainties and costs on innovators. In some industries, especially network industries such as the energy sector or telecommunications, regulation may deter or skew innovation by favouring incumbents or legacy systems.

Particular challenges arise in the context of 'radical' or breakthrough technologies, which represent fundamental breaks with the past, step changes or paradigm shifts. In her book, *Innovation and the State* (CUP, 2017), Ford distinguishes between 'seismic' or radical innovation and 'sedimentary' or incremental innovations, with radical innovation consisting of change which 'outstrips prior experience' and which has the 'potential to significantly alter the landscape on which regulation operates' (p. 167).

Industry 4.0 technologies, both individually and in combination, represent radical breaks from the past. This may lead to a legal or regulatory vacuum, with the attendant uncertainty inhibiting the adoption of technologies. For example, a 2021 report from the Senate Select Committee on Australia as a Technology and Financial Centre identified regulatory gaps as a barrier to the adoption of digital assets in Australia. The report concluded with the general point that:

> The potential economic opportunities are enormous if Australia is able to create a forward-leaning environment for new and emerging digital asset products. It is clear that Australia needs a robust policy and regulatory framework for digital assets, in order to protect consumers, promote investment in Australia and deliver enhanced market competition. (p. 133).

While new laws or regulations may be needed to support new technologies, they may also create uncertainties which inhibit uptake or impose substantial new compliance costs. It may, moreover, take some time for industry to have certainty about how new laws apply in practice. This point was made, for example, by the UK government when it announced its proposed reforms to the UK data protection regime (based on the GDPR) in September 2021 (Department for Digital, Culture, Media & Sport, 2021, [83]):

> The market is still in the early stages of navigating UK GDPR provisions for the purposes of developing and deploying AI systems, and it is therefore difficult to pin down one particular compliance challenge. Rather, there is general uncertainty among those looking to deploy AI-related tools, or to use personal data to help train system development, about how that activity fits within the current regulatory environment. Currently, an AI practitioner needs to consider each use case individually and work out each time whether the data protection regime permits the activities. This creates doubt and uncertainty which may lead to friction and a potential reduction in innovation.

The emergence of radical new or disruptive technologies may not only expose regulatory gaps, but may exacerbate contradictions or inconsistencies between legal regimes. In a March 2019 report on *Regulating* *in a digital world,* the UK House of Lords Select Committee on Communications observed that, in the face of rapid technological change, legislation was often slow to respond; and that regulation was fragmented and characterised by significant gaps and overlaps. Addressing this overall problem may require reforms that better align existing laws and promote 'joined-up regulation' (World Economic Forum (WEF), 2020). As the WEF has explained:

> The Fourth Industrial Revolution is characterized by technological innovations that straddle sectors and institutions alike. Businesses can often find themselves navigating a patchwork of regulation whose complexity can deter them from introducing new ideas, products and business models. (WEF, 2020, p. 38).

A common example of this problem is the extent to which innovative financial technologies (fintech) may be subject to multiple regulatory regimes, including financial services regulation and data protection (or data privacy) laws, with potentially inconsistent regulatory obligations (Ostman & Dorobantu, 2021).

Apart from over-lapping and potentially inconsistent regulatory regimes, there are issues of regulatory capacity, which may include insufficient understanding of new and emerging technologies. As Tabitha Goldstaub, the Chair of the UK AI Council put it in evidence to a House of Lords committee inquiry into 'joined-up regulation', there seems to be no common 'cognitive, practical or technical' capacity across regulators to confront the challenges posed by AI (House of Lords Select Committee on Communications, 2021, p. 7). In practice, this may lead to inconsistent or uncertain application of existing laws or regulations, even where they may appear clear on their face.

Lack of, or inadequate, technical standards

Standards for product performance, safety and environmental impact can create pressures for firms to innovate, improving quality and upgrading technologies (Porter, 1990). Furthermore, as Schröder (2017) reported, firms (and especially SMEs) often have reservations about adopting Industry 4.0 technologies due to a lack of common technical standards.

As explained in the section on technological barriers, a lack of interoperability or integration can present a barrier to the adoption of Industry 4.0 technologies, especially IoT technologies (Müller & Voigt, 2018; Cugno et al, 2021); and this can be exacerbated by a lack of adequate technical standards or legacy standards that constrain innovative solutions. The automation of data sharing can, in particular, be inhibited by a lack of standards for machine-to-machine communications (Sung, 2018). Similarly, different standards across different elements of a supply chain, or a lack of standardisation of interfaces, presents challenges to data sharing (Müller et al, 2021). Moreover, inadequate security standards can undermine cyber-security, inhibiting sharing of data within and between organisations (Cimini et al, 2017). Overall, a lack of standardisation can prevent or erode trust in data sharing which, as explained in the following section on social barriers, is a significant barrier to the adoption of Industry 4.0 technologies, especially by start-ups and SMEs (Müller et al, 2018).

A good illustration of the importance of adequate and uniform technical standards for technology adoption is the history of initiatives for developing common standards for smart meters in the EU (Pelkmans & Renda, 2014). In 2009, it was found that, across EU member states, there were approximately 110 different technical standards, which presented a barrier to the adoption of technologies such as smart grids. This led to the establishment of the Smart Grids Task Force, which was given the mandate (M/441) of advising the European Commission on regulations to coordinate the implementation of smart grids. The coordination of standards for smart meters was allocated to the Smart Meters Coordination Group, which produced a reference architecture (TR 50572), a glossary of terms, an overview of available standards, Smart Metering Use Cases and an overview of technical requirements including those for privacy and security (European Commission, 2021). In addition, the European Commission supported the creation of a common interoperability language called SAREF ((Smart Appliances Reference ontology), which became a standard of ETSI and OneM2M (the Global initiative for Internet of Things standardisation) in 2015. Work is now progressing on extending SAREF to other sectors, including automotive, health and water, with the aim of establishing a common smart cities architecture.

Legal & regulatory barriers to data sharing

The explosion of data in the 21st century has been accompanied by widespread understanding of the benefits of data sharing, including productivity gains. In its landmark 2017 report on *Data Availability and Use,* the Productivity Commission made the following key points (Productivity Commission, 2017a, p. 2):

- Extraordinary growth in data generation and usability has enabled a kaleidoscope of new business models, products and insights. Data frameworks and protections developed prior to sweeping digitisation need reform.
- Improved data access and use can enable new products and services that transform everyday life, drive efficiency and safety, create productivity gains and allow better decision making.
- The substantive argument for making data more available is that opportunities to use it are largely unknown until the data sources themselves are better known, and until data users have been able to undertake discovery of data.
- Lack of trust by both data custodians and users in existing data access processes and protections and numerous hurdles to sharing and releasing data are choking the use and value of Australia's data. In fact, improving trust community-wide is a key objective.
- Marginal changes to existing structures and legislation will not suffice.

The Productivity Commission report led to the Consumer Data Right (CDR) regime, which was introduced as Part IVD of the *Competition and Consumer Act 2010* (Cth) in 2018. The CDR regime is complex, being intended to facilitate data sharing while protecting consumer rights and interests, including privacy, and with responsibility for the regime being shared by Treasury, the ACCC and the OAIC. In May 2018, the Australian government announced its intention to include energy data in the CDR and, in June 2020, the government designated the energy sector as the second sector (after banking) as a sector covered by the CDR. At the time of writing this report the arrangements for rolling out the CDR in the energy sector are ongoing, and it is too early to determine whether the regime will deliver on the promised benefits. Nevertheless, in his farewell speech delivered in February 2022, the outgoing chair of the ACCC, Rod Sims, while acknowledging the time it has taken for the CDR to be implemented, cautioned against underestimating its longer term benefits (Sims, 2022).

In examining barriers to data sharing, the 2017 Productivity Commission report concluded that (Productivity Commission, 2017b, p. 121):

> Legislation restricting access to data was formulated up to a century ago, and much is no longer fit for purpose. The primary legal impediment to more effective use of data is typically *not* the Privacy Act, but regulations and guidelines specific to the field in which the data is collected.

The report focussed on legal barriers to sharing government or public sector information, identifying the following general obstacles (Productivity Commission, 2017b, p. 129):

- a dense web of legislative requirements;
- a culture of risk aversion, leading to overly cautious interpretation of the legislations, and approval process complexity;
- lack of a whole of government approach (including failures to adequately address machinery of government changes);
- jurisdictional barriers — within and between jurisdictions;
- intellectual property and licensing issues.

Similar, although clearly not identical, barriers exist to data sharing between organisations in the private sector. Moreover, while the Productivity Commission report suggested that the Privacy Act was not the main legal obstacle to data sharing, in his 2022 farewell speech, Rod Sims concluded that 'we will only gain the great benefits possible from data if we improve our privacy laws' (Sims, 2022). The Commonwealth Attorney-General's Department is currently undertaking a comprehensive review of the Privacy Act (A-G's Department, 2021), and a fundamental underlying issue in this review is how privacy law can be reformed to build trust in data sharing.

Laws and regulations - including overlapping, inconsistent or outdated laws – can therefore reinforce data siloing, and pose obstacles to technologies that depend upon data sharing, such as IoT technologies. Much, however, depends upon the particular context of any proposed data sharing, including the kinds of data, the entities that propose to share the data and the proposed uses of the data.

It is not merely laws and regulations that can pose obstacles to data sharing in the private sector. Business practices and contractual arrangements my also prevent access to data, which is increasingly regarded as a significant business asset. For example, in relation to non-residential buildings, Business Management System (BMS) providers commonly restrict access to data by both their clients and third parties, such as consultants. These common practices appear to result from the extent to which control over data is regarded as a source of competitive advantage, and therefore to be aggressively protected. Nevertheless, excessive data control, including through contractual arrangements, clearly inhibits the extent to which data can be used to analyse current business practices and therefore inhibits innovation.

Complexity of contracts

Implementation of Industry 4.0 technologies, such as industrial IoT, in supply chains requires integration of processes between supply chain participants – including sourcing, manufacturing and distribution – and sharing of data (Kembro et al, 2017). The number of participants in supply chains means that they are characterised by a complex nest of contracts which regulate the relationships between participants, including data sharing. Each of these contracts is likely to be lengthy and complex but, nevertheless, contain gaps, omissions and inconsistencies (Frydlinger et al, 2019) and legacy features that can constrain change. They may also incorporate KPIs that may distort behaviour in ways that undermine economic efficiency.

Long, complex and potentially inconsistent contracts arise from an underlying lack of trust between parties, with an accompanying desire to protect against all potential contingencies (Frydlinger et al, 2019). But this can impose significant costs on parties, including the costs of contract management. Just as a lack of coherent and consistent standards can inhibit cooperation and integration, a lack of standardised contracts, or overly complex or inadequate contracts, can inhibit adoption of innovative technologies (Pause et al, 2016).

While Industry 4.0 technologies – specifically smart contracts and blockchain – have been proposed as means to overcome the trust and coordination problems in complex supply chain contracting (Bottoni et al, 2020), there are risks and barriers to the adoption of technological solutions, including security risks (Kirli et at, 2022; Staples et al, 2017). To date, adoption of technological solutions has been patchy, with resistance to the implementation of potential solutions including technological barriers, organisational resistance, and legal and regulatory obstacles (Choi et al, 2020). In the absence of clear and broadly accessible solutions, including technological solutions, the complexity of supply chain contracting remains an obstacle to the successful adoption and implementation of Industry 4.0 technologies to enhance the efficiency of supply chain processes. Also, lack of appreciation of the scale of potential benefits, and fears that others will capture more than their fair share, can constrain the uptake of measures aimed at reducing supply change complexity.

3.1.1.4 Social Barriers

The term social barriers in this context is defined as 'barriers that are associated with human beings, either in an employee perspective or organisational perspective' (Obiso et al, 2018, p 242). In this section of the report, the generic term 'employee' will be used to cover both management and workers, unless an issue relates to just one of these groups.

The main social barriers to the adoption of Industry 4.0 technology include: (*i*) lack of trust in the technology or change process, including fear of being 'locked-in' to one provider; (*ii*) resistance to change among employees; (*iii*) lack of management commitment; (*iv*) institutional barriers relating to the structure, culture or operation style of specific organisations (including organisational 'silos' and procedures associated with allocation of funds and resources); (*v*) inadequate reliable information; (*vi*) the need for digital literacy and, more broadly, literacy in development and communication of business cases across silos and to management; (*vii*) A lack of skilled or competent workforces; and (*viii*) the human rather than technical side of cybersecurity.

As there is little substantive literature directly addressing social barriers to the adoption of Industry 4.0 technologies, this section of the chapter focuses on the literature relating to general social barriers to the adoption of new technologies. The observations made, and the conclusions drawn, from this general literature are applicable to social barriers to the adoption of Industry 4.0 technologies, which are best understood within this broader context.

Lack of trust in the technology or the change process

Perhaps the most fundamental social barrier to change related to Industry 4.0 technologies arises from a lack of trust (and transparency) for managers, workers and the public, alike. Where there is a complex supply chain the trust barriers can be even greater, as each organisation's well-being depends on another part of the supply chain.

Trust is an important element of good relationships and in the success of organisations. 'Trustworthiness' has been described in the literature as a 'condition precedent to the development of trust'. Caldwell & Clapham (2003) set up a model which looked at the elements of trustworthiness in organisations, based on established constructs for interpersonal trustworthiness and which were collectively seen to be subjectively perceived aspects of 'organisational effectiveness'. These included:

- Competence;
- Legal compliance;
- Responsibility to inform;
- Quality assurance;
- Procedural fairness;
- Interactional courtesy; and
- Financial balance.

These factors can be useful in looking at organisational and governmental digital failures and for what might improve the success of such initiatives. A lack of trust in technology and adoption processes often arises from scepticism from seeing failures of previous technological promises or breaches of trust. These can be internal failures, such as where a previously promised change, supported by employees because they were told it would be a benefit to them or the business, either did not deliver or made things worse. There is research evidence that this results in poor trust and low motivation for change (Pardo del Val & Fuentes, 2003).

Perhaps equally damaging to trust in Industry 4.0 solutions is the social influence (Talukder & Quazi, 2011) of examples of high cost technological changes, promised by institutions, like governments, which have been poorly implemented or that have been very public failures. In Australia, these include the fraught implementation of the National Broadband Network (NBN) (Freeman et al, 2019), the implementation of My Health Record (Mendelson & Wolf, 2016) and most recently the implementation of the Commonwealth's COVIDSafe application (Selby, 2021). While these are sometimes seen as failures of government rather than the technologies, the significant resources expended on them creates an image of flawed processes for implementing change. Their limitations and the apparent inability of technical experts to resolve the problems with these systems add to general public scepticism about future promises of the benefits of new technologies, such as Industry 4.0 developments, which can bleed into investment decisions.

General public confidence in the accuracy of predictive technologies, artificial intelligence (AI) and the potential use of 'big data' for socially beneficial purposes has also suffered from the Online Compliance Intervention (also known as 'RoboDebt') (D'Rosario et al 2020). Analysis of the problems with RoboDebt has extended to the combination of Intelligent Process Automation (IPA) and Robotic Process Automation (RPA), both of which are Industry 4.0 technologies. IPA in RoboDebt used a combination of RPA with rudimentary AI. Some of the many problems identified with RoboDebt's development and implementation included systematic bias (Miller, 2019), poorly developed and scrutinised algorithms and a failure to establish human oversight or other appropriate checks and balances. This raises more general questions about the interface between technological and human systems.

One particular area where trust can be damaged in a way that may create a barrier to adoption of Industry 4.0 technologies relates to the 'psychological contract' between employees and employers. As Anderson & Schalk (1998) point out:

> Most employees … develop a positive and enduring psychological bond with their organization, based on a pattern of expectations about what the organization should offer them, and what it is obligated to provide them with. If, whatever the reason may be, the organization is not able or willing to fulfil these expectations and obligations, this may lead to strong emotional reactions.

Significant changes like the introduction of Industry 4.0 technologies can fundamentally change the nature of people's work. For example, if the job of a clerk who has responsibility for making decisions to grant or not grant a benefit is brought into a new system, where a machine does a preliminary consideration of approval, that person's work will change to only considering the complex cases. These may take a lot longer and involve having to draft reasons for rejection, which are likely to be reviewed. It may be that that person saw their role as primarily a beneficent one, but when the task changes, the employee loses that part of their professional identity when mainly dealing with refusals and complex decisions.

Similarly, if a maintenance fitter is moved to supervise a machine with a self-diagnosing system, while his work may get easier, it may also mean fewer people to work with and less interesting 'problem solving'. In both cases, the change managers may see these changes as beneficial for everyone. However, the employees may see these as breaches of the 'psychological contract' and a significant shift in their work identity. Research has shown that negative impacts on the psychological contract can result in strong affective resistance to change and be seen as a breach of trust (Van den Heuvel & Schalk, 2009).

It is recognised that an absence of trust within an organisation and between organisations is a barrier at many levels because 'the cost of building structures and controls that substitute for trust in and between organizations is enormous' (Saunders et al, 2010, foreword). A key component for trust to exist is that there are positive relationships between individuals in an organisation, between the employees and the organisation and between organisations in supply and distribution chains (Cugno et al, 2021, p. 13). For example, where business information needs to be shared for Industry 4.0 developments to work, not only is technical infrastructure required, but also complementary inter-company processes and communication channels need to be developed. Moreover, Industry 4.0 supply chains may involve sharing both costs and benefits. If there is little trust between organisations, the likely cost of creating structures and processes to substitute for trust may make the changes less economically sound and durable.

There are widely recognised risks when trust relationships are neglected in periods of significant technological change. Trust building activities need to be part of any significant change process. In his 1995 book *Trust – the social virtues and the creation of prosperity*, Francis Fukuyama noted the importance of trust building in organisations using information technology, which remain applicable to building trust in Industry 4.0 technologies:

> Trust does not reside in integrated circuits or fibre optic cables. Although it involves an exchange of information, trust is not reducible to information. A virtual firm can have abundant information coming through network wires about its suppliers and contractors. But if they are all crooks or

> frauds, dealing with them will remain a costly process involving complex contracts and time consuming enforcement. (p. 25)

He goes on to say that trust needs to be established through common values, cooperative behaviours and commonly shared norms, and these are prerequisites to building social capital and efficient organisations:

> A high trust society … created networks well before the information revolution got into high gear; a low trust society may never be able to take advantage of the efficiencies that information technology offers (p. 26).
>
> Social capital has major consequences for the nature of the industrial economy that society will be able to create. If people who have to work together in an enterprise trust one another because they are all operating according to a common set of ethical norms, doing business costs less. Such a society will be better able to innovate organizationally, since a high degree of trust will permit a wide variety of social relationships to emerge. (p. 27)

As can be seen below, the creation of trust and support of trust throughout the life of an organisation is of primary importance. If trust is breached, it is quite difficult to gain trust again without acknowledgement, apology and, where appropriate, penance being enacted (Henderson et al, 2019).

Resistance to change

Resistance to change has historically been seen as a reason for failure of change initiatives or as a cause of unpredictable delay and cost in implementation (Pardo del Val & Fuentes, 2003). While much of the literature discusses worker resistance to change, there is also extensive evidence that all employees, including supervisors and managers, can be resistant to change (Pardo del Val & Fuentes, 2003). Such resistance could take a number of forms, including:

> … persistent reduction in output, increase in the number of "quits" and requests for transfer, chronic quarrels, sullen hostility, wildcat or slowdown strikes, and, of course, the expression of a lot of pseudo-logical reasons why the change will not work (Lawrence, 1954, p. 49).

Conceptualisations of resistance to change were therefore almost always categorised as negative from the perspective of those proposing the change:

> By the same token, employee reluctance to go along with [organizational] changes can be labelled pejoratively as 'resistance to change'. By implication, this is to be seen as a generally bad thing and, of course, an irrational thing (Watson, 1982, p. 261).

By the late 1990s there was a growing literature that argued that resistance was often not only a legitimate and effective response to change, but could, if notice was taken of the concerns raised, be constructive (Waddell & Sohal, 1998, p. 544). Those supporting change often automatically viewed the attitudes of those who questioned changes negatively, and this led them 'to dismiss potentially valid employee concerns about proposed changes' (Piderit, 2000, p. 784). This had been recognised and discussed in the literature from the 1950s onwards (Jones & Harris, 1967; Dent, 1999). Psychological research into group dynamics had commenced with the work of Karl Lewin in the 1940s (Lewin, 1947; Burnes, 2004).

This had already identified the complex nature of resistance to change, but up to the 1990s, much of this work had failed to create new ways of achieving change in organisations:

> The concept of resistance to change which can be traced to Lewin's systems approach, has been transformed over the years into a not-so-disguised way of blaming the less powerful for unsatisfactory results of change efforts. How many times, after all, have we seen organizations attempt to change without tackling the really difficult issues, whether they be issues of structure, compensation, and so on? When the magical thinking comes to a crashing disappointment, blaming the lower-downs for being resistant is a readily available explanation (perhaps a kind of mantra) that can be mobilized to account for the distressing results. (Krantz, 1999)

Resistance to change is now described more neutrally as an ambivalent attitude to change - an individual's propensity to evaluate a particular [proposal] with some degree of favourability or unfavourability (Piderit, 2000; Eagly, 2007). But the behaviours associated with resistance to change, grouped together as resistance and inertia, are not necessarily negative. In fact, resistance to change can act as an antidote to group-think and facilitate consideration of alternative solutions to the change or to address the reasons given for change (Waddell & Sohal, 1998). As put succinctly by one author, '[r]esistance keeps people from attaching themselves to every boneheaded idea that comes down the pike.' (Maurer, 1996, p. 57). It is also salient to recognise that expressions of resistance to change can be a risky strategy for most employees:

> Rarely do individuals form resistant attitudes or express such attitudes in acts of dissent or protest, without considering the potential negative consequences for themselves. … Thus, frivolous expression of resistance seems unlikely, since individuals who engage in it could face severe penalties and are aware that they should tread lightly. … [W]hat some may perceive as disrespectful or unfounded opposition might also be motivated by individuals' ethical principles or by their desire to protect the organization's best interests (Piderit, 2000, pp. 784-785).

Overall, the degree of resistance to change has been shown to be influenced by a range of factors at both the development and implementation stage. Analysis of these factors has found that deep-rooted values are the largest source of resistance or inertia to change (Pardo del Val & Fuentes, 2003).

Lack of management commitment

Transformational change is highly dependent upon the support of those with positional power. For example, studies of failures in implementation of total quality management (TQM) systems in the 1990s in Australia concluded that their failure to achieve their full potential was 'mainly due to the absence of Chief Executive Officer commitment and the failure of managers to recognize the link between TQM practice and organizational performance' (Terziovski et al, 1999). Colwell & Joshi (2013) showed that corporate ecological responsiveness and change was enhanced when there was a combination of both institutional pressure, such as from shareholders or customers, and when top management commitment was high (p.73).

Greenwood & Hinings (1996) noted that there are two critical factors in effecting organisational change – first, a commitment to reform and, second, a capacity to change. They also note that 'organizationally defined groups vary in their ability to influence organizational change because they have differential power':

> Some groups and individuals are listened to more keenly than others. Some have more potential or less potential for enabling or resisting change. The relations of power and domination that enable some organizational members to constitute and recreate organizational structures according to their preferences thus becomes a critical point of focus. The operation of values and interests can be conceptualized and understood only in relation to the differential of power of groups. Hence, in a situation of a competitive pattern of commitment, radical change would not be the likely outcome, unless those in positions of privilege and power were in favour of the proposed change. Power dependencies either enable or suppress radical organizational change (p. 1038).

As well as requiring top management support, lack of commitment to change in middle management and supervisors can act as a significant practical barrier to change implementation (Pardo del Val & Fuentes 2003). In all cases, there is evidence that leaders often spend 'too much energy on the mechanical and financial aspects of the consolidation and not enough on the cultural integration' (Whipple 2014, Introduction). These observations are equally applicable to the attitudes and practices of management in the adoption of Industry 4.0 technologies.

Institutional barriers

The capacity for a business to successfully adopt transformational change can be affected by the structure, culture or operation style of specific organisations. The example of high trust organisations, discussed above, is one example. If an organisation has low levels of trust and is adversarial in its dealing with staff concerns, then it is likely to promote active resistance to change, in a manner which is likely not to be positive, as described in the section above on 'resistance to change'.

Rothwell (1992) noted that while having a change champion was helpful to maintain the impetus for change and to problem solve when major difficulties arose, their utility for the task depended very much on the climate and culture of the organisation as well as the person's positional power:

> Project champions are especially effective in flat, flexible integrated organisations. In hierarchical and bureaucratic organisations [their] endeavours are often ineffective unless [they] have sufficient power and authority to positively influence the course of the project and 'push' it across internal barriers to change. The presence of effective product champions is strongly associated with innovative success (Rothwell, 1992).

Rothwell went on to describe what he called the 'fifth generation innovation process', known as Systems Integration and Networking modelling (SIN), which he describes as 'the electronification of innovation' using a wide range of technologies. It includes strong links to customers, suppliers and employees, and many collaborative mechanisms to assist the process and shape it. It also extends to an emphasis on corporate flexibility and an increased focus on quality and other non-price factors (Rothwell, 1992, pp. 236-237 and Table 4). Almost 30 years on, the adoption of these same kinds of mechanisms and drivers is still assisting to overcome institutional barriers to adoption of Industry 4.0 (Obiso et al, 2019, pp. 235-236).

The lack of a focus on employee and organisation learning can also be an institutional barrier. Scott & McMurray (2021, p. 280) noted that 'having an organization that allows for its personnel to involve themselves in learning and knowledge creation can be a vital element in promoting innovation' and that such learning can be enhanced by the length of tenure of organizational personnel and … employees with longer organizational tenure tend to foster a more collaborative culture and thus promote knowledge sharing and workplace innovation'.

Other elements of organisational climate and culture (both organisational and national) which research has been shown to positively influence innovation in workplaces include:

- Having a quality-oriented culture with an internal and external customer focus (Rothwell, 1992);
- Non-hierarchical structures, where there is frequent interaction between people at different levels of the organisation and relationships and a shared culture is able to develop (Hope-Hailey et al, 2010);
- Building trust before change and then maintaining it during the change process, and making your words about values and your actions consistent (Whipple, 2014, Chapter 2 especially Figure 2.1 and chapter 14, pp. 124-126); and
- The fostering of social capital through habituation of moral or ethical norms within an organisation to create a community with shared ethical values (Fukuyama, 1996, pp. 26-27).

Inadequate reliable information

When a transformational change is commenced, sometimes people are concerned to not unduly frighten other people when the plan is still in development, and so they do not communicate fully about what is happening. Resistance and inertia towards the changes are strongly influenced by these failures of communication (Pardo del Val & Fuentes, 2003). Access to reliable information and good communication of it is particularly important in any widespread change process:

> Without an understanding of where the organization wishes to go, and the engagement of its employees as internal stakeholders, organizational change faces innumerable difficulties. … [I]nternal communication and organizational change approaches share common influencing factors such as management styles, leadership approaches, and organizational structures and culture. With deeper examination, the two constructs also interact and affect one another in determining the success or failure of change. (Richet, 2016)

Information shortage leaves a vacuum for rumour and sense-making assumptions based on previous experience or organisational cultural defaults, which may or may not lead to success. Similarly, employees need to all be included in the development of a new vision for their work if they are to be asked to support a transition. Salem describes common communication behaviours and consequences in failed organisational change efforts in the following way:

> Communication during failed efforts seldom involves enough communication opportunities, lacks any sense of emerging identification, engenders distrust and lack productive humour. These problems are compounded by conflict avoidance and a lack of interpersonal communication skills. Members decouple the system, sheltering the existing culture until it is safe for it to re-emerge later (Salem, 2008, p. 333).

Welch & Jackson (2007) proposed a stakeholder approach to internal communication, which emphasises ethical management behaviours. Under this model, the success or failure of internal communications around change should be assessed on four factors:

1. Employee awareness of environmental change and flow of information in a two-way manner;

2. Employee understanding of the need for organizational change;
3. Employee engagement where they feel a sense of belonging and that internal communication is participative; and
4. Employee commitment reflected in strong internal relationships (Richet, 2016, p. 296; Welch & Jackson 2007).

All of these strategies are about open timely communication, participative decision-making, shared development, good relationships and mutual respect – each being exhibited through good communication of information and discussion of values and processes. Richet also recommends reducing uncertainty as it contributes to group resistance, as well as the important role of direct supervisors and clear messages in any crisis communication (Richet 2016, p. 297). Given the transformative changes associated with Industry 4.0 technologies, inadequate communication of reliable information by management can be an especially important barrier.

The need for digital literacy

With the introduction and expansion of Industry 4.0 technologies, employees will need to be digitally literate to the extent necessary to do their work. There are practical barriers to addressing this in Australia, including the costs of training for those needing to upskill.

Given the likely development timeframe of these transitions, education and training for staff who wish to remain must be made available; and previous experience with digital work is likely to vary considerably across ages and work experiences.

A representative survey of the Australian community undertaken in mid-2020 supports digital literacy skills being taught to existing workers as a part of the transition to use of these technologies. The report of the survey, which was about Australians' level of trust in AI, emphasised the importance of 'just transitions' when new technologies fundamentally changed the nature of some jobs:

> In the event their jobs are automated, employees clearly expect to be given fair notice and provided with opportunities to retrain or be redeployed. Many Australians believe AI will eliminate more jobs than it creates, making this a real threat. Living up to employees' expectations in the event of automation will require strategic long-range workforce planning and retraining opportunities that are available to employees of all ages (Lockey et al, 2020, p. 50).

These observations emphasise the importance of addressing the need for digital literacy within a broader transition strategy.

There is also a need to improve literacy about the possible socially positive uses for new technology. There is growing public discussion and concern about the use of algorithms and data in the management of familiar social media technologies to manipulate our attention, often to sell products and influence our behaviours in other ways consumers are not consciously aware of (Alter, 2017; Williams, 2018; Zuboff, 2019; Seymour, 2019; McNamee, 2019; Hari, 2022). These discussions can lead to greater public distrust of Industry 4.0 technologies more broadly, bleeding into attitudes about their use by industry. In the *Trust in Artificial Intelligence* Report (Lockey et al, 2020), this broader form of literacy education was seen as an important way of overcoming the barrier of public resistance to the introduction of AI and other technologies (Lockey et al, 2020, p. 51):

> Educating the community about what AI is and when and how it is being used is important for a range of reasons. First, despite the current low awareness and understanding, the community have strong views on the regulation, use and design of AI. Increasing public literacy will assist in ensuring these views are well informed. Second, the more informed citizens, consumers and employees are about AI, the better able they will be to seize the benefits of such systems, while identifying and appropriately managing the associated risks (e.g. of data sharing and privacy). Third, AI literacy is fundamental to the public's ability to contribute to effective public policy and debate on the stewardship of AI in society, and facilitate meaningful consultation with the public on AI design (Lockey et al, 2020, p. 51).

Similar strategies across all of the various Industry 4.0 technologies could be used to address barriers arising from a poor digital literacy, particularly where their use can assist with social goods, such as improving energy productivity and decarbonisation of business, homes and the economy. This objective is included in Australia's AI Action Plan 2021, where the government has committed to work on improving the education of the Australian public to address the trust deficit relating to AI, through forums such as *Techtonic*, 'where the benefits and uses of AI can be promoted and shared' (AI Action Plan 2021, p. 20).

A lack of skilled or competent workforces

It is recognised that organisations sometimes reject innovations involving Industry 4.0 technologies for fear that skilled workers won't be available and are in short supply. Flanding et al (2019) note that 'no matter how intuitive digital-era technologies supposedly are, workers will be ill-equipped to use these new applications so technology adoption must be accompanied by investment in training' (p. 166). Other articles from the industry perspective raise this and its corresponding issue of 'technological unemployment' for those who cannot or do not want to learn these new skills (Obiso et al 2019, p243).

There are repeated references in the literature for the need to include Industry 4.0 technologies in university courses such as engineering, and to enable the development of courses to teach missing skills in, for example, data analytics and Big Data. Predictions by the US Department of Labor as long ago as 2013 noted that there would be a shortage of between 120,000 and 190,000 of people with Big Data skills in the USA by 2018, and it seems likely that internationally, these shortages have expanded further (Alharthi et al 2017, Table 2).

The overall constraint of higher educational spending seems likely to also be constraining the potential to train employees who may be able to remain with companies to make such transitions with appropriate training, as well as designers of Industry 4.0 systems and interfaces who can work with operators and businesses to provide user-friendly and relevant information in suitable forms. The AI Action Plan, however, acknowledges what might be needed:

> While 80% of industry leaders believe that AI will have a transformative impact on their business, 63% of businesses have difficulty knowing where to start when implementing AI technologies. The Australian Government is committed to ensuring that businesses have the knowledge, tools, talent and support to capitalise on AI's potential.

The AI Action Plan also announced additional funding for the establishment of a National AI Centre, four AI and Digital Capability Centres, Regional AI opportunities and further funding for industry-research collaborations to support 21 industry-led AI focussed projects through the Cooperative Research Centres Projects. There are also significant additional funds proposed under the *Digital Economy Strategy* to address training shortfalls (Australian Government, 2021, pp. 32-36).

The human rather than technical side of cybersecurity

When businesses move towards implementation of Industry 4.0 practices and technologies, they must face the imperative of ensuring data security and more broadly cybersecurity (Pereira et al, 2017). As explained in the section on technological barriers, these threats are multiplied with many Industry 4.0 technologies, which depend upon connectivity and data sharing. It is vitally important to understand that cybersecurity should not be seen as purely a technological barrier, as cybersecurity depends upon human systems just as much a technological systems. Inadequate cybersecurity should therefore be seen just as much as a social barrier to technological adoption – to the extent that it depends upon human systems – as a technological barrier.

At a very general level, concerns about cybersecurity are an important factor contributing to a lack of trust in all information technologies, and especially Industry 4.0 technologies. The *Trust in Artificial Intelligence* Report (2020), for example, showed that the vast majority of Australians believed it was crucial for companies and government to carefully manage cybersecurity challenges. People also saw these as real challenges, with the following proportions illustrating that some of the top challenges being likely to impact on a large number of Australians within the next 10 years are directly relevant to Industry 4.0 technologies (Lockey et al, 2020, pp. 38-39, especially Figure 24):

- Surveillance (69%)
- Data privacy (69%)
- Cyber attack (67%)
- Human Resources bias (56%)
- Technological unemployment (51%)
- Misalignment with human values (49%)

More than 90% of the surveyed population, which were representative of the Australian community, believed that companies and governments have an obligation to protect them from as many of these threats as possible, through effective regulation and/or cyber-security measures. It is therefore crucial to understand how these failures can undermine societal trust and reduce support for their use.

Significant areas of concern for the public include the need for adequate data privacy protection in the context of 'Big Data' and the associated analytics and algorithms. Specific concerns arise from technologies that gather personal information without consent, and in ways which may be opaque to people (see Prince, 2017). With Big Data, which involves the aggregation of large data sets, the privacy risk increases compared to when the data are not aggregated. This is because the aggregated data can usually provide more information about a person when the various sources are linked in ways which the person may not be aware. The volume of available data and its velocity is magnified with feedback from sensors in the IoT, including the Industrial IoT. Especially given the extent to which contemporary data analytics enables identification of individuals from large data sets, it becomes increasingly difficult to distinguish personally identifying information from other forms of data. In this sense, the complexities of protecting the privacy and security of data in the context of Industry 4.0 technologies that may depend upon large data sets - which can include personal or confidential data, as well as other less sensitive forms of data – can present social and institutional barriers to technology adoption.

At another level, users (including commercial users) want security that works seamlessly, and which necessarily includes security of end devices as well as network security. Network security is often strongest in siloised firms in secure buildings. As explained in the section on technological barriers, the integration of connected processes across sites and across organisations, such as those involved with integrated supply chains, presents new cybersecurity challenges. These challenges should be seen as just as much social as they are technological, to the extent they require collaboration and coordination between organisations. In essence, the cybersecurity challenge posed by many Industry 4.0 technologies is how to establish security systems in complex technological and human systems, which are not only robust, but also seamless and user-friendly. In other words, technological solutions to cybersecurity systems must always take into account the social and psychological limitations of humans.

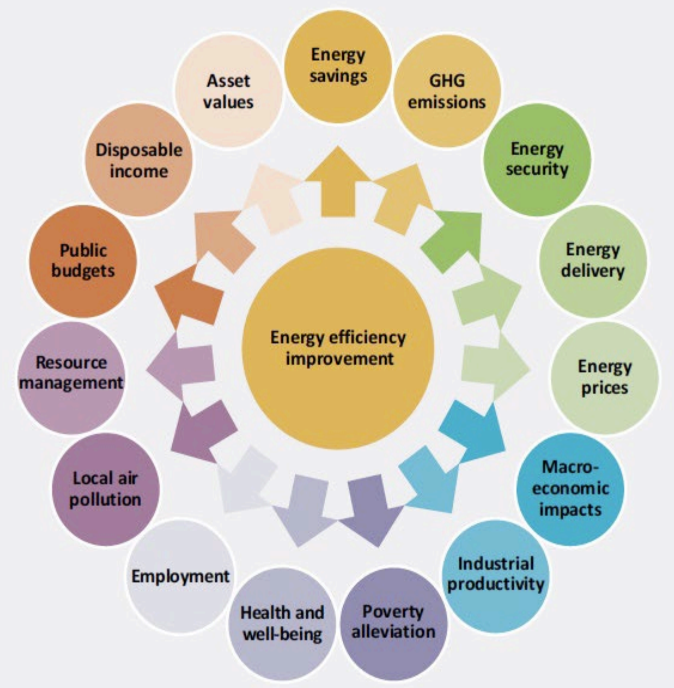
3.2 Specific Barriers to the Adoption of Industry 4.0 Technologies for Energy Productivity

3.2.1 Introduction: Barriers to Industry 4.0 and Energy Productivity

This part of the report identifies and analyses the specific barriers to the adoption of Industry 4.0 technologies for improving energy productivity. Before turning to the specific barriers, it is necessary to first say something about energy productivity, and how that term is used in this report.

In simple terms, productivity refers to the ratio between output and input in production, or how much is produced and in what time. In the energy sector, this effectively means 'the value created from using a unit of energy' (AAEP 2018). Efficiency, on the other hand, refers to how well resources are used to produce a given output or, in general, achieving the same output with fewer resources; it is effectively a measure of waste in a system. While the two concepts are distinct, they are related.

For the purposes of this report, we adopt a broad understanding of both energy productivity and energy efficiency. For example, as explained further below, energy productivity must be understood as more than simply 'saving energy'. Similarly, in a 2014 report, the International Energy Agency (IEA) set a broad scope for understanding the benefits of energy efficiency improvements for businesses and societies (Figure 18), which also goes well beyond simply 'saving energy'.



Note: This list is not exhaustive, but represents some of the most prominent benefits of energy efficiency identified to date.

Figure 18. IEA, 2014. Capturing the Multiple Benefits of Energy Efficiency. Page 20.

In commenting on this diagram, the IEA observed that research has brought to the fore a range of areas, beyond energy demand reduction and lower GHG emissions, in which clear benefits of energy efficiency have been documented'. The IEA went on to add that experts increasingly acknowledge the important role of energy efficiency in generating a broad range of outcomes that support ambitions to improve wealth and welfare – goals that the public and policy makers both understand and aspire to achieve'.

Turning specifically to energy productivity, it is even more important to factor in the full range of potential benefits from technological change or changes in business practices, as understanding the value created should incorporate the widest possible variety of benefits. Moreover, as productivity is concerned with the ratio between inputs and outputs (and not merely cost savings), if an action significantly increases the benefits, but uses more energy, it may still create increased energy productivity. The main point is that for there to be an increase in productivity the ratio of benefits to inputs must increase over time. Therefore, in contrast to energy efficiency, energy productivity has a broader focus, as it allows for situations where energy consumption may increase, so long as the increase in value created exceeds the increase in energy usage or cost. Further, a broad focus on increased value supports consideration of non-energy benefits that often flow from energy-related measures, but which would not arise without the energy-related initiatives.

The broad understanding of energy productivity applied in this report is supported by the approach taken by the European Union-funded Multiple Benefits project, which can be accessed at https://www.mbenefits.eu/. But it differs from the approach adopted by many energy consultants, who commonly fail to adopt a wide view of energy productivity, limiting the analysis to 'saving energy' and RoI versus costs. An overly narrow focus on cost savings, however, can significantly undervalue the benefits from energy productivity measures, with the IEA's 2014 report estimating that 'the (full) value of the productivity and operational benefits derived can be up to 2.5 times (250%) the value of energy savings'

(IEA (2014), p. 2). The IEA report went on to add that 'including such productivity outcomes in financial cost assessment frameworks can substantially reduce the payback period for energy efficiency investments, in some cases from four years to one year' (Ibid). The broader perspective applied in this report therefore allows for a more holistic assessment of the productivity benefits for business, such as incorporating increased work health and safety, or reduced machine vulnerability.

Improvements in energy productivity may arise from a variety of sources. For example, the Australian Alliance for Energy Productivity's 2018 report, entitled *Transforming Energy Productivity in Manufacturing* 2018, lists practices which can transform energy use in manufacturing, including:

- Management practices/Continuous Improvement (such as ISO 50001);
- MEPS – Minimum Equipment Energy Performance Standards;
- Replace central services with point of end use electricity technologies;
- New, less energy intensive process routes;
- Increased renewable energy on-site supply;
- Optimise on-site clean energy with grid using storage and demand management;
- New business model (often using multiple technologies); and
- Plant and value chain optimisation using IoT and AI.

In surveying specific barriers to energy productivity, this section of the report therefore takes into account barriers to the use of Industry 4.0 technologies in ways that assist these practices.

Given that the lack of academic literature specifically addressing barriers to Industry 4.0 technologies to improve energy productivity, this report makes extensive use of qualitative feedback from stakeholders. The form taken by stakeholder input is explained immediately below.

3.2.2 Feedback from focus groups

This section of the report details the feedback from three focus groups held in March and April 2022. The third part of this report outlines feedback from a focus group held specifically for the non-residential buildings sector.

Despite significant effort, it was not possible to reach a quorum for a focus group of finance managers. This seems consistent with the siloed nature of many Australian businesses and the cultural differences that often exist between technical and finance groups. Lack of engagement of finance teams and reluctance to invest in Industry 4.0 and energy productivity infrastructure, including monitoring equipment, has been identified as a barrier earlier in this report.

The first focus group consisted of eight representatives of energy users, which included energy users from water utilities, the beverage industry, breweries/wine industries and building products. The second focus group consisted of five energy consultants serving a range of industries, including mining, transport infrastructure, utilities, the energy sector and industrial and manufacturing. The third group included nine 'innovators' from a mix of small start-ups, large established service providers involved in innovation, and RD&D organisations.

In all focus groups, a series of questions were administered using Slido live polls. In addition, qualitative responses were elicited from focus group participants with regard to specific questions, and there was extensive discussion. The responses to the Slido polls, the qualitative responses and key points from discussion are explained and explored immediately below.

3.2.3 Responses to Slido polls

All focus groups addressed a series of questions about:

- knowledge of Industry 4.0 and energy productivity;
- whether they or their clients were applying Industry 4.0 solutions at the moment;
- which technical, behavioural, regulatory and economic barriers they considered most likely to impact the adoption of Industry 4.0 solutions; and
- which Industry 4.0 solutions would be commonly used in 3-5 years' time and which are already in common use.

In response to introductory questions concerning energy productivity and Industry 4.0 technologies, two focus groups exhibited similar understanding of the basic concepts. For example, there was a shared understanding of energy productivity, which was best captured by the following response from an energy user:

> Producing more using less energy in the least carbon intensive way for the best possible price.

The innovators, not surprisingly, showed a more sophisticated understanding, particularly of the detail of Industry 4.0.

In relation to Industry 4.0 technologies, focus groups saw Industry 4.0 as principally about introducing mechanisms to capture real time data and analyse it to support better informed decision-making across businesses. In addition, individuals in both groups raised three further specific applications beyond data for decision-making: data to facilitate connected supply chains, data for accountability and data to 'digitally support transformation'. In relation to the use of current Industry 4.0 platforms, the energy users' focus group had experience with about 12 different platforms. On the other hand, only one member of the consultants' focus group responded to this question, identifying three platforms used by their clients. Innovators listed numerous platforms, complementary tools, communication networks and distributed intelligence.

The focus groups were polled on their views on barriers to the adoption of Industry 4.0 technologies for energy productivity, using the categories of barriers (and sub-categories) introduced in the first part of this report. The most significant differences between the focus groups emerged in their responses to questions concerning barriers to adopting Industry 4.0 technologies. The following graphs summarise the responses to the categories of technical, behavioural (social), regulatory and economic barriers, with participants in all groups being asked to pick two of five sub-categories in relation to each of the barriers. In the legends of the following graphs, the number of participants in each of the groups is listed in brackets.

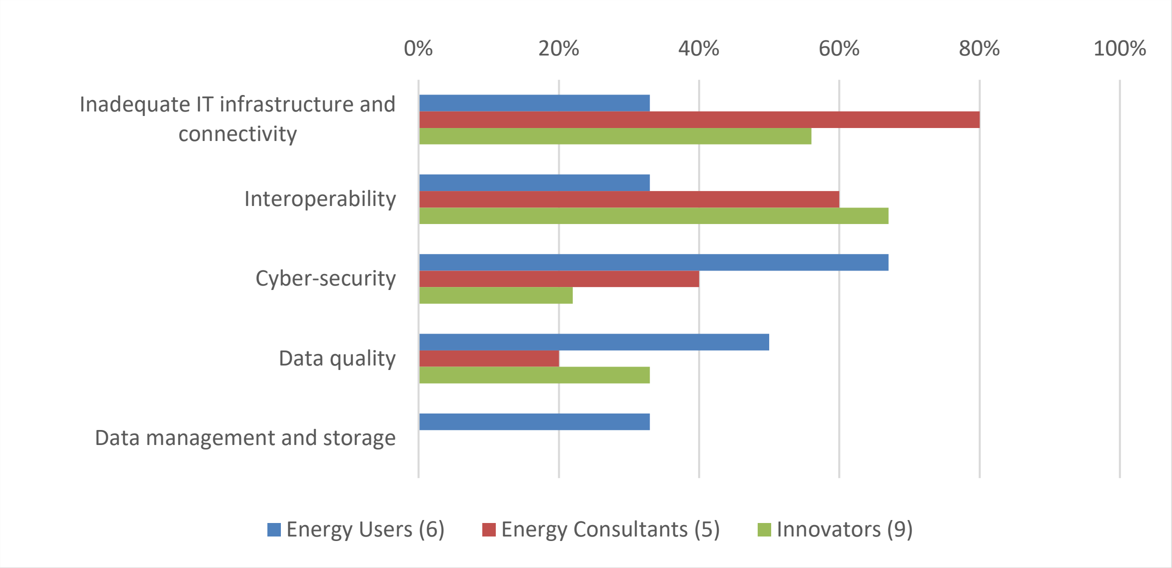


Figure 19. Technical barriers

In Figure 19, the greatest disparities between the groups were in the higher importance attached by the energy users to cyber-security and data quality as technical barriers to adoption, while the energy consultants' group saw inadequate IT infrastructure and connectivity as the largest barrier. Innovators and energy consultants saw interoperability as a significant issue: this may reflect their familiarity with and focus on delivering user-friendly services that deliver value at lowest cost.

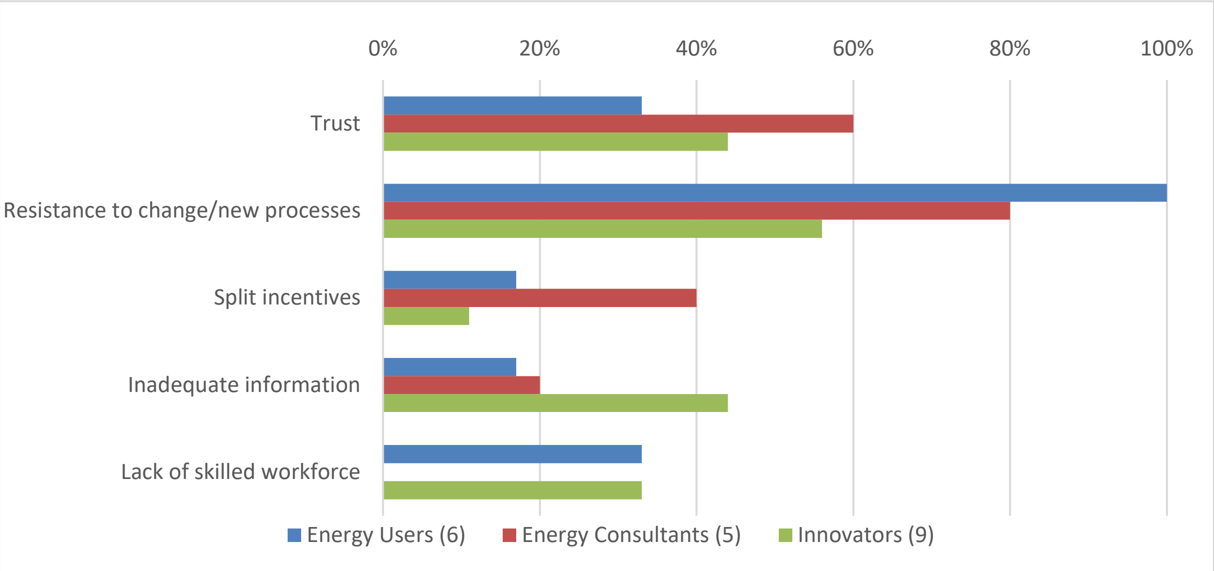


Figure 20. Behavioural barriers

While all groups saw the greatest behavioural (or social) barrier as being resistance to change or new processes, with a lack of trust also being regarded as important, the energy users and innovators were more concerned than the energy consultants about the lack of skilled workforce. Energy consultants saw split incentives as a significant issue, possibly because clients focus heavily on up-front costs and short payback periods, while different cost centres within businesses have differing KPIs and separate budgets. Innovators face inadequate information as a barrier, possibly because they are introducing new business models and practices.

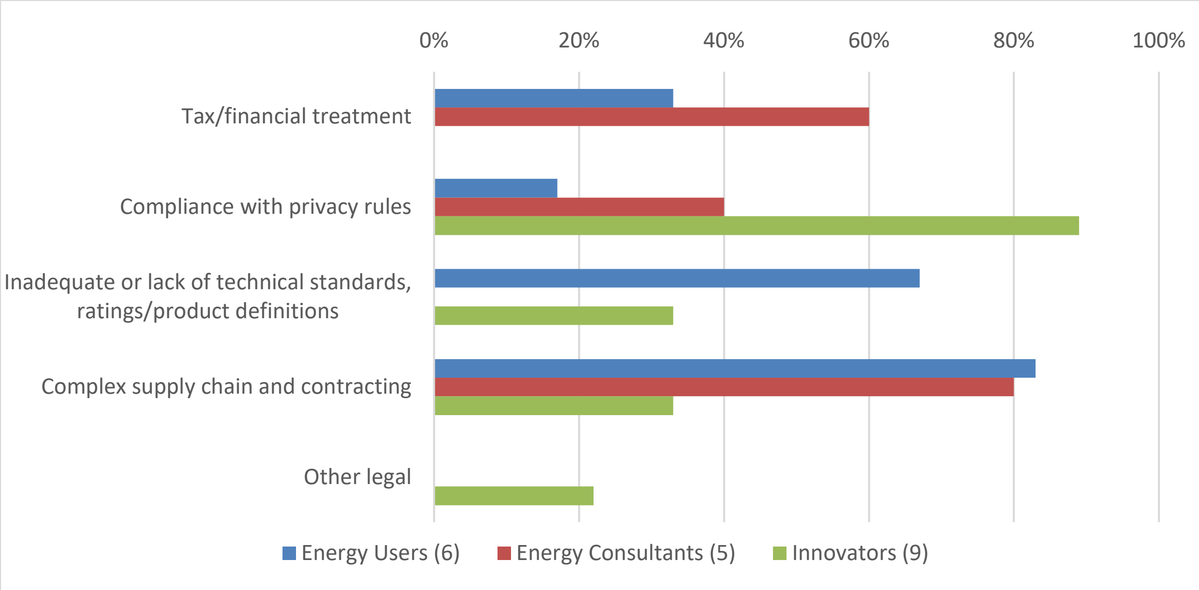


Figure 21. Regulatory barriers

In Figure 21, the greatest regulatory barrier perceived by energy users and consultants was the complex supply chain and contracting. Innovators were most concerned with privacy rules and more broadly, access to data that may be controlled by other service providers – which could also be seen as complexity in contracting. The different perceptions between the groups were most marked in relation to inadequate or lack of technical standards, ratings and product definitions and other legal issues. While the former was the second highest barrier for energy users and significant for innovators, it was not considered important by energy consultants. Innovators were the only ones concerned about 'other legal issues', possibly because they are pushing boundaries for business models and technologies while other groups tend to be involved in more incremental change. Innovators were not concerned about tax/financial treatment: possibly they were more knowledgeable because of their broader business perspectives as start-ups or large (often global) businesses.

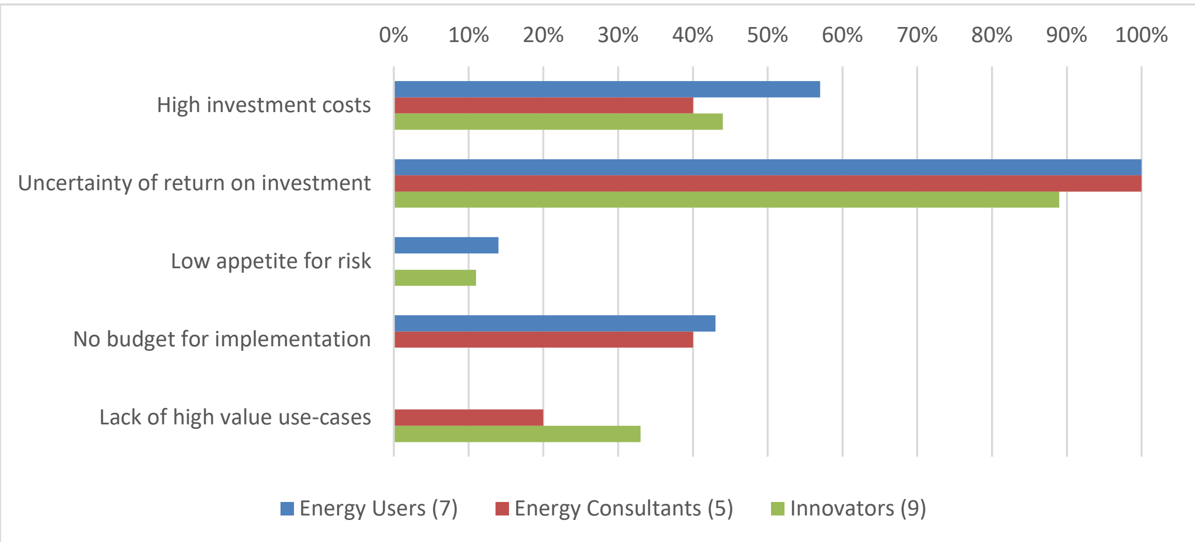


Figure 22. Economic barriers

All groups agreed that the most important economic barrier was the uncertainty about the return on investment (ROI) from Industry 4.0 technologies, which often also applies to energy productivity investments, with the high cost of introducing new technologies of particular additional concern to energy users. This reflects a common Australian business concern about up-front costs, also reflected in a focus on short payback periods for energy productivity investments. Both energy users and consultants experienced limited budgets for implementation. This can occur at a business level or at the cost centre – and may be exacerbated by split incentives and siloed cultures. The focus of consultants and start-ups on a need for high value projects may reflect their need for features that offer a positive and tangible opportunity that is easily understood and valued by the energy user, not just a cost saving. The low ranking of 'low appetite for risk' by all groups potentially seems to contradict the high ranking of uncertainty of return on investment. However, this may reflect the extremely high focus on RoI. Alternatively, it may reflect the narrow interpretation of risk in this context as technical or project risk.

For both the following questions regarding use of technologies now and in the future, the focus groups were provided with a list of nine categories of technology, with no limits on the number of categories each participant could nominate. The responses reflect perceptions and, as such, are influenced by their level of knowledge of each option.

Given that there may be different barriers for specific technologies, it is important to take into account industry understanding of the technologies, including the technologies currently in use and which technologies are most likely to be adopted in the near future. This applies to all groups: while it is obvious that the customer must understand (and value) the proposed action, ignorance of service providers such as consultants, and the inability of an innovator to identify an opportunity for their service model or product, are also fundamental

Figure 23 sets out the categories of Industry 4.0 technologies each group considers to be currently in use.

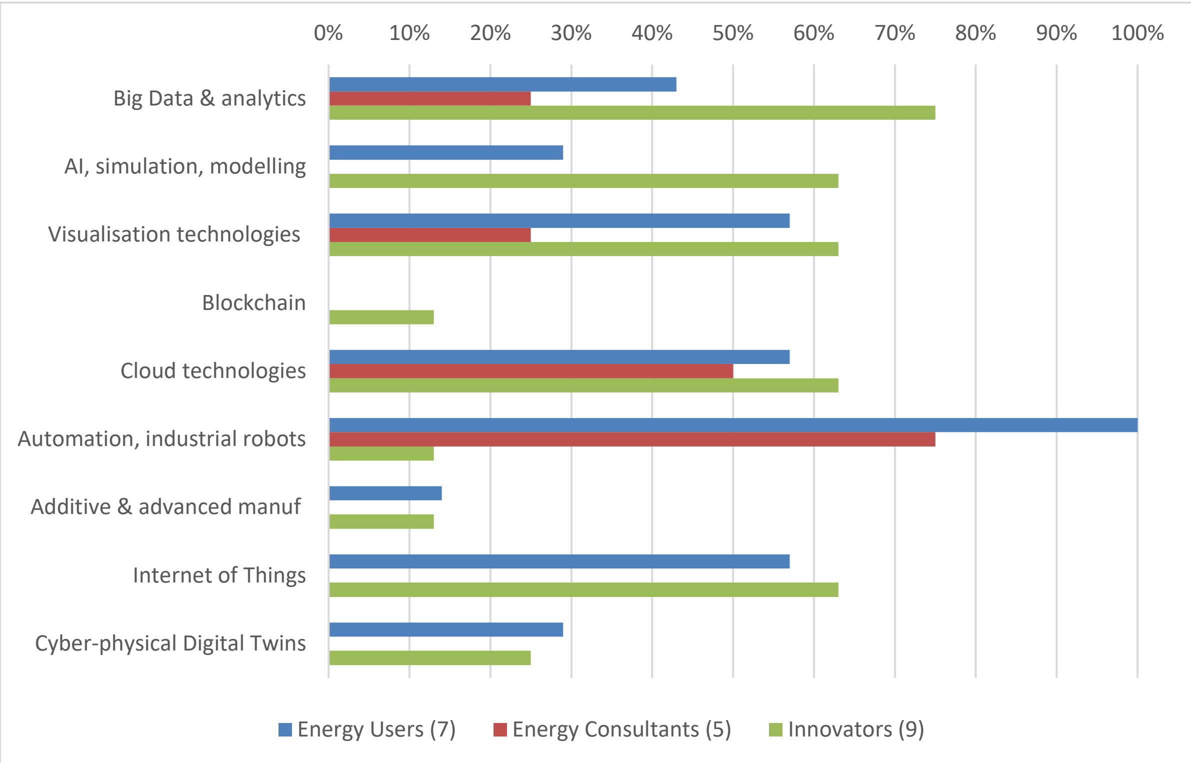


Figure 23. Which of these technologies are commonly used now?

As can be seen, there was general agreement that cloud technologies are commonly used, while the start-ups and energy users' group seemed more familiar with IoT and visualisation technologies. Indeed, relative to the other groups, energy consultants had low awareness of present use of five of the technology areas. There were substantial differences in perceptions of the scale of use of most of the technology areas, particularly automation and industrial robots. Clearly future research into actual levels of utilisation and the reasons for these variations could help to guide marketing, education, training and demonstrations.

The groups were also asked forecast which Industry 4.0 technologies they thought would be most commonly used in the next three- to five-years, with the responses being set out in Figure 24.

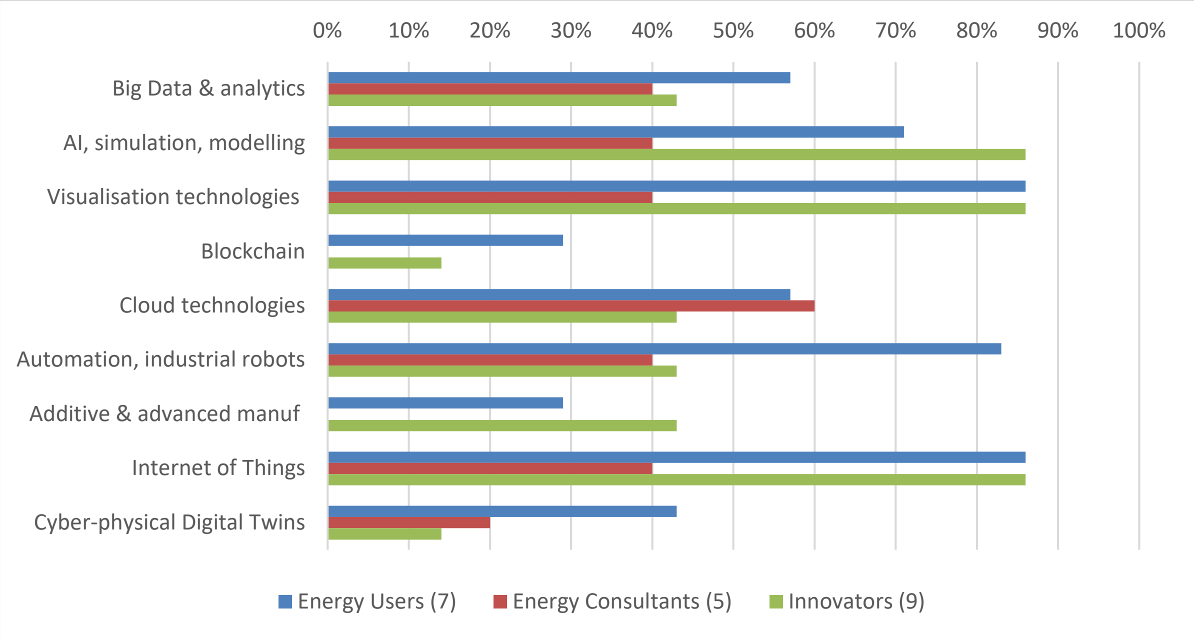


Figure 24. Technologies that can be commonly used in next 3 to 5 years

In most categories there were significant differences in judgements between energy consultants and the other groups.

Unsurprisingly, the responses to this question indicate that all groups consider most technology areas will be much more widely used in future. Automation, industrial robots and cloud technologies will obviously continue to be important. Energy users and innovators, however, clearly consider visualisation technologies, Internet of Things and AI, simulation and modelling, are likely to become progressively more important.

The low scores for blockchain are surprising in a context where the need for secure sharing of information, ensuring accountability and sharing money across value chains was discussed in all groups. The importance of data sharing seems likely to increase in tandem with circular economy and decarbonisation initiatives (especially addressing scope 3 emissions which involve upstream and downstream cooperation). Discussion among innovators reflected a range of views, including the potential for secure management of data to be provided by alternatives to blockchain, involving peer-to-peer engagement and distributed intelligence and data management. There may also be an element of confusion concerning the principles underpinning blockchain with present attention focused on controversial applications such as crypto-currencies such as Bitcoin, and data mining. So, it may be that if the question had been framed in broader language, extending to other systems for sharing data, it may have received a higher ranking.

The moderate scores for additive and advanced manufacturing may reflect the reality that economies are being increasingly dominated by the services sector and 'virtual' solutions, so manufacturing is becoming a smaller segment. Physical product is also being replaced by services, including increased utilisation of products through sharing economy and 'xx as a service' business models.

Overall, the responses to these two questions suggest that energy users and innovators consider that Industry 4.0 solutions are being used more than the energy consultants think, and that users have a greater expectation of their spread throughout industry over the next three- to five-years. While this may reflect a bias in the small samples, it is also consistent with the impression that energy consultants may tend to focus narrowly on energy costs and work more with technical, production and maintenance teams, at the expense of a broader understanding of their clients' activities.

The responses regarding use of digital twins reflect significant existing use and expectations of higher future use among energy users. This may reflect their practical requirements to operate, manage, maintain and optimise performance of equipment in an increasingly complex and changing environment. In this context, the capacity to benchmark performance in real time to identify anomalies and emerging problems in time to avoid failures may be an important benefit of real time models and digital twins.

3.2.4 Qualitative Responses

Participants in the focus groups were also asked to provide qualitative feedback which, in part, expanded on the responses to the Slido polls, but also introduced additional detailed considerations.

The most important observations from members of the energy users' group which are relevant to the barriers and opportunities for Industry 4.0 technologies to be used to improve energy productivity can be summarised as follows:

- Where gas or electricity is used as an energy source, there is limited data available to allow comparison and register the impacts of efficiency. There needs to be standard protocols for data and open access for energy users to their data, as well as analytics to help determine the financial benefits of any efficiency changes. Regulators, like the Australian Energy Market Operator (AEMO), should make available adjusted data to enable analysis and action to improve energy productivity. Therefore, developing protocols for providing access to energy data by users, and to require service providers to allow their clients and approved consultants/service providers access to data that has been paid for by users, should be a priority. This is especially the case in relation to gas data. Lack of timely, detailed and sufficiently accurate data for gas and water is a significant issue that limits capacity to optimise performance. In a later focus group, innovators suggested that 'utility quality' data was not always needed for practical purposes, especially when analytics could extract useful information from multiple sources.
- The network costs of energy suppliers are a high fixed component of energy costs. Therefore, retailers' price signals do not work, and the benefits of lower energy usage can be hidden and minimised. The complexity of pricing contracts can confuse consumers.

- There are apparent distortions between retailer pricing and real time energy costs for businesses, which should be addressed by the Australian Energy Market Commission (AEMC) and the Australian Energy Regulator (AER). At least initially, transparency that shows the differences would be a useful start in terms of consumer empowerment. Digital data could then be used by energy users to negotiate with the retailer and consciously decide how 'cost reflective' a tariff they want.
- There is also an apparent need to develop a formal guideline and training for finance managers regarding investment in monitoring and analytics for energy and relevant data streams. There is a reluctance to invest, seemingly because these investments do not deliver an obvious financial return. The contrast between substantial investment in tracking financial and production data relative to energy data is, on first impression, a puzzling phenomenon.
- When technology and equipment is being purchased, there should be better metrics available to encourage purchasers to improve energy efficiency and productivity. Standards are important so that balanced comparisons can be made.
- Big data and analytics will have a potentially big impact on energy use. There is significant potential for better large load management in businesses, such as wineries.
- As energy is not a significant component of business costs, when compared to production inputs and labour costs, there are real questions as to why businesses should put effort and resources into improving energy productivity if the value of multiple benefits is ignored.
- There is a need to improve links between businesses in supply chains and proper governance systems and provenance tracking are needed to support 'sharing of benefits'.
- More sensors and controls are needed to assist in cutting waste.
- There are commonly tensions with production managers in relation to equipment acquisition and operation. The acquisition of certain machinery can limit flexible optimisation and the purchasing priorities do not necessarily factor in energy productivity. For many processes, production managers also prefer 'smooth and steady' operation over optimal, variable management. This suggests a need for coordination across cost centres in an organisation, so costs and benefits can be better distilled and mechanisms for sharing risk, costs and benefits can be developed and trialled.

The feedback from members of the energy consultants' group which is most relevant to the barriers and opportunities for Industry 4.0 technologies to be used to improve energy productivity can be summarised as follows:

- There have been significant changes in clients' practices and attitudes, including a greater focus on decarbonisation strategy, financiers buying into smaller businesses, and upgrading of management and reporting. These offer increasing opportunities to integrate Industry 4.0 and energy productivity measures that offer broader business benefits, as they are relevant to decarbonisation and more rigorous management and accountability.
- The detailed design of funding schemes has a big impact on measurement and verification (M&V).

- *Perceived* return on investment is a key inhibiting factor. Part of the problem is a failure to value multiple benefits. A shift from capital investment to a 'service-based' model may be a path forward, but this requires trust and confidence in continuity and quality of service, without creating 'lock-in' or risks to continuity and control. Lower risk financing, such as flexible repayments, can potentially be an important mechanism for encouraging investment. There is also a key trust factor regarding the accuracy of estimates of RoI, and this may be linked to lack of relevant quality data.
- Resistance to change was seen as the biggest behavioural (or social) barrier. Participants discussed whether this could arise from a failure to fully appreciate the benefits, or to respond to the fears about risks held variously by the shop floor, middle managers, senior management or at board level. At times, finance and senior management fail to 'buy in' to change because they are narrowly focused on short term profits, or because they are provided with narrow briefs by technical staff or junior managers.
- There are common issues relating to data management and data quality. These include: inadequate IT infrastructure and interoperability problems; ability to access data (such as limited metering); policies (such as providers not allowing access to data); data security; and confidence in data quality.
- Energy consultants are beginning to emphasise broader factors than simply cost reductions, such as decarbonisation strategies, consumer/buyer group expectations, and the need for broader and longer-term engagement across client organisations. This involves building a better understanding of the overall business.
- The complexity of contractual arrangements across supply chains, and between consultants and clients, were described as significant regulatory barriers. The onerous requirements of government funding schemes were also regarded as presenting a 'regulatory' hurdle. Improvements in monitoring, verification and secure data sharing may reduce this problem by providing access to quality data.
- The taxation treatment of investment decisions was considered to present an obstacle to investment. For example, while the ATO treats investment in energy productivity as a capital investment that only allows depreciation, replacement of 'like for like' equipment is treated as maintenance, which can be written off in that financial year.
- While there was a general awareness of Industry 4.0 technologies, overall, energy consultants showed no sense of urgency to engage with the technologies or upskill.

The feedback from members of the innovators' group which is most relevant to the barriers and opportunities for Industry 4.0 technologies to be used to improve energy productivity, can be summarised as follows:

- The innovators have high literacy regarding many aspects of Industry 4.0 and several were heavily involved in energy market issues or renewable energy products and services. They also have well-informed views on likely future technology directions.
- They perceive a low level of consumer trust regarding the energy supply sector. One noted that energy retailers were not well-positioned to play a central role in data management, as a consumer loses access to all data if they change retailers.
- They are focused on data management and business models that involve drawing together and optimising multiple value streams through digitalisation. In many cases, this involves crossing

business boundaries so trust, data security, cost-effective user-friendly data management are important to them.

- Options such as gamification, interoperability, simple secure sharing of data, often peer-to-peer with distributed data and intelligence, and 'activity as a service' business models were discussed. The concept of 'democratisation of data' was raised.
- They saw a need to build greater understanding of the value adding potential, and possibly incentives to encourage adoption. They also saw a role for independent, trusted advisers to guide businesses.

As can be seen from this summary of the qualitative feedback from the focus groups, there were some common themes shared by energy users, energy consultants and innovators in their understanding of barriers to adopting Industry 4.0 technologies. For example, in relation to economic barriers, all regarded uncertainty about ROI as an important barrier. Moreover, they considered a lack of trust in technologies and resistance to change as important behavioural or social barriers, although energy consultants placed greater emphasis on these factors. In addition, users and consultants cited the complexity of supply chains and contractual arrangements as potentially important barriers. On the other hand, there were significant differences between groups in their attitudes to many other issues. While energy users wanted more access to their own data, as well as standardised systems for understanding data usage, energy consultants and innovators seemed more concerned with their own frustrations in accessing data from platforms operated by service providers or in-house specialists. Moreover, although innovators and energy users tended to display a greater level of understanding of Industry 4.0 technologies and how they may be used to improve productivity, consultants had a greater awareness of the potential taxation implications of investment decisions.

3.3 Categories of Specific Barriers to Industry 4.0 Technologies for Energy Productivity

In the previous part of this section of the report (3.1 and following), drawing on the academic literature the general barriers to adoption of Industry 4.0 technologies were grouped under the four headings of: technological barriers, economic barriers, legal/regulatory barriers and social barriers. The consultations held as part of the focus groups to test the knowledge, understanding and experience with Industry 4.0 technologies, and the barriers to adoption, essentially followed this approach, applying the general headings of: technical barriers, behavioural (or social) barriers, regulatory barriers and economic barriers. The practical barriers to adopting Industry 4.0 technologies for the purposes of improving energy productivity are, however, more subtle and nuanced than these broad categories suggest. To better explore these complexities, this section of the report groups the barriers in accordance with five key issues that emerged from the industry consultations, as well as the practical experience of team members.

At the most general level, there is an apparent failure by many in industry to grasp the full potential for change promised by Industry 4.0 technologies and, associated with this, the multiple potential benefits. The failure of participants in the energy system to be fully informed, in relation to both technologies and economics, is therefore an important inhibiting factor. In addition legacy systems and practices, both technological and economic - such as an inefficient current allocation of costs and benefits – contribute to inertia.

This section of the report attempts to analyse the specific barriers to the improvement of energy productivity through Industry 4.0 technologies by grouping them in accordance with the following five key themes, which are drawn from stakeholder consultations and other feedback: (*i*) lack of priority given to energy productivity; (*ii*) Data concerns; (*iii*) supply chain concerns and coordination problems; (*iv*) uncertainty and inadequate information; and (*v*) complexity.

There are obvious cross-overs between these key themes and the categories of barriers introduced in Part 1; and, where this is the case, the cross-overs are explained. Each of the key issues is expanded upon in the following sections of the report.

Lack of priority for energy productivity

> *"Energy represents around 1 per cent of our costs, labour represents between 30 and 40 percent. If I'm looking to reduce costs energy won't be the first place we look"- mining stakeholder at A2EP consultation 2021.*

An important obstacle to investment in technologies and practices that may improve energy productivity is the common perception that energy represents only a relatively small part of the total costs of running a business, and is therefore regarded as a low priority. As illustrated by some of the feedback from the focus groups, reducing other costs, such as labour costs and plant maintenance, are regarded as more important. Moreover, certainty of availability of energy is commonly regarded as more important.

The importance of certainty of supply, as opposed to productivity improvements, was reflected in the following comments from the Australian Alliance for Energy Productivity (A2EP) in relation to RACE Theme B4 on Flexible Demand and Demand Control Technology:

> Energy is not just an input to production. For many it is THE means of production – other inputs are interchangeable, energy is not. This results in a high tolerance for higher prices (unless there is a low margin environment) and a low tolerance for risk exposure. That risk exposure can come in two main categories: risk to production and risk to assets.

As this report has emphasised, one part of this problem lies in a failure to appreciate the full benefits that may arise from improvements in energy productivity. This is partly due to the extent to which some of these benefits are ambiguous or hard to quantify. Unless these benefits are better understood, such as by the research undertaken by the EU-funded Multiple Benefits project, the lack of priority given to improving energy productivity, and the associated lack of information about the benefits of productivity improvements, are likely to remain important obstacles.

Data concerns

Progress in improving energy productivity depends upon the ability to collect and analyse data in a timely manner. In other words, without the right information at the right time in the right form, delivered to the right place, energy productivity improvement simply does not occur. Industry 4.0 technologies can enhance access and use of data to improve productivity but, in turn, the effectiveness of Industry 4.0 technologies, such as IoT and machine learning, depends upon the availability of relevant, good quality and timely data. Yet, there are many obstacles inhibiting access to, and use of, high quality data.

The obstacles to access and use of data to improve energy productivity cut across the categories of barriers identified in Part 1 of this report - technological, economic, regulatory and social barriers – with each requiring different strategies to overcome the barriers. The availability of data may be limited by technological barriers, such as inadequate connectivity or poor systems interoperability. There may be concerns about the costs of technologies for gathering and analysing data, and returns on investment, creating economic barriers. There may be, and often are, legal and regulatory obstacles to collecting and using data, such as restrictions supply chain contracts. And data collection and use may be limited by organisational inertia, fear of change, or a lack of trust about data sharing, creating social barriers.

The interaction between barriers to technology adoption specifically in relation to data issues can be illustrated by the following case study of Exergenics.

This case study is a good illustration of how barriers to the use of technology may interact, and be mutually reinforcing. As this report has emphasised, a general lack of trust in technological solutions is an important social barrier to technology adoption for data solutions, and this can be exacerbated when technology suppliers over-promise and under-deliver. As the study suggests, trust deficits can be overcome, but this requires strategic thinking and the expenditure of effort and resources. Moreover, effective data sharing depends upon interoperable technological and social systems. In this respect, a lack of standardisation can present real obstacles to the implementation of effective data solutions.

These kinds of barriers, and their complexity, are compounded in complex supply chains, where multiple organisations may have disparate data systems, with each organisation prioritising their own institutional practices or interests, potentially to the detriment of data sharing with others. Further issues relating to supply chains are dealt with immediately below.

Exergenics

Exergenics was established to assist building managers to use data sets derived from Building Management Systems (BMS) to improve the energy performance of chillers that control temperature and hot water in large buildings. In an interview conducted for the project, Iain Stewart, the co-founder and CEO, explained some of the barriers encountered in building a business based on optimising data for increased energy productivity. While the business had developed software that could deliver productivity benefits, initially it encountered scepticism, as many building managers had 'heard it all before' from companies making similar claims but without delivering any tangible benefits from investment. The new business was therefore entering a market characterised by low levels of trust.

To overcome this trust deficit, the business needed to develop relationships with potential clients, including by running up front demonstrations. The business worked transparently with clients and used open source software to create user interfaces, so that clients could readily engage with the data being analysed. Exergenics also found that, in many cases, they were bespoke elements in specific buildings and chillers, which required adjustments to the software solutions to cater for the particular clients. In these circumstances, software developers had to work collaboratively with clients to get the best solutions and, in turn, build greater trust.

Supply chain concerns & coordination problems

Industry 4.0 technologies hold out the promise of streamlining supply chain processes and, accordingly, improving energy efficiency and productivity. However, delivering these benefits requires interoperability of technologies and organisations. One particular difficulty arises from the challenges of sharing costs and benefits across organisations. In other words, if each organisation in the supply chain is concerned solely with maximising its own benefits, then the overall benefits that can be derived from Industry 4.0 technologies may be less than optimal.

Problems of coordinating between different organisations can result in market failures where there are 'split incentives'. The problem of split incentives arises where a party responsible for making a decision, such as a party that purchases equipment, faces different considerations to parties that may benefit from the decision. For example, split incentives can arise where the costs of energy efficiency measures are born by landlords but the benefits accrue to tenants (Climate Change Authority (2020) p. 131). Similar problems can arise where one party in a supply chain bears the costs of productivity-enhancing technologies, such as data sharing technologies, while the benefits accrue to others. This suggests the need for better alignment of incentives across supply chains, potentially involving government incentives.

As explained in previous sections of this chapter, complex Industry 4.0 supply chains commonly results in contractual complexity, with multiple parties involved with multiple contracts which may, at times, be inconsistent. Barriers to technology adoption can arise from contracts that reflect the narrow interests of parties, as opposed to the shared benefits that may be achieved from technological innovation. Restructuring of contractual relationships, such as by greater standardisation of contracts or use of standardised smart contracts, therefore has some potential to reduce the costs of implementing Industry 4.0 technologies in supply chains.

Apart from coordination problems between different organisations, there may be coordination problems within a single firm. These can arise, for example, where engineers, finance officers and marketing staff approach the adoption of new technologies from different perspectives: while engineers may focus on achieving the best technical solution regardless of cost, finance officers may focus on reducing costs at the expense of investing for the future, and marketers may focus on marketing existing products and not overall business performance. Intra-firm conflicts between staff with different interests and perspectives can result in inertia, and a failure to make difficult investment decisions.

Intra-firm coordination problems can also give rise to split incentives. In one example provided to the researchers, a maintenance manager for a large site had responsibility for paying for materials and labour for upgrading pipe insulation, but the advantages of reduced gas consumption were not obvious, as benefits would only accrue to the operator of the boiler-house.

Uncertainty and inadequate information

Decisions to invest in technologies are always made in the face of uncertainties relating to the impact of the technologies, especially on the bottom line, and this is even more so in the case of potentially transformative technologies. As explained throughout this report, there are uncertainties about returns on investment in Industry 4.0 technologies, and these are exacerbated by a lack of information about the potential returns, a failure to factor in the full range of benefits and, to an extent, existing accounting practices. Some of the uncertainty about ROI from investment in technologies in the energy sector can arise from a failure to approve investments in accurately measuring, monitoring and analysing energy performance, which is often justified on the basis that these systems do not deliver a direct return on investment. Overall, uncertainties relating to investment are often compounded by an overly narrow approach to understanding investment returns taken by some managers.

A range of additional uncertainties can affect investment decisions. Investing in new technologies is commonly incremental, meaning that Industry 4.0 technologies must co-exist with legacy systems. There are clearly uncertainties about the effects of new technologies on existing systems, including system interoperability. Production managers, many of whom may be on fixed term contracts with KPIs, may be more concerned with maintaining continuity of production than with radical, and potentially uncertain, change. In other words, in the face of uncertain returns, sunk investments in financial, technological and intellectual capital, can present important obstacles to fundamental change. For example, as new technologies can challenge existing ways of operating, they may be dismissed on the basis of what, in the experience of managers, has worked in the past. These sorts of impediments to the adoption of new technologies in the context of legacy techno-social systems clearly cut across technological, economic and social barriers to technology adoption.

One overarching source of uncertainty concerns the ambiguity or unpredictability of government policies. In Australia, investment in improvements in energy productivity and sustainability has been hindered by a lack of clear direction or commitment from government, including uncertainties relating to carbon abatement policies. This has had system-wide adverse effects on technology adoption for improving energy productivity.

The following anecdotal examples illustrate how uncertainty or a lack of information can impede enhanced energy productivity:

- At an alumina refinery, a high temperature calcining process consumed over a third of overall energy. In a workshop, staff were asked to estimate the theoretical (as opposed to actual) energy requirement of the process, but no-one knew the answer. This led to an analysis of where energy was being wasted, resulting in significant savings.
- At a large power station, compliance with the Energy Efficiency Opportunities program required engineers to analyse the theoretical impact of higher ambient temperatures on the efficiency of the power station, with results indicating a higher than expected loss of efficiency. Analysis found that, under extreme circumstances, hot water from the cooling towers flowing into the cooling pond was 'short circuiting' into the inlet to the cooling towers, significantly reducing their efficiency.
- Research undertaken by A2EP has found that monitoring of efficiency of gas boilers across most sites is poor, and actual system efficiencies are rarely calculated. This means most sites believe their boilers are more efficient than they are. This can result in a serious under-estimation of energy saving potential, which clearly impacts investment decisions such as those relating to replacement heat pumps.
- In a supermarket, inefficient lighting was replaced by energy efficient lighting but, surprisingly, energy consumption increased. Independent analysis showed that the old inefficient lighting had provided significant radiant heating. Replacing the lighting led to

the supermarket heating system compensating by blowing more warm air which, in the refrigeration aisles, affected open refrigerators. The energy efficient lighting therefore increased energy expenditure on both heating and refrigeration.

- A project at RMIT University involved designing an energy-efficient drink vending machine. An analyst developed a simulation model, but could not make the model work as inefficiently as data suggested. Analysis found that, when the number of cans stored was increased by adding extra racks inside the refrigerator, the evaporator inside the refrigerator was moved to the rear wall, so the rate of air movement over the evaporator was dramatically reduced due to the fan operating in 'stall' mode. A much smaller fan with appropriate ducting was installed, and this led to substantial energy savings.

A number of lessons can be drawn from these examples. Overall, they illustrate the importance of accurate data for projects aimed at improving energy productivity. They also illustrate how, without adequate data and data analysis, measures aimed at improving energy efficiency or productivity can have unpredictable, and possibly counter-productive, consequences. This suggests that there is significant potential for Industry 4.0 technologies that enhance data collection, monitoring and analysis to assist with developing strategies for enhancing energy productivity.

Complexity

The introduction of Industry 4.0 technologies makes the business ecosystem much more complex than legacy technologies and systems. This can be illustrated by the complexities arising from the use of Industry 4.0 technologies in managing supply chains: the technologies introduce new processes, depend upon interoperation between more elements, and involve new parties, such as platform intermediaries. The complexity of Industry 4.0 systems and processes exacerbate the coordination problems, both between and within organisations, referred to above. Managing this complexity can be daunting, requiring the development of new technological and business skills, mind-sets and workflows; and this can inhibit innovation.

Moreover, the examples given in the previous section illustrate the complexities that can arise in developing and implementing business strategies for improving energy productivity, which can require an understanding of hidden or unpredicted costs. The complexity of Industry 4.0 systems, including the complexities of managing human-machine and human-robot interactions, create the potential for human errors that can cause accidents and other disruptions. In complex supply chains, however, it may be difficult to allocate responsibility, including legal liability, where something goes wrong. Uncertainty about legal liability can deter investment, as well as create difficulties in obtaining appropriate insurance.

Meeting the challenges of managing the complexity of Industry 4.0 systems requires new approaches to management, which can address social barriers to technology adoption. This can require the allocation of resources to support employees that are required to use new systems and processes. Transformational change requires processes to engage employees, including providing appropriate training, supplying information on why change is important, and assuring employees that their interests have been taken into account. For example, resistance to change can be managed by testing interfaces to ensure they are user friendly. Engagement with employees can assist with change implementation by providing essential information about how technologies are being used, which can assist in overcoming organisational obstacles to technology adoption.

3.4 Barriers to the Adoption of Industry 4.0 Technologies for Energy Productivity in Non-residential Buildings

3.4.1 Introduction

The framework for analysing barriers to the adoption of Industry 4.0 technologies has been applied to the specific context of the use of technologies to improve energy productivity in non-residential buildings. The application of the framework to a specific context assists in understanding how the barriers may apply in practice, as well as deliver further insights. Drawing on the analysis of the general barriers to adoption of Industry 4.0 technologies undertaken previously, Figure 25 illustrates the categories (and sub-categories) used to explain barriers to technology adoption in the context of non-residential buildings.

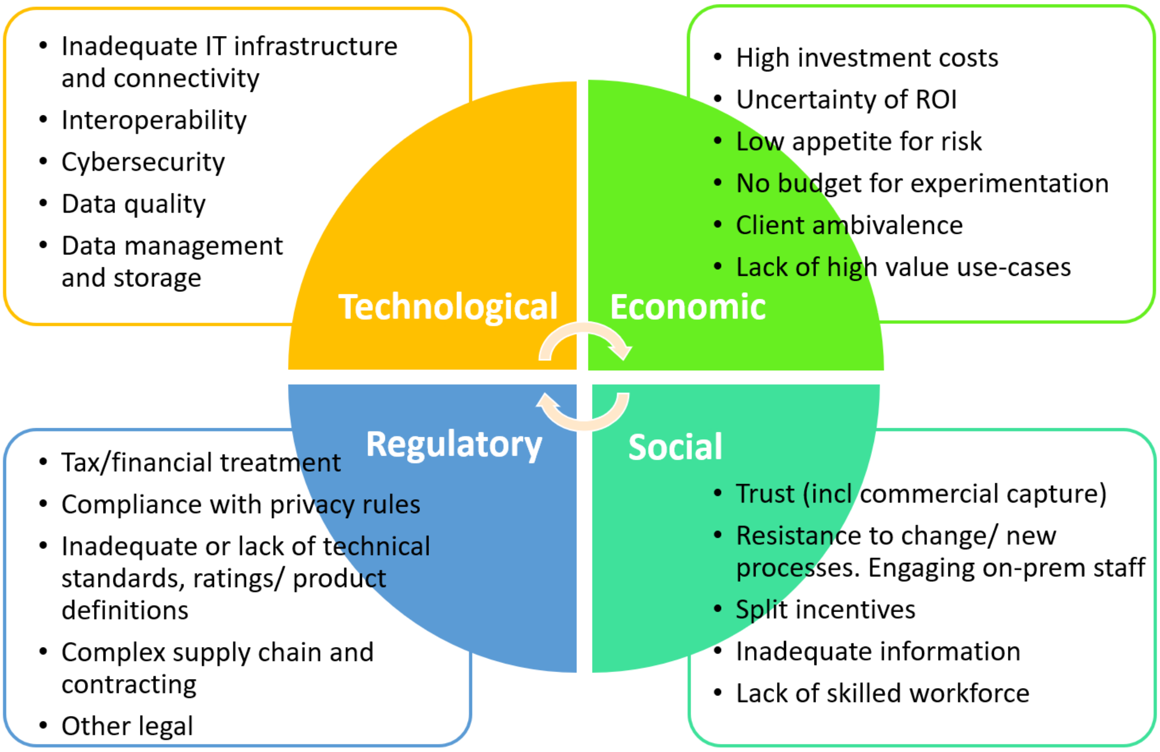


Figure 25. Identified barriers to the adoption of Industry 4.0

3.4.2 Literature Review

This section draws upon the extant literature to summarise the barriers to the adoption of Industry 4.0 technologies in the specific context of non-residential buildings. In doing so, the review draws upon the categorisation of barriers to Industry 4.0 technologies set out in previous sections of this Chapter.

3.4.2.1 Technological Barriers

Inadequate IT infrastructure and connectivity

Energy management functionality can either (i) operate locally in relative isolation on the Building Management System (BMS) (an 'OT solution'), or (ii) it can be operated as an integrated IT solution utilising data feeds from separate metering infrastructure, distributed sensor networks, and external business intelligence and utility systems. Unfortunately, existing buildings with legacy controls hardware do not have the IT infrastructure and connectivity for the more sophisticated IT based approach. Otte et al (2021) citing Zimmerman (2021) notes that 'most commercial buildings were built before 2000, and most control systems are even older than that, so these buildings contain a mix of new and obsolete systems, while new systems are added in a piecemeal fashion'.

Connectivity is further complicated by interoperability issues (see below). Harbor Research (2020) suggest that 'buildings need an application overlay that can ingest data from existing BAS/BMS (Building Automation Systems/Building Management Systems) applications, while retaining the flexibility to integrate with DER (Distributed Energy Resources) systems and advanced metering infrastructure'. They further identify that 'most buildings are not currently equipped for grid interactivity, so regulators and utilities need to work with these buildings to offer the right incentives to meet the technical requirements that GEBs (Grid-interactive Efficient Buildings) demand'.

Interoperability

Most studies point out the significance of interoperability issues in the non-residential buildings sector. Incumbent hardware providers have traditionally used proprietary communication protocols in their products to prevent alternative maintenance services and hardware solutions being deployed. This reduces competition and increases lifetime costs.

The International Energy Agency (2021) claim that 'a key issue for creating market value is interoperability, or the ability of devices to communicate with each other and work in an integrated system'. Valdez et al (2020) identify that '(t)he issue of interoperability is not only an issue of communication between different types of platforms, but also an issue of the interpretation of commands on a central platform which communicates between different types of devices'. The US Department of Energy (2021) identifies that 'the current lack of interoperability results in expensive integration efforts' and that the desired 'seamless connectivity [between devices] is not yet widespread'. The European Commission's Group of Experts on Energy Efficiency (2021) calls for 'technically open and not proprietary interfaces to operational information systems'. Harbor Research (2020) state that 'the Intelligent Building Energy Management Systems (IBEMS) market landscape is fragmented, with many startups attempting to disrupt entrenched incumbents, whose systems are outdated, difficult to integrate, and do not incorporate emerging technologies'. They suggest that 'plug-and-play interoperability between devices and systems' is required to enable software service providers to thrive.

BACnet (a communication protocol for building automation and control networks) has gained some traction in the industry as an open standard to address the interoperability issue. However, the BACnet standard is not uniformly implemented and typically only connects locally to the BMS rather than to the cloud. Harbor Research (2020) also point out that 'buildings have trouble adopting a standard data labelling or naming convention' and 'while BACnet adoption is increasing, further protocol consolidation and data labelling standardization needs to occur'.

Cybersecurity

The cloud enables buildings to connect to external markets (eg electricity markets for flexible demand) and distribute information to supply chains and staff (eg to mobile devices of maintenance contractors). However, cloud connectivity inherently creates the potential for cyber-attack. The European

Commission's Group of Experts on Energy Efficiency (2021) identifies that 'cybersecurity is essential for protecting against malicious attacks and protecting data from unauthorized access'. Memoori (2021) identifies that 'corporate concerns over potential cyber-attacks significantly constrain growth in the market for BIOT (Building Internet of Things) systems, which are fundamental to the delivery of the data required to power AI solutions'. Businesses must weigh up the additional features and benefits from connecting to the cloud compared with isolated site-only solutions.

Data quality:

The quality of any analysis is limited by the quality of the data used to do the analysis. Data needs to be cleaned to remove false/anomalous readings, sensor drift and normalised to avoid skewing the results from analytics. O'Reilly (2020b) surveyed 1,900 people, working in the field of Artificial Intelligence, to get their perspectives on the data quality issues they face. A wide range of data quality issues are of concern (Figure 26).

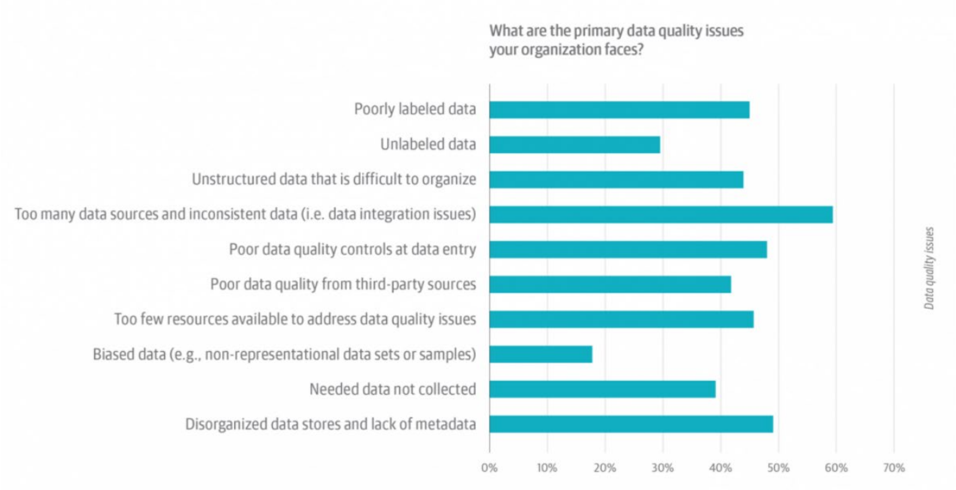


Figure 26. Primary data quality issues faced by respondents' organisations

Data labelling quality is one of the areas of concern. For example, the European Commission's Group of Experts on Energy Efficiency (2021) calls for the 'identity of equipment within buildings (as well as their associated rights) to be verified electronically in real time to enable decentralized units to dynamically respond to its environment and markets by sovereignly switching between modes of operation'. Memoori (2021) notes that 'many AI models are trained through supervised-learning which requires data to be properly labelled and categorized'. Place IQ further identify the importance of large amounts of training data for AI and machine learning, stating that (i) good Apps need big audiences, (ii) good Apps need lots of usage and (iii) good Apps encourage creation of accurate data. These trends compound over time making it increasingly harder for new entrants to catch up with market leaders (Memoori, 2021).

Data management and storage

Data management involves structuring data so that it is discoverable and accessible, both to humans and machines. Zimmerman (2021) asks: '(h)ow do you create a robust, interoperable, integrated smart building automation system that can provide the data you want in the format you need?' and '(h)ow do you extract and present that data from this system so that it's actionable, and without suffering from paralysis by analysis?".

Cost reductions will be achieved when machines can 'reason with data' without human intervention. Memoori (2021) identifies that 'one of the key barriers to enabling widespread automation across the industry is that each building is unique' and that 'developing sufficiently adaptable machine learning algorithms… is a huge challenge'. Metadata schemas (eg Brick) and point naming conventions (eg Haystack) aim to assist with 'de-protoyping' buildings from a software perspective. Memoori (2021) also claims that 'building systems data is notoriously siloed' and notes that 'gaining access to [diverse data] as well as storing, organising, structuring and labelling it in an appropriate fashion … can prove a challenge'.

Governance aspects relating to who gets to access data also needs to be coded into software. The European Commission's Group of Experts on Energy Efficiency (2021) identifies that 'privacy and cyber security considerations require management of data such that it is protected against unauthorized use (confidentiality), that it can be relied upon to be correct (integrity), and that it is accessible when required (availability)'.

3.4.2.2 Economic Barriers

High investment costs

Despite strong evidence that use-cases such as Fault Detection and Diagnosis (FDD) typically have a payback of less than two years (Kramer et al, 2020), there is a widely held perception that digitalisation has high upfront cost. This suggests FDD may currently be limited to deployment in buildings with favourable existing IT/connectivity infrastructure (where deployment costs are lower). The US Department of Energy (2021) identifies that 'costs of many control technologies are by themselves relatively low', suggesting that high costs, where they exist, are typically associated with the labour cost of installing suitable IT/connectivity rather than hardware costs. Navigant (2017) foresees a future where 'IoT solutions can be deployed easily at lower cost in comparison to BMSs, which are traditionally expensive and complex and require specialized installation'. However, Valdez et al (2020) identify that new smart devices, 'with the addition of network connectivity, wireless control, learning, and data analytics capabilities [are] typically more expensive than a comparable consumer product without connected functionality'. This cost barrier is a disincentive, particularly in situations where the benefits of the new device are uncertain. Similarly, a Harbor Research (2020) survey, with more than 1,500 respondents, found that 45% indicated 'lack of capital to purchase and install energy management systems as the biggest challenge in realizing value from an energy management strategy'. They concluded that 'IBEMS (Intelligent Building Experience Management Systems) solutions frustrate operators due to their prohibitive costs, difficulty of use, lack of easy integration with buildings data, and their ultimate inability to articulate their value or provide an immediate, tangible return on investment (ROI)'.

Uncertainty of RoI

Further to the perceived high investment cost of digitalisation is the difficulty of finding ways to monetise the benefits. Tenant productivity and comfort benefits are often difficult to measure, and benefits often don't accrue to the building owner (the 'split incentives' problem). Often energy savings are the most tangible benefit for establishing a clear RoI. Memoori (2021) claims that applying AI to HVAC (Heat Ventilation and Air Conditioning Systems) [for energy efficiency] is seen by many as low hanging fruit'. However, a fair return on investment can be difficult, because utilities often do not have financial or regulatory incentives to consider or reward flexible demand opportunities from buildings (US Department of Energy, 2021).

Low appetite for risk

IT projects, as a general class, are often considered as prone to going over time and over budget. The property sector is a relatively conservative sector with limited appetite for such risk. Memoori (2021) claims that the buildings industry 'has been notoriously slow to embrace change and innovation'.

Perceptions of risk for energy efficiency projects (which are typically relevant to digitalization projects as well) are discussed by Leutgöb et al (2020) in relation to the QualitEE project, which is an EU-funded project aimed at increasing investment in energy efficiency in the building sector. They note that '(a)lthough investors and financial institutions are increasingly looking for sustainable investment opportunities, they are often reluctant to invest in energy efficiency services due to a number of remaining barriers:

- As energy efficiency improvements are intangible, many EES (Energy Efficient Services) projects are perceived as complex and granular. In turn, projects struggle with an unfavourable ratio between perceived project revenue and transaction cost.
- Most EES projects are small, while bundling a number of small projects to one larger project appears to be connected with many difficulties and elevated complexity.
- EES projects are "brain-driven", i.e. a considerable share of the project value does not relate to the value of the invested assets, but rather on the know-how behind the optimal application of the assets.
- Finally, the cash flow of EES projects comes from cost savings and is not generated through sales on the market. Therefore, as compared to renewable electricity projects where the cash flow is generated through sales on the electricity markets the risks for investors are more pronounced in EES projects.'

Leutgöb et al (2020) further note that 'fragmentation and heterogeneity of the energy efficiency service markets make it difficult for clients to differentiate between "good quality" and "bad quality" services'. As a result, they stress the importance of standardisation 'to boost demand and access competitive capital from financial markets'.

No budget for experimentation

The construction industry is a mature industry that constructs a building in the framework of a bespoke project, with a defined budget, and assumes everything will essentially work to plan. This mindset makes it difficult to introduce new technologies, allowing for any level of failure or the need for contingency budget.

Client ambivalence

The industry has an aphorism called the 3-30-300 rule, where the tenant of a building sees an energy cost of ~\$3/ft^2, rent of \$30/ft^2 and staff cost of \$300/ft^2. This aphorism is used to explain client ambivalence to energy matters. The US DoE (2021) notes that 'consumers are increasingly adopting smart technologies. However, they need a compelling reason to do so'. They suggest that 'consumer-focused ... regulatory (including market design) and business models are required to better align corporate and shareholder objectives with those of their customers'. RACE for 2030 (2021) found that alignment with company 'Net Zero' objectives can sometimes elevate energy to a board level discussion.

Lack of high value use-cases

Locatee and Memoori (2017) identified 49 smart-buildings use cases, falling into one or more of seven attributes. The benefits of these use-cases are not limited to energy productivity. Indeed, Navigant (2019) suggests that grid integration of buildings 'will [only] be achieved when multiple solutions or services are delivered at the same time, rather than in a more traditional sequential approach'. Unfortunately, the industry appears to be operating predominantly in siloes, limiting the ability to 'value stack' multiple use-cases. Memoori (2021) identifies that 'AI is being focussed in specific areas, but over the next few years… solutions [will] seek to connect complementary applications for more widespread synergistic benefits'.

Further highlighting the low level of sophistication in the deployment of smart building functionalities, Harbor Research (2020) suggest that even though 'the technological capabilities of IBEMS have grown exponentially …, most operators still struggle to gain value from their IBEMS products beyond simple scheduling and root-cause analysis functions'. The US DoE (2021) suggests that 'intuitive and capable tools that co-optimize energy, non-energy, and financial benefits can improve GEB technology investment and building operational decisions'. Navigant (2017) suggests that 'there is still a challenge in demonstrating value to end users unfamiliar with IoT benefits … However, one thing is clear: customers are seeking benefits beyond energy efficiency'.

3.4.2.3 Social Barriers

Trust (including commercial capture)

Trust issues come in many forms. Trust issues arise from fear around the unethical use of data and AI (Memoori 2021). And there is limited trust that 'black box' AI models can effectively control HVAC equipment without the risk of unforeseen adverse outcomes. From a consumer perspective, regarding connected devices, Valdez et al (2020) identify a 'lack of knowledge regarding the presumed benefits that these devices could offer. In particular, intelligent efficiency and demand flexibility are both still in their nascent stages. Therefore, it is difficult to quantify and visualise the potential benefits that could be achieved in these areas via network connectivity and smart capabilities'. Conversely, from an electricity utility perspective, financial incentives for demand response are diluted because they do not trust that energy users will reliably deliver services (such as automated demand response) (US DoE, 2021).

Similar to other energy productivity initiatives, the energy savings from digitalization solutions must be compared against a baseline of expected (business as usual) energy consumption. Unfortunately, this is a contestable, derived quantity rather than a measured quantity. Hence, it is difficult to trust the claimed benefits from an Energy Performance Contract (EPC) service provider. It is notable that the main driver for EPCs is the 'energy savings guarantee'; and yet the highest barriers are complexity and 'lack of trust in the [EPC] industry' (Leutgöb et al, 2020). Digitalization could potentially be used as a tool for streamlining independent measurement and verification (M&V) to overcome these barriers.

Resistance to change and staff engagement

Implementation of digitalization requires coordination across departments and supply chains and there are many behavioural reasons why implementation could face internal resistance. The IT department will rightly be concerned about cybersecurity, the facilities management industry may perceive digitalisation as policing their activities, or the first step toward job cuts. Older staff may feel threatened by new technology or lack trust in the outcome. The US DoE (2021) found that 'the majority of existing demand response (DR) capability comes from non-automated (i.e., manual) peak load reductions. Some commercial building energy managers perceive that the complexity of automating technology will not actually reduce the amount of manual intervention required, since staff will still need to be trained on the technology and be available to address issues'.

Split incentives

The problem of split incentives was introduced in Part 2 of this report. Split incentives are widely reported across the energy efficiency policy literature. For example, Otte et al (2021) identify that 'the type of contract can have a significant bearing on whether a digitalisation enabling technology can add value to the operation of a building. For example Triple Net Lease (NNN) contracts, which are widely prevalent, provide limited incentives to the building owners and tenants to adopt new technology paradigms'.

Inadequate information

Harbor Research (2020) suggest that building operators 'are struggling to understand which investments to prioritize to generate value and improve occupant satisfaction' and conclude that 'the IBEMS market is fragmented, with operators struggling to choose between many products that require a significant amount of technical knowledge'. Memoori (2021) cites a 2017 survey by IFSEC finding that 63% of respondents 'felt their building was smart to at least some degree', suggesting that there is significant confusion over what is meant by 'smart'.

Lack of skilled workforce

The European Commission's Group of Experts on Energy Efficiency (2021) identifies a 'prolonged market gap in availability' of the required digital skills for the buildings industry. ICT skills are needed to deploy, securely operate, and maintain digital technologies in buildings (e.g. sensors, IoT, energy management, AI, predictive maintenance, etc.). An important share of these new jobs will require specialised ICT skill sets (e.g. cybersecurity, big data analysis, coding, etc.). In relation to cybersecurity skills, Otte et al (2021) identify that '(a) variety of measures to reduce cybersecurity risks exist, but many of these strategies require time, capital investment, skilled network engineers, and all users to be digitally competent and attentive to security needs'.

In relation to IT skills, Harbor Research (2020) claim that 'system integrators are challenged with the need [for] seamless ease-of-use and data sharing between many devices from different manufacturers'. Memoori (2021) claims that 'a lack of available AI related skills amongst workers is widely recognised as one of the key factors holding back progress' and further notes that '(t)hese skills [gaps] are not simple to address, particularly for the smart buildings sector, where many roles will require a blend of IT and OT (Operational Technology) skills'. In relation to data analytics skills, a smart buildings survey by Omdia (SecurityInfoWatch, 2020), found that 'while 77% of end users keep the data generated by their facilities, 42% do not analyse building data to identify variations and patterns that could be used to improve building operation and management'.

3.4.2.4 Regulatory Barriers

Tax/financial treatment

Digitalisation is an enabler of many different property services (of which energy productivity is one category of service). Rather than sharing the cost of the IT infrastructure and digital connectivity across all of these potential services, the cost typically gets allocated to the first digital use-case to be proposed. This unfairly burdens the cost of the first digital use case, preventing any subsequent use-case from getting up (analogous to the 'tragedy-of-commons').

Compliance with data privacy laws

While company information and data from non-residential buildings has inherently less likelihood of being classified as 'personal', and therefore subject to data privacy laws, various use-cases may potentially fall within the scope of laws such as the Australian Privacy Act 1988 or GDPR (eg. People movement, individual mobile data polling, facial recognition sensors etc). Memoori (2021) observes that 'legitimate privacy concerns along with increasingly tough data protection regimes are frequently cited as a major barrier to the adoption of AI use cases'. Otte et al (2021) found that 'consumers are worried about how this data will be used, where the data is stored, and who can access the data' and suggest that 'currently, data ownership and oversight rules can be vague, furthering concerns and generating a need for improved regulatory measures'.

Inadequate or lack of technical standards, ratings/product definitions

The European Commission's Group of Experts on Energy Efficiency (2021) identifies a key role for technical standards and 'strong mandates' (for implementing digitalisation) to 'help alter the balance between the interest of competing businesses and priorities of national governments'.

Complex supply chain and contracting arrangements

The Memoori AI & Machine Learning in Smart Commercial Buildings 2020-2025 report (2021) identifies that the building industries 'procurement practices are highly risk averse and tend toward lowest-cost options'. Moreover, a survey by the EU-funded QualitEE project found that 'around half of survey respondents reported that the complexity of contracts and a lack of trust in service providers were major barriers preventing clients from engaging in pay for performance schemes' (Leutgöb et al (2020)).

3.4.3 Analysis and Ranking of Barriers

Many of the barriers experienced in the non-residential building sector are inter-related and require collaborative solutions. For example, in the case of flexible demand initiatives, Harbor Research (2020) identified that 'while federal organizations have recently accelerated the development of GEB-related research and associated policies, implementing these changes is an expensive undertaking that requires systematic changes'. These changes involve various actors with respective actions as illustrated in Figure 27.

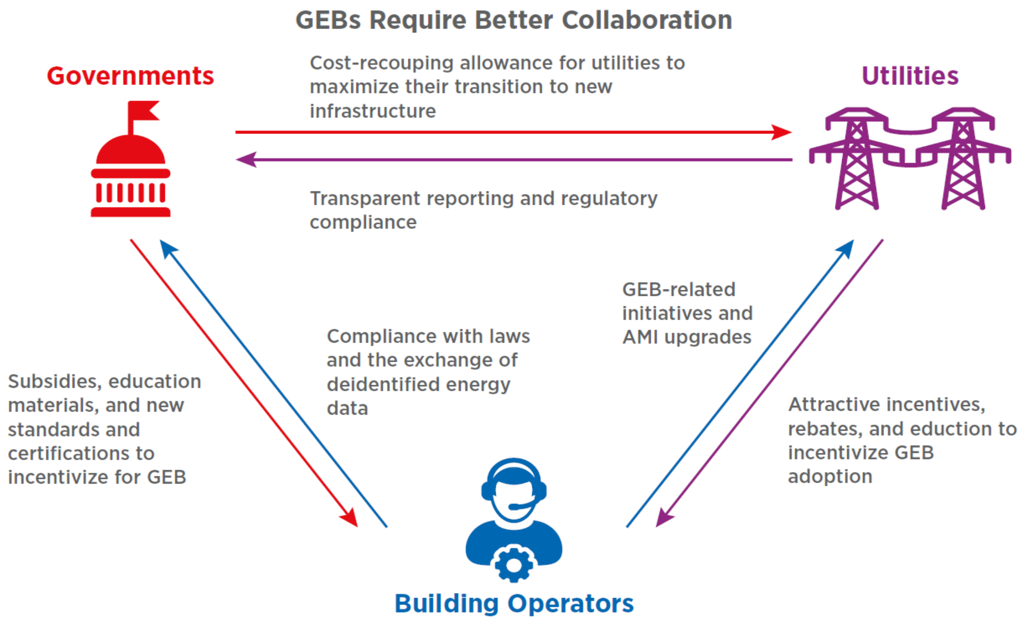


Figure 27. Suggested collaboration approaches to address barriers to extracting flexible demand from buildings (Harbor Research (2020)).

The US DoE's *Grid Interactive Efficient Buildings* roadmap (2021) similarly identifies numerous barriers to the adoption of flexible demand in buildings: a use-case that is somewhat reliant on digitalization. The barriers, as they appear to various actors in the ecosystem (ranging from Developers, System Installers, Owners and Utility System Operators) are illustrated in Figure 28.

The DOE's roadmap subsequently reduces the non-utility-based barriers to: (i) lack of interoperability; (ii) technology is too costly or complex; and (iii) consumers lack incentive or understanding.

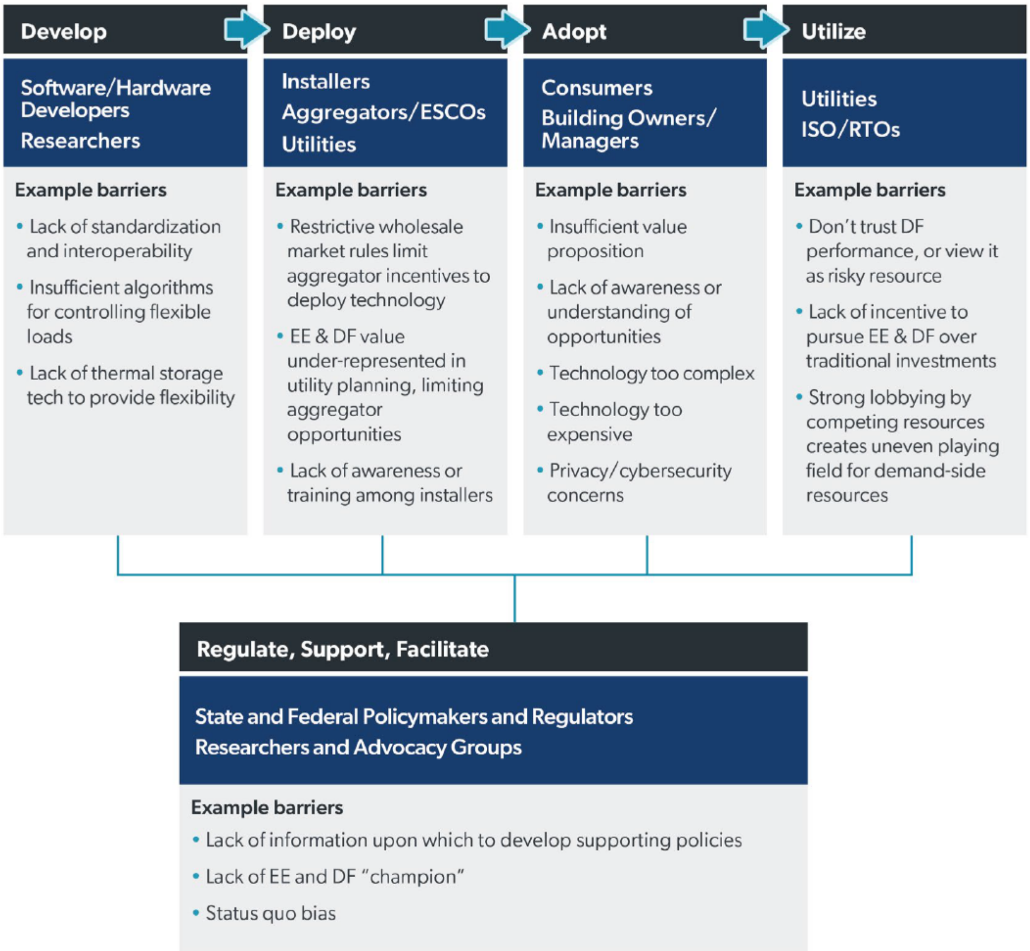


Figure 28. Barriers to widespread adoption of flexible demand from buildings

Leutgöb et al (2020) surveyed 188 respondents across 15 EU countries on the barriers faced by Energy Performance Contracting businesses. The most significant barriers revealed in the survey are illustrated in Figure 29.

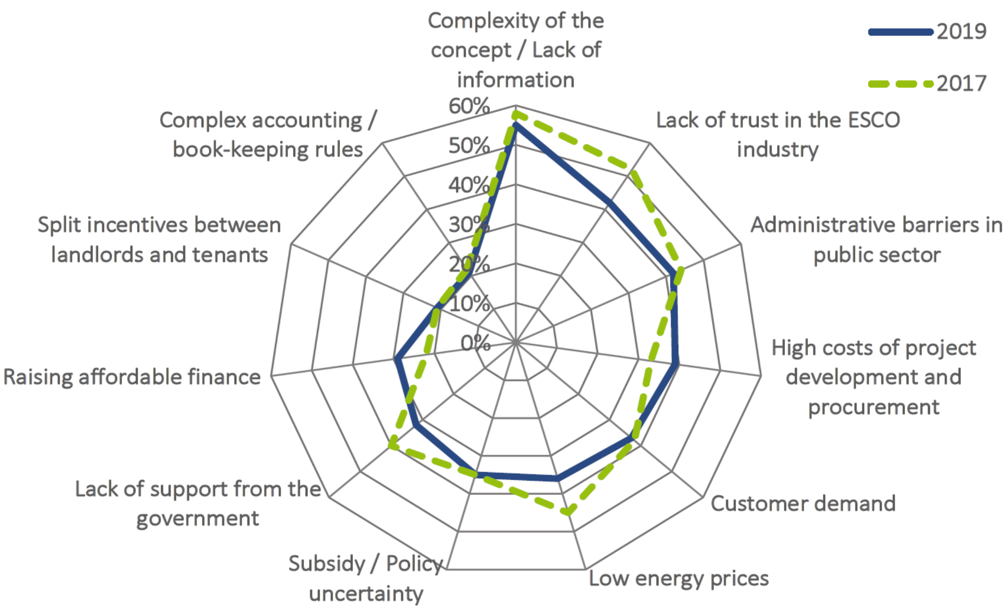


Figure 29. Barriers to the EPC market (Leutgöb et al, 2020)

Looking at AI more broadly than just the buildings sector, O'Reilly (2020a) surveyed 1,388 people on the adoption of AI in their companies. The survey results (Figure 30) illustrated similar barriers to that found in the property sector, albeit with surprisingly low emphasis on legal concerns, risks and compliance issues (such as cyber security and privacy).

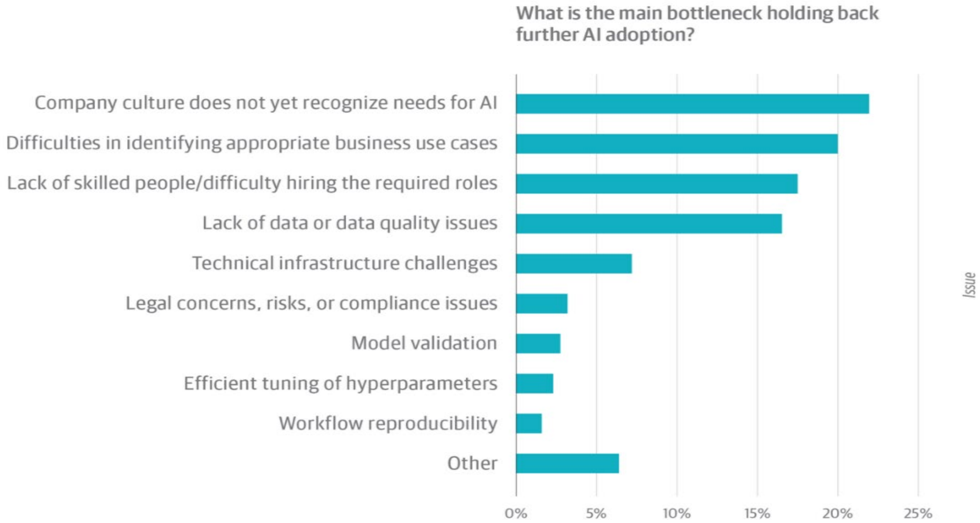


Figure 30. Bottlenecks to AI Adoption (O'Reilly, 2020a)

More specifically, in relation to digitalisation, the International Energy Agency (2021) sums up the barriers by stating that 'common issues involve the needs for research and development, infrastructure development, interoperability standards, cybersecurity and privacy measures, as well as increasing "digital literacy"'. Based on the key barriers they suggest strategies for improving the deployment of digital energy efficiency, which are set out in Figure 31.

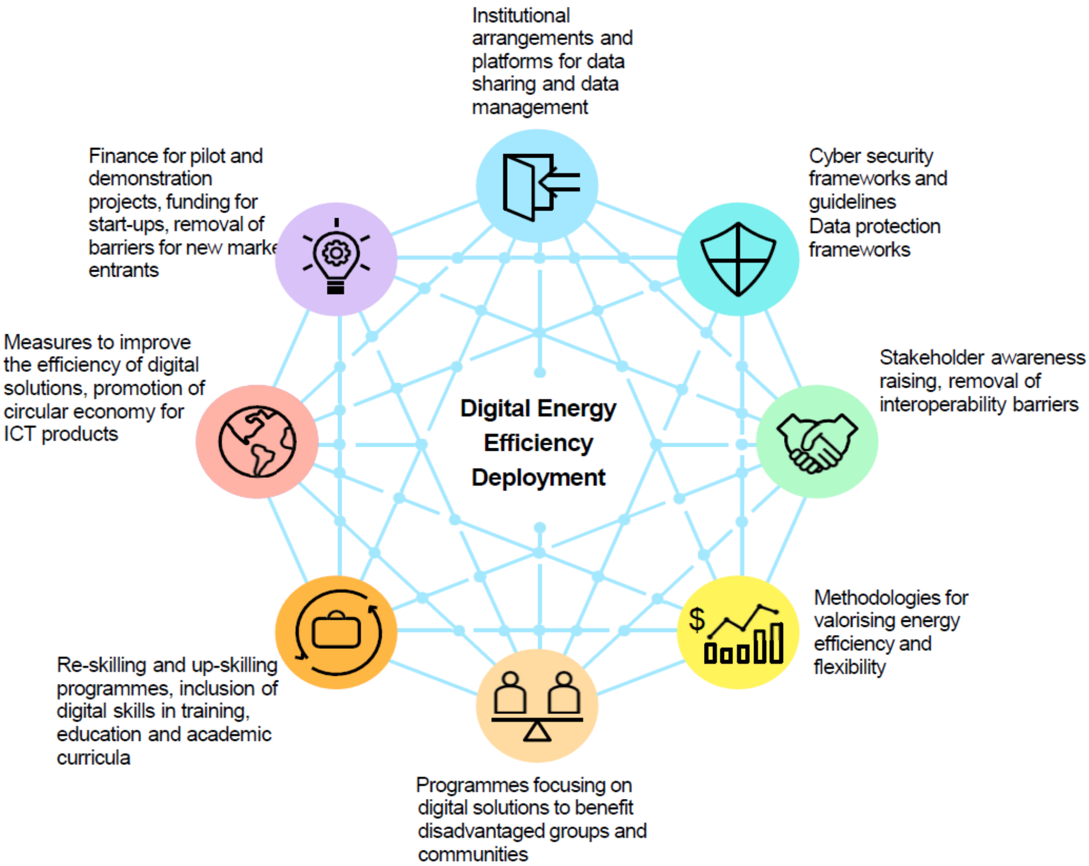


Figure 31. Strategies for improving the deployment of digital energy efficiency (IEA, 2021)

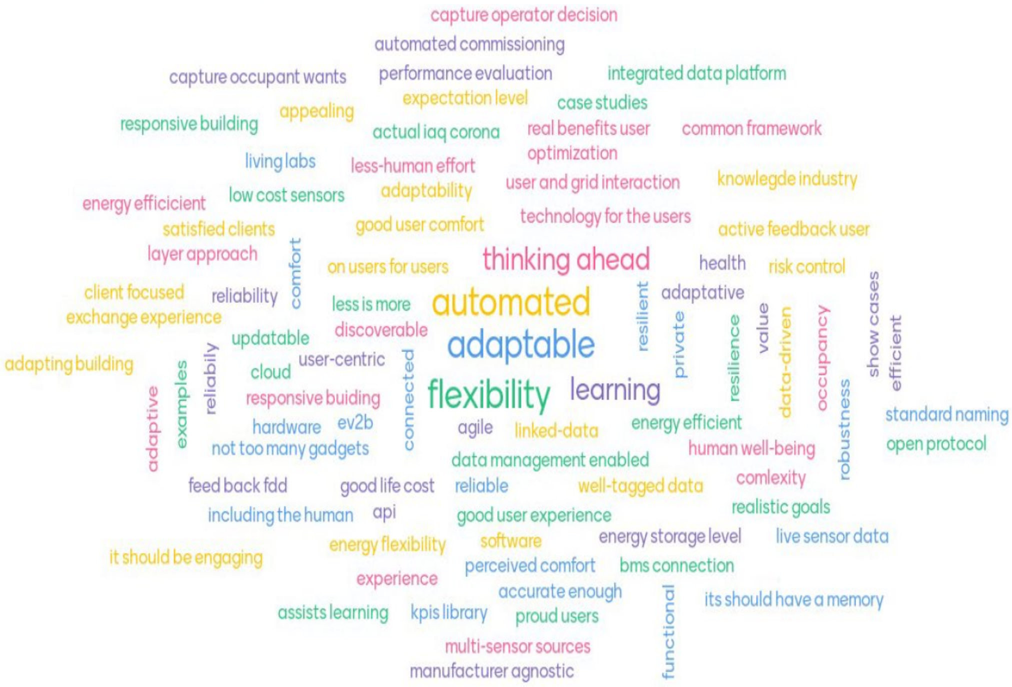
3.4.4 Unpublished Surveys

As the literature specifically on barriers to the adoption of Industry 4.0 technologies for energy productivity in the non-residential buildings sector is limited, this section of the report outlines the results of two recent forums that have discussed the drivers and barriers for 'smart buildings'. The two recent forums were the International Energy Agency (IEA) Annex 81, *Data Driven Smart Buildings* Plenary Meeting held in September 2021 and the IEA Annex 81 Subtask B Survey on *Model Predictive Control.* The results from the unpublished surveys supplement and reinforce the analysis in the limited published research.

IEA Annex 81 Data Driven Smart Buildings Plenary Meeting, September 2021

An industry panel Q&A session was held as part of the IEA Annex 81 *Data Driven Smart Buildings* Plenary Meeting in September 2021. The figure below (Figure 32) illustrates some of the results of the survey mentioned in the previous Chapter conducted to 28 research and industry participants, all with an interest in the topic of 'data driven smart buildings'.

To you, what should be the traits of a "Data-driven Smart Building"?



What are the barriers to smart-building technologies?

- data ontology
- lack of use cases
- current IT engagement
- cost, loosing control
- Perception of users losing control
- Better economic incentives!
- Misusage of the term "smart". Sometimes, it gives users an unrealistic expectation which causes confusion and disappointment
- Data protectiveness
- Scared of vendor 'lock-in'
- lack standards
- cyber security fears
- lack of real data
- Standardised control sequences
- proprietary systems with poor interoperability
- Conservative industrial structure
- "Big brother" watching us
- High cost, especially due to engineering hours
- Lack of tools
- Define and share concrete use cases
- Skills
- Data labelling
- people affraid about data
- data, privacy, and cyber security
- people afraid of AI
- Lack of business case for budgets to be set by decision makers
- Integration Skills. Defined requirement for the detailed operation between different smart technologies. Post occupancy support skills to keep the systems smart or hopefully keep making them smarter
- Horror stories
- siloed thinking

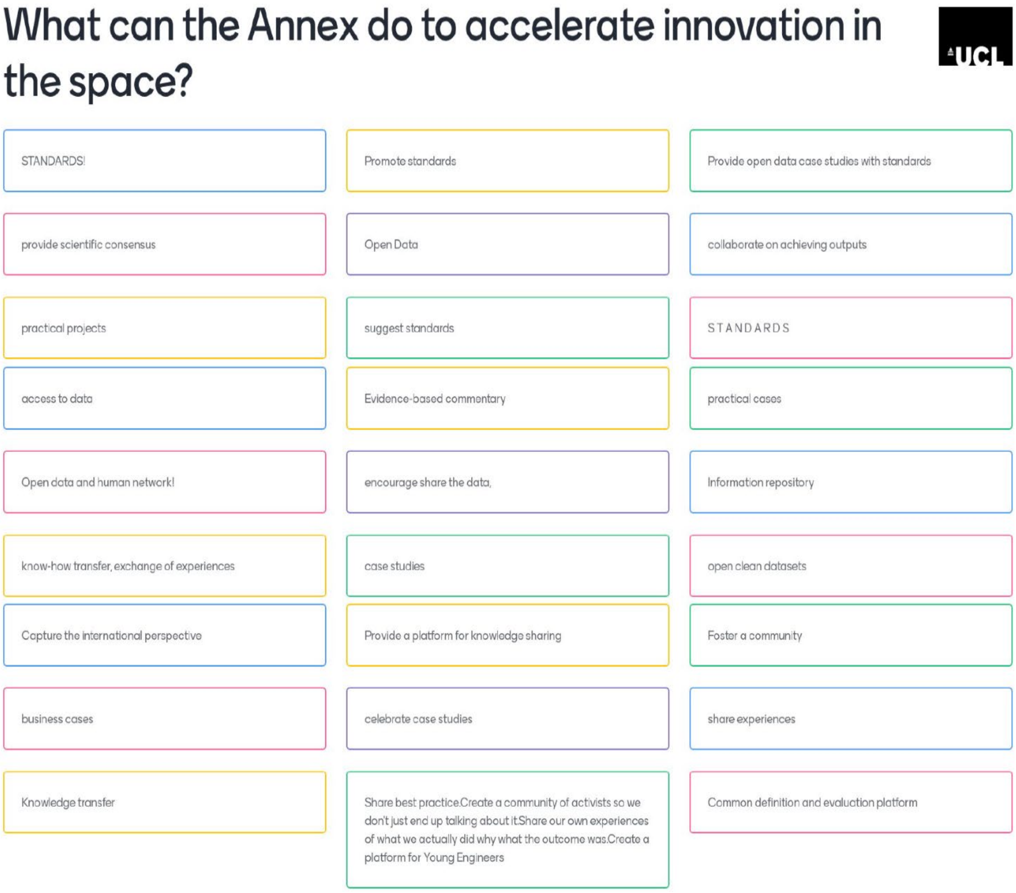


Figure 32. IEA Annex 81 participant perspectives on enabling 'data-driven smart buildings'

These results reinforce the barriers identified in the published literature and in this report, especially:

- The importance of data and lack of (i) interoperability and (ii) requisite data standards;
- Lack of skills, particularly in 'integration';
- Cybersecurity and difficulty engaging with IT department;
- Fear (lack of trust) of AI, conservatism and reluctance to hand over control to machines;
- Commercial issues around vendor lock-in and data hoarding;
- Immaturity of use-cases.

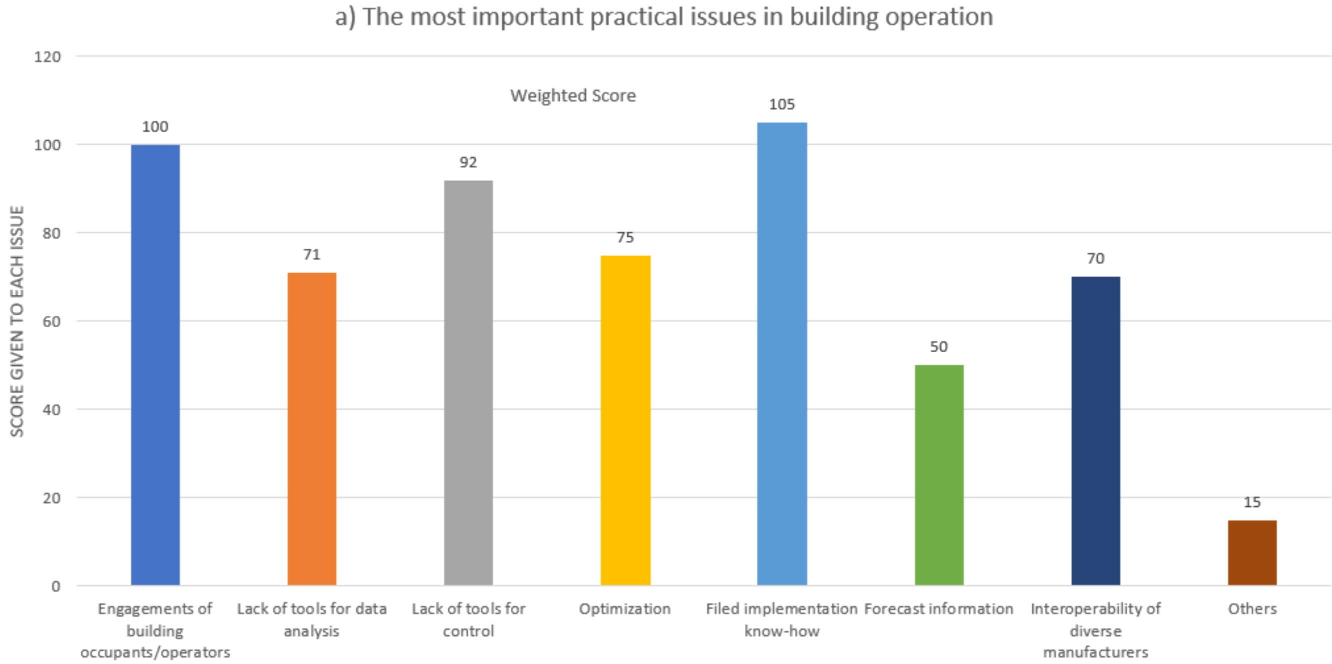
Drawing from the unpublished survey, the main perceived solutions to overcoming the barriers related particularly to:

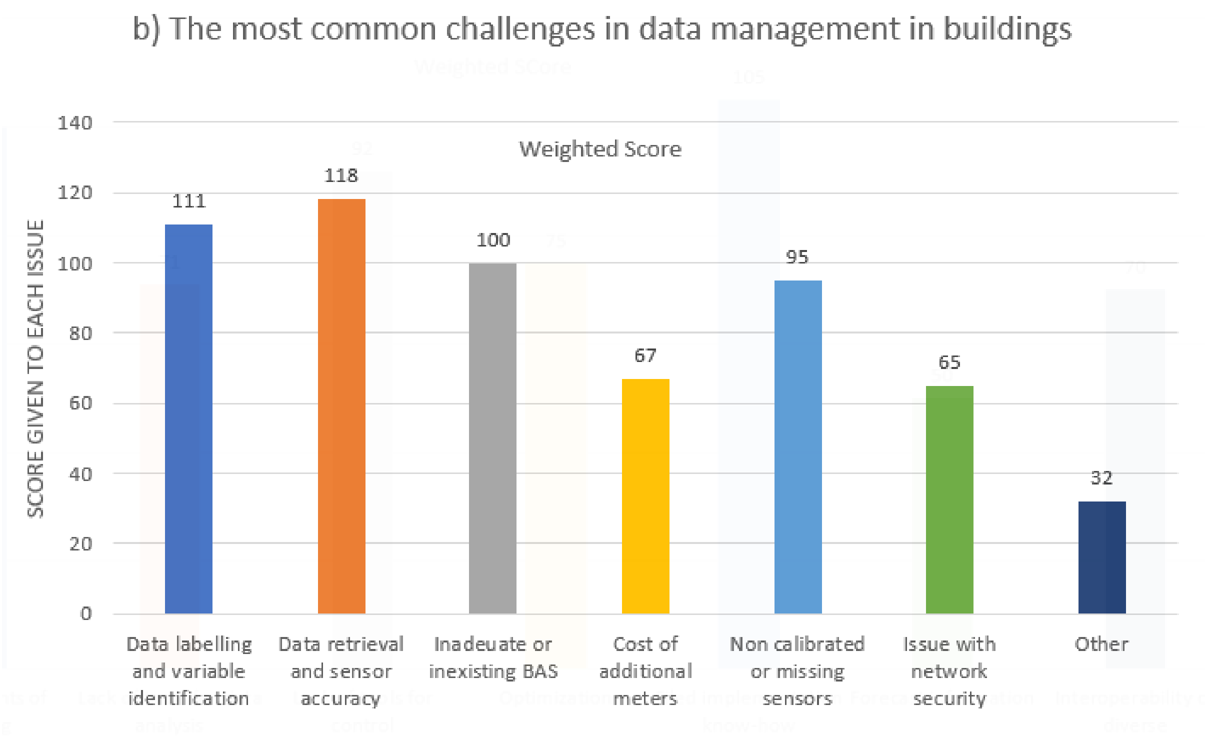
- Greater data sharing and common standards; and
- More case studies and knowledge sharing.

IEA Annex 81 Subtask B Survey on Model Predictive Control

An online survey was conducted of participants of the IEA Annex 81, *Data Driven Smart Buildings Annex,* and relevant stakeholders from their respective networks. The survey particularly focussed on model predictive control (MPC) technology, which is a form of AI used to schedule the operation of HVAC equipment up to a day ahead.

Twenty-one people responded to the survey, predominantly from academia and government. Some results from the survey are illustrated in Figure 33 (a, b, c).





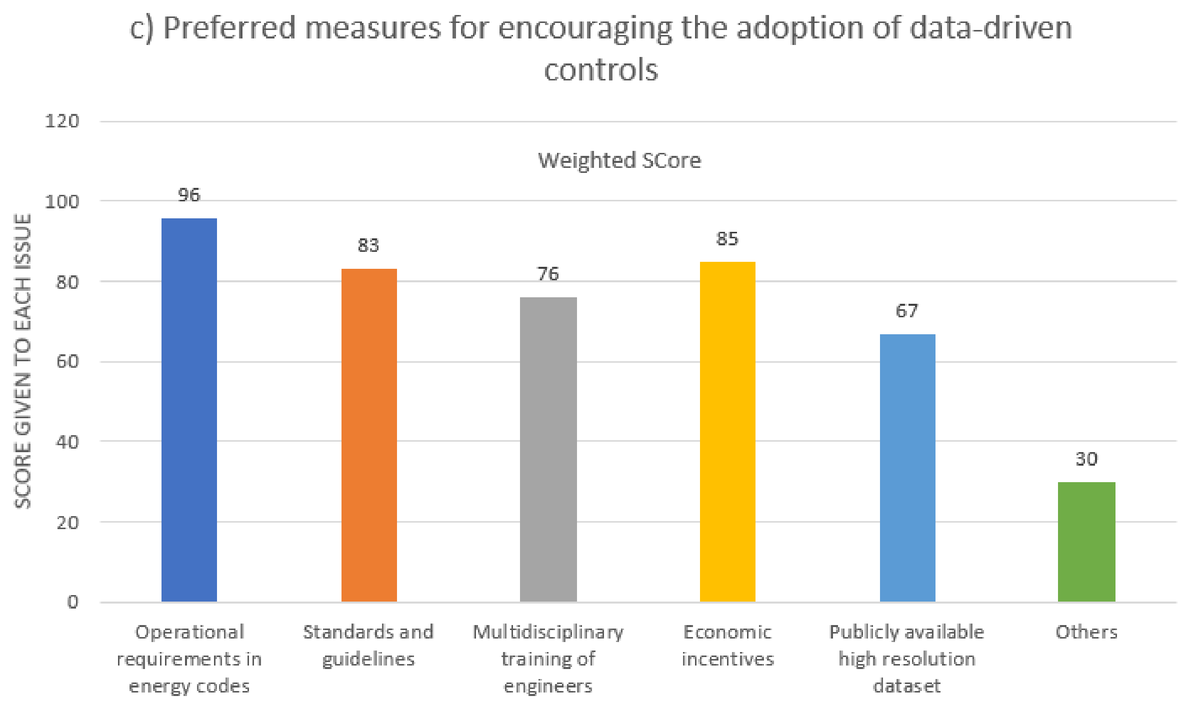


Figure 33. Barriers and solutions for the adoption of model predictive control technology

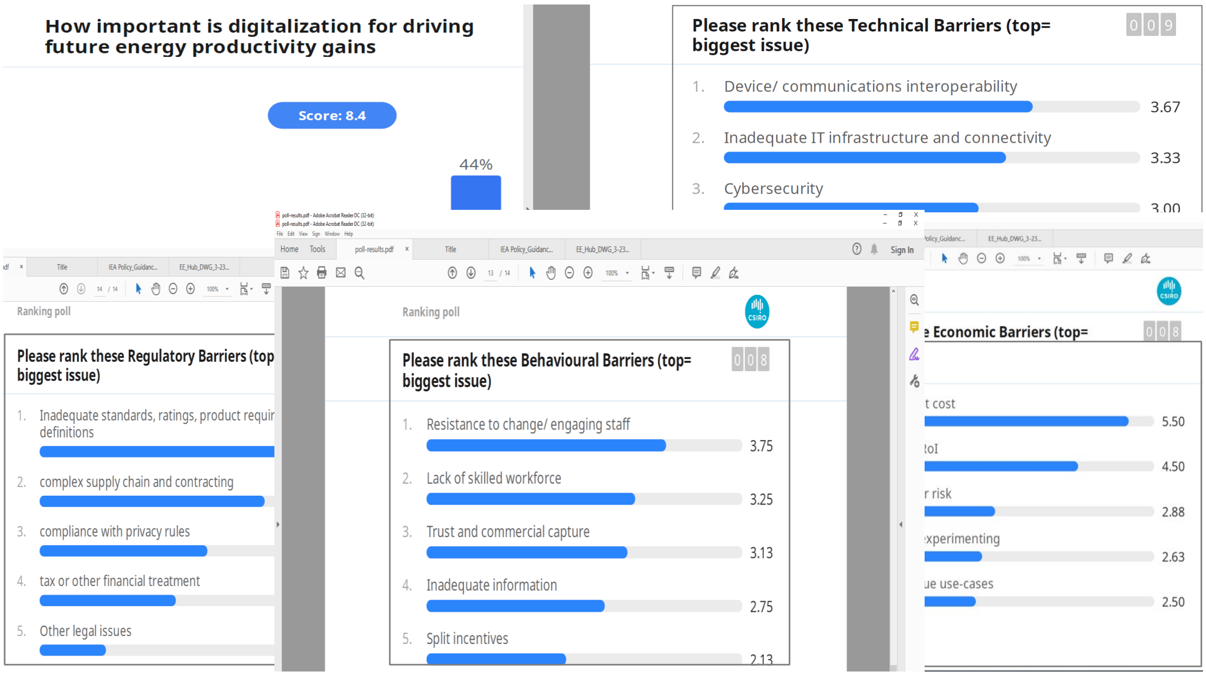
While the sample of respondents lacked industry input, the results generally reinforce the analysis of the main barriers to technology adoption in the building sector identified in this report and the published literature.

3.4.5 Non-residential buildings focus group

As part of this RACE for 2030 opportunity assessment project, in March 2022 a focus group was convened to discuss issues relating to the use of Industry 4.0 technologies to improve energy productivity in non-residential buildings. The focus group contained eight industry participants: four representing large building portfolio owners (one of them government), two representing the consulting industry and two representing facilities management/BMS contracting. The feedback from the focus group consisted of answers to semi-quantitative questions administered using a Slido poll as well as qualitative feedback. This feedback is set out below.

3.4.5.1 Responses to Slido poll

The most relevant responses to the Slido poll are set out in the following graphs.



In general, the results of the Slido poll supplement and reinforce the analysis of barriers to the adoption of Industry 4.0 technologies for energy productivity in the non-residential building sector. In relation to technological barriers, problems of interoperability and inadequate infrastructure were regarded as most significant, but with security and data quality issues also considered important. Perceived high investment costs and uncertain ROI were regarded as the most important economic barriers. In relation to social (or behavioural) barriers, resistance to change, a lack of skilled workforce and trust all ranked highly. Finally, inadequate or missing technical standards and the complexity of supply chains, including supply chain contracts, were all considered important.

3.4.6 Qualitative responses

The focus group also provided an opportunity for feedback on barriers to technology adoption for energy productivity for non-residential buildings. The following summarises the relevant feedback on key issues relating to the drivers and barriers to technology adoption by means of quotes from participants in the focus group. The quotes provide a good qualitative insight into industry thinking on these issues.

Is energy/sustainability a key driver for technology adoption?

"… for the [last] 10+ years in the commercial space, there were strong drivers around the investment community and clients and tenants. I've had government clients, where the strong drive is coming from sort of clear policy directions that have been adopted at state government level that is sort of filtering through to the agencies" – *Consultant*

"Four main pillars … are reducing the energy, using the operational expenditure, reducing their risk and make sure that it's comfortable" – *Facilities Management*

Are maintenance challenges and costs a key driver?

"Considering the importance … I think that hopefully we should be starting to feed into more technology driven maintenance" – *Consultant*

"There are qualitative and quantitative analysis options they can use, especially if you look at CMMS (computerized, maintenance management systems), where you can look at historic data, for example, an escalator, and we can track the historic data, looking at how many times certain components break down and then you can implement a preventative maintenance program and generate automated workflows. I think around maintenance you can actually automate that process" – *Consultant*

"using [analytics] to support commissioning. And that's a real paradigm change from a bunch of people going around the building taking readings, you know, putting them in a spreadsheet. And then you start to get the elements in the systems working together, having it tell you what is and what isn't" – *Facilities Management*

"The industries invested a huge amount of money in the last 5 years, digitalizing its maintenance processes and so it's everything from barcoding and coding and getting text to upload 7 or 8 different attributes and then ensuring that when they work on a pump or a chiller or whatever it might be, they're actually attributing those activities to that asset. And then, all the platforms, the data structuring, the protocols, everything that goes with that and then obviously reporting out of that. Is it reducing total cost of ownership? Probably? But now we've got that sort of data feed, that sort of information in place [that we can] design a whole bunch of different things" – *Facilities Management*

What is the relationship between maintenance and energy efficiency/productivity?

"You've to look at the point in time where you either replace it or you introduce new systems" "[energy productivity and maintenance] are all linked. If you look at the age of the asset, the older it gets the less efficient it gets. So if you can, the more data you get the better" – *Building Owner*

"I agree, a building that delivers on comfort will always be more efficient, they sort of go hand in hand" – *Consultant*

To what extent is future proofing an important consideration? How does this affect investment decisions?

Given that implementing the wrong technology now can severely constrain what can be done later, focus group participants wanted to choose technologies that preserved choices into the future.

> "You could just make it 5 star, ... you have to tick that box, ... but now, especially from the blue chip tenants sort of wanting more and if we can kind of demonstrate that we're doing above and beyond, ... like, you know, performing really well, but we've got the systems to enable us to do really well" - *Building Owner*

> "We'd like to sell the dream. Obviously the more IoT that we can get into a new project the better. But then you've got to do the cost analysis and understand what it is that we're trying to implement and is there any low hanging fruit they can put in place now, which they can later extend and expand on as technology becomes cheaper?"- *Consultant*

> "Often we're just thinking about HVAC data, but someone might want to lift vertical transport data [collected] into their system and oh, oh, no, you've got to pay them to get it out of their system and they own it. You should own it. It's your development. You've got to make sure that potentially the future of the building blocks that you're building right now will enable that in the future" – *Facilities Management*

What are the uncertainties about new technologies, including what to buy and the desirable level of 'smartness'?

In the face of uncertainties in relation to the current wave of technological change, focus group participants expressed a desire for some form of product standardisation and/or greater guidance.

> "The amount of technology that's out there, and the methods that you can apply, is multifaceted in perpetuity; there's always something new coming out, and it's hard to actually benchmark the different solutions against each other" – *Facilities Management*

> "It's easy to think of innovation purely in technology terms. But I think a smart building is a building that achieves outcomes and is adaptive and responsive to the changing ecosystem. So things like interconnectedness and those foundation technologies, they are important but they are a means to and end rather than the smartness itself. A PIR in a room, directly wired to a light in the room, might be as smart as it needs to be, to be responsive" – *Consultant*

> "How smart is smart? Does having a BMS call yourself a smart building or do you need to have, you know, full Internet of Things, and all these sensors, analytics software and so on" – *Building Owner*

> "The greatest problem that I can see with buildings that purport to be smart is complexity in the real world. The challenge we've got in existing buildings is just fly by wire issues and that the degree of difficulty in making all these systems work for outcomes" – *Facilities Manager*

> "The smarter buildings and premium grade - most of them come built with something, but you have got to be careful during development that you are building something that doesn't have ... potentially hidden costs or ongoing costs that appear later in the future" – *Facilities Management*

What are the concerns about practical implementation?

“The building owners are just crying out for actual outcomes … The consistent message is, how can you actually deliver an outcome from this” – *Facilities Management*

“Who's governing this technology and am I the building owner responsible for it? And, then, how do I make sure that the actual outcomes are achieved? Because you've got to orchestrate a lot of parties together within the organization as well as the various service providers” – *Facilities Management*

In practice, what are the impacts of costs of technologies such as IT/connectivity?

Focus group participants indicated that even if technologies may be cost effective, costs can still be an important barrier.

“When you look at the investment required to optimise and tune a building, the payback indeed is usually sub 2 years. So, the process in the first instance is getting your backbone sorted out. There's usually an investment in that, because typically, building systems aren't set up to be tuned, whether that's the box that hasn't been ticked in the BMCS or something's not connected or something's not aligned. So there's usually an initial investment around that. And then the majority of the investment in optimising systems and trouble shooting them is basically time. It's paying attention.... So the payback is there from an energy perspective in most buildings that haven't been tuned, and there's somewhere between half a star, or even 2 stars in some buildings, just by getting things to work properly together and then to optimize them through the different seasons and occupancy and what have you. But, it's an incredibly frustrating thing to sell because you need quite an alignment of interests in a building. You've got owners, you've got tenants, you've got different contractors, you've got the BMCS company, which quite often has got its own agendas. There's a whole bunch of things and then you've got to have an organization that's got the capability to do that” – *Facilities Management*

“We did spend a fair bit of time trying to basically get a digital twin; it wasn't really fully, but it was a platform that was going to be an integrated services sort of platform, which was going to give a little bit of control, even with the BMS and lighting and all that sort of stuff. So we spent a lot of time working at it, and, I mean, there was nothing wrong with the system per se, but the cost that was associated with keeping it going was relatively high” – *Building Owner*

“And then, certainly, in B grade buildings and the areas of incompatibility and the amount of infrastructure you have to upgrade to enable that - does it match the outcome that you are going to achieve?” – *Facilities Management*

“The challenge you have in existing buildings is just the poor quality of the install originally around the BMCS because it was, basically, just set up to be a glorified time clock and a bit more. A lot of things weren't reactive. Then, you've got layer upon layer upon layer of fixes and changes over this. So, unpicking all of that, so that you're getting stuff out that you can understand? You know, inevitably the cost of setting that up in existing buildings is multiples of what you expect” – *Facilities Management*

How much of a challenge are data collection (including interoperability) issues?

"The challenges? One is the technological challenge of collecting data; but I think there's also a challenge that is a huge challenge with any existing building which seems to be, you know, I walk into a building and I'll say, well, with the BMS, where's the functional description? And then, often, it's sort of, you know, there's a blank - there's a lack of information about the building. How was it intended to work? You know, collecting data in the broader sense is still a huge issue" – *Consultant*

"The idea of data interoperability rated fairly highly as a barrier. To this day, you know, any analytics system that gets put in uses BACnet as the prime means of unlocking the data in the basic form. I think the next step of actually a data standard, obviously there's Haystack and Brick and those sorts of things, but it doesn't seem there's really been an attempt at an industry level to try and define how we are going to make data more accessible, and it's a barrier to entry that still needs to be really worked on" – *Consultant*

While data collection is important, is it necessarily sufficient?

"It's not data for data's sake ... I don't think technology makes a building smart" – *Facilities Management*

"I think that the data for data's sake point is an important one. Like, if you're not using it cleverly, you know, with someone intelligent looking at it, but realistically it's more of the systems that are then going to be analysing it, or integrating system A with system B. You've gotta get more out of it than just the input" – *Building Owner*

"I kind of agree ... data is key, but how you use the data is important. There's so much data out there. It's, you know, filtering through all the relevant data to understand what the key fundamentals you're looking for and how we can use it. And then you've got to overlay the privacy issues" – *Building Owner*

What other listed barriers were confirmed?

Focus group participants confirmed the importance of 'split incentives' and problems of supply chain contracting as important barriers.

Split incentives: "We do come across a lot of building owners that sell energy to their tenants and therefore, sometimes it's a contradiction, where going towards net zero they lose a source of revenue - so what's the incentive for a building owner? " – *Facilities Management*

Contracting: "That data-driven maintenance factor, I think what you struggle with is getting a contract that is advantageous to us. The contractors we've spoken to, kind of were taking all the benefits and we weren't seeing it" – *Building Owner*

Were there listed barriers that were regarded as less important in practice?

Data Privacy: "With 'The Edge' building in the Netherlands, the architect a couple of years ago ... was saying that the greatest barrier to that building being truly smart was "Who owns the data" and the court cases around privacy... [although] we don't come up against that in our common garden-variety, broader use of data, whether it's analytics, or maintenance, or design or documentation" – *Facilities Management*

What are some suggestions about possible solutions?

Drive technology 'pull-through' from the construction phase:

"Having the [IT/connectivity] capability translates into a high value add, from an operational perspective - it's actually built in during the construction process and, on the way through, there it is for the operational team to be able to use the information to support performance or training or change, or whatever" – *Facilities Management*

Connect funding incentives to transparency & technology advice:

"It used to be that everyone, like that mid-tier lower-tier office building, with a one or two star NABERS rating, was able, you know, probably didn't even know that they were that low, but if they did, like, didn't want to tell anyone about it. But throw in the fact that all of a sudden you have to tell everyone and then throw in what was sort of talking about, um, you know, funding. It's like, A, you've got a motivation and B, you've got some help to do something about it" – *Building Owner*

"Well, if I point to the past. The revision of DA19 which included data driven maintenance, a 'how to' guide for FMs, to let a data driven based contract. I think that was useful in changing the minds of industry. So potentially something with that theme, with a focus on Energy, could be a useful way forward for us" – *Facilities Management*

"The B grade office class. It's a real struggle for them. I mean, people always love a grant, you know … where it's like, cool, they're going to pay for 50% of my lift upgrade of my chiller this or my lighting that" – *Building Owner*

Provide more relevant and visible metrics for board-level discussion

"I think there's something very much around the whole visibility piece. Ultimately changes are wrought by community sentiment. So, the more visible we can make energy usage in the spaces that people are occupying I think, the more impetus there will be to change.

… So often, when we talk about energy productivity in building we talk about energy usage per square meter. [But] the basic unit of production in a building is a person. It's no more so the case these days when we're all up in the air about what occupancy is going to look like post COVID and what are density level's going to be? And so ultimately how much energy is spent to provide a safe comfortable environment for a person is really the ultimate measure of energy productivity when it comes to the buildings" – *Facilities Management*

4 Productivity Benefits from Industry 4.0

4.1 Energy productivity benefits

Research and development efforts across all businesses are driven by the goal of improving the productivity of industrial processes and business models and processes. Improvements can come in a variety of ways, including lower capital costs and operating costs, increased yields, improved capital utilisation, plant uptime, reductions in labour, and resource & energy use. Many technology developments and business innovations will incorporate one or more of these improvements. Some innovations may primarily be aimed at one goal, but also generally include beneficial impacts on other aspects of a production or business process.

Certain technologies identified as 'energy-efficient' because of their positive impact on energy reduction, will also bring several additional benefits to the production or business process. Such improvements, including lower maintenance costs, increased production yield, safer working conditions, and many others, are collectively referred to as 'productivity benefits' 'multiple benefits' or 'non-energy benefits' (or NEBS), because in addition to reducing energy consumption and/or costs, they all increase the productivity of the firm (Finman & Laitner, 2001; Worrell et al., 2003).

Non-energy benefits are not limited to being effects of improvements in industrial and business energy efficiency; such effects are also seen in other areas, for instance, in the residential and non-residential sectors. In these areas, the effects are commonly known as co-benefits or ancillary benefits. In business contexts, these benefits are also denoted by other terms, such as ancillary savings and productivity or production benefits. The IEA applies a broader view on the concept by describing these additional effects as 'multiple benefits', which includes benefits at all societal levels: the individual level, the sectoral level, the national level, and the international level (*Multiple Benefits of Energy Efficiency – Analysis - IEA*, 2019). Emerging approaches including Circular Economy, value chain and lifecycle thinking identify these broader benefits and highlight the importance of mechanisms that can support secure and fair sharing of costs and benefits across businesses and sectors, so that national benefits can be captured.

Notably, in this report, our focus is on 'energy productivity' which goes beyond saving energy or using energy more efficiently, to incorporate a broader picture. For example, an energy productivity measure may lead to an increase in energy consumption that is outweighed by the financial and/or other benefits that result. As discussed earlier, most business 'energy efficiency' activities focus on reducing energy costs, without factoring in the value of many business benefits that can grow activity or offer valuable business benefits. This approach seriously undermines adoption of energy productivity improvements, as many decisionmakers place much higher priority on actions that increase production over measures that reduce energy costs, which are typically a small component of input costs. Most of the literature, for example IEA reports, separates 'energy efficiency' from the additional or indirect benefits.

Nevertheless 'energy efficiency' literature does explore the 'multiple' or 'non-energy' benefits, so it is important to describe this work, which can be incorporated into an 'energy productivity' framework. The following section reviews two such approaches, one by the IEA, and a more comprehensive one by Cagno et al. (Cagno et al., 2019). These example reflect the variety of language used to describe what this report describes as 'energy productivity'. There is a need to provide greater clarity and consistency in language so that the full potential of energy productivity can be captured. This challenge is reflected in the name of Australia's Energy Efficiency Council, which actively promotes many energy productivity and 'demand-side' measures.

As discussed, Cagno et al. (Cagno et al., 2019) presented a framework to consider the broader impacts stemming from energy efficiency measures (EEMs). The term energy efficiency measures has been broadly used in literature (e.g., Worrell et al., 2003; Fleiter et al., 2012; Trianni et al., 2014). The term EP measure is intended here as a synonym for an EEM with impact on resource productivity. The framework has distinguished among the impacts, particularly, Energy Benefits (direct), Non-Energy Benefits (NEBs), and Non-Energy Losses (NELs). Energy benefits comprises of all direct flow-originated benefits after putting in service an EEM. NEBs refers to the positive indirect benefits that arise because of an EEM, while NELs include all the indirect impacts with a negative effect on the firm.

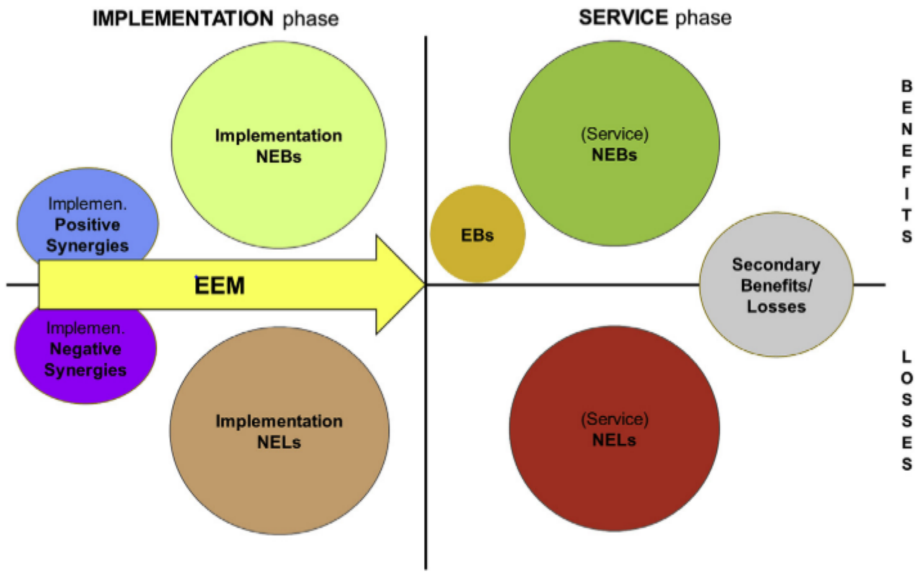


Figure 34. Framework displaying the set of impacts from adoption of an EEM (Source: (Cagno et al., 2019))

For instance, while implementing an EEM, the reduction of the emissions due to saved energy consumption, as it specifically stems from the reduced energy flow, it is certainly a direct benefit. In contrast, a reduction in the workload of people managing the energy contracts into a company is an indirect benefit due to an energy flow variation (reduction). Therefore, it is visible that all measure-originated impacts are indirect, being not strictly dependant on the energy flow variation. On the other hand, the variation of the energy flow can bring both direct and indirect impacts. This feature is designed to help industrial decision-makers pay more attention on the existence of possible indirect impacts that are often overlooked.

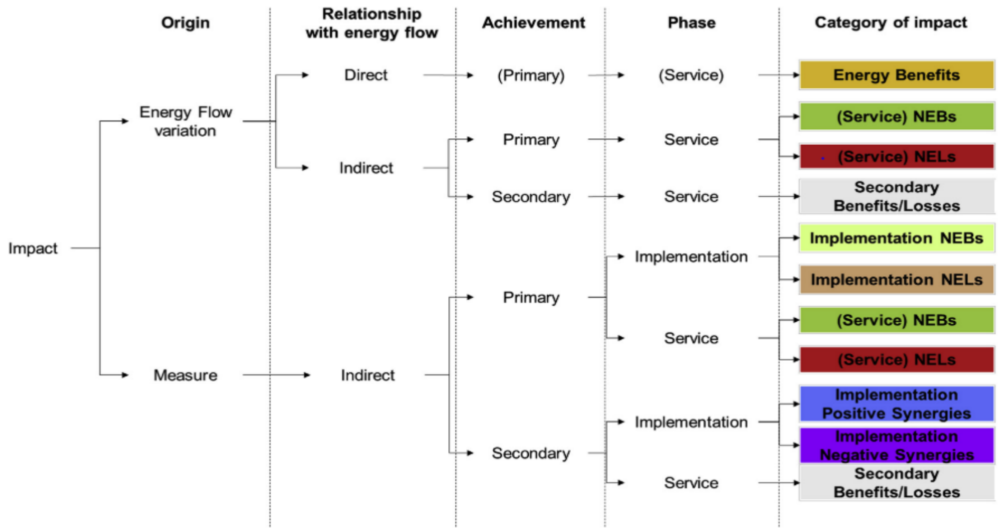


Figure 35. Categorization of impact stemming from EEMs (Source: (Cagno et al., 2019))

As discussed earlier, energy productivity therefore extends far beyond 'savings of energy or energy costs'. It is really about using energy-based analysis as a toolkit to identify and implement actions that deliver net business benefit. Experience has shown that timely collection, analysis and delivery of information from multiple data streams is needed to empower and inform action that can prevent problems, support strategic planning and support optimisation of activities. This is where Industry 4.0 solutions complement energy productivity-related activity.

In fact, Industry 4.0 allows closing the information loop by offering real time data and monitoring. For example, often projects are implemented (e.g. new processes, new equipment) and are only measured on the production rate and quality, overlooking the energy performance of new process / equipment. Industry 4.0 gives promise to allow energy performance more easily. Variable speed drives are a good example. They are recommended for improving energy efficiency without proper consideration and they may often not deliver expected savings. Industry 4.0 solutions offers a pathway for accountability – for both the equipment supplier and the manufacturers who use the equipment. This 'closing the loop' with feedback on actual energy usage can help designers. Currently, when estimating the required heating for a building, say an aquatic centre, 3 different consultants will often advise 3 very different heating requirements (>30% variation) for the same building design. Industry 4.0 technologies offer ways to help with better designing by closing the feedback loop on actual building performance vs expected. Moreover, with the help of Industry 4.0 technologies, cognitive biases (e.g. confirmation bias, recency, anchoring) could be overcome with better flow of information. On top of that, Industry 4.0 solutions can help build trust for EE / EP technologies.

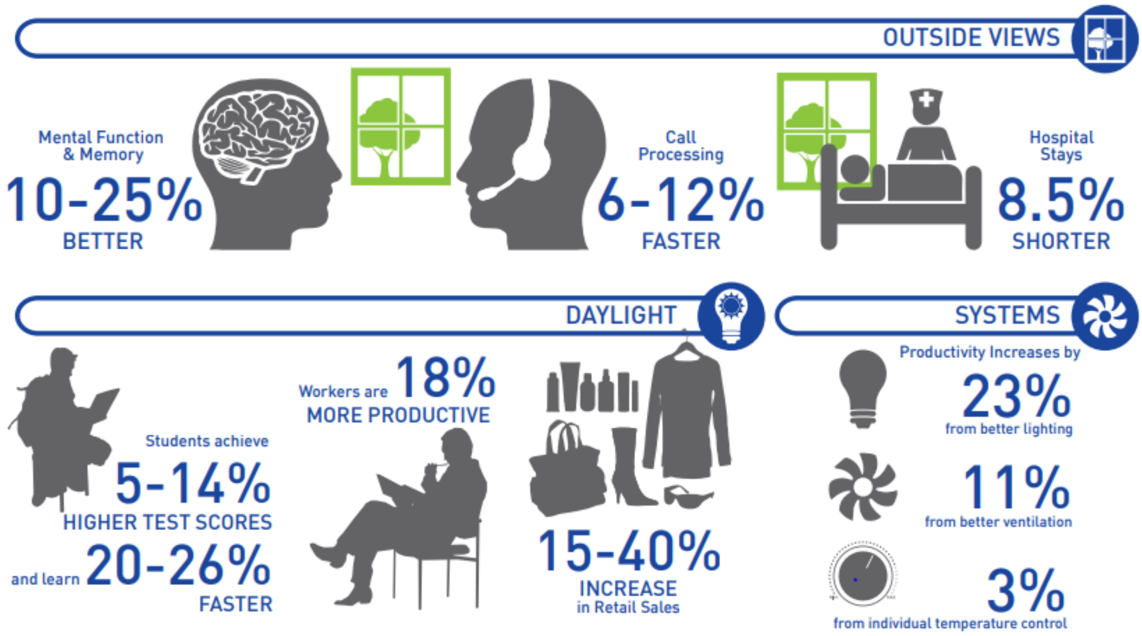


Figure 36. Cost and productivity benefits stemming from energy efficient measures in the buildings (Source: (The Business Case for Green Building: A Review of the Costs and Benefits for Developers, Investors and Occupants, 2013))

While looking at the technologies offered by Industry 4.0, the main feature has been to make manufacturing – and related industries such as logistics – faster, more efficient and more customer-centric through optimization and automation. In practice, Industry 4.0 approaches can be applied across all sectors and by end users – for example applications to buildings are included in this report, but households and the services sector can also apply them: the 'smart home' applies sensors, automation and flexible equipment (see for example Pears, A.; Moore, T. (2019): Decarbonising Household Energy Use: The Smart Meter Revolution and Beyond, in P Newton, D Prasad, A Sproul and S White (eds), *Decarbonising the Built Environment: Charting the transition*, Palgrave Macmillan, Singapore, pp. 99-115.) However, residential activity is beyond the scope of this report.

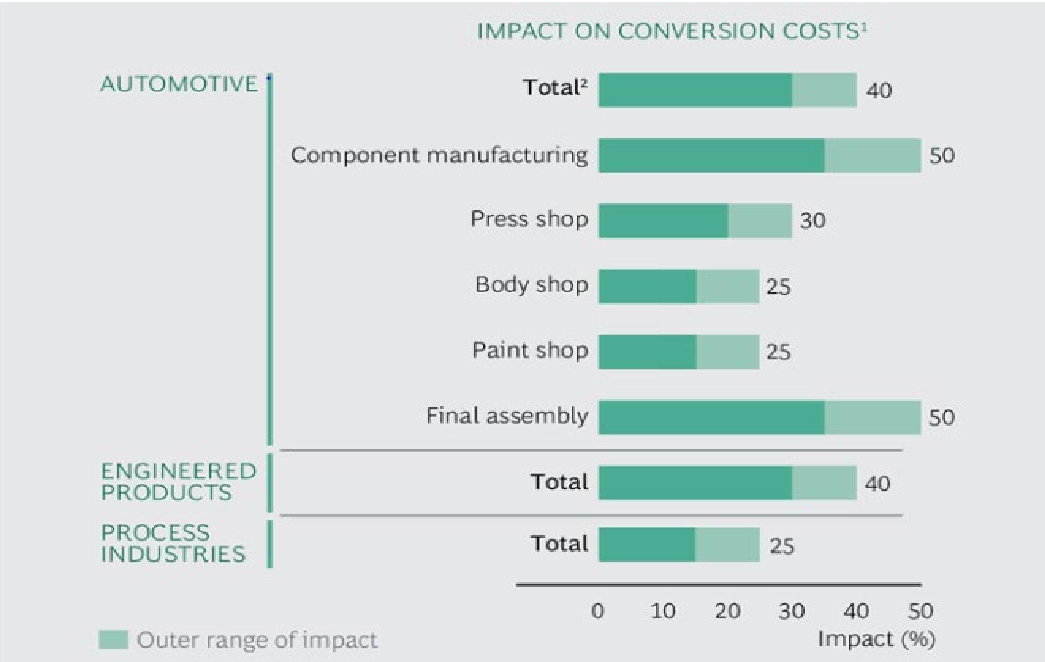


Figure 37. Industry 4.0 technologies promotes operational efficiency (Source: Boston Consulting Group (The Factory of the Future, 2016), Laboratory for machine Tools and Production Engineering of RWTH Aachen University (Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, 2022))

Notably, most of the benefits of Industry 4.0 are similar to the benefits of the digital transformation of manufacturing. Among the benefits, optimization of processes and of productivity is the foremost benefit that manufacturers observe. It is also one of the first goals of Industry 4.0 projects. In other words: saving costs, increasing profitability, reducing waste, automating to prevent errors and delays, speeding up production to work more in real-time and in function of the overall value chain, where speed is crucial for everyone, digitizing paper-based flows, being able to intervene faster in case of production issues and so forth.

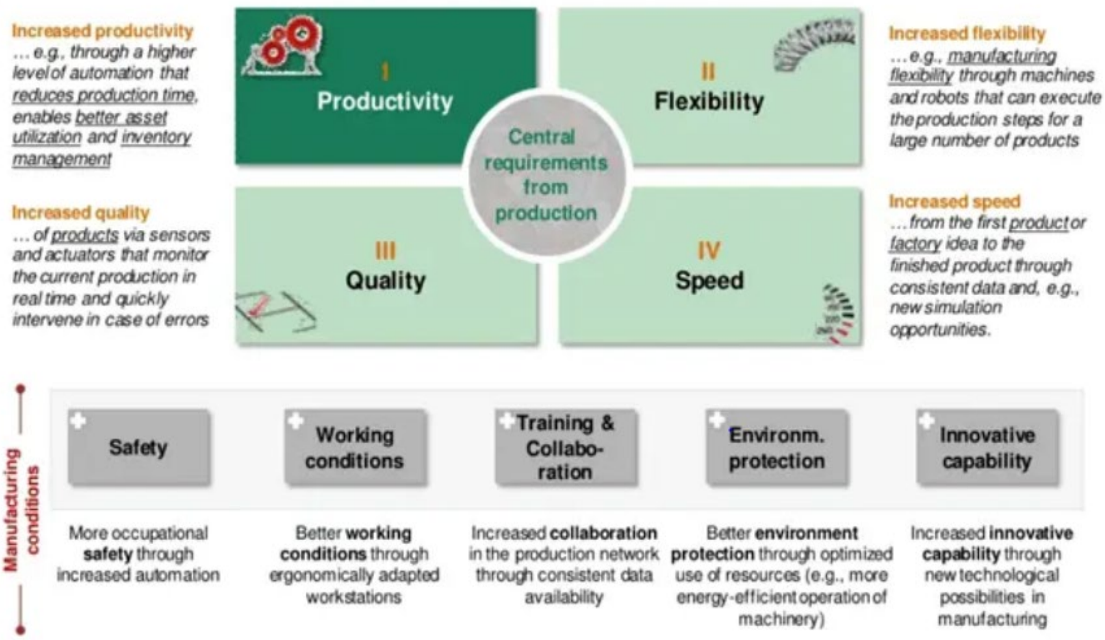


Figure 38. Impact on operational performances stemming from Industry 4.0 (Source: Boston Consulting Group (Sprinting to Value in Industry 4.0, 2016))

In the Industry 4.0 environment, data is the key resource that enables multiple productivity benefits through real time monitoring of the system. But this data must be converted into useful information that underpins actions, so data analytics and communications are also key elements. The better quality products can be achieved also through real time monitoring, IoT-enabled system and industrial robots. On top of that, working environment can be improved based on real-time temperature, humidity and other data in the plant or warehouse, quick detection and enhanced protection in case of incidents, detection of presence of gasses, radiation and so forth, better communication and collaboration possibilities, a focus on ergonomics, clean air and clean factory initiatives. For example, the German manufacturing sector is expected to achieve savings of €90 billion to €150 billion with the help of Industry 4.0 technologies. In fact, industrial-component manufacturers stand to achieve some of the biggest productivity improvements (20 to 30 percent).

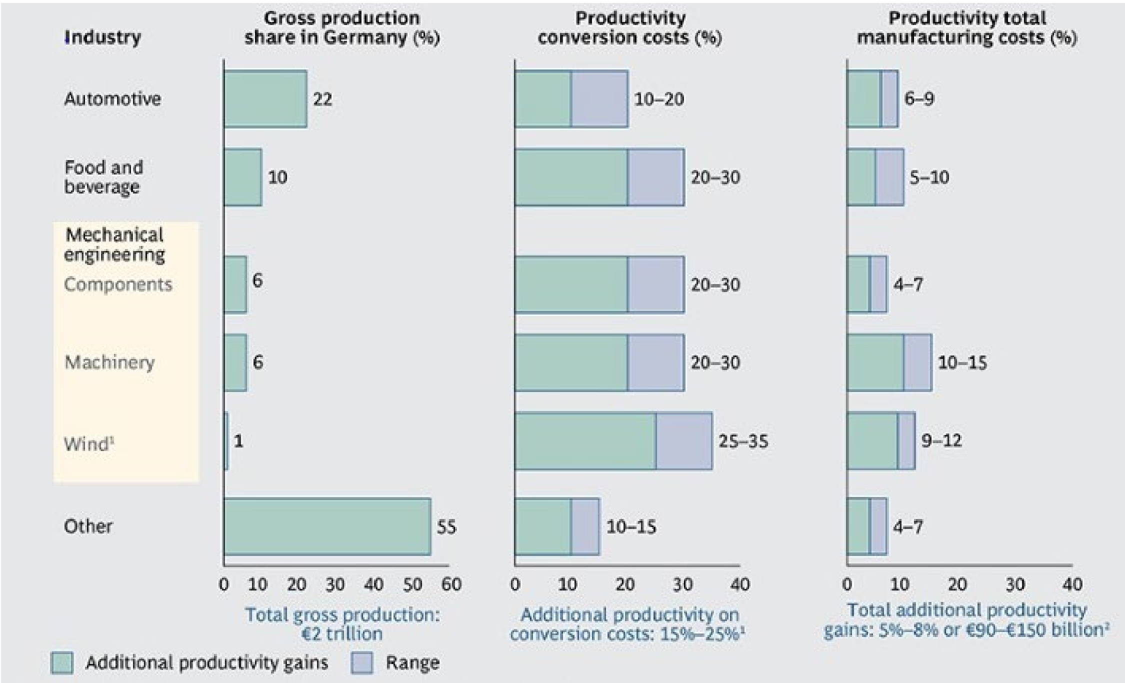


Figure 39. Productivity gains in Germany due to Industry 4.0 (Source: (German Federal Statistical Office, 2022; Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries, 2015))

Interestingly, despite the multiple benefits stemming from energy efficiency measures, inclusion of their additional value is yet to be factored into business models and cost-benefit analysis in most business sectors and, indeed, in most public policy cost-benefit analysis. Studies have argued that savings of energy sometimes may lead to increased energy usage that offsets the savings, referring to "rebound effect" (A. Greening et al., 2000). However, the International Energy Agency has shown that, if the multiple benefits of business energy efficiency measures are considered, total savings can be up to 2.5 times the value of the actual energy saved ("Capturing Mult. Benefits Energy Effic.," 2015). That being said, a significant challenge concerns the measurability or quantification of the benefits. In order to quantify the benefits, specific metrics should be known and the impacts measured, which are far from being guaranteed.

Further, benefits may be captured by agents other than those that incur the cost or effort involved in implementing measures – the 'split incentive'.

Studies have documented a broad set of effects stemming from energy efficiency which are observed in relation to areas such as production, operation and maintenance, work environment, and waste and emissions. Improved labour productivity, the extended lifetime and reduced downtime of equipment, improved air quality, and reduced product waste are examples of commonly observed benefits. In particular, with respect to overall equipment effectiveness, Industry 4.0 technologies allows better management of machine and equipment, thus increasing the lifetime. By increasing the lifetime of a functional equipment, the firm can obviously avoid embedded emissions from new equipment by holding on to assets a bit longer. The multiple benefits website has extensive research and information on multiple benefits (*Library of Multiple Benefits*, 2018). Figure 40 presents examples of non-energy benefits.

Figure 40. Multiple benefits associated with energy productivity measures (Nehler, 2018; Worrell et al., 2003). Note: * OEE is Overall Equipment Effectiveness and **OLE is Overall Labour Effectiveness. These terms are explained in section 4.2.1.

<u>M-Benefits – Valuing and communicating the multiple benefits of energy efficiency:</u>

Although the M-Benefits approach does not refer to energy productivity, it does focus on the multiple benefits of energy efficiency measures. It also highlights the importance of elements of Industry 4.0 solutions based on data collection, analysis and use.

The M-Benefits project (https://www.mbenefits.eu/) was a three year project, completed in 2021, funded by the European Union's Horizon 2020 program. It involved research and case study projects that led to creation of a framework and resources that could be applied by industrial and services businesses to incorporate the multiple benefits of energy efficiency into investment assessment and decision-making. The website provides extensive research papers, fact sheets and other resources.

Figure 41 summarises the approach proposed. Importantly, it adopts a company-level analysis that builds on energy analysis and engages with key decision-makers and identifies benefits that they value. This supports integration of energy efficiency considerations into investment decisions.

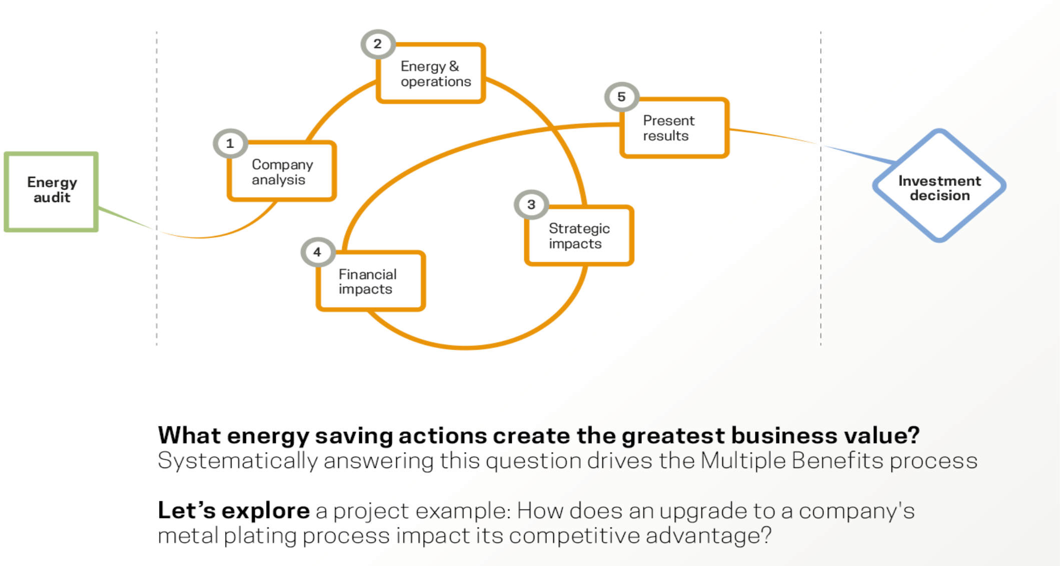


Figure 41. Flow diagram of M-Benefits model applied by companies (source: (Multiple Benefits of Energy Efficiency , 2022))

An example of M-Benefits project outcomes is the complementary *Improving Cold Chain Energy Efficiency* project (*Iccee.Eu*, 2019; Zanoni et al., 2020) which is also funded by the Horizon 2020 program. This project involved IT and energy specialists and considered the whole value chain.

The Australian Alliance for Energy Productivity also implemented a project that explored optimisation of the cold food chain in Australia (see *FOOD COLD CHAIN OPTIMISATION: Improving energy productivity using real time food condition monitoring through the chain*) (Hutton, 2017). This study highlighted the business and community health value of a value chain approach.

<u>Better energy efficiency policy with digital tools:</u>

Industry 4.0 technologies improve energy efficiency and create new sources of detailed data which are supporting new business models and revenue streams. In this regard, policy makers are also increasingly taking advantage of digital tools for energy efficiency policy to deliver more secure, clean, and flexible energy systems. However, the digital transformation also introduces important new risks in terms of cybersecurity and privacy that governments must navigate to ensure that the digital transition has the confidence of citizens and market participants.

Digitalisation offers great potential to change this and enhance energy efficiency policies by providing better information and much clearer vision on distributed energy resources. This can enable new policy design options which allow markets for energy efficiency to operate at a much greater scale.

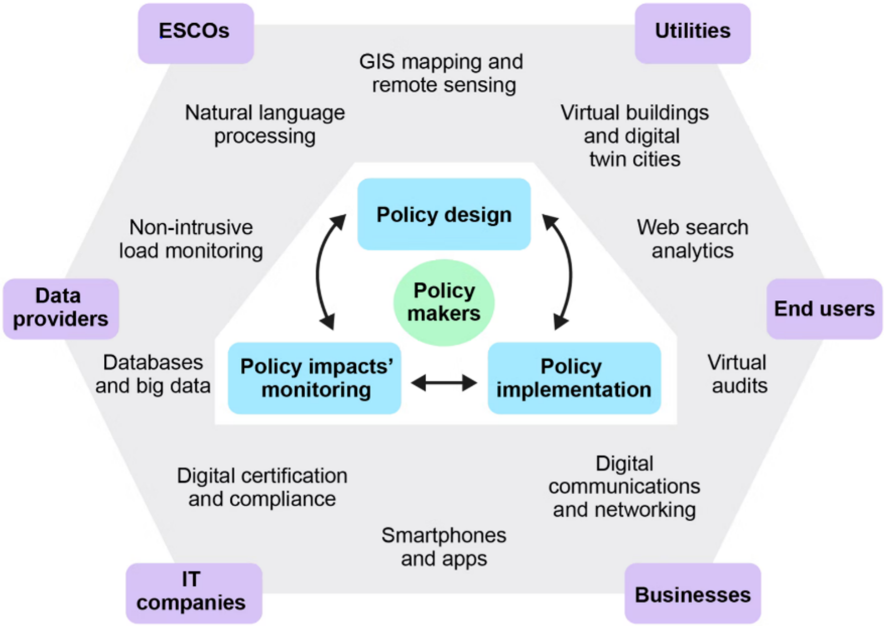


Figure 42. Digital tools for energy efficiency policy ecosystem (Source: International Energy Agency (Better Energy Efficiency Policy with Digital Tools – Analysis - IEA, 2021))

Notably, energy efficiency requires policy makers to interact with a diverse set of different stakeholders including end users, businesses, utilities, information technology (IT) companies, energy performance contracting companies/ energy service companies (ESCOs) and data providers. Developing policies that are both broad enough to effect change on a large scale and targeted to meet the needs of such diverse groups requires detailed data and a level of connectivity which is difficult and costly to achieve. Digital tools can be used to provide easier access to such data and to foster connections necessary for the next generation of energy efficiency policy.

4.1.1 Energy productivity and sustainability perspective

As pressure to limit global heating increases, businesses face voluntary or mandated emission reduction target. This focuses attention on the lowest cost options to cut direct fossil fuel use (Scope 1 emissions), purchases of electricity sourced from fossil fuels (Scope 2 emissions) and Scope 3 emissions from input materials, goods and services. It also drives a focus on reduction of future emissions from outputs, incurred by customers during operation and disposal. Emission trading schemes of various forms are emerging: these set prices that reflect the financial value of emission reductions, or of actions that store emissions for long periods.

Carbon prices have risen from a few dollars per tonne of avoided emissions to $30 to $100 in recent times. At present, Australian electricity produces over 0.7 tonnes of carbon dioxide equivalent per megawatt-hour while fossil gas produces over 50 kg CO_2e per gigajoule. With retail electricity prices at $100 to $300 per MWh and gas prices at $8 to $30 per GJ, energy productivity improvement offers a key means of reducing carbon costs and may provide a source of revenue from creating and selling carbon offsets or credits.

As the emission intensity of electricity falls and renewable alternatives replace fossil gas and oil use, a given level of energy productivity improvement will lead to a smaller reduction in emissions. However, carbon prices are expected to increase over time, with future prices expected to exceed $100 per tonne of avoided emissions.

An important feature of carbon emissions is that, on a lifecycle basis, Scope 3 emissions that are not directly emitted or controlled by a given business comprise a large proportion of total emissions, as shown in Figure 1. The costs of these emissions are incorporated in input costs or are incurred by customers – or the customers of customers. Depending on the sector of a business, the Scope 3 emissions from its product or service may be similar to or up to 28 times the Scope 1 and 2 emissions for which the business is directly responsible. As carbon pricing spreads across the economy, the costs will become more visible either through higher input costs or to customers downstream. This will mean that pressures on supply chains to cut emissions will increase. Pressure on manufacturers and service providers to reduce the carbon emissions of their products or services will also increase as customers face increasing emission costs during operation and disposal.

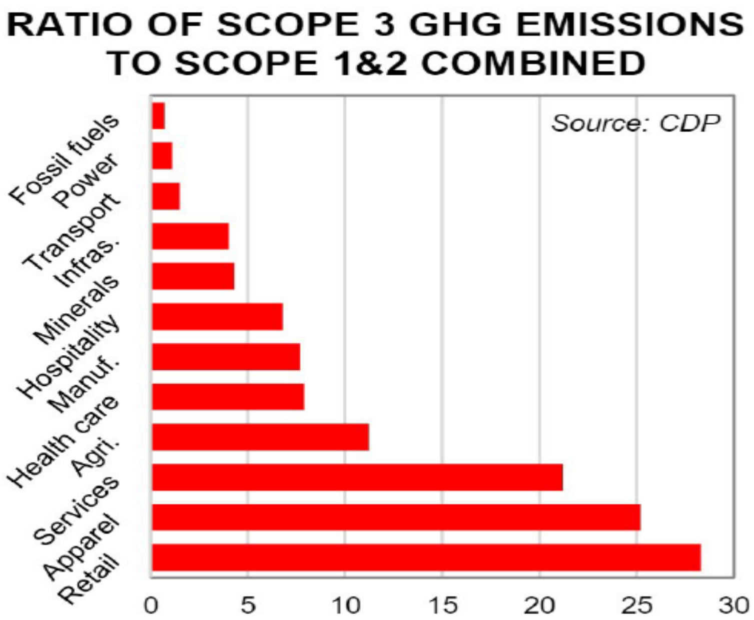


Figure 43. Ratio of Scope 3 greenhouse gas emissions to Scope 1 & 2 emissions combined (Source: p.3 Sustainability Reporting: climate disclosures and implications for Australia, Commonwealth Bank of Australia, 2022)

So, carbon pricing and increasingly stringent emission reduction targets will reinforce existing incentives for businesses to think beyond traditional business boundaries. They will need to cooperate and share costs and benefits with suppliers and customers. Digitalisation and Industry 4.0 will play major roles in identifying and allocating costs and benefits, while energy productivity measures will provide the technologies and practices to achieve emission reductions. Circular economy, value chain thinking, and lifecycle analysis will offer frameworks within which businesses will operate.

Energy productivity will not be the only means of reducing emission costs and climate impacts. Renewable energy (including a shift to renewable electricity) and other zero emission energy sources, as well as carbon capture and storage will also play roles. However, energy productivity improvement is expected to play a major role, comparable with that of renewable energy, as reflected in IEA studies (lots of reports at www.iea.org) and other studies such as IRENA's *World Energy Transitions Outlook* (International Renewable Energy Agency, 2022). Importantly, energy productivity improvement is often profitable and can offer multiple benefits of far greater value than the savings in energy and carbon costs.

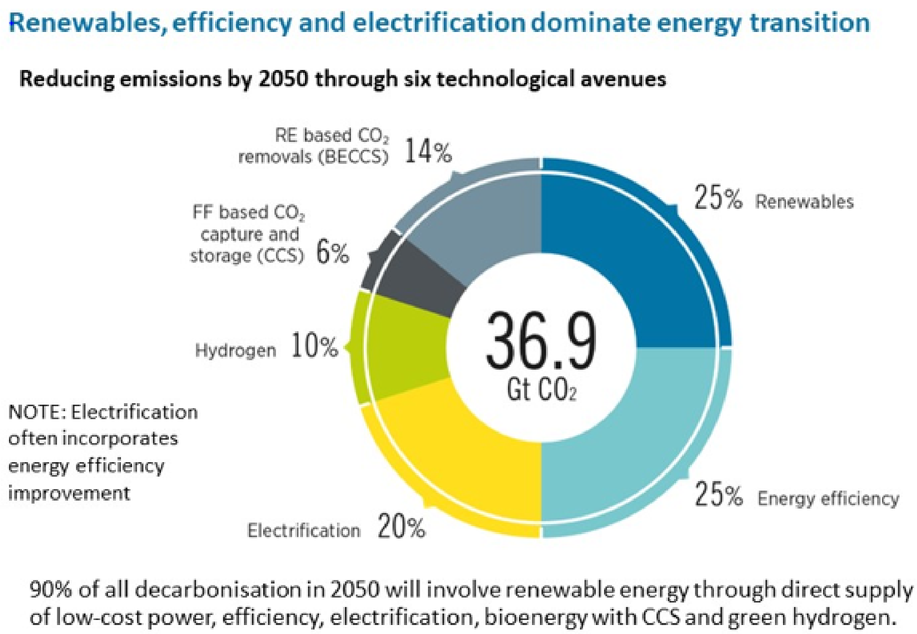


Figure 44. Energy transition scenario by energy sources (Source: (International Renewable Energy Agency, 2022))

4.1.2 Production

The underlying benefits of energy productivity facilitate production activities in different dimensions. Scholars have discussed that the widespread application of energy efficient technologies leads to more than 20% savings on global energy consumption by 2050 (*Tracking Industry 2020 – Analysis - IEA*, 2020). Increased product output, improved operation time, improved production management, improved production method, improved production efficiency, increased production speed and flexibility, and better resource management are among the critical features that are linked to multiple benefits of energy productivity.

The IEA and the IPCC have also noted that combining energy efficiency and productivity improvement with introduction of renewable energy reduces overall costs, allows a given capacity of renewable energy to amplify reduction in carbon emissions and reduces capital investment in energy supply infrastructure (*Energy Efficiency*, 2022).

Notably, Industry 4.0 technologies such as intelligent automation, Internet of Things (IoT), Cyber-Physical Production Systems (CPPS), additive manufacturing, and cloud data provide the information and capability to optimise business activities. For example, industrial robots enable manufacturers to develop sustainable energy practices for production by operating reliably in dark and cold environments, thus, cutting unnecessary lighting and heating. Similarly, sensor-equipped pieces of machinery can continuously diagnose energy consumption in real-time in the smart factory setting, then optimise performance. Also, cloud-based data management tools and integrated feedback systems enable the systematic tracking of energy consumption across the entire plant, building or business, so that 'actionable insights' can be provided so emerging problems can be addressed and systems optimised. Thanks to the real-time production management and process monitoring capability in the smart factory setting, impending machine failures and process fluctuations are measured, predicted, and avoided by early detection systems. This capability in the manufacturing environment offers significant resource-saving opportunities. For example, General Electric is successfully using additive-manufacturing processes to build fuel nozzles for LEAP turbofan engines, which are being developed for next-generation single-aisle aircraft. In the additive-manufacturing process, the nozzles are built by a computer-guided laser from layers of metal powder. According to GE the new nozzle is 25% lighter than the machined component and is as much as five times more durable than the current nozzle made from 20 different parts (*Why Advanced Manufacturing Will Boost Productivity*, 2015).

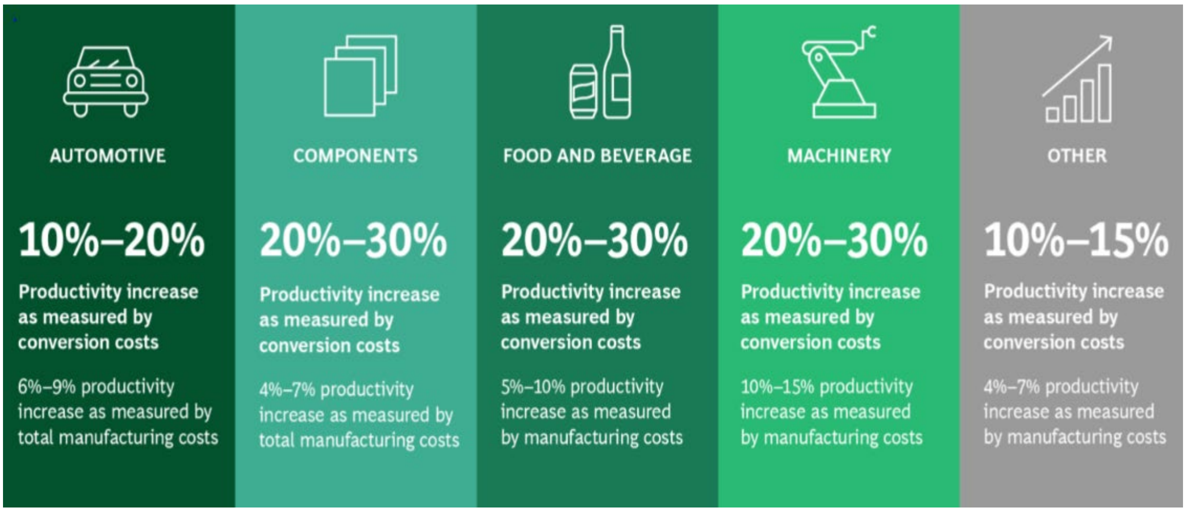


Figure 45. Productivity benefits at different sectors concerning from Industry 4.0 technologies (Source: Boston Consulting Group (Industry 4.0 Strategy Consulting Services | BCG, 2022))

A key aspect of application of data to energy productivity and broader Industry 4.0 measures is utilisation of multiple data streams to maximise and amplify the value of information. For example, combining energy data with data related to weather, production rates, maintenance practices, benchmarking using process models (often called digital twins) can capture multiple business benefits through a range of actions.

Fonterra

Fonterra is one of the largest companies in Oceania region in terms of economic impact, and produces about 30% of the world's dairy exports. IoT has enabled and supports compliance, sustainability, productivity and animal health/welfare through measurement, monitoring, traceability and informed action. With the help of technologies, milk temperature in farm vats and trucks have been monitored and warming of milk by heat from roads issue solved with spray-on insulating coatings. Other productivity features consist of equipment condition monitoring: underpinned maintenance planning, predictive and preventive action, supply chain tracking of location, and HVAC issues (e.g. temperature, humidity, light).

With the help of energy efficient technologies, 20% reduction in energy intensity has been achieved at several plants of Fonterra. Further, the firm has been working to reach 30% reduction in emissions by 2030, and ultimately net zero emissions by 2050.

Unilever

Consumer-goods giant Unilever is adopting virtual versions of its factories, using data streaming from sensor-equipped machines to create digital models that can track physical conditions and enable testing of operational changes. Unilever is working with Microsoft Corporation to create virtual versions of dozens of its roughly 300 global plants. The technology lets the company make real-time changes to optimise output, use materials more precisely and help limit waste from product and optimise energy use. The devices send real-time information on temperature, motor speed and other production variables into the cloud. Algorithms take in the data and use advanced analytics to map out the best operational conditions. Workers on site track product quality with handheld devices, modelling solutions to problems and sharing data with colleagues in other locations.

Unilever and Microsoft set up a pilot project at a facility in Valinhos, Brazil using digital twins, which the company used to set parameters for standards such as the temperature at which soap is pushed out before being cut into bars. The project has saved Unilever about **$ 2.8 million** at that site, the company said, by cutting down on energy use and driving a **1% to 3%** increase in **productivity**. Further, the factories have reduced CO_2 from energy per tonne of production by **77% compared to 2008 and by 14% versus 2020**; water abstraction by **47%** per tonne of production, and waste sent for disposal by **96%** per tonne of production. The reduction in waste avoids the embodied energy, emissions and labour associated with production, transport and disposal of inputs that were previously wasted.

4.1.3 Operation and maintenance

The productivity impacts of energy efficient technologies offered by Industry 4.0 on operation and maintenance are widespread. Manufacturing digitisation in Industry 4.0 setting allows manufacturers to have better overall equipment effectiveness, overall labour effectiveness, increased reliability in production, reduced operation cost, and improved planning and control. For example, the automation, interoperability, and intelligence of CPPS (Cyber-Physical Production System) contribute to production efficiency and productivity by improving operational attributes and process control measures, facilitating real-time maintenance, monitoring machine performance in real-time, increasing scheduling efficiency, and reducing machine downtime. It can also improve efficiency of maintenance contracting and activity. CIM use analytics to identify anomalies, pinpoint a suitable response, monitor pre-repair energy and resource use (*Sustainability Software | Improve ESG Performance | CIM*, 2022). This can be used by the business to inform the maintenance contractor, who can then send an appropriate person with the necessary components and equipment to the location where action is required. After the work is completed, monitoring and analytics are used to confirm that performance has been corrected. This underpins prompt payment and builds confidence in the working partnership. Similarly, industrial automation also reduces human intervention, which leads to lower human errors, reduced risk, and safety concerns (Ghobakhloo & Fathi, 2021).

ArcelorMittal

ArcelorMittal is one of the leading steel and mining companies, with a presence in more than 60 countries and an industrial footprint in 18 countries. Several technical features of Industry 4.0 have been implemented at multiple plants across the world. For example, ArcelorMittal Dofasco in Canada uses autonomous cranes to identify and select coils for customer delivery. Meanwhile, other plants located in USA, Canada, Mexico use fully robotic systems in their production lines. Plants located in Brazil use virtual reality technologies to train the employees. The usage of Industry 4.0 technologies has significantly impacted to improve equipment effectiveness, energy productivity, and efficient utilisation of production resources (e.g. water, materials).

To date, 33 energy projects have delivered annual savings of over $26 million and 230,000 tonnes of CO2. Additionally, several pilot projects are also being adopted across the world. For example, investment in variable speed drive motors with associated sensors and controls at the Dabrowa Gornicza site in Poland, is expected to save electricity costs of over 250 times the initial investment, annually, and indirect CO2 savings of some 24,000 tonnes. Moreover, 25% of energy has been saved with the help of technologies and efficient measures.

4.1.4 Emission and waste

Industrial activities are responsible for more than 40 percent of greenhouse gas emissions worldwide. Experts believe that carbon emission and waste minimisation can be bolstered significantly with the help of energy efficient technologies, manufacturing digitisation and the application offered by Industry 4.0. IoT and AI-based production. For example, these reduce waste, and minimise the carbon emission index per unit of each product. The opportunities offered by Industry 4.0 for the development of new business models, such as the shift from mass production to mass customisation and even product individualisation, can optimise the consumer market and contribute to the materialisation of a low carbon future, further contributing to environmental and social sustainability (Kang et al., 2016). The International Energy Agency has explored the complementary roles of energy productivity improvement and digitalisation in several reports (*Energy Efficiency 2019 – Analysis - IEA*, 2019; *Energy Efficiency 2021 – Analysis - IEA*, 2021).

4.1.5 Working environment

The work environment, risk management and anticipation implications of Industry 4.0 are multifaceted. The application of IoT, semantic technology, cloud data, and advanced analytics, and the resulting removal of information silos and the streamlined flow of information about HVAC facilities, inventory level, machine conditions, plant capacity, transportation routes, and procurement schedules will eventually lead to a greater End-to-End (E2E) visibility. Data-driven E2E visibility, in turn, leads to the manufacturing risk reduction and stability improvement. Therefore, Industry 4.0 allows staff to identify potential hazards in real-time and act upon them before they become real risks. Energy productivity improvement relies on being able to identify emerging faults, and anomalies between theoretical energy and resource performance and actual performance in time to act before failures, and to assist process designers to identify opportunities to capture energy and resource efficiencies, and to exploit the laws of physics and chemistry to deliver better services with lower energy and resource use.

In particular, tools such as intelligent cameras, smart sensors, smart safety wearables, and AI- based location awareness systems can detect and report any human or machine behaviour that might pose a risk to safety. Besides, many Industry 4.0-related technologies nowadays have advanced built-in safety measures for safe and reliable operation. Industry 4.0-compatible technologies for maintenance management that allow real-time and autonomous assets troubleshooting and problem-solving reduce the safety concern of dynamic production environments significantly. Industry 4.0 has also been associated with the ever-increasing application of safer and more intelligent Collaborative Robots (cobots) in smart factories. Thanks to the advancements in AI, data analytics, and machine learning, the smarter co-bots nowadays offer a better hazard identification and risk assessment capability. Smart co-bots better interpret the world around them, involve reduced operation risk, and keep their human co-workforce safer.

Ford Motor Company

Ford Motor Company is breaking new ground in the way workers and robots are collaborating to manufacture vehicles. Collaborative robots are being used to help workers fit shock absorbers to Fiesta cars, a task that requires pinpoint accuracy, strength and dexterity. One of the Ford Transmission plants in Michigan, USA where robots help assemble torque converters now includes a system that uses AI to learn from previous attempts how to wiggle the pieces into place most efficiently. Inside a large safety cage, robot arms wheel around grasping circular pieces of metal, each about the diameter of a dinner plate, from a conveyor and slot them together. Another Ford assembly plant in Cologne, Germany, is embracing automation, data exchange and manufacturing technologies. The technologies implemented have significantly improved overall labour effectiveness (OLE), overall equipment effectiveness (OEE), employee safety, and reduced energy consumption in the plants.

In 2020, Ford implemented more than **$19.7M** in energy efficiency projects which have delivered more than **$2.5M** in annual energy and operations savings. The energy usage has been reduced by 25% over the last 5 years with the help of energy efficient technologies. Further, Ford has reduced water consumption by **75%** since 2000.

Ford Motor is also using ICME to reduce the time and cost of developing Aluminium castings for engines. The conventional method is to design an engine block on a computer, build a physical prototype, test it, and then tweak the design, rebuild the prototype, and retest it—again and again—until the product is ready to be manufactured. Using an ICME process, digital models of castings are tested virtually, and a prototype is built only after engineers are convinced that they have created the best design. Ford invested $15 million over five years in this ICME experiment, which involved 15 of its own engineers and 10 university researchers. So far, the company estimates that it has generated cost savings of more than $120 million—a 700 percent return on investment—while development times have been cut by 15 to 25 percent.

4.1.6 Miscellaneous

There are several miscellaneous productivity benefits associated with energy efficiency measures offered by Industry 4.0. For example, Industry 4.0 contributes to corporate sustainability by enabling manufacturers to develop a more agile and flexible manufacturing system. Industrial simulation, digital twins, and big data analytics allow the business to deal with environmental uncertainties efficiently and micromanage change processes or transform their existing business model in a turbulent business environment as economically and promptly as possible. Studies (Ghobakhloo & Fathi, 2021; Nehler, 2018) have discussed that energy efficiency and productivity measures positively impact towards morale of the employees and better corporate image of the firms.

Furthermore, in Industry 4.0 and digitised manufacturing environment, the issue of energy sustainability not only is addressed at the components (machines, infrastructure, and equipment) level but also is addressed as a strategic objective at the factory level. Data mining and AI (machine learning in particular) have enabled modern manufacturers to implement innovative planning strategies such as energy-oriented scheduling and significantly improve energy efficiency, mostly on short to mid-term production planning. Similarly, digital twin and industrial simulation of production nowadays enable manufacturers to visualise material flows, simulate automation, identify potential bottlenecks, and even plan the entirety of a manufacturing process virtually while prioritising energy consumption optimisation. The resulting virtual commissioning helps troubleshoot and optimise production lines or cells and achieve energy sustainability while capturing broader business benefits.

4.2 Indicators that support Energy Productivity

KPIs are critical to achieve business goals within organizations. It is critical that business objectives are adequately communicated throughout an organization. KPIs also guarantee that performance is measured in reference to the larger business perspective. In this study, we focus on the KPIs associated to energy productivity in industrial and non-residential building context.

Most of the companies in the manufacturing sector, especially those which have been established for decades, have found it challenging to capture real-time production data as they often still own legacy machines or equipment that have limited to no network connectivity, lack operational flexibility and are operating with proprietary data and communication formats. In some cases, production data are still collected manually that can only processed offline. The manual data entry process is also prone to error. A poorly designed data collection mechanism can jeopardise the accuracy and integrity of the data collected, which could seriously affect the analysis and decisions made based on them. The lack of the "digital last mile" makes it impractical for production data to be aggregated and conveyed to the relevant decision makers in close to real time. To overcome such hurdles, IoT gateways or middleware, can be deployed for bridging operational technologies (OT), such as on-board programmable logic controllers (PLCs), with information technologies (IT), including time-series database, interactive dashboard, and data analytic platforms. This middleware is responsible for translating across heterogeneous data storage and communication standards, and provides an access mechanism, in the form of Application Programming Interfaces (APIs) to enable system interoperability. Once a connection has been established, data collection can be automated with the help of manufacturing execution system (MES) and enterprise resource planning (ERP).

In (Muchiri & Pintelon, 2008), Muchiri et al. provided guidelines in measuring losses. Production output loss or time loss can be used to calculate the quality and speed losses of a process respectively. Downtime can be used to obtain the availability of equipment. In their work, they further proposed a framework to use overall equipment effectiveness (OEE) to measure equipment-level effectiveness and total effective equipment performance (TEEP) to measure operational-level effectiveness of a business. They suggested that the utilisation of OEE as a performance indicator is highly suitable for flow shops [sites where multiple tasks must be carried out in sequence and/or parallel on multiple machines, where the aim is to minimise overall time taken for production of the final item] due to their low unscheduled production time and the high cost of having an unplanned downtime event.

Benedick et al. conducted a case study with an electromechanical components manufacturer on adopting Industry 4.0 technologies to digitise its industrial system for capturing real-time OEE data (Benedick et al., 2019). Their objective was to find and develop a common strategy for transforming existing manufacturing facilities and make them Industry 4.0 ready. Their approach begins with developing a model, i.e., a digital twin, of the equipment under study via creating a list of its sensors, actuators, controllers, and their associated data and control parameters that are relevant to OEE.

4.2.1 Technical/operational KPIs

4.2.1.1 Capacity Utilisation

Capacity utilisation rate is a key metric used by the companies to assess their current operating efficiency. Capacity utilisation is most relevant to industries that produce physical products rather than services. It indicates the slack in the organisation at a given point in time. It also provides insight into the cost structure of the business in the short term or long term because it can be used to determine the point at which unit costs will rise as it increases production.

The formula for finding the rate is:

Capacity Utilisation Rate = (Actual Output / Potential Output) x 100

4.2.1.2 Production volume

Production volume is an important metrics that tracks the total number of products manufactured over a set period of time (days, weeks, months, quarters, years) and focuses on total output. Having production volume in the manufacturing analytics dashboard can express several issues about the manufacturing process, including how efficiently the production resources are being used.

To measure production volume, it needs to first select the time period we wish to monitor. After establishing the correct time frame, we should collect overall production data on every product manufactured and combine it to form an aggregate figure. Notable to mention that the production volume may vary depending on the period.

4.2.1.3 Throughput

The idea of throughput, also known as the flow rate, is part of the theory of constraints in business management. Throughput is a term used to describe the rate at which a company produces or processes its products or services. The goal behind measuring the throughput concept is often to identify and minimize the weakest links in the production process. When a company can maximize its throughput, it can also maximize its revenues. However, maintaining high throughput becomes a challenge when different products are being produced using a combination of joint and separate processes.

Throughput can be calculated using the following formula:

T = I/F

Here, T = throughput; I = inventory (the number of units in the production process); F = the time the inventory units spend in production from start to finish.

4.2.1.4 Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is a common metric used in the manufacturing sector for quantifying the quality, performance, and availability of a device, machine, or workstation. Nevertheless, OEE can be applied not only on machines, but also on workforce and materials that can affect the production performance of products.

OEE is expressed in percentage, which comprises three components, namely Quality (Q), Performance (P), and Availability (A). Its corresponding mathematical representation is expressed as

$$\text{OEE} = (Q \times P \times A) \times 100\%,$$

A typical enterprise can have an OEE of around 60%, while an OEE of 40% or below is considered as low (Dal et al., 2000). According to Japan Institute of Plant Maintenance, a world class company should have an OEE≥85% with A ≥90%, P ≥95%, and Q ≥99.9%. OEE can be used to identify losses and frictions across a supply chain, and for generating solutions to eliminate them strategically.

4.2.1.5 Overall Operations Effectiveness (OOE)

Overall Operations Effectiveness (OOE), is designed for measuring the availability of production lines. Its definition is like that of OOE, such that

$$\text{OOE} = (Q \times P \times A') \times 100\%,$$

Where the availability factor in OOE (A') is defined as

$$A' = \frac{t_{\text{actual production}}}{t_{\text{actual production}} + t_{\text{unplanned downtime}}}$$

4.2.1.6 Overall labour effectiveness

Overall labour effectiveness (OLE) is a key performance indicator that measures the utilisation, performance and quality of the work force and its impact on productivity. OLE also can be expressed with availability, performance, and quality (Braglia et al., 2021).

Availability is calculated by the ratio of "time operators are working productively" and "scheduled time for production". Performance is expressed as the ratio of "actual output of the operators" and "expected output". Quality is expressed as the ratio of "saleable parts" and "total parts produced".

Other commonly used technical/operational key performance indicators (KPIs) used in the manufacturing sector are listed in Table 9.

Table 10. Other common technical/operational KPIs adopted across companies

KPI	Meaning/Description
Production Downtime	Track the downtime of machines/processes. Use for analysing and planning maintenance.
Production yield	Production yield is a metric that results from dividing the number of good parts produced divided by the total number of parts started in production.
Defect Density	Defect density measures the number of defective units of a product produced against the total number of units made. Defect Density = Defect count/total unit made
Product return rate	The percentage of sales orders that have a product return.
Right First Time	It measures how often a manufacturing line can produce something without any defect over the whole production process. Right first time = (Number of satisfactory products / total products) x 100.

4.2.2 Economic/ financial KPIs

4.2.2.1 Return on Investment (ROI)

Return on investment (ROI) is a performance metric used to assess an investment's efficiency or profitability, as well as to compare the efficiency among many investments. ROI attempts to directly assess the amount of profit made on a given investment in relation to its cost. The benefit (or return) of an investment is divided by the cost of the investment to calculate the ROI.

The return on investment (ROI) formula is as follows:

ROI= (current value of investment-cost of investment)/cost of investment

What constitutes a "good" ROI will be determined by factors such as the investor's risk tolerance and the time it takes for the investment to pay off. All else being equal, investors who are more risk-averse will likely accept lower ROIs in exchange for taking less risk. Likewise, investments that take longer to pay off will generally require a higher ROI in order to be attractive to investors.

4.2.2.2 Payback Period

The pay-back method provides answers to how long it takes before the investment's payment surplus covers the basic investment cost. Payback period is often considered for energy efficiency investment opportunities. There are multiple gains from improved energy efficiency. Therefore, investment proposals aiming to increase energy efficiency require comprehensive economic evaluation: use of Net Present Value and/or Internal Rate of Return provide a more meaningful indication of overall financial benefit. As discussed earlier, multiple benefits from an action can be very significant, so they should be considered and quantified where possible.

The payback time is as follows:

Pay-back time= I/ (R-C)

Here, I= investment cost, R= revenue per year, C= operating cost per year

4.2.2.3 Net Present value (NPV)

With the net present value (NPV) method, it is possible to evaluate whether an investment is profitable by comparing the investment with the present value of all future deposits and payments. If the net present value is greater than zero, the investment is profitable.

$NPV= R_t/ (1+i)^t$

R_t = net cash flow at time "t"

i= discount rate or return which could be earned in alternative investment

t= number of time period

4.2.2.4 Internal Rate of Return (IRR)

IRR is a discount rate which makes the NPV of all cash flows equal to zero in a discounted cash flow analysis. In fact, IRR is roughly equivalent to the rate of interest that would be earned if the same amount of money was invested in an interest-bearing deposit so it can be compared with the cost of borrowing money ore foregone interest on money invested in a bank.

Other commonly used key performance indicators (KPIs) used in the manufacturing sector are listed in Table 10.

Table 11. Other commonly used economic/financial KPIs adopted across companies

KPI	Meaning/Description
Production Costs	Monitor the costs implied in the production
Asset Turnover	It represents the value of business revenue (or sales) relative to the value of its assets. Asset turnover = revenue / total assets. The higher this ratio the better, as it means that you generate more revenue per dollar of asset.

Unit Costs	The total costs involved in the production of one item, including the fixed costs and the variable ones. This unit cost can also be broken down to show all the costs (labour, warehousing, equipment, material, etc.) and analyse what are the major input costs and how much they represent in the total.
Return on Assets	It shows how profitable a business is relative to its overall assets. Return on asset = net income / total assets.
Maintenance Costs	Evaluates equipment costs in the long run. It can indicate which equipment needs more work than others, where the resources should be focused, and what kind of preventative measures can be implemented to optimise that maintenance for the future.
Revenue Per Employee	It is calculated by dividing the company's revenue by the current number of employees. It gives a strong signal for evaluating the efficiency and productivity levels.

These KPIs provide examples of useful indicators that can provide 'actionable insights' to improve productivity. Exploration of relevant KPIs can guide decisions regarding what data should be collected, in what form and at what frequency in order to provide useful information instead of large amounts of data that is not utilised for business benefit.

4.3 Impact framework and pathways

The applications of Industry 4.0 technologies simultaneously manifest in various sectors and across multiple levels. In 2021-2022, the stock of connected appliances, devices and sensors is expected to overtake the number of people on the planet. Over the last five years the stock of connected appliances, devices and sensors has grown by an average of around 33% per year. Most of these are measuring devices, such as sensors and smart meters.

Considering the large number of devices in today's industrial and building system, it is thus necessary to consider the impact of devices at each point, as well as the interactions among them. Industry 4.0 technologies are involved in almost all the impacts along the value chain. However, taking inspiration from the previous literature ("Capturing Mult. Benefits Energy Effic.," 2015; Worrell & Biermans, 2005), we consider five different dimensions to assess the impact level and associated KPIs beyond the individual business level related to energy-efficient, productive technologies stemming from Industry 4.0, which are:

- Macroeconomic impacts
- Industrial sector impacts
- Public budget impacts
- Health and well-being impacts
- Energy delivery impacts

4.3.1 Macroeconomic impact

Macroeconomic assessment is a mainstream branch of economic analysis that has built up a huge body of knowledge and evidence over many years. However, the way in which energy efficient technologies influence macroeconomic performance still needs to be better understood by many stakeholders (i.e.

policymakers, investors and managers). Notably, in the Net Zero Emissions by 2050 Scenario, the energy intensity of the global economy improves (that is, falls) by 35% by 2030. Energy efficiency, in combination with related initiatives such as electrification and behavioural change, are driving this. In this scenario, the global economy grows by 40% by 2030, owing to increased population and income levels, while using 7% less energy (*Energy Efficiency 2021 – Analysis - IEA*, 2021).

In 2020, the Italian Ministry for Technological Innovation and Digitalisation launched the National Coalition for Digital Skills and Jobs. The coalition builds on Repubblica Digitale, an initiative that promotes digital skills at all levels of the economy and society (*Energy Efficiency 2021 – Analysis - IEA*, 2021). In Germany, the employment growth in manufacturing sector is expected to increase by 6 percent during the next ten years. And demand for employees in the mechanical-engineering sector may rise even more—by as much as 10 percent during the same period.

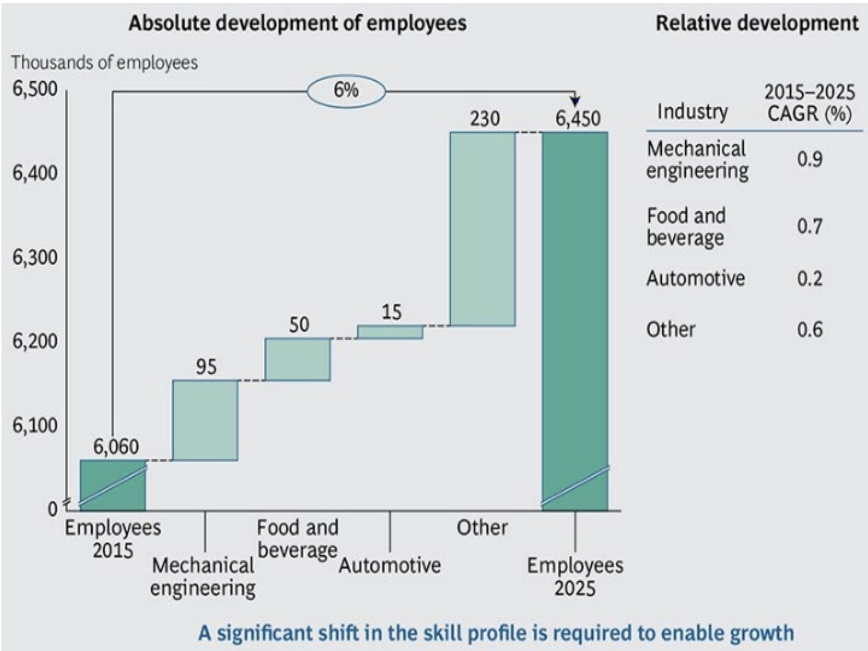


Figure 46. Industry 4.0 will lead increased manufacturing employment in Germany (Source: (German Federal Statistical Office, 2022; Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries, 2015))

A summary of estimates of the four macroeconomic impacts typically assessed in energy productivity is provided in this section (Table 11) to illustrate the scale of their importance. Readers should be aware that comparing studies is difficult as they often differ in several aspects (i.e. method used, energy efficiency measures, and sector).

Table 12. Macroeconomic KPIs and impact of Industry 4.0 energy-efficient technologies ("Capturing Multiple Benefits Energy Efficiency," 2015; Dawood & Hanna, 2015)

Area	Impact	KPIs/ Metrics	Remark
Financial output	GDP (+)	-Investment -Consumer spending -Import-export	GDP covers the aggregation of several variables across the economy at the national or regional level, integrating energy production, labour markets, financial structure and energy policies. Therefore, the impact of energy productivity activities is likely to be measurable only if the investment or energy efficiency enhancement is large. The

		-Governmental expenditure	International Energy Agency, among others, reports on 'energy efficiency' of economies calculated as GDP per unit of primary energy consumed
Employment	Job creation (+)	- Net new jobs - Sectoral job shifts - labour intensity	Estimation should be as open and reliable as possible, and it should include nett employment gains and losses. A thorough sectoral study is required to fully comprehend current spare labour capacity, skills available, and changes in labour rates for relevant industries. This indicator is used in a variety of ways. For example, indirect employment (eg jobs in the local economy to support the direct workers employed in the project or facility) may be reported. For short term projects use of 'job-years' may be a more appropriate indicator.
Cost	Reduction in energy unit price	- Per unit energy cost - Energy substitution options - Market condition	When the demand for energy is reduced while the service provided remains constant, energy prices should decline if all other factors remain constant. However, the reduction level is determined by several factors (i.e. quantities of energy supply, substitutability, market trading conditions), so accurate estimation of this effect can be a challenge.
Economic output	Trade balance	Import & export	Reduced energy demand lowers the cost of energy imports for energy-importing countries. If foreign demand for energy resources exceeds supply, a fall in energy demand frees up more supply for export for energy exporters. Reduced demand from existing consumers frees up existing supply for use by others?

* Legend: '+' - Positive impact

In the IEA Net Zero Emissions by 2050 Scenario, focus on energy efficiency would create nearly 6 million jobs by 2030 through increased spending on building retrofits, more efficient appliances and other measures. When taking into account announced policies currently being implemented, energy efficiency provides more than 2 million additional jobs by 2030, more than any other clean energy technology (*Energy Efficiency 2021 – Analysis - IEA*, 2021).

4.3.2 Energy efficiency investment can also help to combat energy poverty. For example, the Advanced Virtual Power Plant Grid Integration Trial in South Australia was able to leverage Industry 4.0 technologies (e.g., smart metering and control) to help low-income customers. The Clean Energy Finance Corporation, the South Australian government, and Tesla each contributed AUD 61 million to the initiative, ensuring that there were no upfront costs for the 3000 social housing residents that took part. Industrial sector impacts

Studies and several projects related to energy productivity have discussed numerous benefits to business, making it difficult to produce a definitive list of essential ones. What has become evident is that the influence of energy-efficient technologies and energy productivity measures varies depending on the industry, the type of business, and the priorities of the company. One strategy to handle the complexity is to divide the impact into a reasonable number of generic categories based on the areas they affect - competitiveness, production, operation & maintenance, working environment, or environment.

In a recent study, Hasan et al. (Monjurul Hasan et al., 2022) also discussed implications on operational productivity features (e.g. throughput, OLE, OEE, resource utilization, production speed) stemming from energy efficient measures. In fact, energy efficiency measures also intensely impact on the production resources. However, the study pointed that while considering the energy efficiency measures, the implications are generally overlooked. It seems that while considering the energy efficiency measures, energy has been the only key focus. In this regard, it should be mentioned here that conservation supply curves (CSC) could be an effective tool to critically analyse energy as a production resource in the industries, as, CSC provides the cost of conserved energy (CCE), annual cost of energy-efficiency measures, annual energy cost saving, annual net cost saving, and annual energy saving by each individual technology or a group of technologies. Notably, Industry 4.0 technologies could effectively support gathering information to asses such issues. Furthermore, the technologies could also play a great role in modelling and analysing the system before considering the adoption, so to improve decision-making process.

Table 13. Industrial manufacturing KPIs and impact of Industry 4.0 energy-efficient/productivity technologies ("Capturing Mult. Benefits Energy Effic.," 2015; Dawood & Hanna, 2015)

Area	Impact	KPIs/ Metrics	Remark
Production	Productivity (+)	- Resource utilisation - Quality - Throughput - Flexibility & reliability - Production speed	More efficient equipment or processes can lead to better resource utilisation, throughput, shorter process times and use of lower cost factors of production that can enable higher product output.
Operation & Maintenance	- Improved operation - Reduced need for maintenance	- Overall equipment effectiveness (OEE) - Overall labour effectiveness (OLE)	Improved operation leads to better reliability, reduced equipment downtime, reduced system failures and can entail reduced process time (which can contribute to increased productivity including improved utilisation of capital).
Working environment	- Improved environmental quality - Increased worker health & safety	- Thermal quality - Indoor environment quality (IEQ)	Improved thermal comfort, lighting, acoustics, and ventilation create a better working environment. Improved working conditions can aid in the retention and recruitment of competent individuals.
Competitiveness	- Increased market share - Corporate risk reduction - Improved corporate image	- N/A -Surveys showing greater trust, maintenance of 'license to operate' reflected in reduction of opposition to activities, scope to increase market share	Reduced per unit costs and enhanced attributes of products or services stemming from improved energy productivity enable the company to access and capitalise on a new complementary or substitute factor of production and in doing so opening up new opportunities for growth.

Environment	- Reduction of pollution & emissions - Solid waste minimisation - Waste-water reduction	- Energy & natural resources (E) - Water and Water Conservation (W) - Materials used, Durability and Waste (M) - Greenhouse Gas Emissions (GHG)	Sulphur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), as well as CO_2 emissions can be reduced with the help of energy efficient technologies. Evidence of good environmental performance enhances reputation, achieves compliance

The European Commission has set a roadmap up to 2050 to focus on a low-carbon economy with an emphasis on energy efficiency to illustrate the importance of industrial energy savings from a regional perspective. The Advanced Manufacturing Office (AMO) was formed by the US Department of Energy to increase energy and material efficiency, productivity, and competitiveness of manufacturers across all industries. In the United States, AMO has supported over 1300 industry partnerships and programmes linked to energy conservation. In China, the 13th Five-Year Plan for Energy Development was jointly released by the National Development and Reform Commission (NDRC) and the National Energy Administration (NEA), with a focus on optimising energy systems, reducing energy consumption, promoting renewable energy supply, promoting efficient energy technology.

In 2009, the Indian government set up Energy Efficiency Services Limited that has implemented large-scale energy efficiency projects. These programmes have resulted in over 50,000 GWh of annual electricity savings, as well as creating jobs and boosting living standards. Further, several programmes were launched since 2017 to promote efficient retrofits of commercial buildings in industry, government and other institutions, including large public buildings. The programme employs demand aggregation of efficient equipment purchasing to negotiate lower prices for its projects, lowering costs for the public budget. By September 2021 the programme had completed projects in almost 7000 buildings, with another 4000 under way. Completed projects are saving 224 GWh/year and emissions of 184 kt CO_2-equivalent.

In South-East Asia, the Ministry of Energy, Green Technology and Water of Malaysia have also allocated an annual budget of MYR 54.3 million (approximately 13 million USD) to improve energy efficiencies of appliances within the country. Evidently, countries around the globe prioritize energy savings and energy efficiency of industrial systems heavily, as it is critical for sustainable development on a macro-perspective (Teng et al., 2021).

4.3.3 Public budget impact

Energy efficiency measures in any sector might have a budgetary impact. While the research and methodologies focus primarily on national policies and budgets, they can also be used for more local energy efficiency measures and their impacts on municipal or other sub-national budgets. Energy efficiency and productivity measures often involve a shift from ongoing costs to up-front investments. Since many businesses and households have limited cash-flow or access to finance, governments often fund incentives, subsidies or fund other policy measures such as development of regulations and standards to accelerate adoption. Such actions usually involve consideration of societal benefits and costs before they are adopted.

Table 14. Public budget impact concerning from Industry 4.0 energy-efficient technologies ("Capturing Mult. Benefits Energy Effic.," 2015)

Area	Impact	KPI
Change in GDP	Public budget impacts due to economic activity, including funding of incentives and other policy measures	- Fiscal multiplier - Societal level cost-benefit analysis
Investment	- Jobs created and locations and skills involved - Changes to unemployment and social welfare benefits Training and education	Employment factors
Employment created	- Change in GDP - Increase in revenue from taxes on income - Unemployment benefits reduction	- Gross value added (GVA) - Employee Unemployment rates - Regional economic development
Energy saved	- Change in energy tax revenue - Change in emission tax revenues - Diversion of capital from energy supply infrastructure - Reduction in impacts of climate change	- Energy tax/ subsidy rates - Carbon tax/ emission trading scheme

4.3.4 Health and well-being impact

Energy efficiency has been connected to a wide range of health advantages as well as flow-on effects on society's psychosocial functioning. Clear evidence has developed that energy efficiency solutions can promote good health and mitigate the harmful effects of poor building and interior environmental quality. Reduction in the severity of impacts of climate change is a major benefit (Doctors for the Environment Australia, 2020).

Health and well-being are the results of complex interactions between various physical, social, economic, and environmental elements that can both trigger and counteract the potential health effects of energy efficiency measures. Improved insulation, heating and cooling systems, lighting, and energy-using equipment are all part of a whole-building approach to energy efficiency that can lower energy costs and enable more comfortable indoor conditions.

Table 15. Impacts on health and well-being concerning energy-efficient technologies ("Capturing Mult. Benefits Energy Effic.," 2015)

Energy efficiency measures	Impact associated with energy efficiency measures	Potential health impact (direct)	Potential health impact (indirect)
Efficient, effective HVAC system	- Comfortable temperature - Reduction of gas & particulates - Increased usable living space - Good air quality	- Reduced allergies - Reduced respiratory diseases - Reduced injuries & death - Reduced stress - Reduced close-contact infectious diseases	- Reduced public and private spending on health - Increased sociability Lower absenteeism
Efficient refrigeration system	- Reduced energy cost - Increased sense of control - Extended shelf life of food	- Improved nutritional status - Reduced stress, illness and death	- reduced pressure on healthcare systems - Increased access to preventive healthcare

4.3.5 Energy delivery impact

Energy-efficient technologies can substantially impact the whole energy delivery value chain, from generation to transmission and distribution to final consumption. Energy productivity improvement is a core element of a revolution in energy supply systems that complement renewable energy solutions by enhancing management of energy, reducing the amount of energy required to deliver each service, and transforming how services are perceived and delivered. Energy efficiency measures, in general, refer to actions aimed at reducing energy consumption or demand, as well as load reduction and load shifting. Nonetheless, energy service companies (ESCOs) can provide and have a significant impact by offering energy services (i.e. energy advice, financial incentives, equipment installation). The recent emergence of Industry 4.0 technologies on the end-user side facilitate the transition for both energy providers and their customers: consumers can more actively control their energy consumption while energy providers can better monitor, aggregate and control end-use loads.

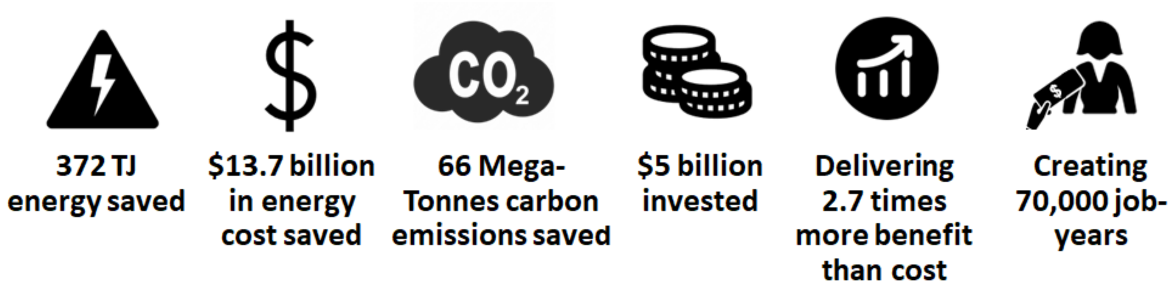
Table 16. Energy provider impact due to energy-efficient technologies ("Capturing Mult. Benefits Energy Effic.," 2015; Worrell et al., 2003)

Direct impact	Indirect impact
- Avoided generation cost (operation and capacity)	- Reduction in financial risk
- Avoided transmission capacity cost	- Reduction in credit & collection cost
- Avoided environmental regulation cost	- Improved corporate relations
- Minimising reserve requirements	- Improved customer retention
- Avoided CO_2 cost	- Fuel savings
-Transition impacts on incumbent energy providers	- Reduced price in wholesale market
-Creation of new energy business models	
-Enhanced utilisation of energy supply infrastructure	

An analysis of nine large countries and regions, including the United States of America, European Union and China, shows that efficiency standards helped save about 1,500 TWh of electricity per year. In the countries with the longest-running programmes the effect is so large that around 15% of total electricity generation is being saved through appliance programmes. If a similar 15% improvement had been achieved by all countries, electricity consumption could have been reduced by 3,500 TWh (*Energy Efficiency 2021 – Analysis - IEA*, 2021).

4.4 Summary of Impact

Our thorough review of previous literature has allowed us to conclude that, at present, there is insufficient analysis based on scenarios for the uptake of industry 4.0 solutions specifically for energy productivity. For what concerns Australian non-residential property sector, CSIRO has conducted a coarse-level initial assessment that shows the tremendous potential impact of energy productivity aspects of digitalisation. The results of this coarse level technical potential analysis are summarised below, in terms of the outcomes and economic benefits over 10 years, at a 7% discount rate (see Appendix 1: National Benefit Potential for details).



Unfortunately, when looking at industry, there are just some exploratory studies starting to test adoption models for industry 4.0. For instance, Jayashree et al. (2022) conduct a broad investigation in Malaysia trying to understand the dynamics of industry 4.0 adoption with regard to achieving sustainability goals. However, the conclusions are largely qualitative in terms of impacts across the major KPIs of interest for RACE for 2030, with no explicit mention of energy savings, reduced bills, increased number of employees, etc. Likewise, Culot et al. (2020) takes a value chain perspective to analyse the evolutionary trajectories of manufacturing companies, with the attempt of showing the profound changes to the configuration of manufacturing companies brought by industry 4.0. Again, the conclusions are qualitative and no quantitative impact on KPIs is provided.

Furthermore, as published when referring to energy efficiency's potential positive impact on GDP (IEA, 2022), the European Commission in 2017 modelled four different scenarios for the EU's 2030 energy efficiency target. In their own words, "each scenario modelled resulted in a positive change, ranging from 0.1% annual increase in GDP in the least ambitious scenario, up to 2.0% increase in most ambitious scenario of increased energy efficiency". As it can be seen, the increase of GDP could be either minimal or 20x bigger according to the scenarios.

With such uncertainty, any further consideration of the impact of industry 4.0 for energy productivity would be quite challenging. In this regard, taking inspiration from most recent research and as extensively discussed with project sponsors, partners and IRG, RACE for 2030 could fund specific studies building scenarios and discussing the implications across the major KPIs of interest. However, in the following we have included the major impacts based on preliminary broad estimations. For more detailed impact analysis and modelling, it is recommended that more specific econometric modelling tools may be considered by RACE for 2030 (such as e.g, E3ME and FTT).

Detailed and categorized impact of energy efficient technologies are presented in earlier sections. In this section, Table 16 provides a summary of preliminary estimation of impacts. Notably, the impacts are dependent on several circumstances (e.g. social, geo-political) and might be varied from time to time.

Table 17. Summary of initial impact estimation

Research Activities	● New feature development as well as current technology trial and feasibility studies (both for industries and non-residential buildings) ● Business model development ● Validating innovative solution and business models to prove suitability, application range, and economics. ● Skill/ capacity development to patronize Industry 4.0 technologies ● Knowledge sharing/ symbiosis between industries to support energy productivity through Industry 4.0 technologies.

	● Pilot project demonstration, subsequent modelling and analysis, to kick-start market adoption of Industry 4.0 technologies for large industries and SMEs in Australia. ● Accelerating novel innovation and technical opportunities in existing technologies ● Mechanism to support industry lead development of decarbonising technology for Australian firms
Outputs	● Reports for the industrial partners and other stakeholders featuring the best opportunities and feasibility study to enhance energy productivity. ● Guidelines for businesses to increase energy productivity both for industrial context and non-residential buildings. ● New business models, products, both virtual and physical. ● AI enhanced reporting and feedback systems that drive improved business, and work practices that minimize operational costs and enhance business productivity. ● Innovative Industry 4.0 pilot projects with demonstrated substantial energy savings and high replicability potential. ● Training and knowledge sharing resources with evaluation of effectiveness of resources.
Outcomes	● Implementation of state-of-the-art technologies, featuring Industry 4.0 in the industries, non-residential buildings, and agricultural sector. ● Industrial production systems will become more dynamic, flexible, efficient, environmentally sustainable and inclusive through extensive customization and personalization. For example, Siemens' largest factory, located in Germany, was established twenty years ago with one thousand employees and still has one thousand employees. It is close to being called an Industry 4.0 factory, with output ten times higher and of much higher quality than in its early years. The error rate has been reduced to ten faults per million pieces, thereby decreasing production costs and enabling electronic systems to be built (United Nations Industrial Development Organization, 2016). ● Installation of smart measurement and metering system of key variables and plant-wide integration and optimisation in the manufacturing sector for electricity and fuel usage. ● Industry 4.0 will also contribute to realizing the circular economy, in which end-of-life products are reused and recycled.
Expected impact	Industry 4.0 is already having impact on companies. In 2011, only one of the top five companies on the Standard & Poor's 500 Index was technology based, whereas in 2021, all top five companies, worth more than \$3.3 trillion, were technology-based (United Nations Industrial Development Organization, 2016). The possible impacts of Industry 4.0 technologies are presented below: • Gross cumulative energy savings of \$1.1B by 2030-31 and \$2.4B by 2034-35 (after risk adjustments and a 5% discount on net present value; adapted from RACE for 2030, 2022). • Energy efficiency improvement in the manufacturing sector by 15% over the next ten years with the help of improved measurement and analysis techniques, IOT, and AI (*Industry – Energy Efficiency 2020 – Analysis - IEA*, 2020). • AI is expected to produce a \$16 trillion increase in GDP by 2030, 55 per cent of which will result from productivity enhancements, consumer personalisation and a higher quality of services; and in 2030, 57 per cent of GDP gains will stem from the consumer impact of AI. The entire world will benefit from AI, with China leading by 2030, with a 26 per cent increase in GDP (United Nations Industrial Development Organization, 2016). • Cumulative emissions reductions of 5.9 Mt and 12.9 Mt of CO_2e by 2030-31 and 2034-35, respectively (adapted from RACE for 2030, 2022). • Investment in energy efficient technologies also offer several NEBs (non-energy benefits) which are not limited to reduced operational cost, increased number of new jobs, improved work environment, new markets, more competitive pricing. • Operational and productivity benefits can be achieved up to 2.5 times and beyond in manufacturing (*Multiple Benefits of Energy Efficiency – Analysis - IEA*, 2019). • With the help of digitalisation of energy, energy savings can be achieved up to 25% and more including the NEBs. Energy cost reduction due to implementation of AI enabled demand control systems by matching load flexibility with price signals.

5 Regulatory Framework for Industry 4.0 Technologies for Energy Productivity

This Chapter explains the most important and relevant regulatory frameworks that apply to Industry 4.0 technologies for energy productivity. As outlined in Chapter 2 and Chapter 3, Industry 4.0 technologies incorporate the collection, processing and use of data at scale. This Chapter therefore focuses on the main frameworks for regulating large-scale data collection, processing, analysis and use under Australian law.

Given the near-ubiquitous data generation and use across the digital economy, it is impossible to exhaustively address all legal and regulatory issues relating to Industry 4.0 technologies in the energy sector. For example, in sectors such as non-residential buildings, there are a range of industry-specific regulations and technical standards that are relevant to data collection and use. This Chapter therefore focusses on the most significant general laws and regulations that apply to Industry 4.0 data practices and, where appropriate, draws implications for the energy sector.

First, this Chapter introduces the legal status of 'data', explaining how Australian law does not recognise property rights in data. As outlined in this report, however, there is a range of important rights and interests that exist in data, such as the legal interests that individuals have in their 'personal information', as recognised under Australian data privacy law. Second, the Chapter introduces the Australian Data Strategy (ADS), which was released by the federal Government in March 2022, and is aimed at creating a national ecosystem of data that is accessible, reliable, relevant and easily used. Many of the elements of the regulatory framework set out in this report form part of the ADS. Third, the main Australian legal initiative for promoting data sharing and use while also protecting data, the Consumer Data Right (CDR), is outlined. This Chapter explains the extension of the CDR to the energy sector and canvasses the potential implications of extending third party action initiation for Industry 4.0 technology providers. Fourth, the Australian data privacy regime, which is the most significant economy-wide regime for regulating data, is introduced; and the current law reform process (including implications for data use in the energy sector) explained. Fifth, the recent cyber security reforms that establish a regime for protecting critical infrastructure, including the security obligations imposed on businesses holding data in the energy sector, are outlined. This Chapter also introduces the voluntary cyber security framework that applies to the energy sector. Finally, this Chapter describes the regulatory framework that applies to data generated by smart meters, and how the current review of smart meter regulation includes recommendations for a new framework for promoting access and use of smart meter data.

5.1 Rights in Data

Although there is no single, accepted definition of 'data', the term is commonly equated with 'information' (Guihot & Bennett Moses, 2020, p.7). On the other hand, 'data' is sometimes distinguished from 'information' on the basis either that (a) data is machine-readable, but information is not; or (b) information is data that has been processed in a way that makes it comprehensible by humans (Guihot & Bennett Moses, 2020, p. 8). In any case, it is the processing and use of data at scale that fuels the constellation of technologies known as Industry 4.0 technologies.

The first stage in outlining the legal frameworks that apply to Industry 4.0 technologies is therefore to clarify the legal status of 'data'. It is common for people and businesses to refer to 'data' as if it is something that is, or can be, 'owned'. For example, individuals and businesses very commonly refer to 'my data' or 'our data'. As a matter of law, however, this is inaccurate. In general, there are no property rights in data; and therefore data cannot be owned (Bennett Moses, 2020). As is commonly the case with the law, however, the position is more complex than this, as there can be strong legal rights in data in certain circumstances.

When a person receives or obtains information, they may come under legal obligations in relation to that information. This will be the case if the circumstances in which the information was obtained create an obligation to keep the information confidential (*Australian Broadcasting Corporation v Lenah Game Meats Pty Ltd,* 2001; *Franklin v Giddens,* 1978). Where there is an obligation on a person to keep information confidential, this can extend to third parties who obtain the information from the person the person to whom the confidential information was initially imparted. Particularly in relation to the category of confidential information known as 'trade secrets', the legal effect of this protection can begin to look like a form of property. As was pointed out by Gummow J in a well-known intellectual property case, however, there is an important difference between property rights and the potentially proprietorial consequences of a legal relationship:

> The degree of protection afforded by equitable doctrines and remedies to what equity considers confidential information makes it appropriate to describe it as having a proprietorial character. This is not because property is the basis upon which that protection is given, but because of the effect of that protection (*Smith Kline & French Laboratories* (*Aust*) *Limited v Secretary, Department of Community Services and Health*, 1990).

What this means is that, while there is no 'ownership' of data, as that term is commonly understood, in considering the legal status of data it is important to determine the particular rights or legal interests that may arise in data; which will depend upon the circumstances in which data are created, shared or used. For the most part, where data is 'shared' by a number of parties – such as in a value chain involving Industry 4.0 technologies – the respective rights in the data will be determined by the contractual relationships between the parties. However, the contractual rights occur against the background of the general legal regimes that establish rights in data, which are introduced in this section of the report.

5.1.1 The Australian Data Strategy (ADS)

In March 2022, the Commonwealth Government released the Australian Data Strategy (ADS) for consultation (Australian Government, 2022). The ADS, which is aimed at transforming Australia into a modern data-driven society by 2030, focuses on the following three themes:

- *maximising the value of data* – describes why data is important, its economic and social value, its use in responding to priority issues, and the benefit that can be gained through using and safely sharing data.
- *trust and protection* – describe the settings that can be adopted in the private and public sectors to keep data safe and secure, and the frameworks available to protect Australians' data and ensure its ethical use through the entire data lifecycle.

- *enabling data use* – sets out approaches and requirements to leverage the value of data, such as capabilities, legislation, management and integration of data, and engaging internationally.

The ADS incorporates an Action Plan, which sets out tangible measures that the Government is implementing to improve data settings across the Australian economy. The first priority of the Action Plan is to improve control of sensitive information held by government, building on initiatives such as the Government's Hosting Strategy and the critical infrastructure reforms, referred to later in this report. Following that, the Strategy intends to address measures for improving data settings for individuals and businesses.

5.1.2 'Data Sharing': the Consumer Data Right (CDR) Regime in the Energy Sector

The Consumer Data Right (CDR) regime is an essential part of the ADS.

The 2017 Productivity Commission (PC) report on data availability and use (Productivity Commission, 2017) identified the then-existing legal obstacles to obtaining the potential benefits of greater data sharing and use in the following terms:

> The legal and policy frameworks under which public and private sector data is collected, stored and used (or traded) in Australia are ad hoc and not contemporary. Privacy has carved out a space, but privacy is only one aspect of data use, and a defensive one at that. Restrictions on use for data collections in the same field, even the same institutional setting, vary significantly. Uncertainty endorses inaction.
>
> Yet the impetus for changes in governance structures around data — changes that deal head-on with the fact that data is increasingly digital, revealing of the activities and preferences of individual people or businesses, and distributed widely in the private sector — will not diminish. It is a global movement and, to its detriment, Australia is not actively participating; and has remained nervous about making decisions (Productivity Commission, 2017, p. 12).

The PC report therefore recommended the creation of a new data sharing framework that would be aimed at promoting competition by giving consumers more control of their data (Productivity Commission, 2017, p. 14). Partly in response to this report, in August 2019 the Commonwealth government introduced the Consumer Data Right (CDR) regime, which established by Part IVD of the *Competition and Consumer Protection Act 2010* (*Cth*) (the 'CCPA'). The CDR is intended to promote the better use of consumer data (which includes data of businesses as 'consumers') by enabling consumers in certain sectors of the economy to require information about themselves to be disclosed safely, efficiently and conveniently, either to themselves or to 'accredited persons', but always subject to privacy safeguards (CCPA, s. 56AA(a). The safeguards are necessary in order to recognise that, while data sharing may have benefits, it also creates substantial risks.

The main feature of the CDR is that it gives consumers a right to determine whether the data businesses hold about them are released to other providers of their choice so consumers can seek better value. For example, the CDR can allow consumers to require a business, such as an energy retailer, to share their data with an accredited service provider, such as a comparison site, to get more competitive services. The regime also requires businesses to provide public access to information about goods and services, thereby empowering comparison websites and consumers with up-to-date information. The CDR was first implemented in banking (known as ‘open banking’) and is currently being rolled out in the energy and telecommunications sectors. Only providers accredited by the Australian Competition and Consumer Commission (ACCC) can offer services using the CDR.

The CDR is a complex regulatory regime, which includes the following four core components:

- *Part IVD of the CCPA,* which contains the primary CDR legislation, as well as other components of the legislative framework;
- *CDR Designation Instruments* made by the Minister pursuant to Part IVD of the CCPA, which designate sectors of the Australian economy for the purposes of the CDR;
- The *Consumer Data Right Rules* (the ‘CDR Rules’) made by the Minister responsible for the CDR. The Rules set out the circumstances in which data holders are required to disclose data, and to whom, in response to a valid consumer request. They also set out consent requirements, how data may be used and, importantly, privacy safeguards; and
- The *Consumer Data Standards* (the ‘Standards’), which set the technical requirements by which data needs to be provided to consumers and accredited data recipients (ADRs) within the CDR system – ensuring safe, efficient, convenient, and interoperable systems to share data are implemented.

In May 2018, the Australia government announced its intention to include the energy sector as the second sector (after banking) subject to the CDR; and, in June 2020, the Treasurer designated energy as a sector covered by the CDR (Frydenberg, 2020). In November 2021, the then Minister for the Digital Economy made energy-specific CDR Rules, which include phased compliance dates. Sharing energy data is intended to commence from October 2022, beginning with product data to provide consumers with better information about energy products and service offerings so as to support more detailed comparison of services and, following that, consumer data. The overall objective of extending the CDR to the energy sector is to provide Australian households and businesses with more accurate information about their energy use and plans.

As explained in the ADS, the CDR is an opt-in regime:

The CDR creates the secure infrastructure for easy and safe, opt-in consumer data-sharing, and it is explicitly consent-based. This means that, if consumers choose to use the CDR, they choose which data will be shared, for which purpose and for how long. Strong privacy safeguards are built into the system, including a right for consumers to ask for their data to be deleted (Australian Government, 2022, p. 14).

In December 2021, the then federal Government announced its response to Treasury’s inquiry into future directions for the CDR (Australian Government, 2021). An important part of the Government response was support for expanding the CDR regime to incorporate third party action initiation (also known as ‘write access’). Action initiation enables third parties, with consumer consent, to initiate actions on behalf of consumers beyond merely requests for data sharing. The application of action initiation to consumer data in the energy sector clearly has the potential to foster the creation of new data intermediary business models. However, the Government response to the future directions inquiry indicated that a sectoral assessment would be required before designating action initiation in a sector, such as the energy sector.

At the time of writing this report, key elements of the CDR regime as applied to the energy sector were yet to be put in place. While increased access to and use of consumer data under the regime have the potential for energy productivity benefits, especially through the potential for increased competition, much obviously depends on up-take of the regime. While there is some future potential for third party action initiation to assist in the development of new business models associated with the use of Industry 4.0 technologies in the energy sector, much depends upon the details of the regime implementing CDR on the energy sector, including the implementation of appropriate consumer safeguards in the context of action initiation.

5.2 Data privacy: the protection of 'personal information'

Some of the data or information that is collected or used by businesses in the energy sector will be 'personal information' and, as such, will be regulated by Australia's data privacy laws. Data privacy laws regulate the collection, use and disclosure of 'personal information' (or 'personal data'). The main Australian law is the *Privacy Act 1988* (Cth) (the 'PA'), which regulates the collection and processing of 'personal information' by federal government agencies and private sector organisations. As explained below, the PA is currently subject to a fundamental review, which is aimed at updating it so that it is fit for purpose in the context of contemporary data practices.

The PA regulates interferences with the privacy of an individual, which includes an act or practice of an APP entity which breaches an Australian Privacy Principle (APP) in relation to personal information. The scope of the PA, in general terms, is confined to: 'APP entities'; 'acts or practices' of an APP entity that breach an APP; and breaches involving 'personal information'.

An 'APP entity' is a public sector 'agency', such as a Commonwealth government department or a private sector 'organisation'. Although the PA applies to private businesses, it does not generally apply to small business operators, meaning that it applies to businesses that have an annual turnover of more than $3 million (PA, ss.6, 6C, 6D, 6DA). The exemption for small business operators does not apply, however, where an entity discloses personal information about another person for a benefit, or provides a benefit for collecting personal information about another person (PA, ss 6D(4)(c), (d)). In other words, the PA applies to small businesses that trade in personal information.

Under the PA, an APP entity must not engage in an act or practice that breaches an APP (PA, s 15). The APPS are 13 principles that regulate the collection, storage, use and disclosure of personal information (PA, Schedule 1), and are summarised further below. The PA also incorporates important exceptions to the operation of the APPs. For example, under section 16, the APPs do not apply to personal information that is held by an individual for the purposes of personal, family or household affairs.

The PA is confined to interferences with privacy that consist of acts or practices that involve 'personal information'. Under section 6, 'personal information' is defined to mean:

> ... information or an opinion about an identified individual, or an individual that is reasonably identifiable:
>
> (a) whether the information is true or not; and
>
> (b) whether the information or opinion is recorded in a material form or not.

The interpretation of 'personal information' by the courts has given rise to some difficulties, especially in the context of contemporary data processing practices. In *Privacy Commissioner v Telstra Corp Ltd* ('Telstra 2017'), the Full Federal Court interpreted the requirement for information or an opinion to be ‘about an individual’ as meaning that the individual must be ‘the subject matter of the information or opinion’ (Telstra 2017, p. 63). The judgment, however, went on to say that it is the ‘totality of the information’ that must be considered, so that ‘even if a single piece of information is not ‘about an individual’ it might be about an individual when combined with other information’ (Telstra 2017, p. 63).

The appeal in *Telstra 2017* was from a decision of the Administrative Appeals Tribunal (AAT), which held that certain metadata held by the telecommunications carrier, such as an IP address, Uniform Resource Locator (URL) or mobile cell tower data, was not personal information, as it was not information ‘about an individual’. However, the Full Federal Court did not determine whether, in this case, such metadata was ‘personal information’, as it concluded that the grounds for appeal did not raise the question of whether the AAT had erred in applying the definition to conclude that the relevant data was not *about* the individual concerned. That said, the practical outcome of *Telstra* is that it is uncertain whether data, such as an IP address, is ‘personal information’ as it may, depending upon the circumstances, be ‘about’ a device and not an individual or, alternatively, if combined with other information, may be interpreted as being ‘about’ an individual.

The PA adopts a ‘principles-based’ approach to regulating the processing of ‘personal information’, with more or less flexible principles being applied to encourage compliance across all stages of the personal data life-cycle. The 13 APPs that apply to ‘personal information’ may be summarised as follows:

- APP1: Open and transparent management of personal information (mainly, privacy policies);
- APP2: Anonymity and pseudonymity;
- APP3: Collection of solicited personal information;
- APP4: Dealing with unsolicited personal information;
- APP5: Notification of the collection of personal information;
- APP6: Use or disclosure of personal information;
- APP7: Direct marketing;
- APP8: Cross-border disclosure of personal information;
- APP9: Adoption, use or disclosure of government related identifiers;
- APP10: Quality of personal information;
- APP11: Security of personal information (including data retention policies);
- APP12: Access to personal information;
- APP13: Correction of personal information.

The details of each of the principles are spelt out in Schedule 1 to the PA, and further elaborated in guidelines provided by the regulator, the Office of the Australian Information Commissioner (OAIC) (OAIC, 2019). While the PA provides certain minimal guarantees regarding issues such as transparent data use, in practice most uses of data are permitted provided consent is given. Moreover, under the PA consent does not need to be express, but may be implied from the circumstances (PA, s.6-definition of consent).

In its *Digital Platforms Inquiry* (*DPI*) report, released in June 2019, the Australian Competition and Consumer Commission (ACCC) made it clear that Australian data privacy law has not kept pace with the data practices of digital platforms, such as Google and Facebook, and made substantial recommendations for addressing deficiencies in the law (ACCC, 2019, Recommendation 16(a), page 458). The recommendations have implications that go beyond the practices of digital platforms and are especially relevant to the regulation of data practices by Industry 4.0 technology providers. The *DPI* report included specific recommendations to strengthen the protections available under the PA, as well as issues that it recommended should be subject to further review.

The six specific recommendations made for strengthening the PA were as follows:

1. Amending the definition of personal information 'to clarify that it captures technical data such as IP addresses, device identifiers, location data, and any other online identifiers that may be used to identify an individual' (ACCC, 2019, Recommendation 16(b), p 461);.
2. Strengthening the notification obligations of APP entities to ensure that notices of data collection and processing practices are 'concise, transparent, intelligible and easily accessible' (ACCC, 2019, Recommendation 16(c), page 464);
3. Strengthening the consent requirements for processing personal information by expanding the circumstances in which consent is required, and by increasing the thresholds for valid consent and for consents from children (ACCC, 2019, Recommendation 16(d), page 470);.
4. Introducing a right to have personal information erased on request, unless retention is necessary for performing a contract, required by law or otherwise necessary in the public interest (ACCC, 2019, Recommendation 16(e), page 473);.
5. Introducing a right to bring individual and class actions, which currently does not exist, against APP entities for interferences with privacy under the Privacy Act (ACCC, 2019, Recommendation 16(f), page 475);. and
6. Increasing maximum penalties under the Privacy Act to mirror the penalties under the ACL (ACCC, 2019, Recommendation 17, page 476).

Recognising the need for consultation on the implications of broader reforms of data privacy law, the *DPI* report identified the following seven issues to be taken into account in reforming the PA, to ensure that it remains 'fit for purpose' (Department of the Treasury, 2019):

1. Reconsider the objectives of the PA to ensure that consumer privacy is properly protected, including a reconsideration of the balance between protecting privacy and the commercial interests of businesses in processing personal information.
2. Establish higher levels of protection, such as an obligation limiting use and disclosure of personal information to lawful and fair uses and disclosures, in order to shift some of the onus from consumers to APP entities.
3. Review the scope of the PA, especially the exceptions for small businesses, employee records and registered political parties.
4. Review whether the PA should be extended to protect 'inferred information', particularly where this includes sensitive information, such as information about an individual's health, religious beliefs or political affiliations.
5. Consider the need for new protections or standards to safeguard against increased risks of re-identification of de-identified data.
6. Given the importance of cross-border data flows, consider measures to ensure that Australian data privacy law affords an 'adequate level of protection' for the purpose of article 45 of the GDPR.
7. Consider the introduction of a certification scheme, where an independent third party would certify that an APP entity's practices are privacy compliant.

The Commonwealth Government's response to the *DPI* report, released in December 2019, announced support for a fundamental review of the PA (Department of the Treasury, 2019).

In October 2020, the Commonwealth Attorney-General's Department released an Issues Paper seeking public submissions on 68 questions relating to fundamental reforms of Australian privacy law (Attorney-

General's Department, 2020). Subsequently, in October 2021, the Attorney-General's Department released a Discussion Paper (the 'AGDP') which took into account feedback on the Issues Paper and proposed fundamental reforms for addressing the many issues identified with the operation of the PA (Attorney-General's Department, 2021). At the time of writing this report, it was expected that a final report would be released in mid-2022. If the reforms proposed in the AGDP were to be adopted, this would result in a strengthening of Australia's data privacy law, aligning it more closely with what has emerged as the general global standards, namely the European Union's *General Data Protection Regulation* (*'GDPR'*).

One of the main benefits of big data practices in the context of Industry 4.0 technologies for energy productivity is the ability to personalise services according to the characteristics of individual users. Where energy services are supplied to businesses, this may – although not necessarily always – fall outside of the scope of the PA, as it may not involve the collection and processing of personal information. Two of the main reforms proposed in the AGDP are: (i) clarifying the definition of 'personal information', by bringing it more into line with the definition of 'personal data' under the GDPR and, for example, making it more likely that metadata that can be linked to an individual will be regulated; and (ii) strengthening the notice and consent regime, by making it more likely for express consent to data collection or processing to be required. These reforms would have the potential to increase the costs of businesses, such as data intermediaries, in accessing and using data in the energy sector. On the other hand, they could reduce current uncertainties in the application of the law and, by increasing the transparency and accountability of data practices, potentially increase the level of community trust in data sharing practices.

5.3 Cyber security and Industry 4.0 technologies for energy productivity

As the ADS points out:

> As the amount of data created, accessed and shared by Australians increases, so does the need for data to be stored in trusted and secure ways. We must strike a balance between enabling broader access to data to leverage its benefits, whilst mitigating security and other risks (Australian Government, 2022, p. 29).

The use of data by Industry 4.0 technologies to promote energy productivity therefore depends upon implementing measures to address security risks, which include measures to ensure data integrity. A core element of the ADS is the recently established legal regime for securing critical infrastructure assets, which include assets in the energy sector.

While the *Security of Critical Infrastructure Act 2018* (Cth) (the 'SOCI Act') (Australian Parliament, 2018) initially focused on the physical security of traditional infrastructure assets - such as ports, water and energy – recent reforms have expanded the focus to address the impact of cyber threats (Australian Parliament, 2021). In March 2022, the final package of recent reforms aimed at securing Australia's critical infrastructure against cyber threats was passed in the form of the *Security Legislation Amendment* (*Critical Infrastructure Protection*) *Act 2022* (Cth) (the 'SLACIP Act') (Australian Government, 2022). The SLACIP Act amends the SOCI Act by introducing two new key obligations for owners and operators of critical infrastructure assets:

- a ‘positive security obligation’ requiring responsible entities to create and maintain a critical infrastructure risk management program; and
- ‘enhanced cyber security obligations’, which must be complied with by operators of Systems of National Significance (SoNS).

The SOCI Act defines ‘critical infrastructure assets’ by reference to particular industry sectors, ranging from telecommunications, to banking and finance, energy, food and grocery, and transport (SOCI Act, s. 9). In the energy sector, critical infrastructure assets include critical electricity assets, critical gas assets, critical energy market operator assets and critical liquid fuel assets (SOCI Act, ss. 5, 10, 12, 12A). Critical infrastructure assets also include critical data storage or processing assets (SOCI Act, s. 12F). The definitions in section 9 of the SOCI Act are expanded upon by the *Security of Critical Infrastructure* (*Definitions*) *Rules 2021* (Cth), which specify particular assets in particular sectors. The security obligations extend to obligations to secure operational information which, for example, in the context of critical energy infrastructure assets, extends to data communicated by smart meters.

SoNS are a subset of the most important critical infrastructure assets, as declared by the Minister for Home Affairs (SOCI Act, part 2C). At the time of writing this report, no declaration had been made. The enhanced obligations imposed on SoNS are: to adopt, maintain and comply with an incident response plan; undertake cyber security exercises; undertake vulnerability assessments; and provide access to the Australian Signals Directorate (ASD) to system information.

As mentioned above, the critical infrastructure regime applies only to owners or operators of critical infrastructure assets. Nevertheless, data that are generated or shared by other entities in the energy supply chain may obviously become subject to the regime. Beyond this, an important voluntary security framework has been established by the Department of Industry, Science, Energy and Resources (DISER) and the Australian Energy Market Operator (AEMO) in the form of the *Australian Energy Sector Cyber Security Framework* (the ‘AESCF’) (DISER & AEMO, 2022). The purpose of the AESCF is to enable participants in the energy sector (meaning all market participants in the electricity, gas and liquid fuels sub-sectors) to assess, evaluate, prioritise and improve cyber security and maturity levels. The AESCF includes two components:

- A criticality assessment tool (CAT), with different versions for the electricity, gas and liquid fuels sectors; and
- A cyber security capability and maturity self-assessment, which is relevant to all participants in the energy sector, and aligns with the US C2M2 framework (US DOE, 2014).

Therefore, even if an Industry 4.0 technology service provider in the energy sector is not subject to legal obligations under the critical infrastructure regime, it is important that all data collected, held and processed is securely stored and managed. Moreover, apart from the energy-specific regime, all businesses subject to the Privacy Act must comply with the general data security obligation under APP11, which requires ‘APP entities’ that hold personal information to take such steps as are ‘reasonable in the circumstances’ to protect the information from misuse, interference and loss, and from unauthorised access, modification or disclosure.

Regulation of Smart Meters

While it is acknowledged that smart meters are essential to ensuring productivity gains in the energy sector, their roll out has been challenging. As the 2021 AEMC *Directions Paper* on the Review of the Regulatory Framework for Metering Services out it:

> The current arrangements for smart meter deployment are not optimal. Meters are generally replaced one-by-one with meter providers often having to travel significant distances within one day to install meters. Further, the benefits of smart meters also accrue to different parties within the electricity supply chain. For consumers, the benefit to them individually is often not sufficient for them to proactively request a smart meter (AEMC, 2021).

The potential for smart meters to deliver productivity gains is achievable only if arrangements relating to the full range of data generated by smart meters are optimised. As the 2021 AEMC Paper put it:

> Obtaining some of the key benefits from smart meters also relies on efficient access beyond consumption and billing data. Parties such as distribution network service providers (DNSPs) and others can obtain benefits from other types of information such as power quality data to develop improved management of the LV network, safety improvements and provision of other value-added services (AEMC, 2021, p. i).

The 2021 Directions Paper canvassed options for improving smart meter rollout and use, including options: to accelerate rollout; to assist in aligning incentives; to enable appropriate access to data; and to reform the installation process. In relation to aligning incentives, the Paper pointed out the problems arising from 'split incentives', in that the party responsible for the costs of installing meters does not necessarily receive the benefits. The Paper suggested the following two options:

- *Development of additional revenue streams* to allow retailers to recover more of the costs of installation. Suggested revenue streams included paid access to data, such as the provision of power quality data to Distribution Network Service Providers (DSNPs).
- *Multiple parties responsible for metering,* so that instead of energy retailers being solely responsible, parties that obtain benefits, such as traders or DSNPs, may also be responsible for bearing the costs of metering.

In relation to access to smart meter data, the AEMC found that, 'the current arrangements for negotiating and utilising data that the meter can provide are inefficient and likely not contributing to the long-term interest of consumers' (AEMC, 2021, p. iii). In particular, the AEMC found that significant problems were encountered access to smart meter data. In relation to consumer access to billing and consumption data, the AEMC found that:

> The Commission is aware that some consumers have found the process to access their energy data problematic. For example, consumers access to historical usage data is not always provided in a timely manner, or if it is provided, it is not in an accessible or practical format. While some retailers are providing their customers access to near real-time data through their websites or portals, the Commission understands this is not a common market practice. Newgate's research suggested that apps and portals were required to enable consumers to make the most of smart

> meter data provided, and would be highly valued as a way to access real time information without too much effort (AEMC, 2021, p. 65).

In relation to access to additional data, such as power quality data, the National Electricity Rules (NER) provide limited guidance. In essence, under the current regulatory framework, a data service can be provided by a Metering Coordinator (MC) to an accessing party on commercially negotiated terms, so long as this conforms with the MC's obligations under the NER (AEMC, 2022, clauses 7.6.1 and clause 2.4A.1). In practice, the AEMC found considerable problems with access to additional data, such as power quality data:

> Voltage, current, reactive, and active power measured at the connection point can offer visibility of local network conditions. Today's smart meters are sufficiently capable of recording and transmitting this data remotely.
>
> However, stakeholder submissions to the consultation paper strongly indicated that access to this data is limited. Parties such as distribution businesses and small generation aggregators indicated that they often could not secure power quality data over the long-term that they consider as acceptable and in a standardised format across providers.
>
> Data that a smart meter can provide market participants could enable a range of service outcomes and offers that directly benefit the consumer, such as participation in a VPP or indirectly through improved voltage management.
>
> Submissions also stated that the potential benefits on offer from particular use cases and the broader market reform, such as DER integration and demand-side participation, depend on access to this data. The services that the market demands … depend on data access, not a service specification in the rules.
>
> Currently, clause S7.5.1 of the NER requires the metering installation to be capable of providing the following types of information at a minimum: supply status; voltage; current; power; frequency; average voltage and current; and events that have been recorded in the metering log, including information on alarms. However, this data is accessible under the meter installation inquiry service, not a scheduled read.
>
> The Rules specify that ongoing access to these data types be determined on a commercially negotiated basis between metering parties, and DNSPs, and small generator aggregators. There is no clear accountability on which the data services can be provided besides the minimum billing data (AEMC, 2021A, p. 62).

To address these challenges, the AEMC Directions Paper proposed the development of a data access and exchange framework to facilitate efficient exchange of energy data. To provide guidance on the options for implementing a data access and exchange framework, the AEMC commissioned a report from NERA Economic Consultants. The NERA report identified the following initial options for a data access and exchange framework:

1. Authorising a centralised organisation to provide all metering data - with high prescription on data exchange;

2. Minimum content requirements to standardise contracts and agreements on data exchange between market participants;
3. Exchange architecture to facilitate a common interface for data exchange, with low obligation but a high incentive to participate;
4. A negotiate-arbitrate framework for utilisation in access disputes (AEMC, 2021A, p. iv).

The Directions Paper supported the introduction of a data access and exchange framework, but indicated that the NERA options could be implemented either on a stand-alone basis or as a combination of measures. Moreover, regardless of whether a framework were to be introduced, the AEMC considered that there is a need to standardise some elements of power quality data (AEMC, 2021A, p. 73).

Due to sequence changes resulting from other energy market reform priorities, progress on the smart meter review was paused in 2021, and only re-commenced in April 2022. In announcing the re-commencement of the review, the AEMC indicated an intention to work with stakeholders to support efficient access for both industry participants and consumers to smart meter data (AEMC, 2021B).

The difficulties encountered in ensuring access to, and use of, metering data represent a microcosm of the issues raised more generally in optimising access data for use in Industry 4.0 technologies to promote energy productivity. In the absence of adequate regulatory frameworks for standardising data, and ensuring access and use, there are insufficient market incentives for efficient data sharing. Nevertheless, while establishing a data access framework is a priority, as the example of the CDR illustrates, it is essential for an access regime to be accompanied by safeguards imposing obligations on data holders.

5.4 Conclusion

Large-scale data practices – including the collection, analysis and use of data – form the core of Industry 4.0 technologies. Given that these technologies and business practices are both recent and continuously evolving, it is unsurprising that there is an ongoing need for legal and regulatory frameworks to adjust. Consequently, there are completely new regulatory regimes – such as the CDR and critical infrastructure regimes – that have been specifically developed to achieve policy objectives, such as promoting data use and sharing, and securing data. Moreover, existing legal regimes, such as data privacy laws, are being challenged by evolving data practices, contributing to current proposals for fundamental law reforms. In addition, there is increased use of less formal (and more flexible) rules, often known as 'soft law', such as voluntary codes and standards.

This report summarises the diverse, and complex, set of regulatory frameworks that may apply to Industry 4.0 data practices in the energy sector. As explained in this report, the regimes that apply depend upon: the type of the data; the ways in which the data are collected and used; and the nature of the entities that are responsible for the relevant data practices. Beyond this, however, the difficulties experienced with access to, and use of, smart meter data in the energy sector, illustrate the need for coherent regulatory frameworks to promote responsible data access and sharing. At present, the extent to which the regulatory initiatives forming part of the ADS – such as the CDR regime – are able to achieve the objectives of transforming Australia into a data-driven society, is unclear.

6 Business Models for Industry 4.0 and Energy Productivity

Energy productivity has long been considered a significant outcome of Industry 4.0 adoption – the combination of which (i.e., energy transformation and Industry 4.0 adoption) was also said to "substantially alter the way people live, consume, produce and trade" (Nagasawa et al. 2017, p. 25). At the same time, the accelerated interest in these two complementary phenomena has been garnered by the potentially lucrative business opportunities that exist in their nexus. Ideals of "faster, better and cheaper" as well as other more nuanced opportunities to generate and capture value have emerged as advancements in energy productivity and Industry 4.0 technologies begin to take a foothold in industry as well as in society as a whole. Digital twin platforms, product service systems, cloud manufacturing, smart metering and resource optimisation systems are just a few of the enablers spurring on a fundamental shift in how organisations as diverse as manufacturing, services and energy provision do business. One way to understand the impact and potential opportunities of this shift in commercial logic is through the consideration of their business models.

Though various conceptualisations exist, a business model is generally defined as the "design or architecture of the value creation, delivery and capture mechanisms" an organisation employs (Teece 2010, p. 172). The same logic can apply for business models with more of a sustainability agenda as well. So-called business models for sustainability typically draw attention to the way an organisation creates value by explicitly taking into consideration social and environmental phenomena. This also permeates into the way an organisation designs and executes its business processes and the interactions between customers and other stakeholders, with a focus on shared responsibility concerning both production and consumption (Schaltegger et al. 2016). Such a premise, in addition, draws parallels with the emerging theme of circular business models that pay particular attention to the principles of the circular economy vis a vis material and energy loops (Geissdoerfer et al. 2020).

In the first instance, the underlying logic guiding business models can be captured by the use of business model patterns. Here, a pattern is typically referred to as describing "a problem which occurs over and over again in our environment, and then describes the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice" (Alexander 1977). Translating this into the domain of business models, a business model pattern thus 1) describes a solution to a recurring problem, however, 2) this solution only accounts for a certain part of an organisation's business model and, 3) requires a certain level of generalisation i.e., can be used over and over again (Remane et al. 2017). Considering such patterns are a worthwhile endeavour in understanding business models for industry 4.0, Weking et al. (2020), along similar lines with others (Wee et al. 2015, Agostini and Nosella 2021, Florén et al. 2020) uncovered three overarching "super patterns" i.e., integration, servitisation and expertisation. This framework (see Figure 47) has been adapted for the purposes of describing the potential opportunities for leveraging Industry 4.0 for business models in this report.

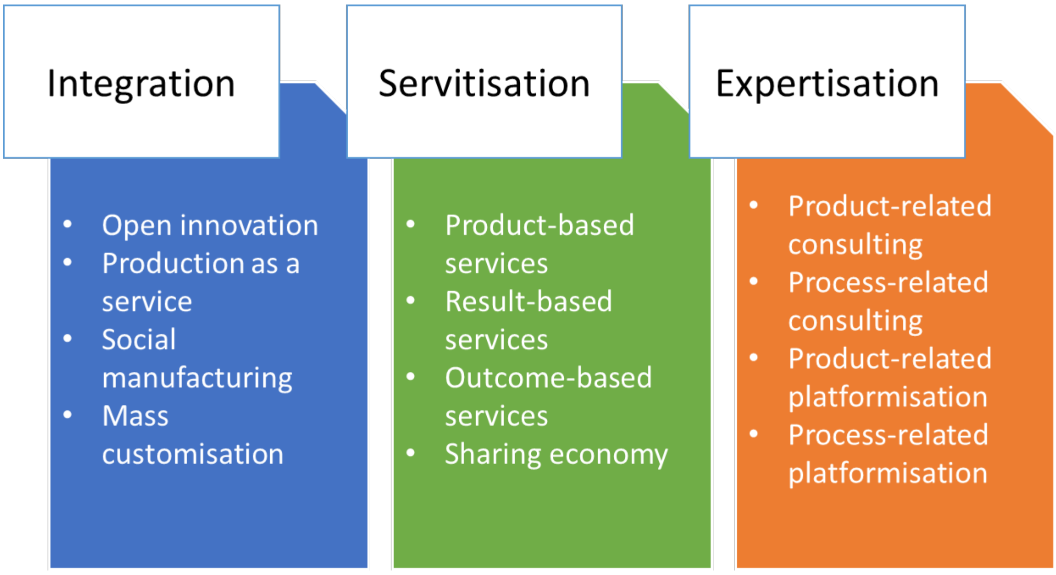


Figure 47. Overview of business model patterns for Industry 4.0 adapted from Weking et al. (2020)

6.1 Integration Business Models

The integration superpattern refers to those business models that wish to shift firms from focussing on one single activity in the value chain to covering (or integrating) a lot more – thus placing a greater focus on processes (Weking et al. 2020). Some prominent examples in the context of Industry 4. 0 and the broader sustainability agenda include the likes of open innovation, production-as-a-service, mass customisation and social manufacturing.

6.1.1 Open Innovation

Open innovation has become a reknowned driver for achieving global sustainability targets as well as in creating and sustaining a competitive advantage in an organisational context (Mubarak et al. 2021, Obradović et al. 2021). The term stems from an increasing necessity to involve others in an organisation's innovation journey, particularly for the purposes of solving problems in a marketplace characterised by growing volatility, uncertainty, complexity and ambiguity (Schoemaker et al. 2018). Open innovation is generally recognised as a "distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model" (Chesbrough and Bogers 2014). As such, it can be deployed through many mechanisms including crowdsourcing, co-creation, co-innovation and anothers – also depending on the nature of collaborative effort (e.g. whether the organisation is leveraging in-bound, out-bound or combined knowledge flows). Because it allows for stakeholders as far reaching as customers, suppliers, competitors and even entire communities to breach the front-end of an organisation's value chain, open innovation has also been met with the emergence of potentually lucrative business models where Industry 4.0 is also seen as a key enabler. Though, the complementary adoption of open innovation and industry 4.0 is not so straight forward, particularly when it comes to the inclusion of a sustainbility agenda.

To begin, industry 4.0 adoption towards sustainable outcomes is often met with significant knowledge gaps, not least stemming from the complexity of the solutions involved. Indeed, it has been found that merely an organisation's adoption of industry 4.0 technologies does not guarantee sustainble outcomes (Lardo et al. 2020). Rather, it requires a significant collaborative effort among a diverse range of stakeholders including consultants and the emergent business model of capability providers. Such a "Sustainable Industry 4.0 Environment" relies on, among others, open innovation practices to help co-create value with partner organisations involved in the industry 4.0 and sustainability journey (Lardo et al. 2020) . Indeed, there also seems to be a need for support and development of techniques that allow organisations to define and implement incremental change in low risk parts of their processes, to build confidence and expertise.

Keeping with the capability support theme, the notion of digital innovation hubs (DIHs) is also an emergent concept that helps organisations leverage industry 4.0. So-called DIHs are defined as "public-funded collaborative networks that, guided by an open innovation strategy, support and promote partnerships between SMEs and technologically intense organizations towards increasing the digitalization of industry"(Dalmarco et al. 2021, p. 446). As with other publicly-funded collaborative organisations, DIHs also have to strive for financial sustainability and have developed their own business models to help create value through e.g. building ecosystems, networking and brokering to name a few. On the other hand, they are not only able to capture value through the means of providing these services and a platform for interactions, but also through running workshops and various training programs; as Dalmarco et al. (2021) describes, all within the sphere of open innovation. Given much of the work of DIHs has spillover benefits and involves building confidence and upskilling, the provision of adequate public funding in early years is an important consideration.

All things considered, it is also necessary to keep in mind that the degree of involvement amongst value chain participants collaborating with the aim of leveraging industry 4.0 and sustainbility can vary considerably. In some instances the customer is deeply involved in the design and development of solutions, other times it may be key suppliers, and the customer takes on a lesser role (see Bigliardi et al. 2022 for recent exmaples of this in the food industry). In part, the degree of involvement is guided by the overarching strategic intent that bounds collaborative initatives and, at the same time, can reach significant road blocks if not managed effectively. Themes including trust, intellectual property, cost and other resource necessities continue to emerge as barriers in this respect and should be considered when taking on-board such opportunities (Camarinha-Matos et al. 2019).

Klöckner & Co

Klöckner & Co is a German origin steel and metal distributor. Klöckner's core business is the sale of steel and non-ferrous metals and its operations span across 13 countries with around 140 locations. As part of its digitalisation strategy, Klöckner & Co founded a digital unit, Kloeckner.i, in Berlin in 2014. The aim of this endeavour was to reduce "information asymmetries by digitally connecting all market participants" (Klöckner and Co 2022). This involved the creation of an open ecosystem in the form of a platform (XOM Materials) that enables these steel market participants (including customers, suppliers and even direct competitors) to create additional value in a mutually beneficial manner – citing benefits including increased transparency and decreased lead times through demand matching (The Innovator 2019). In 2021, XOM Materials yielded a gross merchandise volume of around €150 million (Klöckner and Co 2021).

6.1.2 Production-as-a-service

Production-as-a-service is based on the notion of providing physical production capabilities to customers. In the manufacturing industry, this means opening the door for designers, hobbyists and other prosumers to fill the gap between design inception and physical product development and production. This shifts the value chain from expert designed and mass-produced products, to user design and individualised products (Weking et al. 2020). With the introduction of advanced manufacturing and ICT technologies stemming from Industry 4.0, this business model has facilitated the move from a transactional one-to-one relationship between customers and production, to a distributed one-to-many approach. Cloud computing in particular has given rise to novel opportunities to create and capture value from a production-as-a-service business model, thus you may often find production (or manufacturing)-as-a-service squared under the umbrella of the anything (X)-as-a-service paradigm as well. So-called cloud manufacturing involves the interaction of three key stakeholders i.e., users who do not possess the required production capabilities; application providers that interpret user requirements and convert them into specific data to be used for capability planning, production planning and control and general management of the cloud manufacturing environment; and finally, the physical resource providers that have the production capabilities and know-how to produce a product, assembly, or part according to the customer requirements and that participate in the production-as-a-service ecosystem (Wu et al. 2013).

This business model not only has important implications for production-providers, but also introduces different ways for others to participate in the value chain as well. For example, in the case of prototyping SMEs, they can either be involved in the production-as-a-service ecosystem as a product development service provider, conventional prototype provider, manufacturing service provider or an intermediary that serves as the conduit that helps link value chain participants to potential users (Bulut et al. 2021). In the energy sector, another example is the flexibility-as-a-service business model that provides the opportunity for industrial and residential stakeholders to earn additional revenue from appliances such as heat pumps (Singh et al. 2022). In terms of Industry 4.0, this business model works on the basis of providing flexibility in energy grids by enabling a wide variety of value chain participants (DSOs, TSOs, consumers and others) to trade or sell flexibility through e.g., the use of platforms for a subscription fee (Singh et al. 2022), something also discussed in the following sections.

6.1.3 Social Manufacturing and Distributed Production Networks

Geographically distributed production systems have observed quite a rich history through idioms such as virtual enterprises, production networks and, as will be described shortly, social manufacturing (Mladineo et al. 2018). The general idea of these business model patterns is to distribute different production processes (potentially from different parts of the value chain) through a network of organisations. Though early adoption of the concept proved challenging, thus significantly limiting initial uptake, the emergence of Industry 4.0 has reignited the greater potential for organisations to create and capture value from such an approach (Mladineo et al. 2018) – opening the door for a wider range of enabling mechanisms.

One of the core processes in this approach is in defining key criteria for partner selection, including sustainability goals, then taking on one of two pathways for partner selection and network formation i.e., a push-type or pull-type approach (Mladineo et al. 2018). In the former, the production network is determined based on a set of predefined criteria whilst the latter involves a process of competitive bidding by potential network partners. Building off the notion of cloud manufacturing, social manufacturing, on the other hand, takes this a step further by investing in the notion of self-organisation by way of network participants and the increasing trend of socialisation in the broader sense. This offers smaller producers the chance to leverage their core capabilities by forming "dynamic resource communities" that observe increased flexibility compared to larger counterparts – offering significant potential to achieve greater mass customisation capabilities too (Jiang et al. 2016). By explicitly considering the advantages of social interactions in social networks (something organisations already do at great length), bringing this into the realm of distributed manufacturing systems means that the network also exists beyond the initial engagement with the customer i.e., it doesn't stop once the product is produced. This offers additional benefits in the form of ongoing collaborative and knowledge sharing efforts, better resource utilisation, improved production efficiency and reduction of production costs (Zhang et al. 2021), particularly enabled through the use of industry 4.0 technologies.

6.1.4 Mass Customisation

Mass customisation is a term that rose to prominence given the burgeoning demand for customised solutions at prices and lead times that reflect that of a mass produced item. Traditionally, this involves carefully considering two important factors i.e. 1) how and where to involve customers within the value chain and 2) how to facilitate the production of customised products on the shop floor (Rudberg and Wikner 2004). A critical strategic activity thus resides in deciding where on the continuum of flexibility and efficiency the producer is going to find itself – the more upstream in the value chain, the more flexibility is involved in the solutions and production systems, whilst deferring the customer involvement more downstream yields to greater gains in efficiency by way of production output though constraining flexibility (Katic and Agarwal 2018). However, with the introduction of Industry 4.0 technologies, organisations have found a way to better reconcile these seemingly conflicting objectives towards a more synergistic 'both/and' strategy.

Additive manufacturing, in particular, has had a significant impact on the ability of manufactuers to induce product variety and flexibility into their production systems. Cloud-based additive manufacturing technologies and platforms have also paved the way towards decentralised business models, and similar to those listed earlier, involves the creation of new value-propositions that service not just the production end of the value chain, but the management of the entire value chain itself as well (Cui et al. 2022).

The idea of providing customised solutions is not only placed in organisations where production/manufacturing is a core capability. In the energy sector, for instance, the microgrid-as-a-service business model is an example where revenue is gained from providing customised microgrid solutions (Singh et al. 2022).

6.2 Servitisation Business Models

Servitisation came about as a term that describes an organisation's pursuit of capturing additional value from the sale of products through the inclusion of services that span its entire lifecycle (Baines et al. 2009). These so-called product-service systems have become a mainstay in recent years, though it appears the traditional means of doing so may not be as effective as it once was, particularly when it comes to the emergence of Industry 4.0 (Pirola et al. 2020). Here, the integraton of sensors into physical products has raised the value creation potential of servitisation strategies (Weking et al. 2020), not only in terms of economic potential, but environmental and social potential as well (Langley 2022). So-called digital servitisation business models can emerge in a variety of forms depending on the degree of customisation offered by solutions, pricing mechanisms and degree of digitalisation capabilities (e.g., from monitoring activities to fully autonomous solutions) (Kohtamäki et al. 2019). In this report, we consider some emerging Industry 4.0 enhanced servitisation business models under the the broader themes of product-based services, use-based services, results-based services and the sharing economy.

6.2.1 Product-based services

Generally, product-based services have been characterised as those business models based on the addition of services to product sales. Thus, in this case, the ownership remains with the customer having purchased the physical asset and the onus is on the supplier to comply with the agreed upon services (Reim et al. 2015). Some more traditional examples of this include the provision of after-sales service with the purchase of new machinery or the potential for a buy-back scheme after a certain period of the product life cycle. With the addition of Industry 4.0, these product-oriented product-service systems are able to benefit from enhanced analysis capabilities stemming from the inclusion of sensors and other ICT technologies in the physical products they have purchased. Some of these capabilities can range from descriptive analysis by allowing the producer to sense what is happening to their products on the field right through to, more recently, prescriptive analysis processes that hold the potential for the product to pre-emptively engage in decisions concerning e.g., maintenance activities (something we also discuss next). These kinds of business models can be coupled with potentially lucrative contractual agreements that allow for life-long partnerships to ensue as an additional service to the initial purchase of a particular product (Weking et al. 2020). This can also be observed in the energy domain where, for example, the battery-as-a-service business model involves revenue generation from swapping batteries and providing charging services (Singh et al. 2022). From a consumer perspective, this model offers significant benefits but may also create ‘lock-in’ as was found in our consultations during this research project.

Pirelli

In 2016 Pirelli, a well-regarded tyre manufacturer, embarked on a journey to create a data-driven business to complement its existing manufacturing operations (Schaefer et al. 2017). One of the ways this is being conceived is by inserting smart sensors into their tyres that can help determine tyre pressure, temperature and wear characteristics. Such information has been successfully shared over a 5G network with plans to expand the networking capabilities with other vehicles and surrounding infrastructure (Pirelli 2021b). In addition, Pirelli has developed “Pirelli Care”, a subscription-based model that allows users to sign up for additional services that can either be an add-on to a tyre purchase (i.e., does not include the provision of tyres) and provides the likes of roadside assistance and puncture protection services, or include the sales and fitment of tyres with options for additional services according to a defined service level (Pirelli 2022). Pirelli care uses data based on driving style, distance driven and registration details to send push notifications to drivers to encourage more eco-sustainable behaviour as well as feeding into internal technological and product innovation efforts (Pirelli 2021a, 2022).

6.2.2 Use-based services

Under the use-based services business model, the producer does not sell the physical asset but rather leases or rents the asset and thus retains ownership rights (Reim et al. 2015). In the context of Industry 4.0 this has enabled the creation of multiple emerging business models with benefits that span beyond economic performance. For instance, in a sharing and leasing arrangement where the producer of the machinery retains ownership over their products and leases them out within their own premises, the utilisation rate of equipment can be improved thus minimising resource consumption. Such an approach also makes manufacturing capabilities more accessible to smaller producers with limited budgets whilst ensuring timely and accurate data collection that unlocks the potential for data-driven preventive maintenance and prolonged machinery life (Wang et al. 2020).

SWW Wunsiedel GmbH and Siemens

Wunsiedel, a municipality in Germany, is working towards complete energy independence and a target of zero CO_2 emissions. A utility company (SWW Wunsiedel GmbH) and Siemens are engaged in a partnership to help make this a reality through, amongst others, the inclusion of one of the largest green hydrogen plants in Germany. Mindsphere, a Siemens software-as-a-service platform, is being adopted to help form a larger control system whereby data can be "analyzed, evaluated, and used by SWW Wunsiedel and its end customers to create a stable and extremely reliable power supply system that allows excess production volumes and reserves to be sold on the energy market" (Siemens 2022).

Keeping with the theme of maintenance activities, the servitisation of maintenance activities in the context of industry 4.0 also has the potential to significantly change the way value is created and captured in maintenance eco-systems. In this case, maintenance is not just an add-on service that OE suppliers have to perform, but becomes a core function in its own right that facilitates better collaborative efforts amongst customers and suppliers – shifting them from a passive role, to one in which they are actively engaged in knowledge sharing and creation activities (Grijalvo Martín et al. 2020). The practicalities of this kind of business model are also presented in Figure 48 and described in detail by Dorst et al. (2018). Here, a tire manufacturer would sell tires to a service provider (that is also the owner) who, in turn, leases these to a fleet operator. Thus, it is the role of the service provider to ensure that the fleet operator is provided with a product equipped to perform according to expected specifications (in this case, a tire). Thus, some core activities the owner and the service provider must perform include the likes of tire management, coordinating procurement, performance monitoring and installation of tyres. In this example, the owner and service provider rely on a maintenance network for maintenance duties whereby data from an IoT platform is used to monitor the condition of tires for use in invoicing activities and other operational, design and strategic decisions later on.

Such a business model also finds itself as a staple in the energy sector with the likes of heating-as-a-service (users pay a subscription or leasing plan for heating), solar-as-a-service (users pay a subscription or leasing fee for solar infrastructure) and charging-as-a-service (users pay a subscription fee for charging points) (Singh et al. 2022). Though presenting emerging business logics, all of which also having been implemented under certain jurisdictions, these business models involve a number of contingencies that should be taking into consideration. For instance, data privacy and technological (interoperability) constraints and ownership characteristics continue to be barriers in the heating-as-a-service model where clear policy and regulatory guidelines are also a necessity (Singh et al. 2022).

6.3 Result-based services

Like use-based services, result-based services involve the provision of services where the producer retains ownership. However, in this model, the manufacturer/producer agrees to provide a certain service level according to results or outcomes from the use of the physical asset. These can also fall under the umbrella of pay-per-outcome (e.g. zero downtime of machinery) and pay-per-output (e.g. a defined rate of consumption of compressed air or energy generated from airline engines, also referred to as pay-per-value created) revenue models (Schroderus et al. 2022, Langley 2022). A prominent example of this business model pattern is that of energy-as-a-service. Based on a pay-per-outcome revenue model, the customer in an energy-as-a-service contract will only pay for the benefits they obtain from the use of the physical asset (whether that be in energy saving, optimisation or otherwise), not for the asset itself or its maintenance or upgrading (Bornstein 2019). This type of business model can also incorporate the use of energy performance contracts (Singh et al. 2022). In addition, and in a similar fashion, comfort-as-a-service has also emerged as a potential business model that leverages quite heavily on the benefits of Industry 4.0 technologies (Gómez-Romero et al. 2018). Here, users pay for the comfort level that they want to achieve in their property, but are obliged to hand over control of comfort enabling devices (e.g. HVAC systems) to a third party that will then manage the desired comfort level for a fee (Gómez-Romero et al. 2018, Singh et al. 2022).

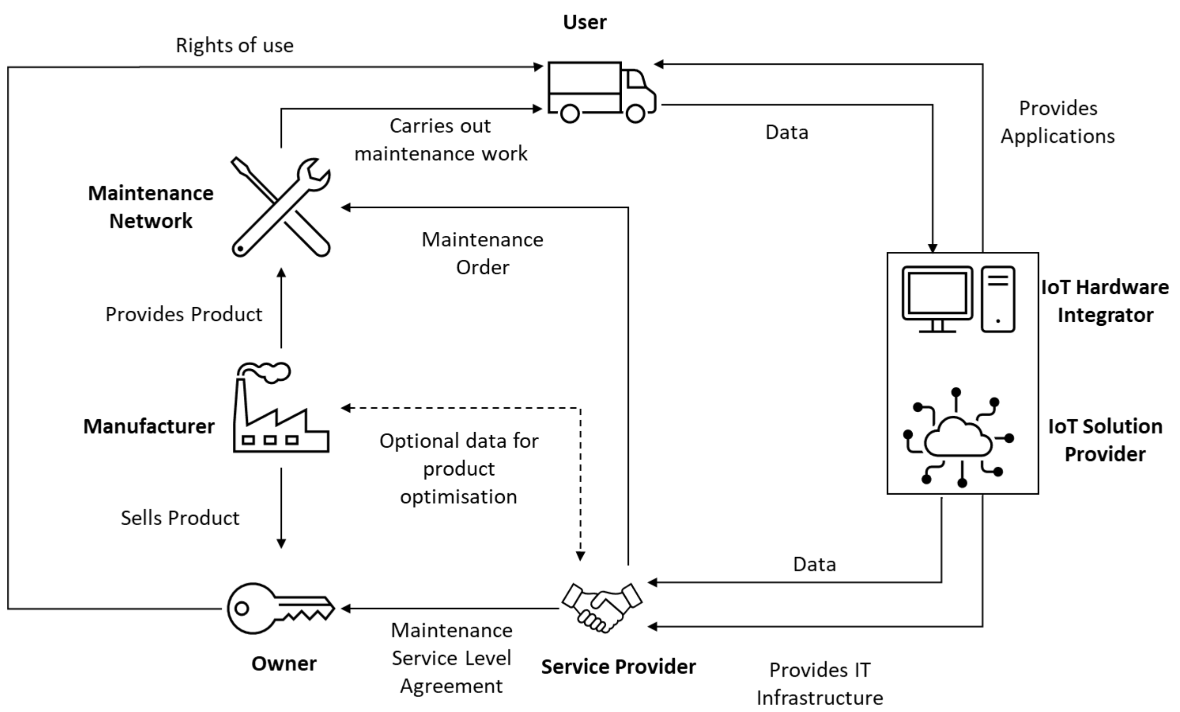


Figure 48. Sample of a value network in the context of a "tire as a service" business model adapted from Dorst et al. (2018)

6.3.1 Sharing economy

The increasing shift towards circular economy principles as well as the changing shape of global markets and customer needs have led to the emergence and popularity of so-called sharing economy business models (Jabbour et al. 2020).Though still a hotly contested and relatively novel endeavour, these business models are generally seen to operate on the basis of shared consumption of goods and services (Veith et al. 2022, Jabbour et al. 2020) with benefits that span the likes of increased utilisation of resources, and therefore reduce environmental impacts and costs, as well as helping to build community relationships (Boons and Bocken 2018). Though, it is also important to keep in mind the degree to which this occurs is subject multiple contingencies including the nature of the relationship between sharing parties, the level of participation (e.g. single individuals or entire communities) and the means in which the sharing activities are conducted (e.g. through the use of online platforms) (Veith et al. 2022). The introduction of Industry 4.0 in this realm has led to improved sharing practices and organisational performance outcomes given such technologies help "facilitate product sharing and optimize the traceability of products, as well as the circularity of materials, components and products" (Jabbour et al. 2020, p. 3).

Sharing economy business models have been explored at the nexus between sustainability practices and industry 4.0 adoption in a variety of industrial contexts. For instance, Jabbour et al. (2021) describe the use of sharing economy practices (by way of circular economy principles) in the context of food waste in food supply chains. Industry 4.0 technologies were found to be beneficial throughout the food supply value chain, from production planning and control through to retailing and beyond – contributing to the reduction in food waste and improved collaboration efforts amongst value chain participants. In a manufacturing context, Jabbour et al. (2020) detail the case of two Brazilian organisations that have moved to a sharing economy business model. One organisation produces smart gymnastics and other fitness equipment with embedded sensors and IoT technology to help facilitate additional value-add for their B2B partners, citing the importance of artificial intelligence and Big Data to leverage sharing activities and also help in new product development. The other organisation, a lighting company, has also moved towards a sharing economy business model through embedded sensors and associated technologies in LED lighting fixtures, enabling the collection and dissemination of use data. In the case of SMEs, who greatly benefit from a sharing economy business model, Soltysova and Modrak (2020) detail three possible modes of operation i.e., on demand sharing (e.g. Uber and AirBnB), second-hand sharing (donations, gifts and purchases) and product-service models (similar to the use-based methods described earlier and include activities like e.g., renting and swapping).

6.4 Expertisation Business Models

Lastly, expertisation business model patterns rely on the in-house expertise and knowledge of a firm and leverage this to provide new products/services (Weking et al. 2020). This can be achieved in the form of providing consulting services as well as in the development of various platforms based either on a physcial asset, e.g., developing a digital product that can address a larger number of customer requirements when they purchase a product, or a process e.g., leveraging internal knowledge on, for instace, smart production and developing complementary digital solutions to help provide support for customers, rather than necessarily addressing further customer needs (Weking et al. 2020).

6.4.1 Product and process-related consulting

Leveraging in-house product and process knowledge developed through the implementation of Industry 4.0 in associated business models has opened the door up for further value creation and generation in the form of additional consulting services focal firms hold the potential to provide. Generally, this can come in two forms i.e., product-related and process-related consulting services (Weking et al. 2020). In the former, product-based knowledge concerning Industry 4.0 implementation could be used as a complementary add-on (or an extension) to physical product sales. The latter, on the other hand, is based on operational (process-based) consulting and does not involve physical product sales. Here, know-how in leveraging Industry 4.0 through designing business processes or organisational strategy can form areas of further value creation.

Oftentimes, as eluded to in prior business model sub-patterns, consulting services can form part of a service-based ecosystem. Liu et al. (2022), for example, highlights how consulting activities form a part of a wider value-creation mechanism in the world's largest copper smelting organisation. Here, product-based consulting services and process-based consulting services (by way of intelligent product and digital transformation) are a part of a service-based ecosystem that, when combined with a sustainability-based business model and human-cyber-physical collaboration, help such an organisation to realise economic, social and environmental benefits.

6.4.2 Product and process-related platformitisation

Platforms are regarded as amongst the most significant drivers in leveraging Industry 4.0 (Wortmann et al. 2022). As is evident throughout this report, they appear central in both integration and servitisation super-patterns as enablers for a raft of additional opportunities for value creation and capture as digitalisation becomes more and more prominent in today's operating environments. Like consulting, platforms can also be classified as either product-based or process-based (Weking et al. 2020). In the case of product-based platforms, an organisation will leverage its technical product know-how in terms of production and sales and transform this into a digital product. The idea, in this case, is to widen the value creation potential of physical products to include the possibility of solving additional problems and providing additional opportunities for end-users through the use of digital platforms underpinned by a carefully orchestrated collaborative effort amongst partners. As with the open innovation paradigm in general, the degree of opennes of these product-based platforms can vary – each inducing different levels of competitive risk and uncertainty as well as different ways to create and appropriate value for the end user.

365 FarmNet

365 FarmNet is a subsidiary of Claas, a global farm machinery manufacturer. This organisation provides a farm management solution that encompasses a farm equipment system, weather data, seed optimisation and irrigation systems. As an open platform, 365 FarmNet also allows for the opportunity for partner organisations, customers, and potentially other competitors, to leverage a wide variety of data to help enhance a data-driven strategy for agricultural operations. Here, Claas itself remains a manufacturer of farm equipment at its core and Industry 4.0 is also being adopted on the shop-floor (Wurzer et al. 2019). However, by providing an integrated platform for farm management, Claas can ensure it delivers (and capures) value well beyond physical machinery enabled by Industry 4.0.

On the other hand, process-based platforms leverage an organisation's Industry 4.0 process knowledge and transform this into a digital platform. The aim, in this case, is to provide ongoing services and support through the development of integrated IT solutions. An example of this in the energy sector is the emergence of the trading-as-a-service business model. Linked to the ideals of inducing flexibility into energy grids, trading-as-a-service relies on digital platforms where energy can be traded amongst users in a peer-to-peer fashion, usually including a subscription fee (Singh et al. 2022).

6.5 Conclusion

These business models are all designed to leverage the mass of data that stems from the adoption of Industry 4.0 technologies – from the digital design of a product, through digital monitoring and control of production, to digitally enabled after sales service, maintenance and finally disposal or recycling. This so-called "digital thread" (Wee et al. 2015) acts as an enabler for improved communication, monitoring and ultimately decision-making. However, it is also important to note that business model patterns such as these are rarely found in isolation, typically there are multiple patterns being leveraged within a single business model (Osterwalder and Pigneur 2010) e.g., the X-as-a-service suite (Singh et al. 2022) and pay-per-X business models (Schroderus et al. 2022). There is also the possibility to observe redundancy in the patterns with closely linked characteristics (see the review by Remane et al. 2017).

In addition, it is worthwhile mentioning that, whilst these business models hold great market potential, some are yet to secure a strong foothold in extant markets. The flexibility of the servitisation approach, for example, has often been met with challenges in terms of the ambiguity customers may experience whilst trying to decipher the value proposition of some service offerings, as Langley (2022) mentions "many new servitization solutions result in a worse customer experience as new ways of working have not yet been optimally designed" (p. 7). This, combined with the operational and managerial nuances associated with the shift to a servitisation strategy result in the persistence of considerable barriers to uptake, particularly in the case of manufacturing organisations (Romero et al. 2021) and the steel industry (Tolettini and Lehmann 2020). Along the collaborative front, when it comes to the necessity for collaborative activities in leveraging Industry 4.0 enabled business models, such activites, and the formation of collaborative networks in particular, are still being treated as a burden on organisations (Camarinha-Matos et al. 2019).

Other challenges to the implementation of Industry 4.0 enabled technologies include the likes of conflicting business models with traditional modes of operation, potential for significant impact on entire value chains, impact on prices and regulatory concerns as well as the intellectual property rights and patent considerations stemming from the democratisation of production that may be a core existing activity (Godina et al. 2020). Nonetheless, the opportunities associated with their adoption hold the potential to also be of significant benefit for participating stakeholders. Digital platforms, for instance, are already well-established in many industrial contexts and are a pillar of effective industry 4.0 application, having changed not just how organisations operate, but how society operates as well (Roblek et al. 2020). Blockchain (and other similar emerging models), has opened up the potential for greater transparency in supply chains, decreased operational costs and the provision of better monitoring and performance control – helping to enable social manufacturing and the sharing economy (Esmaeilian et al. 2020). Thus, whilst some kinks remain in the adoption of Industry 4.0 enhanced business models, and the impact of their adoption in practice (Fonseca et al. 2021), there are certainly many more opportunities to explore and exploit in this space.

7 Roadmap to Industry 4.0 Energy Productivity

The Australian manufacturing industry includes a broad range of businesses engaged in a wide variety of activities. In particular, the manufacturing industry, accounting at the end of 2021 for a total of more than 86,000 businesses (ABS, 2021), includes key sectors such as:

- Food processing and manufacturing
- Beverages including brewed and bottled drinks
- Textiles, leather, clothing, footwear and accessories
- Wood products
- Pulp and paper products
- Printing including small and large production runs
- Chemical manufacturing and processing including fertilisers, pesticides, pharmaceutical, medicinal, cleaning products, toiletries, cosmetics, photographic and explosives
- Metal and plastics manufacturing
- Machinery and equipment manufacturing including parts
- Furniture manufacturing
- Household goods production
- Any manufacturing of a whole or partial product

Australia's manufacturing sector contributes to a significant share of the economy (accounting in 2020 for more than $ 108 billion AUD and employing more than 860,000 people) Furthermore, by looking at the non-residential building sectors, the value of non-residential construction work done in Australia in the first 3 quarters of 2021 amounted to approximately $ 35.7 billion AUD.

From a purely technical standpoint there are some energy productivity gains available via the use of digital technologies at almost every one of these sites. By narrowing the attention to those sites for which the gains from adoption of energy productivity measures might be large enough and/or considered important enough to attract business attention, then there are still thousands of Australian targets for the utilisation of Industry 4.0 ideas and IoT technologies for bringing about energy productivity. In manufacturing especially, these technologies of course bring broader benefits to business in terms of capability, profitability and sustainability.

The US experience (CESMII roadmap, 2020) shows that to achieve sizeable whole-of-system impact in energy productivity across manufacturing it is necessary to address both the energy intensive industries (such as cement and metals production) and the run-of-the-mill supply chain participants. Energy productivity gains upstream in supply chains can be diffused and negated by poor utilisation of energy and materials downstream. A suite of energy productivity technologies and initiatives for manufacturing therefore must drive innovation and investment across participants large and small, upstream and downstream, energy intensive and otherwise. However, in order to be effectively deployed, they need to leverage on a number of drivers to overcome existing barriers. In the following, a set of drivers for industry 4.0 and energy productivity are briefly presented and discussed.

Drivers to industry 4.0 and energy productivity

Drivers of various nature stimulate enterprises in the adoption of Industry 4.0 technologies. In particular, scholars (Ghobakhloo et al., 2022; Horváth & Szabó, 2019) have recently highlighted the existence of drivers within a company (e.g. improved production planning & control, management commitment, or cost reduction due to lower energy use), acting in combination with external ones (e.g. financial incentives, corporate image). Furthermore, research has started linking drivers in the decision-making process tackling multiple barriers to energy efficiency (Trianni et al., 2016). However, the theoretical background for drivers has received very little attention by scholars. Studies focussing on specific drivers for Industry 4.0 and its actual application still seem to be sparse in extant academic literature. Interestingly, research has shown how drivers of energy efficiency and productivity may be seen as factors acting on barriers during the decision-making-process of adopting an energy efficiency measure (Trianni et al. 2017, Horváth and Szabó, 2019). Such drivers might be promoted internally, or come from an external stakeholder. The number and type of stakeholders operating in this market is increasing and the market is under constant evolution, with new players and new solutions brought up.

As previous studies noted, a critical success factor for EEMs (and, to this extent, also industry 4.0 solutions for energy productivity) is the cooperation between stakeholders operating in the energy efficiency market (Reddy et al., 2013). Indeed, investors, utilities, governmental agencies, financial institutions, local authorities, research and development organizations, equipment manufacturers, market institutions, ESCOs, and international institutions can all play vital roles. It is thus important to try enlarging as much as possible the perspective, identifying which stakeholders may be in the best position to develop and stimulate the most effective drivers to promote industry 4.0 solutions for energy productivity. In the following an overview of drivers is presented, with the aim at illustrating the many factors that can leverage the promotion of industry 4.0 solutions for energy productivity.

The combination of digital, physical and virtual worlds creates unparalleled opportunities for growth and productivity while reframing the competitive landscape with smart products, enabling "mass customization". For instance, smart communicative data technologies of Industry 4.0 would allow energy consumers to have real-time control of their energy needs, consumptions, and costs, further supporting the global move towards more reliable, affordable, and cleaner energy. Similarly, in the manufacturing environment, IoT, cyber physical system, sensor-equipped machines, and other intelligent components of a smart manufacturing system allow factories to develop and integrate intelligent energy management systems for real-time energy monitoring into their production management systems. The resulting energy-aware system can perform the real-time energy monitoring of each process point and use AI to link granular energy data with other relevant data streams and respective production units and industrial processes, execute the energy-flexible and efficient production planning, optimize the energy supply, and ultimately improve energy productivity.

Furthermore, Industry 4.0 technologies such as intelligent automation, IoT, CPPS, additive manufacturing, and cloud data, facilitate energy sustainability in the manufacturing setting. Scholars predict that the widespread application of additive manufacturing leads to more than 20% saving on global energy consumption by 2050 (Ghobakhloo & Fathi, 2021). Product weight reduction and transportation efficiency, minimal material wastage, and manufacturing flexibility improvement are among the critical features of additive manufacturing that directly impact energy productivity.

Driving force	***Factor***		***Barrier***
Increasing labour shortages Reducing human work Allocating workforce to other areas (higher added value)	**Human resources**		Lack of appropriate competences and skilled workforce Longer learning time (training of staff)
Reducing costs e.g. human resources, inventory management and operating costs	**Financial resources and profitability**		Lack of financial resources Return and profitability Shortcomings in tendering systems Long evaluation period for tenders
Market competition Follow market trends Increasing pressure from competitors Business model innovation	**Market conditions and competitors**	**Management reality**	Lack of a leader with appropriate skills, competencies and experience Lack of conscious planning: defining goals, steps and needed resources
Demand for greater control (from top management) Continuous monitoring of company performance	**Management expectations**		
Reducing the error rate Improving lead times (compliance with market conditions) Improving efficiency Ensuring reliable operation (e.g. less downtime)	**Productivity and efficiency**	**Organizational factors**	Inadequate organizational structure and process organization Contradictory interests in different organizational units Resistance by employees and middle management
		Technological and process integration, cooperation	Lack of a unified communication protocol Lack of back-end systems for integration Lack of willingness to cooperate (at the supply chain level) Lack of standards incl. technology and processes Lack of proper, common thinking Unsafe data storage systems The need for large amounts of storage capacity

Figure 49. Drivers and barriers to Industry 4.0 (Horváth and Szabó, 2019).

Businesses take different approaches to increase energy productivity. In the Industry 4.0 environment, energy-sustainable product design concerns the entirety of the product life-cycle, from exploration of the nature of the services to be provided, design, prototyping, manufacturing, and usage to disposal. Furthermore, the cost-saving advantages that Industry 4.0 offers to the manufacturing industry is widely-discussed. The autonomous 24/7 non-stop production, improved process controllability, improve manufacturing precision and quality, real-time monitoring and accident prevention, maintenance efficiency, higher equipment effectiveness, lower human errors, quality decision-making, streamlined procurement processes, reduced human resource costs, and material/resource/ energy efficiency are examples of Industry 4.0 implications for manufacturing cost reduction. Furthermore, Industry 4.0 connectivity supports the development of new service-oriented business models such as manufacturing-as-a-service (MaaS), product-as-a- service (PaaS), individualized manufacturing, or lean-digitized production, leading to significant productivity and energy efficiency.

Stricter environmental regulations or standards application—such as mandatory energy-saving obligations (Waide and Buchner 2008) and associated costs to their compliance—could force final users to adopt metering systems to effectively showcase the use of energy and other resources, thus supporting introduction of industry 4.0 solutions with potential for future energy productivity. As Stenfotft et al. (2021) recently empirically found for SMEs, legal regulations demanding the use of new digital technology may override existing barriers and resistance to change.

To make the complex manufacturing processes as efficient as possible, manufacturers need to autonomously collect and analyse a massive amount of material, equipment, process, financial, environmental condition, and other data to make informed decisions. IoT, data mining, and cloud ERP services can collect real-time data across supply chains, extract transparent information, offer numerous analysis options, and transform them into meaningful performance indicators across business partners. The information processing capability of Industry 4.0 and the resulting communication improvement and process visibility across value networks will streamline informed decision- making and support energy productivity improvement.

In addition, the actual application of Industry 4.0 technologies can be affected both directly and indirectly by management's perceptions of drivers. A response to a driver can determine if the adaptation of Industry 4.0 technology is a reactive response to, for example, a specific customer requirement to use a specific technology as an order qualifier, or new requirements due to a change in legislation. However, the Digital Business Development Manager finds three of the listed drivers relevant to the company. First of all, the company's customers are demanding solutions that can help them to increase the Overall Equipment Effectiveness (OEE) of their machines. Such requirements have been important demand signals from which Gamma has developed new digital value propositions in addition to its physical machines (Stentoft et al., 2021).

Towards industry 4.0 and energy productivity – how to make it possible

Energy productivity is one of the benefits available from digitalization in industrial and commercial settings. In some cases, future work by the RACE 2030 CRC around energy productivity and Industry4.0 will be about motivating the integration of use cases and functions relating to energy productivity within already digitally-transformed (or transforming) business and sites. However, much more often in the present Australian context future work by RACE for 2030 in harmony with others will have to simultaneously promote energy productivity via Industry 4.0 and the actual adoption of Industry4.0 in a broader sense. That is, energy productivity and Industry4.0 adoption are interdependent, with Industry 4.0 being the broader issue, as it impacts on broader aspects of business value and productivity than does energy productivity. RACE for 2030 efforts to encourage energy productivity improvement must fit within this broader Industry 4.0 context and will need to dovetail with the already-extensive public and private sector activity that seeks to move businesses up the Industry 4.0 staircase.

For this reason, before introducing and discussing the proposed research roadmap for B2, some key factors underpinning the necessary change are explored, so to overcome barriers and motivate adoption of energy productivity improvement. While previous sections of this report have explored in detail the barriers to adoption of Industry 4.0 and energy productivity, these factors draw upon the aforementioned drivers necessary to address the barriers, trying to contextualise them and express them in the form of more concrete pathways for action. In doing so, this OA has leveraged on the extensive review plus the consultations in this project, as well as extensive experience of authors in development and implementation of programs and other studies across industry and business sectors. These factors, and actions that can influence them, often overlap, and include:

- Reframing what is possible – overcoming deep assumptions about what, how and why things are done and processes operate, and how change could open up new possibilities
- Raising the level of priority of Industry 4.0/EP relative to other business activities at a broad level, so that adequate resources will be allocated to exploring and implementing options
- Shifting the balance for decision-makers between perceptions of risk (financial, personal and organisational reputation, etc), benefits and opportunity to capture the benefits
- Identifying transition pathways for adoption of Industry 4.0/EP that provide and build on positive experiences

7.1 Reframing what is possible

Many managers and decision-makers struggle to grasp the potential for change in technological and business systems offered by Industry 4.0 Industry 4.0/EP. If someone initially perceives and stereotypes a change as impossible, very difficult, risky or a threat, they are unlikely to invest time and effort into exploring it further. This is a common situation.

Industry 4.0 as it is typically presented is BIG. It challenges existing paradigms at every level of business and production. It is abstract. Advocates describe the boundless opportunities, but many decision-makers see complexity, loss of control, consumption of scarce in-house time and resources, and high costs.

While energy is often framed as the 'engine' of development, most business energy decisions focus on narrow criteria related to reliable, low-cost supply of energy. Most energy consultants focus on energy cost savings and incremental change when making their business case. They often install expensive monitoring systems that generate large amounts of energy-related data, but this is not combined with other data streams to provide useful actionable insights that focus on highly valued business benefit. Often the outcomes are not effectively communicated to finance and broader management groups.

Businesses often treat energy as just one of several essential inputs that include capital, labour, technology and materials they use to make profits by delivering products and services valued by their customers. Indeed, they often do not grasp the significance of the roles energy plays in business success and they often assume it is an unavoidable cost. No-one wants energy for its own sake and energy is typically a small contributor to input costs. Energy efficiency measures often seem complicated technically and organisationally. So, if the only obvious benefit from saving energy is a reduction in energy costs, it faces high hurdles.

We typically see Industry 4.0 and energy productivity being treated in isolation in Australia, when they are actually interdependent. Without the right information at the right time in the right form, delivered to the right place, optimal energy productivity improvement does not occur. But Industry 4.0 relies on flexible, efficient, connected technologies, appropriate analytics and staff or automated systems to create and respond to its 'smart' messages. This separation is partly due to consumer perceptions but also due to approaches of Industry 4.0 and EP service providers. Consultation for this project showed that Industry 4.0 and EP practitioners had little awareness of what each offered, or the synergies they could potentially capture through cooperation.

Industry 4.0 has very wide applications, while productive use of energy is critical to a productive, sustainable business and economy. So, while energy productivity is a specific application of Industry 4.0, it is one with very broad but often unrecognised implications for a business or household. Energy productivity-driven monitoring and analysis unravels the fundamentals of business processes and identifies waste and potential to do things differently. Measures that improve energy productivity can transform business outcomes and models. Its pursuit provides a toolkit to deliver substantial business benefit.

Options to reframe perceptions of what is possible:

Some approaches may include:

- Starting with 'baby steps' that are tangible, offer low risk, build familiarity and demonstrate benefits, for example, installing a variable speed drive on a motor, suitable sensors and controls, with effective monitoring and alert mechanisms make it possible to consider the potential benefits of flexible operation. If these are proposed in part of a process where there is low perceived risk to production or core business there is a greater chance that they will be introduced. Assisting relevant operators and managers to utilise data to vary motor operation can demonstrate how improved data can facilitate process optimisation and identify potential for improvement.
- Iterative development of models or digital twins of processes can drive an enhanced understanding of the fundamental physics, chemistry and logistics underpinning processes. This can provide a new perspective to open up business value and opportunities. It can be useful to begin with a simple spreadsheet-based model to test assumptions about drivers and characteristics of processes, raise questions, explore 'what-if' scenarios and identify areas where increased sophistication of the model are most likely to provide useful insights. Development of a model can be seen as an exploratory journey, rather than a large commitment of resources with limited short-term benefits.
- Visits (either real or virtual) to demonstration sites provide tangible evidence of what is possible, insights into the issues that must be addressed, contact with potential service and equipment suppliers, etc.
- Personal testimonials from respected and trusted authorities, including production managers, finance managers, CEOs, educators etc. who have experienced unexpected benefits from action can be influential. The motives of many services delivery and product suppliers are often questioned, and doubt undermines trust and acceptance of their advice.

7.2 Raising priority

Decision-makers typically prioritise achieving their local KPIs within a context of their estimates of the time and resources required to achieve them when they are often under heavy pressure to maintain output and profit, with divergent interests from other major agents (Trianni et al., 2013). They also care about their reputation with peers (within and beyond the business), managers and staff, and friends and relatives.

If a manager or decision-maker in most businesses only values savings from Industry 4.0/EP in energy cost reductions and ignores the broader benefits, they will rationally see energy as a low priority, because it is a small component of input costs and is (often perceived to be) difficult to change, while making changes also involves potential risk to profits.

Factors underpinning the low priority of Industry 4.0/EP include information failures, lack of technical analysis and technological factors, trust issues, inefficient allocation of costs and benefits and organisational failures. In turn, these lead to a lack of motivation to allocate resources and act.

The challenge is to influence key decision-makers to place higher priority on Industry 4.0/EP. This must be addressed at multiple levels. First comes awareness of what is possible, as discussed earlier. Second comes creating motivation to act: this can take many forms, but must lead to a situation where a decision-maker includes the Industry 4.0/EP option in the initial short list of options being considered. Visibility of options in media and networks each decision-maker engages with is important to place it 'front-of-mind'. Access to expert input regarding costs and benefits, capacity to manage logistics and cultural aspects of transition/implementation, and confidence that market intermediaries and supply chains can deliver are important elements supporting greater likelihood of adoption.

Perception of value to each decision-maker and the overall organisation is fundamental. This relies on recognition of the value of the multiple benefits available and management of perceptions of risk, fear and threat.

Key challenges here can involve conflicting perceptions of what is important and split incentives between business cost centres and organisations in a value chain. For example, the driver of a refrigerated truck may have a KPI to save fuel. If the importance of maintaining product temperature and condition is not visible and rewarded, this KPI may be achieved by shutting down the refrigeration equipment at the expense of loss of value of the product being transported. Appropriate sensors and real time communication systems, as well as appropriately designed contracts and training can be important. They can also identify other factors such as poorly insulated trucks, inefficient cooling equipment, opportunities to reduce transport time, poor practices at loading docks, etc.

Options to raise priority

These include:

- Promotion and education campaigns targeting senior managers, consultants, supply chains, market intermediaries and consumers
- Train suitable consultants to understand and apply relevant KPIs (see earlier chapter) and identify which staff could make use of specific indicators, then train them how they could use them effectively, and how Industry 4.0/EP actions could improve them or utilise them to identify issues.
- Funded projects implemented by credible specialists (not necessarily energy or Industry 4.0 advocates) to collect, analyse and present data to support estimation and incorporation of multiple benefits into rationales for Industry 4.0/EP actions

- Introduction of appropriate standards, design, installation and training guides to build confidence
- 'Try before you buy' approaches, funding of trials (e.g. via government programs)
- Gamification (e.g. MBenefits project, 2022)
- Business culture to reward innovators, establish mechanisms that encourage change – e.g. a watching brief on innovations that reports regularly to key staff and involves them in discussions about them. Government, industry or business level awards and publicity can be important motivators.

7.3 Shifting the balance

Once Industry 4.0/EP action is on the agenda, the proposal must be shepherded through a number of decision-makers, each of whom applies different criteria and concerns. A production line worker may be concerned about job loss. A middle manager may be concerned about incurring costs or workloads without being able to recover the costs. A technical worker may fear reputational damage if the project does not work as well as expected. A CEO may be half-way through a 5-year contract, and want to look good before renegotiating a future contract. A finance manager may be expert at minimising tax and ensuring financial accountability, but have limited grasp of key technical aspects of production.

As noted earlier, an operator may not even be aware of the implications of their actions for the rest of a business or the overall value chain.

Figure 49 provides an example of the complex interactions that exist in operation of a business. These interactions occur between individual staff, business units, contractors, service providers, occupants of buildings or users of goods and services, customers and more. The reality is that implementing Industry 4.0/EP involves potentially complicated processes and effort by people who may have other priorities. Failure to engage and motivate (by positive or compliance mechanisms) just one key player can block action.

It is important to understand the drivers of behaviour and the mechanisms that can influence the behaviour of each decision-maker and service provider. Often, KPIs of one business or business unit potentially conflict with others.

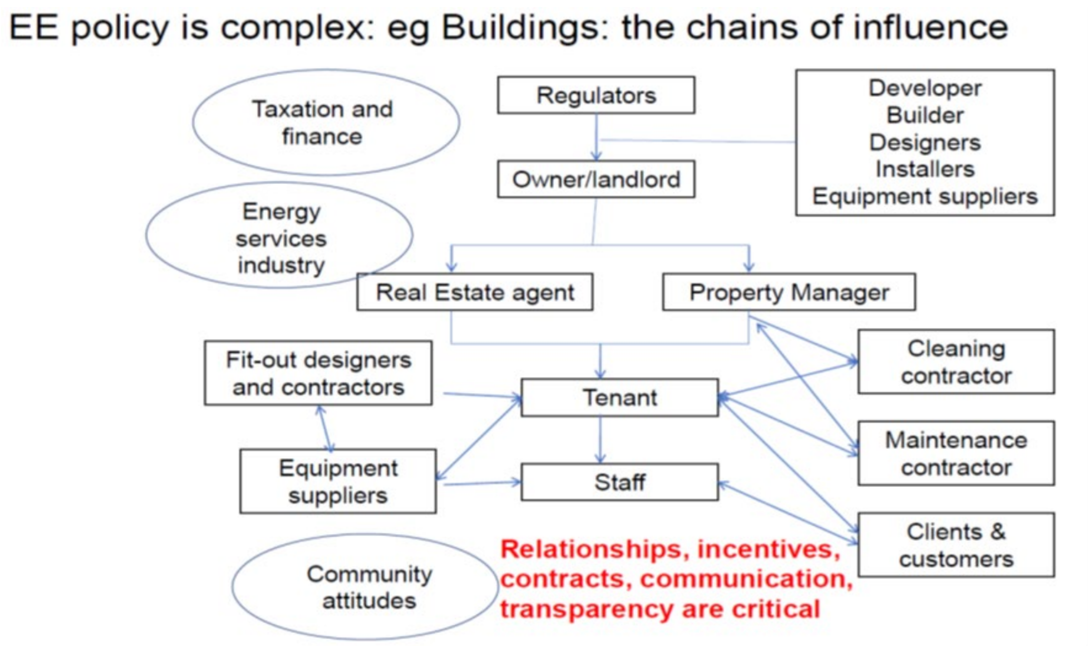


Figure 50. Influences and agents involved in operating a commercial building

Beyond the individual organisation, others in the value chain may gain windfall benefits and profits from the project without contributing. These are split incentives, where the agent that incurs the cost and effort 'loses' the benefit to another agent who captures a windfall gain. As business models evolve, improved inter-organisational allocation of costs and benefits that overcomes split incentives is increasing in importance. Emerging issues include:

- Responding to climate change: to date, most businesses have focused on Scope 1 (on-site emissions from activities the business controls) and Scope 2 (emissions from purchased electricity). However, there is increasing focus on Scope 3 emissions associated with upstream inputs and downstream impacts. Further, it is cumulative emissions over time and the concentration of greenhouse gases in the atmosphere that drive climate change and determine our global remaining carbon budget, not annual emissions. Some businesses are already working with suppliers to cut Scope 3 emissions, and promoting their product features that reduce downstream climate impacts. As organisations focus more on cumulative carbon budgets, the timing of implementation of abatement measures will gain more attention as urgency builds.
- Circular Economy models: CE relies on the 'waste' of one business being treated as an input to another business. This requires allocation of agreed value and quantities to the 'waste' and cross-business cooperation to achieve overall benefit.
- Value Chain thinking: The value chain approach is similar to supply chain models but differs in some important ways. First, it focuses on the useful service the end consumer wants (or thinks they want) and the value they attribute to it. Second, it emphasises that all the participants in the value chain rely on each other: improvements or mistakes of one participant flow through to energy, resource and operating cost and reputational impacts for all participants.
- Consumer rights and supplier accountability and provenance: consumers are increasingly demanding to be able to hold suppliers to account for sub-standard goods and services. So it is increasingly important to be able to track the provenance of goods and services along the supply chain to manage quality and allocate responsibility.

All of these trends involve a need to securely, accurately and cheaply track the attributes of materials and inputs, and support fair allocation of costs and benefits across value chain participants. Industry 4.0/EP play essential roles through data collection, analytics and communication to enable this interaction and provide the toolkit to optimise performance and avoid waste.

Options to shift the balance:

Examples of options include:

- Identify all agents that make decisions or take actions that impact on business performance, and the performance criteria and KPIs they apply to their operations. Work with them to develop improved KPIs and introduce tracking systems to achieve accountability and facilitate allocation of costs and benefits. Utilise information to support broader use of Industry 4.0/EP.
- Map out organisational flow charts to identify who influences, manages, controls and implements relevant actions, and what their criteria are. Show management why the detail of decisions, procedures, monitoring and management using Industry 4.0/EP matter to the business.
- Work with industry associations and government agencies to build greater awareness of the importance of informed and integrated action within businesses and value chains, and to develop policies and programs to enhance outcomes.

7.4 Identifying transition pathways

Development and adoption of new products and services involves time, costs, training and risk. Some consumers place higher value on some features or perceive risk differently than do others. They may be prepared to pay more, to tolerate performance shortcomings, or to accept higher risk in return for these highly valued benefits. Innovators can identify these niche markets and use them as steps towards broader markets. For example, buyers of laptop computers have accepted screen limitations, lower computing power in exchange for light weight and acceptable battery life to provide portability.

It is important for innovators to identify niches occupied by potential early adopters. Within a site, this could involve identifying 'non-core' processes or equipment, or applying an innovation where there is a back-up option that can be called upon if necessary. In most businesses, a small minority of staff and managers may be more open to innovation, while others are risk-averse.

Innovation may appeal to a new market entrant, who is seeking a 'point of difference' relative to incumbents.

Industry 4.0/EP often involves redefining how a service can be provided, so it may be suited to a business that has traditionally operated in another market, as a way of expanding.

Options to drive transition:

- Conduct analysis to identify potential niche markets and early adopters
- Develop and implement innovation strategies that offer attributes likely to appeal to early adopter niches
- Document and promote outcomes of pilot/demonstration projects through informal networks, media, conferences, seminars etc.

- Work with industry associations, governments and other influencers to build understanding and overcome barriers to change.

7.5 Research roadmap

With so many relevant businesses operating across all industrial sectors of the economy as well as in commercial real estate of varying sizes and function, the research and development activity by the RACE 2030 CRC needs to be designed for impact at scale. This means seeking impact through the numerous and diverse innovation and adoption actions of many actors, more than "with our own hands". The emphasis needs to be on work which motivates and enables one or more of:

- End-user investment in enterprise capabilities and IT/OT, Industry 4.0 and energy productivity technologies;
- Technology and business innovations by third parties, agents active in spaces relevant to Industry 4.0/EP but not involved in it;
- Changes in the standards and regulatory landscape
- Development and implementation of education, training, awareness-raising and capacity building.

Mitigation or elimination of the barriers to adoption and innovation has to be our research priority, with the responsibility for the vast majority of the technical problem-solving and change-making lying with those we inform and empower. Building understanding of the value of potential opportunities to create positive motivation is also important. With this as background, some potential activity in four areas as in the diagram below (Figure 51) have been considered.

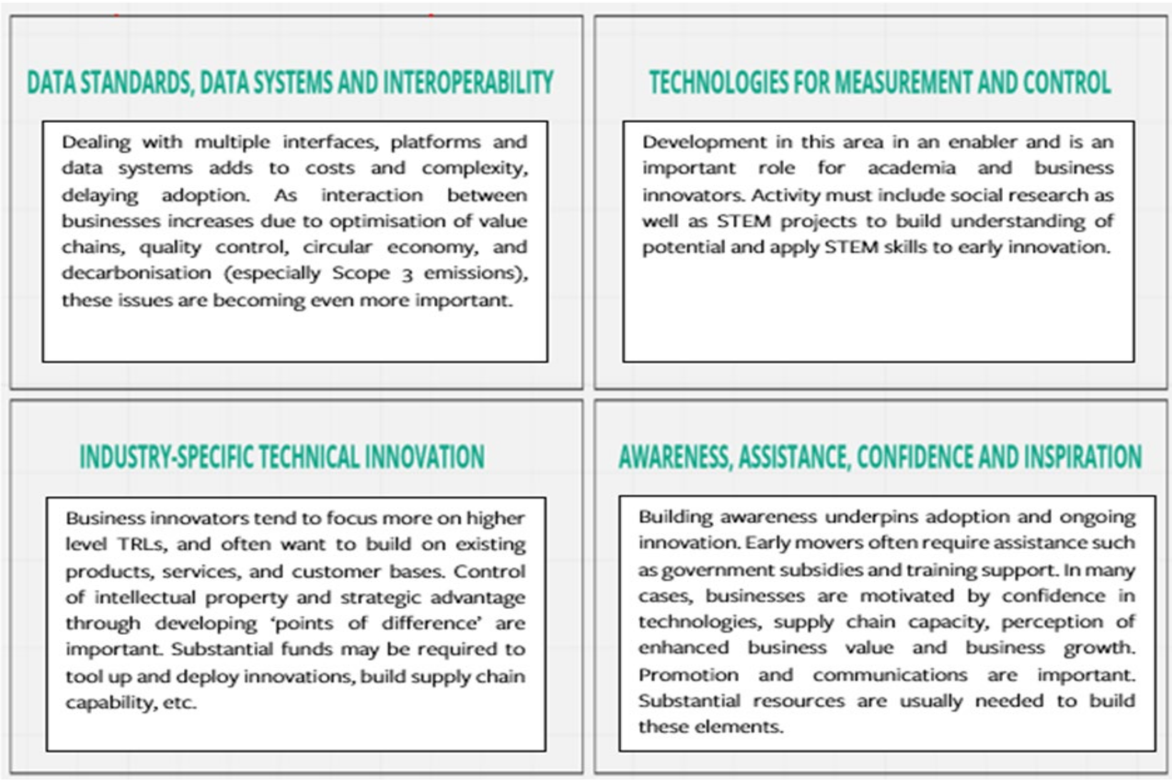


Figure 51. Possible dimension to consider for future Industry 4.0 energy productivity projects

Candidate major projects and project types have been considered within each of these, and they are organised into the proposed roadmap which follows.

Highly valuable work can be done by RACE for 2030 and its participants in each of these four areas. However, in line with the preceding reasoning around achieving impact at scale, it is proposed that the core work should be done by RACE for 2030 on the major diagonal axis in 50, that is, focussing on activities in the top-left and bottom-right areas. Such work emphasizes enablement of innovation by others.

It is important that numerous research and development projects leading to adoption of technologies for energy productivity occur in Australia. Such activity sits on the minor diagonal axis of Figure 50, that is, top-right and bottom-left areas. Based on the impact-at-scale principle, the work by the CRC should often underpin development of knowledge and methodologies to *promote and support* this activity in preference to *undertaking* this activity.

Moreover. the activity on the major axis needs to be carefully designed in scope and over time so that investments in technology developments and technology adoption are best supported. As a key example, work on data trusts and data interoperability is highly enabling for innovation by both end-users and technology developers, and so needs to be prioritized to deliver early and strongly. It is additionally relevant that the R&D resources available to the RACE for 2030 resources are chiefly academic rather than being associated with hardware/software development that will reach middle or high Technology Readiness Levels (TRL).

A major partnership with one or more sizeable technology development enterprises (public or private sector) in Australia and/or overseas will be needed to bring any given IT/OT technology to market, and very significant R&D funding will also be required if mid-high TRL is to be achieved. These partnerships are certainly attainable by RACE for 2030 and some are foreshadowed in the roadmap which follows. They are, however, less able to be planned/scheduled in a roadmap prior to the emergence of the development and commercialization partners, who will of course come to the table with independent commercial and IP positions. Along similar lines, the review of similar experiences and consultation with both the IRG, the project sponsors and a number of key stakeholders throughout the project allowed to point out that in this stream research project opportunities and priorities identified have an immediate connection to industry development opportunities.

In fact, as extensive empirical research within industrial energy efficiency has discussed, some of the initiatives that have been mentioned regarding the economic development and/or commercialisation of solutions represent effective research projects leading to valuable research outcomes (e.g., see the impact evaluation of an energy efficiency network policy programme for industrial SMEs in Sweden, (Johansson et al., 2022)). Such initiatives could well find room within RACE for 2030, thanks to the unique positioning at the intersection between tech developers, policy makers, energy consultants, system integrators and final users. Therefore, the initiatives proposed in the roadmap represent research project opportunities closely linked to industry development opportunities. Our roadmap is organised on two axes, one temporal and the other segmenting activity according to the following diagram adapted from the IEA (Figure 52).

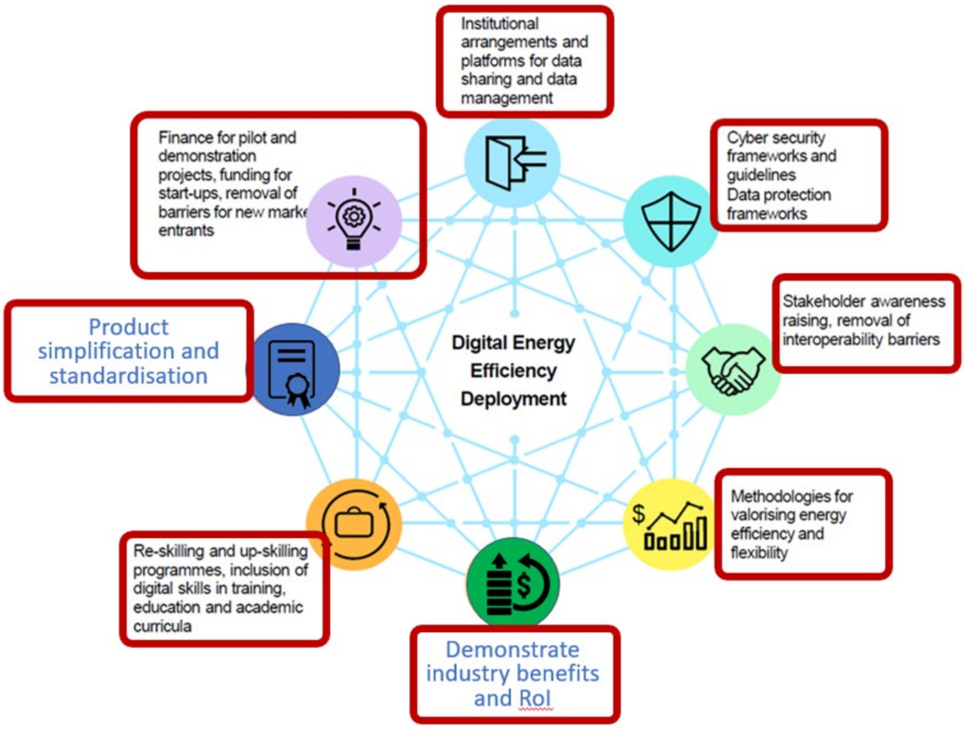


Figure 52. Strategies for Industry 4.0 energy productivity (adopted from Energy Efficiency 2021 – Analysis – IEA, 2021)

Based on the broad picture suggested by IEA, taking feedback from the project sponsors as well as meetings and interviews, the roadmap and future initiatives are planned across a number of directions. Notably, the roadmap comprises actions that industry may implement on its own, measures that require cooperative investment from business and industry, and legislative recommendations for the government to reduce market barriers and speed up transformation. It is also important to make sure that future energy productivity plans are aligned with national and state productivity, innovation, and carbon reduction goals. However, the roadmap may change as the market and technology evolve, as well as the level of success of the actions adopted. Some of the recommendations in this paper can be adopted right now, while others will require more research.

Furthermore, despite the current gap between rhetoric and reality on energy productivity, our roadmap shows that there are still many pathways and options to achieve higher energy productivity through Industry 4.0. Those on which the roadmap focuses are technically viable, cost-effective and socially acceptable. Even so, that pathway remains extremely challenging, requiring all stakeholders – governments, academia, businesses, and investors – to take action every year so that the goal of improving energy productivity does not slip out of reach.

In the following, a set of prioritised project initiatives has been put forward. Such initiatives have been developed to respond to the main areas highlighted by IEA, also highlighting the focus/targeted sectors, the key beneficiaries, the main challenges addressed and the timeframe for their implementation (short = now-2024; medium = 2024-2027, long = 2027-2030).

https://www.mbenefits.eu/static/media/uploads/site-6/library/Deliverables/d4.4-serious_game-final.pdf

Table 18. Institutions for data custodianship: Data Trusts (project 1)

Title: Institutions for Data Custodianship: Data Trusts	
Focus/target sector	Businesses that generate and use energy data
Key beneficiaries	All businesses that generate or use energy data
Main challenge/barrier addressed	Social and regulatory barriers. Establishing legally binding obligations on data custodians builds trust in data sharing.
Timeframe	Short-medium-long term
Contribution to main IEA objectives	(see below)

Contribution to main IEA objectives	Score (1-5)
Pilot & Demonstration projects	✓✓✓
Institutional arrangements and platforms for data sharing and data management	✓✓✓✓✓
Stakeholders' awareness raising and capability building	✓✓
Removal of interoperability barriers	✓✓✓✓
Methodologies for valorising Energy Productivity/Efficiency	
Cyber security framework and guidelines	✓✓✓

Main Activities	• Survey of current and proposed initiatives for imposing legal and ethical obligations on data holders, including trust-like obligations, and analysis of respective strengths and weaknesses; • Analysis of essential features of a workable data trust, including identifying areas of potential legal uncertainty and establishing appropriate accountability mechanisms; and • Statement of the rules that might apply to ethical data sharing, including legal obligations of data custodians.
Outcomes	• Map of legal obligations that apply to custodians of energy data • Final report with recommendations for legal and policy reform
Project budget	<500,000 $

Project description:

Many of the benefits of Industry 4.0 technologies for energy productivity depend upon greater sharing of data, such as power quality data. Trust in data sharing can be built by legal and institutional arrangements that ensure that those that hold data (or 'data custodians') have clearly defined obligations. Data trusts are a form of legal arrangement that can guarantee effective data custodianship.

The benefits of a traditional trust relationship include that it separates management of an asset from ownership; and ensures that the managers (the trustees) have duties to act wholly and solely for the benefit of those with rights or interests in the assets (the beneficiaries).

However, while there are clear potential benefits with data trusts, significant challenges must be addressed before this reform can be implemented in practice. The challenges include: determining the core features of data trusts, including the legal obligations of data holders; operational considerations, including building sustainable business models; technical architectures for data sharing; and the details of accountability mechanisms.

The project will build on research being undertaken internationally, including by the Global Partnership on AI (GPAI), investigating the benefits of data trusts for promoting responsible data sharing.

Table 19. Reference architecture models for Industry 4.0 interoperability in the energy sector (project 2)

<table>
<tr><th colspan="2">Title: Reference architecture models for Industry 4.0 interoperability in the energy sector</th></tr>
<tr><td>Focus/target sector</td><td>Businesses that may benefit from Industry 4.0 technologies for improved energy productivity</td></tr>
<tr><td>Key beneficiaries</td><td>Businesses implementing Industry 4.0 technologies for energy productivity</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Barriers to interoperability of Industry 4.0 technologies. A reference architecture can assist in overcoming these barriers by developing ‘rules of the road’ to allow better integration of Industry 4.0 technologies and systems.</td></tr>
<tr><td>Timeframe</td><td>Short-medium term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td>
<table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓ ✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Stakeholders’ awareness raising and capability building</td><td>✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td></td></tr>
<tr><td>Cyber security framework and guidelines</td><td>✓ ✓ ✓ ✓</td></tr>
</table>
</td></tr>
<tr><td>Main activities</td><td>

Critically analyse strengths and weaknesses of the relevant reference architectures
Map relevant technical standards to the reference architectures
Consult with industry on development of a reference architecture for Industry 4.0 technologies for energy
Make recommendations for a reference architecture to be used to interoperability in Industry 4.0 technologies for energy productivity

</td></tr>
<tr><td>Outcomes</td><td>

Report on strengths and weaknesses of existing reference architectures
Following industry consultation, report with recommendations for a reference architecture for building interoperability of Industry 4.0 technologies for energy productivity

</td></tr>
<tr><td>Project budget</td><td><500,000 $</td></tr>
</table>

Project description:

One of the main barriers to the adopting Industry 4.0 technologies is the failure of systems – cyber, physical and institutional – to interoperate. One path to overcoming this obstacle is to develop “rules of the road” to allow the components of Industry 4.0 technologies and systems to be better integrated. In recent years, various reference architecture models have been published for Industry 4.0, smart manufacturing, IoT and Industrial IoT.

A reference architecture model creates a uniform virtual representation of technical objects and can help enable more specific system architectures. System architectures provide common terminology and structure for different technological systems, which often have different nomenclatures or names. One prominent model, developed in Germany, is RAMI 4.0 (Reference Architect Model Industrie 4.0), which has subsequently become an international standard, published as IEC PAS 63088. RAMI 4.0 is a three-dimensional layered model that represents a basic architecture for Industry 4.0 using a coordinate system. In essence, RAMI is a sort of 3D map of Industry 4.0 solutions, which allows the requirements of sectors ti be plotted together with national and international standards (Gotz, 2016). RAMI is, however, not the only reference architecture model. For example, the Industrial Internet Reference Architecture (IIRA), developed by the Industrial Internet Consortium Architecture Task Group, sets out a layered common framework for system engineering. Unlike RAMI, the IIRA is aimed at supporting design and not implementation, meaning that standards are not given the same importance (Burns et al, 219). There are therefore considerable divergences between current reference architectures, including important differences between architectures for Industry 4.0 and those for Industrial IoT (IIoT).

In 2017 Standards Australia recommended developing use cases for RAMIndustry 4.0 and to contribute to the work of developing reference architecture models; and some of this work has been progressed by the Industry 4.0 Advanced Manufacturing Forum (Industry 4.0 AMF). However, to date, this work has not progressed sufficiently and there are no initiatives directed at the energy sector.

Consultations for this project will engage Standards Australia and the Industry 4.0 AMF, as well as industry groups, such as IoTAA.

Table 20. Cybersecurity frameworks & guidelines (project 3)

<table>
<tr><th colspan="2">Title: Cybersecurity frameworks & guidelines</th></tr>
<tr><td>Focus/target sector</td><td>Businesses that share energy data</td></tr>
<tr><td>Key beneficiaries</td><td>Businesses that share energy data an energy users</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Inadequate cybersecurity in the energy sector which contributes to a lack of trust</td></tr>
<tr><td>Timeframe</td><td>Medium-term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td>
<table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td></td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓✓✓✓</td></tr>
<tr><td>Stakeholders' awareness raising and capability building</td><td>✓✓✓✓✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓✓✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td></td></tr>
<tr><td>Cyber security framework and guidelines</td><td>✓✓✓✓✓</td></tr>
</table>
</td></tr>
<tr><td>Main Activities</td><td>Critically analyse cyber security laws and technical standards for energy infrastructure and energy data
Develop best practice guidance for cyber security for firms in energy sector
Make recommendations for law reform to enhance cyber security for energy infrastructure (including energy data)</td></tr>
<tr><td>Outcomes</td><td>Best practice guidance for cyber security in the energy sector
Final report incorporating recommendations for enhancing cyber security relating to energy infrastructure (including energy data</td></tr>
<tr><td>Project budget</td><td><500,000 $</td></tr>
<tr><td colspan="2">Project description:

An essential part of building trust in Industry 4.0 systems is ensuring that technical systems and data are secure. A lack of understanding of, and confidence in, cyber security is a significant barrier to Industry 4.0 adoption. This was confirmed in consultations undertaken in this project. Enhancing cyber security is an essential, but complex, pre-requisite for promoting Industry 4.0 technologies.

The overall objective of measures aimed at enhancing cybersecurity is establishing "security by design"; that is, baking security into the design of technologies and technological systems. A number of initiatives are being pursued for enhancing cyber security across the Australian economy, including recent critical infrastructure regulatory reforms. Other initiatives are aimed at building understanding among businesses about their level of cyber security preparedness. For example, DISER and AEMO have produced the voluntary Australian Energy Sector Cyber Security Framework. The purpose of the framework is to allow all market participants in the electricity, gas and liquid fuels sectors to assess, evaluate, prioritise and improve cyber security and maturity levels. The framework does this by means of assessment tools, which allow businesses to determine their cybersecurity maturity levels.

There remains an unmet need to promote greater awareness and practical understanding of cyber security and cyber security initiatives among participants in the energy sector, including businesses whose data may be shared by Industry 4.0 technologies. Moreover, there are gaps in the existing regulatory regimes, including the recent critical infrastructure reforms. This project will address these deficiencies by promoting greater understanding of cyber security and making recommendations to address gaps and weaknesses with the current regulatory regime.</td></tr>
</table>

Table 21. Defining digital ready for non-residential buildings (project 4)

<table>
<tr><th colspan="2">Title: Defining Digital Ready for Non-Residential Buildings</th></tr>
<tr><td>Focus/target sector</td><td>Non-residential buildings</td></tr>
<tr><td>Key beneficiaries</td><td>Building owners who want to de-risk investment in digitalisation technology
Electricity retailers who need to know if its cost effective to procure flexible demand services
Digitalisation technology providers who would like endorsement of their technologies</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Perceived complexity, risk and cost of establishing the requisite IT infrastructure and connectivity for implementing Industry 4.0</td></tr>
<tr><td>Timeframe</td><td>Short-medium-long term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td>
<table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Stakeholders’ awareness raising and capability building</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓ ✓ ✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓ ✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td>✓ ✓ ✓</td></tr>
</table>
</td></tr>
<tr><td>Main activities</td><td>

Work with stakeholders to define/ agree minimum digital requirements for enabling key energy productivity solutions, including

Requirements for demonstrating sufficient interoperability
Deemed to satisfy digital tools for demonstrating independent measurement and verification

Pilot digital ready requirements in case-study buildings
Investigate impacts of incorporating into relevant policy mechanisms and rating schemes.

</td></tr>
<tr><td>Outcomes</td><td>

Reduced cost of connecting buildings to energy markets
Policy opportunities for incentivising industry to adopt digitalisation and software-based energy productivity solutions
Increased deployment of energy analytics and advanced building controls
Unlock an industry with potential to save >6MT/yr CO2 and $1billion/yr energy bills
Unlock potential 1GW of flexible demand to help improve the reliability of the electricity grid

</td></tr>
<tr><td>Project budget</td><td>> $1 million for the overall research, testing and industry utilization support journey.

But this would be staged investment, contingent on success of previous stages</td></tr>
</table>

Project description:

While the property industry has high interest in energy productivity solutions, the literature and focus group research identified that they find Industry 4.0 complex and that they find it difficult to know what/how to buy relevant products and services. For example

> “The amount of technology that’s out there, and the methods that you can apply, is multifaceted in perpetuity; there’s always something new coming out, and it’s hard to actually benchmark the different solutions against each other” – Facilities Manager

> “how smart is smart I guess it’s like it’s, you know what I mean? Does having a BMS call yourself a smart building or do you need to have, you know, full Internet of things, and all these sensors, analytics software and so on” – Building Owner

> “who’s governing this technology and am I the building owner responsible for it? And then how do I make sure that the actual outcomes are achieved? Because you’ve got to orchestrate a lot of parties together within the organisation as well as the various service providers” – Facilities Manager

Not surprisingly then, industry stakeholders asked for better standards, guidelines and product requirements definitions to create more certainty and to de-risk investments.

The Property industry is well used to ratings and certification schemes such as NABERS, GreenStar and GRESB, which have traditionally been the main lever for driving adoption of environmental sustainability goals. In this way, various ‘Smart

Building' rating systems have been identified which could provide the necessary guidance. However, these have not yet seen significant adoption in the Australian Property Industry. This project looks to support such schemes with informed guidance on how to deliver energy productivity outcomes utilising Industry 4.0 technology.

The project proposes the need for some standardised way of defining 'digital ready' in a manner sufficient to drive energy productivity adoption, and in a way that could be incorporated into existing or new rating/certification schemes.

The digital ready definition would provide a means for consolidating information and providing guidance on solutions that address key barriers such as cybersecurity, data privacy and interoperability. It would also provide performance-based guidance on Industry 4.0 technologies that can streamline data-exchange and relevant Measurement and Verification processes.

The project would conduct research and engagement work, with industry stakeholders, to define/agree minimum digital requirements for achieving 'digital ready' status. The selected requirements would be piloted in different building typologies and use-case scenarios, in order to determine the effort and the practicality of the proposed definitions.

Subject to the technical success of the research, and the efficacy of the research outputs, the project would further investigate potential utilization avenues. For example, one possible utilisation pathway for a 'digital ready' definition is in the various state based white certificate schemes. Consultation on a possible EMIS (digitalization) activity in the Victorian Energy Upgrades program suggested the need for

"A register of approved products"

"Definitions of the energy saving features that EMIS and ASO products should be required to have"

Clarity on any "hybrid deemed/measurement approach for calculating incentives"

Digital ready definitions could underpin these needs.

Table 22. Industry 4.0 energy productivity networks-sharing knowledge to improve competitiveness (project 5)

Title: Industry 4.0 Energy Productivity Networks – sharing knowledge to improve competitiveness	
Focus/target sector	Manufacturing sector
Key beneficiaries	Key decision-makers of companies operating in clusters within manufacturing sector
Main challenge/barrier addressed	Awareness and lack of skills
Timeframe	Medium-long term
Contribution to main IEA objectives	**Contribution to main IEA objectives** / **Score (1-5)** Pilot & Demonstration projects: ✓✓✓✓ Institutional arrangements and platforms for data sharing and data management: ✓✓ Stakeholders' awareness raising and capability building: ✓✓✓✓✓ Removal of interoperability barriers: ✓✓✓ Methodologies for valorising Energy Productivity/Efficiency: ✓✓ Cyber security framework and guidelines:
Main activities	• Joining industry 4.0 energy efficiency networks • Implementation of industry 4.0 energy audits and development of future action plans (individuals and for the network) • Networking and shared learnings among participant companies
Outcomes	• Adoption of industry 4.0 smart metering for energy productivity in clusters of companies (depending on number of companies involved) • Energy productivity improvements implemented into companies (with likely 10-20% savings) • Improved awareness over final users and decision-makers (depending on number of companies involved)
Project budget	500,000 -1million $ or over (depending on number of companies involved)

Contribution to main IEA objectives	Score (1-5)
Pilot & Demonstration projects	✓✓✓✓
Institutional arrangements and platforms for data sharing and data management	✓✓
Stakeholders' awareness raising and capability building	✓✓✓✓✓
Removal of interoperability barriers	✓✓✓
Methodologies for valorising Energy Productivity/Efficiency	✓✓
Cyber security framework and guidelines	

Project description:

The Australian Industry 4.0 Energy Productivity network aims at developing an Australian-based energy productivity network program for manufacturing SMEs.

Each network (usually 10-15 companies) is led by a network coordinator and assigned to an energy expert, providing individual and group consultancy with respect to energy efficiency and industry 4.0 deployment.

Companies conduct an energy audit and construct an action plan for the subsequent 5 years. After completing the project, companies should be equipped to address energy efficiency thanks to the implementation of industry 4.0 technologies, in a systematic manner.

The project has 4 phases: (i) An initial phase where companies become network members. (ii) Then energy audits take place and companies develop energy policies, action plans and individual goals, beside network common goals.

(iii) A third phase (networking) will have companies joining meetings and individual/group training, plus support on funding applications. (iv) The assessment phase will review action plans and reduced energy consumption thanks to the implementation of industry 4.0 solutions.

After the implementation of industry 4.0 energy audits, 50 companies will be selected to finance industry 4.0 improvement actions identified in the previous phase (selection will be done based on several KPIs such as innovativeness, energy saved, replicability/value added for Australia, improved competitiveness etc.)

Table 23. Smart metering for industry decarbonisation (project 6)

Title: Smart metering and Artificial Intelligence for industry decarbonisation	
Focus/target sector	Manufacturing sector
Key beneficiaries	Key decision-makers of companies operating in various manufacturing sectors
Main challenge/barrier addressed	Lack of awareness
Timeframe	Short-medium term
Contribution to main IEA objectives	**Contribution to main IEA objectives** — **Score (1-5)** Pilot & Demonstration projects — ✓ ✓ ✓ ✓ ✓ Institutional arrangements and platforms for data sharing and data management — ✓ ✓ Stakeholders' awareness raising and capability building — ✓ ✓ ✓ ✓ Removal of interoperability barriers — ✓ ✓ ✓ Methodologies for valorising Energy Productivity/Efficiency — ✓ ✓ ✓ ✓ Cyber security framework and guidelines —
Main activities	• Selection of prioritised industry clusters for impact • Cluster analysis of the improved performance thanks to smart metering implementation • Dissemination of the findings
Outcomes	• 80-100 companies providing empirical evidence over the improved performance thanks to the adoption of smart metering systems • Identification of the highest priority clusters for improved energy productivity thanks to smart metering implementation
Project budget	500,000 -1million $ and over (depending on the number of companies involved, and in partnership with State programmes, e.g., NSW DPE programme on metering and monitoring systems for businesses)

Project description:

A crucial component for the expansion of circular economy practices is industry 4.0 and digitalisation. In particular, thanks to the adoption of digital technology and IoT devices for energy productivity, additional savings in other resources may be achieved, thus favouring a transition to circular systems. Key benefits for firms are represented by reduced energy use in industrial operations, save on logistical routes, and reduced GHG emissions. Therefore, industry 4.0 technologies are claimed to be a key component towards industrial sustainable development. Among others, smart metering and artificial intelligence are widely acknowledged to have a great potential for this transition. However, the effective understanding of how much smart metering and AI can positively affect the adoption of industry decarbonisation practices is still far from being determined, with a lack of empirical knowledge.

In synergy with other programmes under development, this project aims to deploy smart metering and the use of AI across manufacturing industries and monitor its contribution to the adoption of circular economy practices. The project is structured in 4 phases:

Phase 1 – Industry clusters for impact. The project will select 4-5 clusters based on its relevance for Australian economy and decarbonisation, spanning across several sectors (*i.e.* within manufacturing, both energy intensive and non-energy intensive ones). Companies operating in the selected clusters may apply through an EOI process for the implementation of smart meters in production. It is envisaged to get 8-10 companies per cluster. A selection process of the best representative companies will be run.

Phase 2 - Pilot demonstration. Selected companies will implement smart meters and monitor energy and other resources in production, thanks to the support provided by AI, with the use of available platforms. Support to companies by research institutions will be provided with coaching and specific training in collecting, monitoring, analysing, and data processing for improved decision-making. A report per company will be generated with indication of the savings achieved (thanks to the implementation of smart metering) and improved decision-making.

Phase 3 – Cluster analysis. Companies will be analysed by clusters to identify the most promising areas for the promotion and implementation of smart metering and AI on a broader scale in industrial SMEs.

Phase 4 – Dissemination and policy for broader impact Results from the pilot activities will be disseminated and policy for broader impact will be established and discussed.

Table 24. Australian smart energy SMEs – from energy audits to an integrated approach (project 7)

<table>
<tr><th colspan="2">Title: Australian Smart Energy SMEs – from industry 4.0 energy audits to an integrated approach</th></tr>
<tr><td>Focus/target sector</td><td>Manufacturing sector</td></tr>
<tr><td>Key beneficiaries</td><td>Key decision-makers of companies operating in various manufacturing sectors.</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Lack of awareness / Energy auditors</td></tr>
<tr><td>Timeframe</td><td>Medium-long term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td>
<table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓ ✓ ✓</td></tr>
<tr><td>Stakeholders’ awareness raising and capability building</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓ ✓ ✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td></td></tr>
</table>
</td></tr>
<tr><td>Main activities</td><td>• Analysis and scouting of companies
• Implementation of industry 4.0 energy audits by qualified and certified experts
• Selection of most effective energy productivity measures and related techno-economic feasibility studies</td></tr>
<tr><td>Outcomes</td><td>• Industry 4.0 energy audits implemented in 200 Australian manufacturing SMEs
• 1,800-2,000 energy productivity measures recommended for consideration
• 50 techno-economic feasibility studies published on RACE for 2030 portal with energy productivity performance</td></tr>
<tr><td>Project budget</td><td>500,000 -1million $ or above (depending on the number of companies involved)</td></tr>
<tr><td colspan="2">Project description:

The Australia Smart Energy SMEs aims at starting a virtuous and innovative programme to support and coach businesses aimed at the improvement of their energy productivity and competitiveness. The programme leverages on the deployment of industry 4.0 solutions that, over 3 years, will call for the development of future initiatives for funding and involvement of tech and services suppliers.

The first of these initiatives will consider the support of 200 energy audit in Australian manufacturing SMEs that will represent the starting point for assessing the opportunities in the implementation of industry 4.0 solutions for energy productivity.

SMEs could have their energy audit through a list of qualified professionals (according to ISO 50001 series) that will express their interest, plus other competent experts with proven expertise and track record of collaboration in the field of industry 4.0 for energy productivity (e.g., certified experts from EEC). The expression of interest will remain open throughout the whole project.

After the implementation of industry 4.0 energy audits, 50 companies will be selected to finance detailed techno-economic feasibility studies over the adoption of industry 4.0 improvement actions identified in the previous phase (selection will be done based on several KPIs such as innovativeness, energy saved, replicability/value added for Australia, improved competitiveness etc.). The selected activities will also pay particular attention on the integration and synergies with productivity data. After an assessment of those feasibility studies, companies can apply to support in financing relevant industry 4.0 equipment for the improvement of energy productivity and competitiveness (within RACE for 2030 or outside).</td></tr>
</table>

Table 25. Optimising energy productivity and consumable lifetime in machining process (project 8)

<table>
<tr><th colspan="2">Title: Optimising energy productivity and consumable lifetime in machining processes</th></tr>
<tr><td>Focus/target sector</td><td>Manufacturing sector</td></tr>
<tr><td>Key beneficiaries</td><td>Manufacturers, Consumers (lower cost)</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>1) Inadequate Infrastructure
2) Uncertainty about ROI
3) Resistance to Change</td></tr>
<tr><td>Timeframe</td><td>Short-Medium term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td><table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓✓✓✓✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td></td></tr>
<tr><td>Stakeholders’ awareness raising and capability building</td><td>✓✓✓✓✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓✓✓✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓✓✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td></td></tr>
</table></td></tr>
<tr><td>Main activities</td><td>• Identify production data relevant to energy productivity
• Create strategy to capture, transmit, process, and visualise the data using Industry 4.0 technologies
• Provide suggestions in operating and tuning manufacturing machinery in real-time to yield higher energy productivity</td></tr>
<tr><td>Outcomes</td><td>• Best practices in identifying and capturing data for measuring energy productivity
• Cases studies and analyses on improving energy productivity using real-time production data with decision support/AI systems.</td></tr>
<tr><td>Project budget</td><td>100,000 -300,000 or above</td></tr>
<tr><td colspan="2">Project description:

Grinding machines, aka grinders, are common power tools used in metalworking. Its key component, the grinding wheel, is generally made of composite materials. Grinding wheels are consumables, which will wear along its lifespan. The duration of the lifespan can vary significantly depending on the speed of the motor (RPM), the dimensions of the wheel itself, and the characteristics of the composite material. The lifespan of the wheel can be extended by lowering the RPM, which could, however, impose negative impacts on productivity. The problem becomes more challenging when considering the energy efficiency of the motor when driving the wheel at different speed and with different loading. This project will investigate the nonlinear relationship among consumable lifetime, energy efficiency, and productivity in grinding and other machining processes. Real-time information will be collected continuously using industry 4.0 sensing systems. The data will then be processed using AI to determine the optimal machining parameters adaptively without human intervention.</td></tr>
</table>

Table 26. Optimising energy productivity of HVAC system (project 9)

<table>
<tr><th colspan="2">Title: Optimising energy productivity of HVAC Systems – Energy Consumption, Air Quality, and Comfort</th></tr>
<tr><td>Focus/target sector</td><td>Building Management</td></tr>
<tr><td>Key beneficiaries</td><td>Building Managers, HVAC Plant Operators, Occupants</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>1) Inadequate Infrastructure
2) Uncertainty about ROI
3) Resistance to Change
4) Inadequate Information</td></tr>
<tr><td>Timeframe</td><td>Short-medium term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td>
<table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓ ✓ ✓</td></tr>
<tr><td>Stakeholders' awareness raising and capability building</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓ ✓ ✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td></td></tr>
</table>
</td></tr>
<tr><td>Main activities</td><td>• Identify indoor air quality (IAQ) data relevant to energy productivity of HVAC systems
• Create strategy to capture, transmit, process, and visualise the data using Industry 4.0 technologies
• Provide suggestions in operating and tuning HVAC systems in real-time to yield higher energy productivity and response to changes in IAQ.</td></tr>
<tr><td>Outcomes</td><td>• Key IAQ that are relevant to energy productivity of HVAC systems
• Controllers for improving energy productivity of HVAC systems using real-time IAQ data with decision support/AI systems.</td></tr>
<tr><td>Project budget</td><td>100,000 -300,000 or above</td></tr>
<tr><td colspan="2">Project description:

In modern HVAC systems, sensors have been used to capture ambient parameters, which form a feedback loop for the HVAC system to control the indoor temperature at a desired level while keeping a relatively low energy consumption. While existing systems are effective in regulating temperature and sometimes as well as humidity, other indoor air quality (IAQ) measurements, like CO¬2, PM, air flows etc., however, have often been omitted. These IAQ measurements can have significant impacts on the subjective comfort level of the occupants, which could have direct effect on their productivity (e.g. sick leaves due to poor IAQ). In this project, indoor IAQ sensor networks will be deployed to capture all those missing variables. The variables will then be used to study the indoor ventilation and air exchange level using Computational Fluid Dynamics (CFD) modelling. They will also be used to obtain Predicted Mean Vote (PMV) values which are good representations of the subjective comfort levels of the occupants. All the information will then be used for developing an AI-based HVAC controller for solving this multi-objective optimisation problem.</td></tr>
</table>

Table 27. Overcome or bypass barriers to real time smart data collection due to limited meter capability (project 10)

<table>
<tr><th colspan="2">Title: Overcome or bypass barriers to real time smart data collection due to limited meter capability, reduce M&V cost</th></tr>
<tr><td>Focus/target sector</td><td>Manufacturing and non-residential buildings with potential, based on outcomes, to expand to other sectors including energy consumers in all sectors with limited metering and monitoring of electricity, gas and/or water.
Government operators and delivery agents of M&V for white certificate programs</td></tr>
<tr><td>Key beneficiaries</td><td>Industry 4.0, EP businesses and their clients, white certificate program operators, Third party energy service providers, energy auditors, water authorities, energy retailers and network operators</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Limited numbers of smart meters (for electricity, gas and water) and high up-front Monitoring & Verification costs are major barriers to adoption of Industry 4.0 and Energy Productivity measures</td></tr>
<tr><td>Timeframe</td><td>Short-medium term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td><table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓ ✓</td></tr>
<tr><td>Stakeholders' awareness raising and capability building</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓ ✓ ✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td></td></tr>
</table></td></tr>
<tr><td>Main activities</td><td><u>Develop specifications for devices</u>
Manufacture prototypes, develop methods of utilising the data they will produce and trial pilot technology and business models
Engage with potential businesses that can utilise the technologies and business models</td></tr>
<tr><td>Outcomes</td><td>Prove practicality of monitoring solution
Through engagement, key organisations adopt and utilise monitoring technologies and associated analytics to enhance consumer energy productivity.</td></tr>
<tr><td>Project budget</td><td>500,000 -1million $</td></tr>
</table>

Project description:

The slow roll-out of smart meters and sub-metering is a bottleneck impacting application of data analytics, adoption of Industry 4.0 and capture of business value through energy productivity improvement. Further, enhancement of data analytics, including utilisation of multiple data streams (e.g. weather, production data, maintenance and other business activity indicators), as well as maximum use of inferential techniques with existing limited data, is needed. Techniques to maximise useful insights from existing limited metering and data are important preliminary steps to designing and implementing successful energy productivity improvement strategies. High upfront costs combined with lack of demonstrated business benefits are barriers that must be overcome. As government programs such as Victorian Energy Upgrades and NSW Energy Saving Scheme evolve to focus more on delivered outcomes, reducing M&V costs, increasing useful outcomes and accelerating improvements in provision of actionable insights that offer business value will underpin adoption rates. This initiative will drive development and trial application of relevant approaches.

Table 28. Development of strategies to assist early-stage adoption of basic Industry 4.0/ EP measures in compressed air (project 11)

<table>
<tr><th colspan="2">Title: Develop strategies to assist early-stage adoption of basic Industry 4.0/ EP measures and trial in Compressed Air across selected sites</th></tr>
<tr><td>Focus/target sector</td><td>Businesses using existing inflexible equipment and inefficient technologies that are unable to respond to real time data to optimise performance, have high standby losses, etc, and who still focus on narrow consideration of EP in terms of energy savings (not multiple benefits) and short payback periods (instead of attractive rates of return on investment)</td></tr>
<tr><td>Key beneficiaries</td><td>Accelerate adoption of Industry 4.0/EP across business; help i4.0/EP service providers to identify ways of overcoming major barriers identified in this project</td></tr>
<tr><td>Main challenge/barrier addressed</td><td>Compressed air is used widely throughout industry and uses 10-15% of site electricity with high (80+%) losses and impacting on business productivity</td></tr>
<tr><td>Timeframe</td><td>Short term</td></tr>
<tr><td>Contribution to main IEA objectives</td><td><table>
<tr><th>Contribution to main IEA objectives</th><th>Score (1-5)</th></tr>
<tr><td>Pilot & Demonstration projects</td><td>✓ ✓ ✓ ✓ ✓</td></tr>
<tr><td>Institutional arrangements and platforms for data sharing and data management</td><td>✓</td></tr>
<tr><td>Stakeholders' awareness raising and capability building</td><td>✓ ✓ ✓ ✓</td></tr>
<tr><td>Removal of interoperability barriers</td><td>✓</td></tr>
<tr><td>Methodologies for valorising Energy Productivity/Efficiency</td><td>✓ ✓ ✓</td></tr>
<tr><td>Cyber security framework and guidelines</td><td></td></tr>
</table></td></tr>
<tr><td>Main Activities</td><td>Identify suitable existing smart, flexible electric products to replace key services now provided by compressed air, and sites where their installation would allow part or all of a compressed air system to be replaced and the hosts are prepared to participate in trial
Carry out installations and monitoring, documenting energy savings, productivity improvements and any other benefits
Engage with manufacturers, government agencies, media etc to promote outcomes of project and assist them to build on experiences to replace CAS across businesses</td></tr>
<tr><td>Outcomes</td><td>Demonstrate benefits of replacing Compressed Air equipment and systems across manufacturing sector
Use this to build awareness, confidence to apply Industry 4.0 in a wider range of situations to deliver energy productivity improvement and associated benefits</td></tr>
<tr><td>Project budget</td><td>500,000 -1million $</td></tr>
<tr><td colspan="2">Project description:

Consultation and research have demonstrated that many Australian businesses are at very early stages in adoption of Industry 4.0 solutions, especially regarding energy productivity. Energy efficiency consultants have limited understanding of Industry 4.0 potential, while Industry 4.0 providers have had limited focus on energy productivity as a value adding opportunity. This initiative aims to identify low risk, high value opportunities to apply Industry 4.0/EP to facilities with inflexible, inefficient technologies, focusing on Compressed air systems (CAS). CAS has been selected as a target area based on lessons from a recent NSW pilot program involving assessments of over 100 sites and potential to work with sites from this program. CAS consumed around 15% of site electricity and assessments typically identified 50% savings with rapid paybacks, while a report identified numerous electric alternatives that could deliver much greater energy productivity benefits by introducing Industry 4.0 solutions along with providing broader business benefits.</td></tr>
</table>

7.6 Conclusions

This research roadmap is structured according to six strategic focus areas, or pillars, that are highly integrated. Each pillar serves RACE for 2030's work of creating the ground for and accelerating the deployment of industry 4.0 solutions for energy productivity in industry and non-residential buildings, for transformative performance, energy productivity, and sustainability of all Australian businesses. The proposed roadmap provides an overview of initiatives to be implemented from now to 2030 to support and facilitate the market transformation. Most of the activities are designed to be seeding actions that will induce, stimulate and nurture market transformation towards improved energy productivity and sustainability of businesses.

The proposed roadmap spans across the major IEA suggestions as outlined in Figure 52. Particular attention has been given to the identifying and involving key agents or taking actions with significant impact on business performance, as well as developing clear methodologies, criteria and KPIs to point out the major impacts stemming from the adoption of industry 4.0 solutions for energy productivity. Further, the documentation and promotion of outcomes of pilot/demonstration projects, through several potential avenues (either networks, or media, or seminars, round tables etc.) represent another crucial pathway to drive the transition to a more sustainable industry 4.0 for energy productivity economy. However, such actions would have a limited impact without the development of clear guidelines, frameworks and platforms for data protection, sharing and data management.

Table 29. Proposed projects and their focused dimensions

Project Number	Criteria					
	G. Pilot	H. Arrangements	I. Stakeholders	J. Barriers	K. Methods	L. Cyber
1	✓✓✓	✓✓✓✓✓	✓✓	✓✓✓✓		✓✓✓
2	✓✓	✓✓✓✓	✓✓✓	✓✓✓✓✓		✓✓✓✓
3		✓✓✓✓	✓✓✓✓✓	✓✓✓		✓✓✓✓✓
4	✓	✓✓✓✓	✓✓✓✓	✓✓✓	✓✓	✓✓✓
5	✓✓✓✓	✓✓	✓✓✓✓✓	✓✓✓	✓✓	
6	✓✓✓✓✓	✓✓	✓✓✓✓	✓✓✓	✓✓✓✓	
7	✓✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓	✓✓✓✓✓	
8	✓✓✓✓✓		✓✓✓✓✓	✓✓✓✓	✓✓✓	
9	✓✓✓✓✓	✓✓✓	✓✓✓✓✓	✓✓✓✓	✓✓✓	
10	✓✓✓✓✓	✓✓	✓✓✓✓✓	✓✓✓	✓✓✓✓	
11	✓✓✓✓✓	✓	✓✓✓✓	✓	✓✓✓	

Within the scoring matrix of Table 28, the metric is from 1-5. Detailed description of each criteria is:

G. Pilot & Demonstration projects
H. Institutional arrangements and platforms for data sharing and data management
I. Stakeholders' awareness raising and capability building
J. Removal of interoperability barriers
K. Methodologies for valorising Energy Productivity/Efficiency
L. Cyber security framework and guidelines

Additional initiatives that may follow could be more related to understanding more effective business models to promote Industry 4.0 solutions for energy productivity, as highlighted in Chapter 4. In particular, the market for Industry 4.0-related services, exploiting potential synergies outside the strict "energy productivity" domain, appear as crucial to exploit the potential. In this regard, we see that the potential of Industry 4.0 for energy productivity could make a substantial contribution towards the 20-50% potential productivity improvements in businesses suggested by most recent reports.

Furthermore, it is important to remark the need to increase skills and competences across several agents operating in the energy productivity value chain, such as e.g., decision-makers in industry (plant managers, energy managers, etc.), energy and industry 4.0 consultants, vendors etc. This is of course in synergy with other training programmes as highlighted by other Opportunity Assessments (OA) in RACE (e.g., RACE for Everyone, E3 OA – Developing the future energy workforce). Indeed, training programs to stimulate the uptake of industry 4.0 solutions for energy productivity should aim at increasing skills and competences around the elicitation and quantification of the benefits stemming from the adoption of i4.0 solutions, with a focus of integrating such solutions within the core industrial operations.

Finally, it should be noted that industry 4.0 and energy productivity are still in early days, with significant effort required to capture their full potential. Therefore, it will be important for RACE for 2030 to run a process to inform broad audiences about the outcomes of the B2 project, and build public interest commitment (e.g., governments, business organisations, universities) to encourage practical implementation.

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Appendix

Appendix 1: National Benefit Potential

An initial coarse-level assessment was made of the size of the energy productivity opportunity, that could be obtained through the widespread adoption of digitalisation across the Australian non-residential property sector. The assessment was based on the energy productivity benefits (energy savings and demand shifting) that are typically achieved in buildings using the various energy productivity use-cases/applications. The benefits were scaled across the national building stock.

These calculations incorporate several assumptions and datasets taken principally from the Commercial Building Baseline Study (Strategy Policy Research, 2022) and from previous analysis. The key assumptions made for the analysis are as follows.

1. The existing building stock in terms of gross floor area and energy consumption is taken from the CBBS FY2020 values in Tables 77 and Tables 86 respectively (Strategy Policy Research, 2022). From these, 6 building typologies were selected for analysis based on perceived potential for digitalisation; (i) Retail and wholesale trade buildings, (ii) Offices, (iii) Education buildings, (iv) Health facilities incl. aged care (v) Entertainment and recreation buildings and (vi) Short term accommodation buildings.
2. Buildings were classified as either small or large. Small buildings were considered as buildings with an area less than 10,000m2.
    a. The proportion of existing buildings gross floor area attributable to small and large buildings as described above was provided as a supplementary information by Strategy Policy Research, 2022. They found that 38.7% of existing buildings gross floor area is small buildings, and the remaining 61.3% of gross floor area is large buildings.
    b. Large buildings are deemed to have a BMS and be capable of 'Deep Tuning', while small buildings are deemed to have potential for simple IoT connectivity only, with relatively limited 'Simple Tuning' technology levers for energy productivity improvements.
    c. Values for energy savings potential are based on a combination of DeltaQ experience and the results of Kramer et al (2020) and were taken to be 10% and 20% of site energy consumption for the simple and deep tuning scenarios respectively.
3. The cost to apply Simple or Deep Tuning includes both the establishment cost for the Energy Management Information System (EMIS) and the cost of performing rectification works to improve settings in the control systems. Rectification works includes consulting labour, to consolidate and communicate requirements, and contract labour from BMS contractors responsible for maintaining the control systems. Costs are based on a combination of DeltaQ experience and the findings of Kramer et al (2020). The values used in the national potential assessment are:
    a. EMIS Cost
        i. Deep Tuning - \$0.9/m² for Year 1 installation decreasing to \$0.3/m² for annualised software subscription cost
        ii. Simple Tuning - \$0.75/m2 for Year 1 installation decreasing to \$0.5/m2 for annualised software subscription cost
    b. Rectification Cost

i. Deep Tuning - $2/m2 for Year 1 decreasing to $1/m2 for later years when tuning is in maintenance mode

ii. Simple Tuning - $4/m2 for Year 1 decreasing to $0.8/m2 for later years when tuning is in maintenance mode

4. A discount rate of 7% per year is applied across a 10-year period.

5. Energy savings from digitalisation and controls tuning are likely to be obtained progressively as time-series data is collected and trends are identified. The energy savings model therefore assumes that energy savings improve steadily over the first three years after installation of the EMIS, before remaining steady at the final savings level indicated in 2c.

6. The electricity and gas cost are a flat rate of $48.6/MJ and $20.85/MJ respectively.

7. Building electricity and gas usage proportion are estimated based on historical building-related energy consumption from the Commercial Building Baseline Study (Strategy Policy Research, 2022). The average proportion across all states is 86% electricity usage and 14% gas usage.

8. A fixed flexible demand benefit of $0.3 billion per year is taken from the RACE for 2030 Flexible Demand and Demand Control Opportunity Assessment report (Brinsmead et al, 2021). This is apportioned between small and large buildings based on relative energy savings.

9. The HVAC energy usage of a building is considered as 50% of the building's total energy consumption. Values are based on engineering estimates. HVAC energy consumption for each of the selected building typologies is then based on the respective floor area and energy intensity from Strategy Policy Research, 2022 (Figure 5.1).

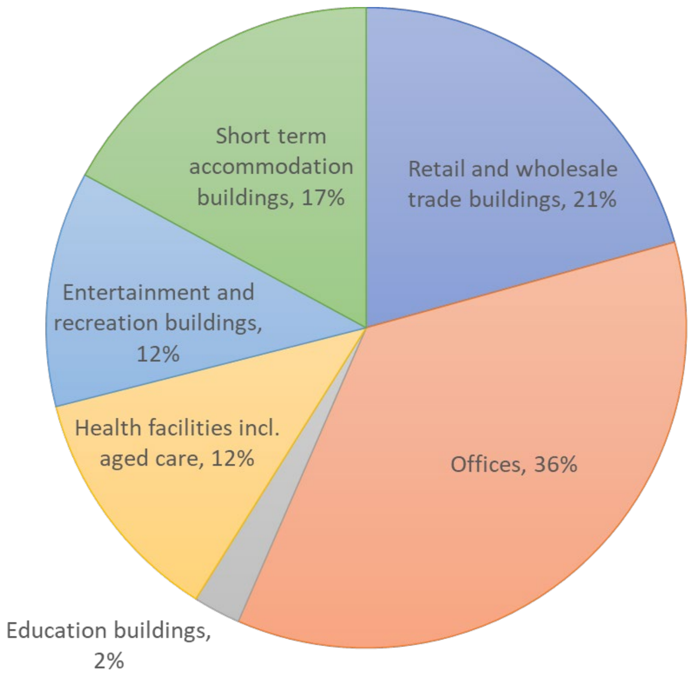

Figure 5.1: Fraction of HVAC energy usage attributed to each of the relevant non-residential building typologies with potential for digitisation

Results

Ten-year discounted costs and energy savings potential for small and large buildings are detailed in Table 5.1 and Table 5.2 respectively. The overall opportunity is summarised in Table 5.3.

Table 5.1: Energy savings and required investment over ten years, in small buildings for each of the selected building typologies

BUILDING TYPOLOGY	ENERGY SAVINGS (TJ)	ENERGY COST SAVINGS ($MILLION)	EQUIPMENT AND LABOUR COSTS ($MILLION)
Retail and wholesale trade buildings	18,050	$563	$375
Offices	31,266	$976	$804
Education buildings	2,086	$65	$146
Health facilities incl. aged care	10,564	$330	$146
Entertainment and recreation buildings	10,359	$323	$352
Short term accommodation buildings	14,896	$465	$261
Total	**87,222**	**$2,722**	**$2,084**

Table 5.2: Energy savings and required investment over ten years, in large buildings for each of the selected building typologies

BUILDING TYPOLOGY	ENERGY SAVINGS (TJ)	ENERGY COST SAVINGS ($MILLION)	EQUIPMENT AND LABOUR COSTS ($MILLION)
Retail and wholesale trade buildings	58,976	$1,858	$532
Offices	102,156	$3,218	$1,141
Education buildings	6,814	$215	$207
Health facilities incl. aged care	34,517	$1,087	$207
Entertainment and recreation buildings	33,848	$1,066	$499
Short term accommodation buildings	48,672	$1,533	$371
Total	**284,984**	**$8,977**	**$2,956**

Table 5.3: Summary of the economic potential for energy productivity gains through digitalisation of non-residential buildings over ten years at a discount rate of 7%

	$MILLION
Small building energy cost savings	$2,722
Large building energy cost savings	$8,977

	$MILLION
Flexible demand cost savings	$1,955
Total	**$13,654**
Small building implementation costs	$2,084
Large building implementation costs	$2,956
Total	**$5,040**
Benefit to cost ratio	2.71
Energy savings	372,000 TJ
Carbon emissions savings	66 MT CO_2-e

Larger buildings (with opportunity for deep tuning) yield higher savings than that of smaller buildings (limited to simple tuning only). Larger buildings have lower cost per unit of floor area than smaller buildings, due to economies of scale. This is in spite of the more detailed scope of work that is required to achieve deep tuning, compared with simple tuning.

As a direct result of the coarse level assumptions, the buildings with higher energy intensity (MJ/m^2) yield concomitantly higher energy savings intensity – while the area normalised costs are fixed. This leads to higher benefit to cost ratios for those building typologies with high energy intensity (healthcare and accommodation).

With low energy intensity, schools appear to be relatively poor targets. Despite this, schools may be an attractive target for flexible demand opportunities due to the greater tolerance of occupants, relating to control of comfort conditions in classrooms.

The International Energy Agency (IEA) *Sustainable Recovery* report (July 2020) found that energy efficiency in buildings is a particularly attractive target for jobs, creating 10-15 jobs for every million dollars invested (Figure 5.2: Construction and manufacturing jobs created per million dollars of capital investment and spending by measure. (Source: IEA-World Energy Outlook Special Report Sustainable Recovery, July 2020. Figure 2.1, page 40)

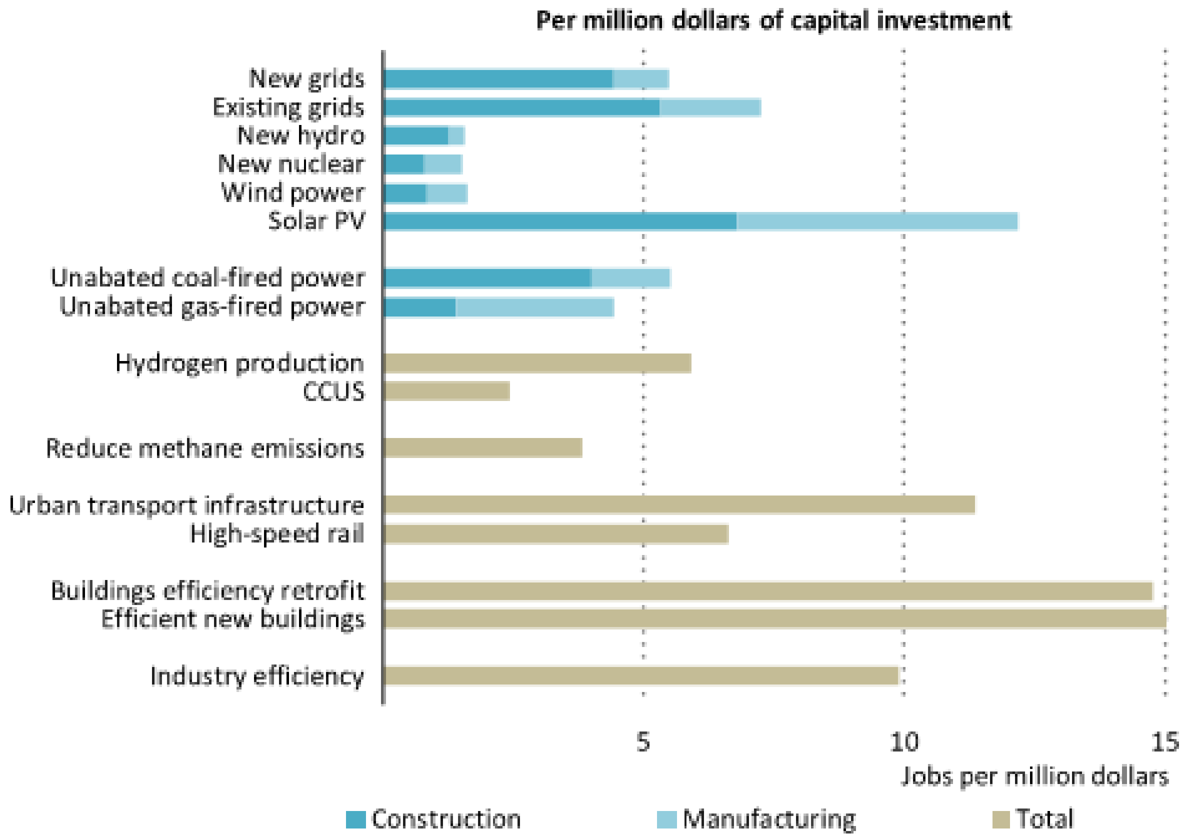

Figure 5.2: Construction and manufacturing jobs created per million dollars of capital investment and spending by measure. (Source: IEA-World Energy Outlook Special Report Sustainable Recovery, July 2020. Figure 2.1, page 40)

Based on these job creation rates, there is opportunity to stimulate around 70,000 job-years across the non-residential buildings sector.

The results of this coarse level technical potential analysis are summarised below, in terms of the outcomes and economic benefits over 10 years, at a 7% discount rate.

372 TJ energy saved	**$13.7 billion in energy cost saved**	**66 Mega-Tonnes carbon emissions saved**	**$5 billion invested**	**Delivering 2.7 times more benefit than cost**	**Creating 70,000 job-years**

It should be noted that the benefits above relate only to Energy Productivity aspects of digitalisation. The financial value of other benefits are potentially much greater. To illustrate the relative scale of benefits, Research and Markets (2021) claim that the 'smart buildings' market was worth USD66.3 billion in 2020 (growing at 10.5% CAGR), of which Harbor Research (2020) claim the 'integrated building energy management' market segment was worth USD1.01 billion – suggesting a 60 times multiplier between energy services and the broader smart buildings market, that could be tapped.

Report at a glance

What is the report about?

This opportunity assessment report explores the various benefits, barriers, regulation, and business models currently available for Industry 4.0 technologies. Industry 4.0 technologies aim to improve energy productivity within industry I.e., the ability to shift part or whole [industrial] energy usage to times of the day when it is either/both cheaper and more economical with renewable energy sources. Given the complexity of Industry 4.0 technical features (Artificial Intelligence (AI), sensors, big data & analytics, Internet of Things (IoT)), the breadth of analysis this report provides insights into how to unlock future potential by leveraging benefits and overcoming barriers to this technological transition.

Why is it important?

This report serves as the crucial introduction of a new wave of technological innovation. Industry 4.0 has the potential to drive innovative new practices for businesses resulting in improvements to equipment effectiveness, labour effectiveness, quality, flexibility, and resource efficiency. In the same way mobile phone technology revolutionised the way society communicated with each other; Industry 4.0 is expected to drive behaviour change and benefit businesses across different sectors and business segments. Ensuring a smooth implementation of this will strengthen business competitiveness in global markets, while reducing the demand for expensive excess infrastructure.

What did we do?

The project team analysed the current climate surrounding Industry 4.0 technologies. This included a comprehensive review of the key issues, like data concerns, barriers to adoption, productivity benefits, the regulatory framework, business models, and a roadmap to Industry 4.0 energy productivity.

What difference will it make?

This project has estimated cumulative figures that the possible impacts of Industry 4.0 technologies include:

Gross energy savings of $1.1B by 2030-31 and $2.4B by 2034-35, and Emissions reductions of 5.9 Mt CO_2e by 2030-31 and 12.9 Mt CO_2e by 2034-35.

Broadly, energy efficiency can boost economic and social development, improve energy system sustainability, contribute to environmental sustainability, and boost wealth in general.

What's next?

The following recommended actions are outcomes of this report:

1. Implement the proposed research roadmap (projected from now to 2030),
2. Promote discussion focusing on technologies or projects targeting a specific sector within the Australian business context to help industrial stakeholders see where the value is for Industry 4.0 in their own business contexts, and
3. Work towards reducing barriers around Industry 4.0 technological adoption; including the development of guidelines, frameworks, and platforms for safe data storage, sharing, and data management.

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