WHAT'S BEHIND DISTRIBUTED ENERGY?

QIC GLOBAL INFRASTRUCTURE

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TABLE OF CONTENTS

SUMMARY

In our 2016 Red Paper *'Technology disruptions affecting infrastructure'* we highlighted households, businesses and industries are progressing towards an era where they are no longer reliant on supply from centralised, capital-intensive, electricity systems. We noted users are set to become providers of energy generation and storage capacity, and that doing so is likely to undermine the traditional electricity generation and distribution model.

Continuing trends in distributed solar and energy storage are validating this thesis. The dramatic decline in the cost of solar panels – now at just US$0.75 per watt (W) today, which is 1% of the price in 1977[1] – is fuelling a significant increase in the installation of new solar generation capacity. In the United States (U.S.), over 30% of this capacity relates to distributed residential, community and commercial and industrial (C&I) segments.[2] This is combined with a significant reduction in battery costs, which are down to less than US$230 per kilowatt-hour (kWh), compared to almost US$1,000 per kWh in 2010.[3]

Remote and off-grid generation assets are also becoming increasingly efficient, with greater scope for customisation and modularity, leading to changes in regional markets where there is less reliance on the centralised system. The public push for environmental sustainability has manifested in the growing adoption of renewable energy, low carbon technologies and waste-to-energy projects, all of which disrupt the traditional energy value chain.

Users are now shifting away from their traditional position as end consumers at the end of the electricity value chain, to become active participants. Now, they are capable of generating, storing and dispatching their own power through distributed energy assets or generating energy without reliance on traditional centralised systems.

Distributed energy is an emerging infrastructure sub-sector which is forecast to double by 2026 from its current 94 gigawatt (GW) of installed capacity.[4] It is gathering momentum through the convergence of several major underlying trends including technological innovation, environmental sustainability, customer empowerment and regulatory evolution. These trends, which are headwinds for traditional, centralised and capital-intensive energy systems, are tailwinds for decentralised distributed energy infrastructure.

The more attractive distributed energy investment opportunities we believe are those with embedded operating and growth capabilities within a platform structure, as this maximises value capture across asset creation and optimisation. Beyond this essential feature, infrastructure investors are likely to also be attracted to business models which apply innovative and sustainable technologies to address specific customer needs. In addition, those opportunities which operate in markets where there is scope for significant growth, ideally across multiple markets, as well as economies of scale, will also appeal. In these instances, building a platform requires efficient capital deployment into small-scale assets, which in turn requires experienced management with specialist expertise.

Distributed energy assets, we believe, are key to delivering essential, sustainable and cost-effective energy services to consumers into the future. However, investing in this sector requires an understanding of existing energy systems, the regulatory regimes applying and the technological, social and political forces shaping its current evolution. Active infrastructure investors able to respond to the increasingly dynamic energy environment have the opportunity to lead the growth of distributed energy platforms and their important effect on the energy system of the future.

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[1] Babbage Blog (2013, October 28). *Cell a Million?* Retrieved from The Economist: https://www.economist.com/babbage/2013/10/28/cell-a-million

[2] Solar Energy Industries Association. (2019, June 18). *U.S. Solar Market Insight* . Retrieved from Solar Energy Industries Association: https://www.seia.org/us-solar-market-insight

[3] Frankel, D., & Wagner, A. (2017, June). *Battery storage: The next disruptive technology in the power sector*. Retrieved from McKinsey & Company: https://www.mckinsey.com/business-functions/sustainability/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector

[4] GE Power. (2018). *The Digital Energy Transformation.* Retrieved from General Electric: https://www.ge.com/content/dam/gepower-pw/global/en_US/documents/hybrid/des/GE_Digital_Transformation.PDF

1 MEGATRENDS DRIVING DISTRIBUTED ENERGY

The times are changing for infrastructure. For decades, communities relied on large, centralised, government-financed structures to deliver essential services, either through natural or regulated monopolies. Today, many infrastructure sub-sectors are transitioning towards decentralised models of delivery, and no more so than in the energy space.

Energy assets are being disrupted by this decentralisation trend resulting in a transformation in the way our economy will be powered. Large-scale, fossil fuel power stations, which have historically sustained the energy system, are being replaced by distributed energy systems, which have an increasing renewables component. Concurrently, national transmission and distribution networks are increasingly being challenged by the emergence of micro-grids. The four key megatrends shaping the evolution of the energy system are:

Figure 1: Megatrends driving distributed energy

These megatrends are combining to increase the risk profile of assets across the traditional, carbon intensive and centralised energy system as they struggle to compete with, and accommodate, assets that are smaller in scale, distributed in configuration, renewable in resource and smarter in application. The changing methods and patterns of generation, distribution and consumption of energy are however creating new opportunities for both investors and consumers.

1.1 Technological innovation and improving economics

Technological innovation is disrupting the energy industry at the micro level. This trend is particularly manifesting in smaller and more modular power generation such as solar panels and hybrid systems. These are improving economics/costs through the combined forces of increased generating efficiencies and reduced unit costs from more advanced manufacturing techniques, resulting also in economies of scale being realised. In the past when solar panels were more expensive, the benefit of distributed energy, such as customisation, network flexibility and resilience, was often outweighed by the exorbitant costs. However, the price of solar panels has decreased dramatically. In the U.S., solar panels are just US$0.75 per W today, which is just 1% of the price in 1977.[5]

In addition, advances in associated technologies – such as enhanced software capabilities that analyse and control distributed assets – have contributed to the efficient deployment of a broad range of distributed generation assets. These advances have also reduced costs including: sensors which monitor asset condition and generation performance; batteries to store electricity; and engines used in higher-capacity hybrid systems.

In 2017, distributed energy technology had an installed capacity of 94 GW. With the installed capacity of these technologies expected to double by 2026, the annual average growth rate of capacity from distributed energy technologies is forecast to be 7.7% between 2017 and 2026.[6]

Further, distributed generation projects generating less than one megawatt (MW) of power are expected to displace the need for 300-350 GW of new, large-scale power plants globally between 2017 and 2023.[7]

What is a Hybrid System?

A Hybrid System combines more than one technology to produce power. Generally, this refers to a combination of a renewable technology combined with a traditional fossil powered technology. An example of this is the combination of a gas or diesel-fired reciprocating engine with solar panels. The benefit of Hybrid Systems is that they combine the renewable and cost-effective power generation attributes of solar, while making the system dispatchable and therefore reliable.

Attribute	Solar	Engine	Solar + Engine “Hybrid System”
Renewable	✓	×	~
Free Fuel	✓	×	~
Dispatchable	×	✓	✓

[5] Babbage Blog (2013, October 28). *Cell a Million?* Retrieved from The Economist: https://www.economist.com/babbage/2013/10/28/cell-a-million

[6] GE Power. (2018). *The Digital Energy Transformation.* General Electric.

[7] Vrins, J. (2015). *Distributed Energy Resources: Lead or Follow.* Navigant Consulting Inc.

1.2 Environmental sustainability

Recent decades have seen a growing social consciousness regarding responsible human interaction with the environment, specifically those long-term sustainable activities which avoid the degradation of natural resources. This trend towards greater environmental sustainability presents real financial risks and opportunities for infrastructure investors. It is also forcing the market to revisit the current system and devise more sustainable and flexible energy generation, production and distribution modes. There are two key implications of environmental sustainability for the energy industry: the increased need for system resiliency and decarbonisation through increased renewable energy.

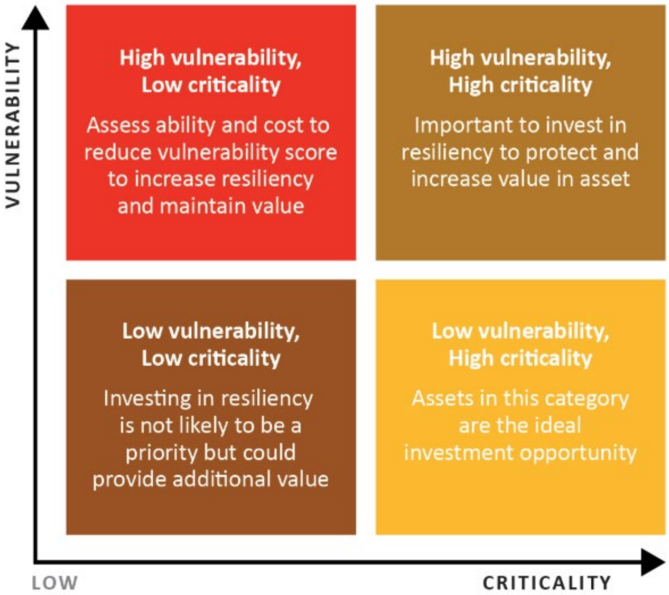
1.2.1 Increased need for resiliency

In our 2017 Red Paper, *'Climate change: Building resilience in infrastructure'*[8] we revealed an analytical framework to assess climate risks in an infrastructure context, based on the physical vulnerability of assets to extreme weather and the criticality of service delivery regarding the assets' reliability.

From this framework, we identified distributed energy as an attractive investment opportunity due to its high criticality, particularly in relation to its off-grid settings, and its low vulnerability due to the diversification provided by the network deployment model, limited dependence on distribution infrastructure and the flexibility provided by modular assets.

The modularity of distributed generation assets allows for efficient replacement of equipment should it be damaged by climate events. For example, residents of Puerto Rico lost electricity for 11 months after 2017's hurricane Maria destroyed the main transmission and distribution lines. Puerto Rico is rebuilding its electricity grid by dividing the island into eight different, small-scale grids to increase the system's resiliency.

Figure 2: Vulnerability and Critical Matrix for assessing climate risk[9]



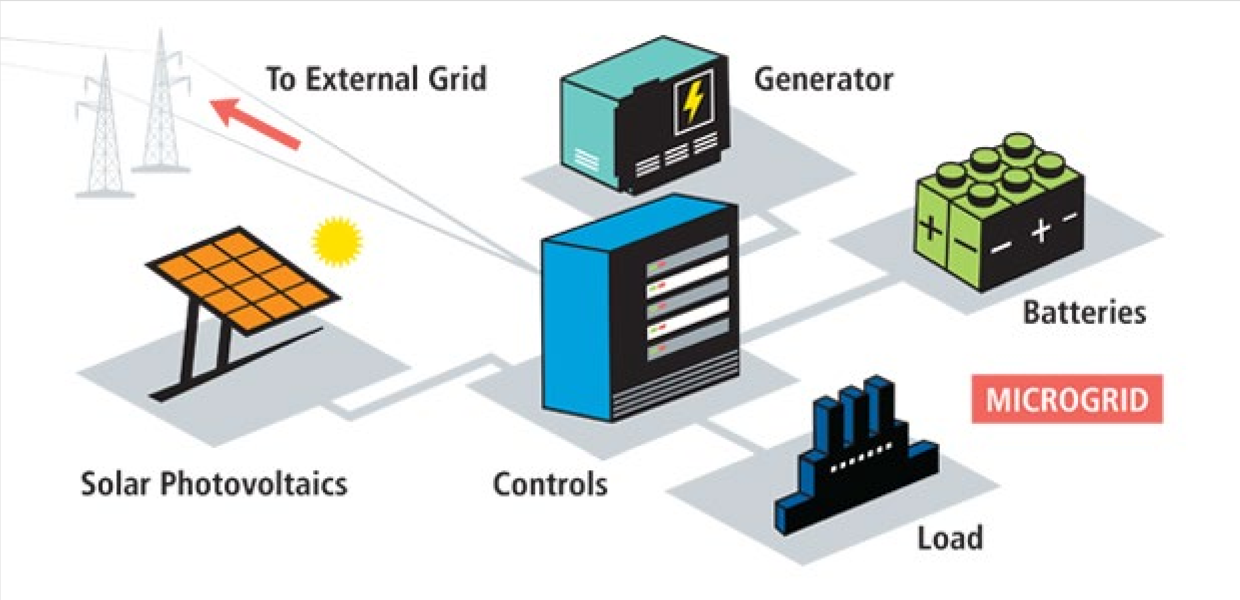
[8] QIC. (2017). *Climate change: building resilience in infrastructure assets*

[9] QIC. (2017). *Climate change: building resilience in infrastructure assets*

At the residential level, an increasing number of customers are pairing residential solar with batteries that can provide backup power. Those who want the peace of mind that their home can operate through a short black or brown-out can now afford to do so given the decreasing costs of the technologies. Commercial and industrial companies generally seek similar outcomes through larger reciprocating engines or microgrids. Hospitals and other essential service providers such as telecommunications companies also install backup generators to ensure power is supplied during blackouts.

What is a Microgrid?

A Microgrid is a group of distributed electricity sources and a single set of controls that can operate either in parallel with the broader electricity grid or disconnect and operate in isolation from the broader grid. The generation technologies do not necessarily have to be renewable, and historically almost always included fossil powered technologies to ensure the system had enough resiliency and ability to operate at all times. With the evolution of battery storage technologies to store more electricity for longer periods of time, more microgrids are appearing using renewable only technologies, such as solar and storage. The benefits of microgrids are that they provide resiliency for when the broader electricity system is down; they allow customers to control power generation if the customer desires increased renewables; they allow for greater transparency into the price of future electricity costs; and in certain situations, they can be a cost effective alternative when compared to purchasing electricity from the grid.



1.2.2 Decarbonisation through renewable energy

There are a range of highly-modular distributed generation assets which are benefitting from the increased emphasis placed on renewable energy and energy efficiency initiatives across government, households and industry.

Building upon the established popularity of residential solar installations in the U.S. is “community solar”. This is another budding distributed generation industry that allows homeowners to sign-up and purchase solar energy from a small-scale and collective local solar installation.

In the C&I space, distributed cogeneration plants use excess heat from burning oil or gas to heat buildings or use in industrial processes. Currently, the most efficient centralised combined cycle gas turbine plant can produce a total efficiency of 62%, while cogeneration efficiencies can reach 80% due to their use of waste heat. This increased total efficiency means less overall fossil fuels are burned.

Climate change: The focus on a transition to a low carbon economy

In December 2015, the world took a significant step forward with 197 countries signing the Paris Agreement. Through this agreement there was recognition that global warming of 1.5°C would lead to severe consequences. Therefore, action to reduce CO2 emissions should be anchored at limiting global warming to 1.5°C or well below 2°C. This requires achieving zero net emissions by no later than 2050.

Last year, the Intergovernmental Panel on Climate Change (IPCC) delivered a special report – *Global Warming of 1.5°C* [10] – on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. The below is a short summary of the report's findings, which highlight how climate change is driving an increased focus on low carbon and emissions reduction technologies.

Understanding the impact of Global Warming of 1.5°C

i. Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate (estimated with high confidence).
ii. Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (estimated with high confidence), but these emissions alone are unlikely to cause global warming of 1.5°C (estimated with medium confidence).
iii. Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C. These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (estimated with high confidence).

Emission Pathways and System Transitions Consistent with 1.5°C Global Warming

Pathways limiting global warming to 1.5°C with no or limited overshoot would require rapid and far-reaching transitions in energy, land, urban and infrastructure (including transport and buildings), and industrial systems (estimated with high confidence). These systems' transitions are unprecedented in terms of scale, but not necessarily in terms of speed, and imply deep emissions reductions in all sectors, a wide portfolio of mitigation options and a significant upscaling of investments in those options (estimated with medium confidence).

QIC has undertaken scenario analysis to assess and understand the impact of transition risk for its various infrastructure assets under a 1.5°C, 2.0°C and 4.0°C scenarios consistent with the methodology for the Task Force for Climate Related Disclosures.

In addition, across a number of QIC portfolio assets, there is an increased focus on installing renewable generation and energy efficiency activities with targets for emissions reduction. For example, Brisbane Airport installed 6MW of Solar PV with a target to install up to 10MW by 2025.

[10] The Intergovernmental Panel on Climate Change (IPCC) (2018) "Global Warming of 1.5°C". Accessed from IPCC: https://www.ipcc.ch/sr15/

1.3 Customer empowerment

The role of the electricity consumer is evolving. In our 2016 Red Paper *'Technology disruptions affecting infrastructure'* we noted users are set to become producers of energy and providers of energy storage services - a movement likely to undermine the traditional, centralised, generation model.[11]

Recent trends are validating this thesis, as distributed energy is empowering customers, enabling them to shift away from their traditional position at the end of the electricity value chain, to a position of greater control where they generate and store their own power through distributed energy assets such as solar panels and battery storage.

Generating their own electricity also allows them to have greater visibility over long-term electricity costs and plan accordingly. For example, households in the U.S. have options to enter into 20-year fixed price contracts, rather than paying the prevailing utility rate. Further, software enabled services, such as "demand response", grant consumers an additional layer of control. When paired with smart household appliances, and even electric vehicles, software can enable consumers to change their electricity consumption and battery storage behaviour in real time and in response to energy market dynamics.

1.4 Regulatory and policy risks

Globally, policies which promote power generation and storage at consumer nodes are emerging. Policies such as "Net Metering", which allows electricity consumers with behind the meter generation systems such as roof top solar panels, to only pay for the net electricity drawn from the grid (net of any electricity dispatched into the grid). This policy materially enhances the economic benefits of distributed generation. Similar policies such as "Feed-in Tariff" programs which compensate consumers for electricity dispatched into the grid at pre-agreed rates, also supports economic benefits while creating a transparent and more flexible framework for adopting distributed energy systems.

Just as regulatory reforms incentivise the transition to distributed generation, increasing regulatory risks to centralised generators and large-scale transmission and distribution networks, are accelerating the trend. Key headwinds for centralised generation include policy uncertainty about revenue structure and low carbon initiatives against a backdrop of political interference in the operation of energy markets. Electricity grids face regulatory risks from customer tariff structures and the method and adequacy of cost recovery which is associated with investments necessary to accommodate increasing intermittent generation. In recent years, regulated networks have also suffered from increased scrutiny on cost and return on capital allowances.

The defining features of distributed energy assets notably mitigate, and in some cases benefit from, the policy and regulatory risks facing centralised energy system assets. The small-scale and modular deployment of distributed energy assets allows them to be accurately positioned for customer value maximisation, reducing the reliance on macro policy trends and energy pricing models that centralised assets require. Distributed energy assets and energy storage also benefit from decarbonisation policy trends as they are typically based on renewable energy. The low capital intensity of distributed energy assets also improves diversification of policy and regulatory risks as portfolios of assets can be spread across location, regulatory framework, energy market, technology and even government jurisdictions. The smarter and more flexible operation of distributed energy assets also makes them well suited for a dynamic energy system and policies valuing responsiveness.

[11] https://www.qic.com/knowledge-centre/technology-disruptions-affecting-infrastructure-20160414

Case Study: Regulatory risk in the transmission and distribution (T&D) sector

Regulatory and policy risks are particularly evident in the T&D segment of the market. In Germany, there has been a significant build out of utility-scale renewable projects in the northern part of the country due to generous subsidy programs. However, there is lack of regulatory and public support to build the required transmission to transport the energy to the load centres in the south. Similarly, in the U.S., while there was a major build-out of transmission lines in the 1960s, transmission has been difficult to build due to increased regulatory requirements. The charts below show this trend in Australia, where capital expenditure for transmission network expansion has declined (Figure 3) alongside the return on transmission assets allowed by the regulator (Figure 4). This is despite sustained construction of centralised renewable energy generation in Australia, which is creating challenges with respect to grid connection and transmission congestion for these projects.

Figure 3: Australian historic transmission CAPEX by driver (A$m)[12]

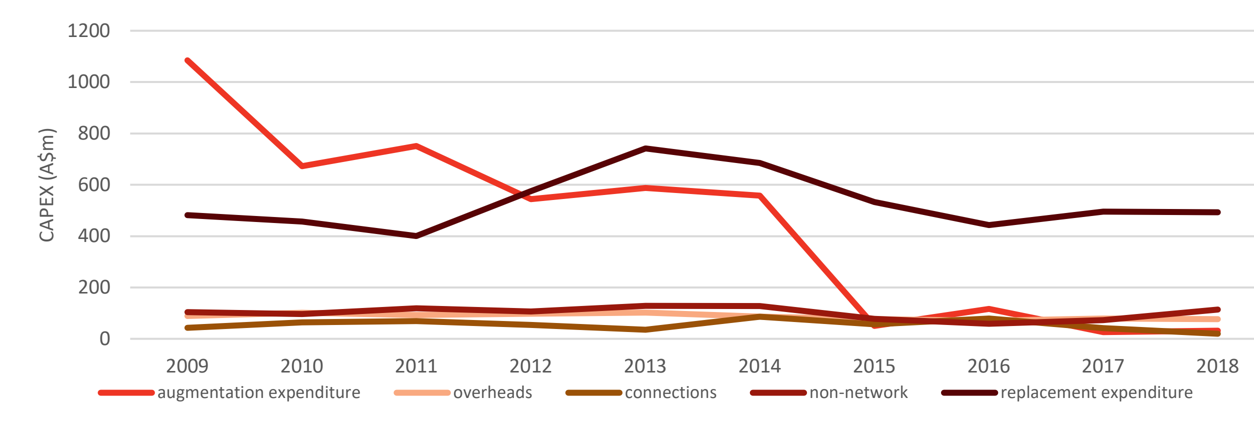
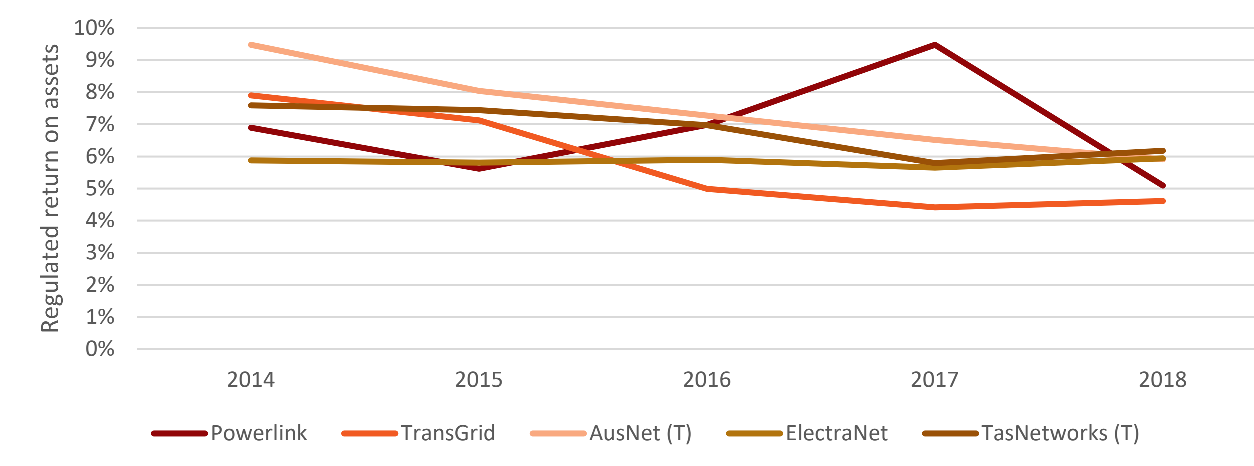


Figure 3: Australian regulated return on transmission assets including incentive scheme rewards and penalties (EBIT/RAB)[13]



[12] Transmission Performance Data 2006-2017. Accessed from Australian Energy Regulator: https://www.aer.gov.au/networks-pipelines/network-performance/transmission-performance-data-2006-2017

[13] ibid

2 DEFINING THE DISTRIBUTED ENERGY OPPORTUNITY

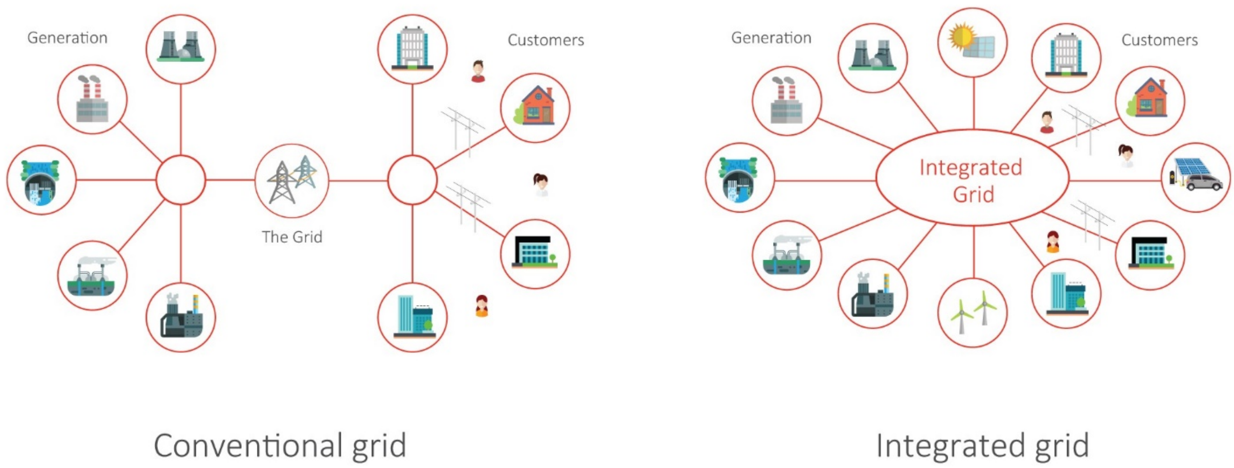
2.1 Opportunities along the energy spectrum

We expect the current transition in the energy system will result in investment opportunities for infrastructure investors across all segments of the energy supply chain. In particular, there are attractive opportunities in distributed generation, network adaptation (e.g. battery storage), energy efficiency technologies and customer-led sustainability initiatives.

GENERATION	TRANSMISSION & DISTRIBUTION	CONVERSION & STORAGE	CONSUMPTION
The identified megatrends are driving the shift towards more efficient, flexible, cleaner and more resilient power generation. Distributed generation is an alternative way of deploying assets to utilise existing fuel sources in a more efficient, cost-effective and reliable way. This in turn improves the quality and reduces the cost of energy supply to consumers. The key opportunities in distributed generation currently include distributed solar deployment and remote generation solutions.	Distributed generation generally requires less investment in transmission and distribution infrastructure due to co-location of electricity generation and consumption. However, the transition to distributed generation may require stronger distribution lines and wider bandwidths in some regions. Crucially, the distribution network was historically unidirectional, and will need to technically evolve to accommodate bi-directional electricity flow as distributed generation assets come online. This will also require increased asset management tools and new safety regulations to manage power flows.	Energy storage systems can be deployed and managed via distributed network models to overcome the intermittency of increasingly widespread renewable generation. While electrochemical energy storage systems are currently experiencing significant growth, hydrogen- based energy storage also presents a potential alternative investment opportunity.	Networked devices such as smart grids are allowing real-time monitoring and demand response management, while consumer preferences are also driving the rapid adoption of more sustainable technologies. The key opportunities for investors in this space relate to the deployment of energy efficiency technologies and energy-from-waste assets.

2.2 Distributed Generation

Distributed generation networks are based on localised, small-scale generation assets such as solar power, reciprocating engines or small gas turbines. Distributed generation networks are expected to be the primary enabler of the energy system of the future, due to their ability to leverage emerging physical and digital technologies to optimise network outcomes for communities. By leveraging two-way network flows, energy storage solutions and data analytics software, distributed generation networks can be used to dynamically scale load and generation to improve network efficiency and resilience.



Source: Peterson, S. (2015, April 30)

CONVENTIONAL APPROACH

- Expensive
- Large-scale
- Monolithic/inflexible
- Long lead times
- Government contractors
- Regulation risk
- Single fuel source
- One-way flow
- Carbon intensive

VS

NEW PARADIGM

- Cheap and efficient
- Distributed
- Modular
- Quick construction
- Private contractors
- Resilient to failures
- Combines energy
- Hybrid network
- Carbon neutral and renewable

Figure 5: The generation and distribution of distributed energy networks[14]

[14] GE Power. (2018).

2.2.1 Distributed solar generation

Distributed solar is growing rapidly in developed markets. This year, the U.S. will install 13 GW of new solar generation capacity, up 25% from 2018.[15] Of this figure, approximately 4 GW is distributed, which is comprised of the residential, community, and Commercial and Industrial (C&I) segments. This figure is forecast to increase by 50%, to 6GW per year, by 2024. In Australia, almost two million Australian households and businesses have installed rooftop solar PV systems.[16]

Residential solar

In the U.S., the residential solar market has grown at a pace of over 2GW per year since 2015.[17] Regulations vary within each state and have been a major driver towards determining where residential solar makes sense; historically states such as California, Massachusetts, and New Jersey have had the most favourable regulations. As the market in those states saturate, states such as Florida, South Carolina, and Texas have had favourable rule changes that will support growth. As panel prices and the soft costs of installation fall, the potential market continues to grow.

Community solar

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[15] Solar Energy Industries Association (SEIA). (2019, June 18). *U.S. Solar Market Insight* . Retrieved from Solar Energy Industries Association: https://www.seia.org/us-solar-market-insight

[16] Australian Energy Regulator. (2018). *State of the Energy Market 2018.* Canberra: Australian Competition and Consumer Commission.

[17] SEIA. (2019, June 18).

Community solar is a commercial model that replicates the effect of rooftop solar PV generation for consumers who physically do not have (or are unable to have) rooftop PV systems. Small local installations of around ~1MW sign-up residential subscriptions that purchase a percentage of the total capacity. The primary benefit is that by building larger installations, the costs of the plant are up to 50% cheaper than the costs of installing comparable capacity on individual rooftops. The structure also overcomes physical barriers to distributed solar generation (apartment residents, roof top orientation, shade, rooftop footprint size etc). The main drawback is that these installations are highly structured transactions with bespoke rules varying between each state, and therefore achieving scale can be challenging.

C&I Solar

Any facility with a large roof, ground area, or car park may be a suitable candidate for distributed solar generation. This includes shopping malls, hospitals, schools and universities. Similar to community solar, C&I solar benefits from lower installation costs than residential solar but is also hampered by the complexities associated with customised deployment according to unique site and customer characteristics. In the U.S., the combined C&I solar and Community solar markets have been growing at just over 2GW per year since 2015, the majority of which is C&I.[18]

2.2.2 Remote and off-grid generation

Off-grid generation assets are small-scale reciprocating engines or turbines, utilising gas, diesel or renewable energy (or a combination) to provide reliable energy in situations where grid-connection is uneconomic or unreliable.

Driven by the development of new technologies, off-grid generation assets are becoming increasingly efficient, with greater scope for customisation and modularity. This modularity is key for unlocking the benefits of network scale for investors, as it increases scope for redeployment of generation assets to alternative sites as needed to optimise network operations. This scope for redeployment in turn unlocks value for customers by increasing the reliability and resilience of energy generation.

Regional markets for off-grid generation assets can differ greatly, depending on the dispersion of industry and network configuration. The efficiency and reliability of small-scale generators are also variable depending on the approach to configuration and maintenance.

For these reasons, capturing opportunities in this sub-sector requires a detailed understanding of regional dynamics and an appropriate platform to enable efficient deployment of capital, underpinned by experienced management and superior engineering capabilities.

Case Study: Remote power generation in Australia

The Australian mining sector consumes roughly 500 petajoule (PJ) of energy per year, 10% of Australia's total energy use. Energy consumption has risen at 6% per annum over the last decade driven primarily by increased mining volumes.[19]

The most economic source of electricity for mining depends on a mine's proximity to electricity or gas infrastructure, life of mine, electricity demand and mine production. In Australia, many mine sites are located too far from established energy grid infrastructure such that remote power generation is the only feasible solution, as opposed to grid connection or pipeline gas.

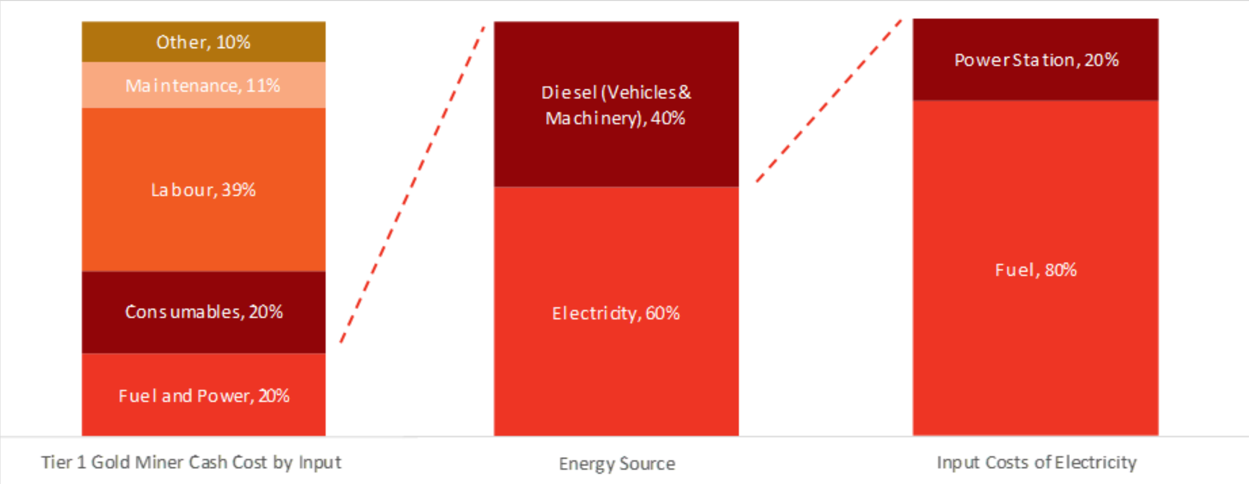
Reliable and uninterrupted power is fundamental to mining operations. Miners typically outsource all remote power generation requirements including construction and operations and maintenance (O&M) with minimum service level requirements.

[18] ibid

[19] Sunshift (2017) "Renewable Energy in the Australian Mining Sector". Retrieved from Arena: https://arena.gov.au/assets/2017/11/renewable-energy-in-the-australian-mining-sector.pdf

The decision to outsource power supply is driven primarily by the operating efficiencies which can be gained by utilising specialist providers, as this allocates risk to those who are best equipped to manage it and allows miners to focus on their core business. Electricity generation accounts for 15-25% of total mining operating costs, with fuel representing 80-85% of electricity costs (see Figure 6 below). This means fuel efficiency is paramount, emphasising the value-add which power generation specialists can provide, particularly those with in-house expertise in modifying and maintaining remote generation assets.

Figure 6: electricity generation breakdown for mining operations[20][21][22][23]



Trends in remote power generation in Australia

Remote electricity generation in the Australian mining industry currently use either gas, diesel, dual fuel (diesel and gas) or solar. With volatility in fuel costs and companies focused on reducing carbon dioxide emissions, miners are increasingly looking to use gas powered generation (CNG or LNG) or hybrid renewable solutions over diesel.

Due to this transition, the nature of infrastructure opportunities at mine sites is changing. In the future, due to the increasing role of gas, lateral opportunities such as gas pipelines or onsite LNG storage are expected to be available to industry players.

Approximately one in seven tenders for remote power generation at mine sites in Australia currently include a renewable component, and this is expected to increase. Due to the intermittency of renewable power supply, it is not viable for off-grid mining operations to rely exclusively on solar and/or wind.

However, hybrid systems overcome this limitation and ensure a reliable electricity supply by combining renewable sources with existing fossil fuel-based generation.

Recently installed hybrid systems in Australia and Canada combine diesel with solar PV or wind, with capacities up to 47MW diesel/9.2MW wind and 19MW diesel/10MW solar PV. For example, at the DeGrussa Copper-Gold Mine in Western Australia, a hybrid solar PV and diesel system is offsetting more than 450,000 litres of diesel per month, which adds up to ~25 million litres of diesel saved over 5.5 years or around 20% of the mine's total fuel consumption.

[20] Baillieu Holst Research (2016, August 11). "Pacific Energy Initiation of Coverage".
[21] Hartleys (2015, April 8). "WA Industrials: Remote Power – Pacific Energy Ltd (PEA)".
[22] Sunshift (2017) "Renewable Energy in the Australian Mining Sector". Retrieved from Arena: https://arena.gov.au/assets/2017/11/renewable-energy-in-the-australian-mining-sector.pdf
[23] Goldmoney (2018, July 12) "Gold Price Framework Vol. 2: The Energy Side of the Equation – Part II". Retrieved from Seeking Alpha: https://seekingalpha.com/article/4186837-gold-price-framework-vol-2-energy-side-equation-part-ii

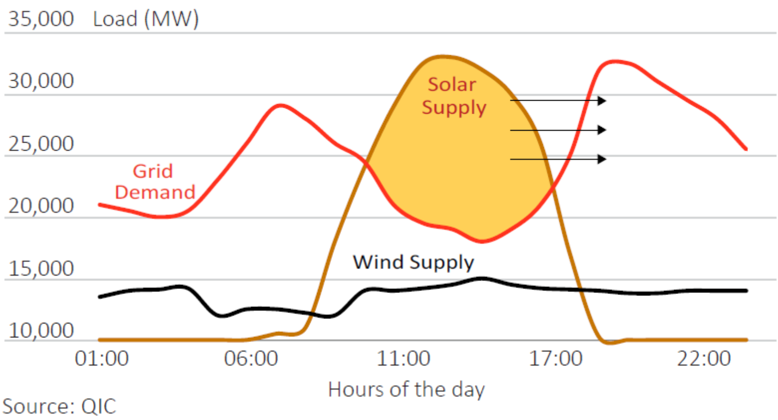
Table 1: Recent hybrid renewable power generation systems[24]

Project	Location	Company	Fossil Fuel		Renewable		Storage
			Type	**MW**	**Type**	**MW**	**MW/MWh**
DeGrussa	WA	Sandfire	Diesel	19	Solar PV	10	4 / 1.8
Weipa	QLD	Rio Tinto	Diesel	26	Solar PV	1.2	-
Granny Smith[25]	WA	Gold Fields	Gas	24.2	Solar PV	8	2 / 1
Raglan	Canada	Glencore	Diesel	21.6	Wind	3	0.6 / 4.3
Diavik	Canada	Diavik	Diesel	46.8	Wind	9.2	-

2.3 Network adaptation – Battery Technology

As the electricity sector transitions to low-carbon generation, battery technology, with its ability to instantly dispatch capacity, can allow the partial de-synchronisation of electricity generation from demand. This can aid the electricity sector's transformation as it adapts to consumer demands, the intermittency of renewable generation and the ongoing need for increased network efficiencies (see Figure 7).

Figure 7: Time-shift benefits of energy storage[26]



Source: QIC

A key driver of declining costs for battery storage has been the growing market for electric vehicles and consumer electronics, which has been bolstering lithium-ion manufacturing and resulting in significant economies of scale. Battery-pack costs are down to less than $230 per kWh, compared with almost $1,000 per kWh in 2010.[27]

An investment that recently brought the growth in battery production into the spotlight was Tesla's investment in a "Gigafactory", with partner Panasonic, in order to manufacture its own battery cells. The goal of the Gigafactory is to supply 500,000 Tesla electric vehicles per year by 2020.

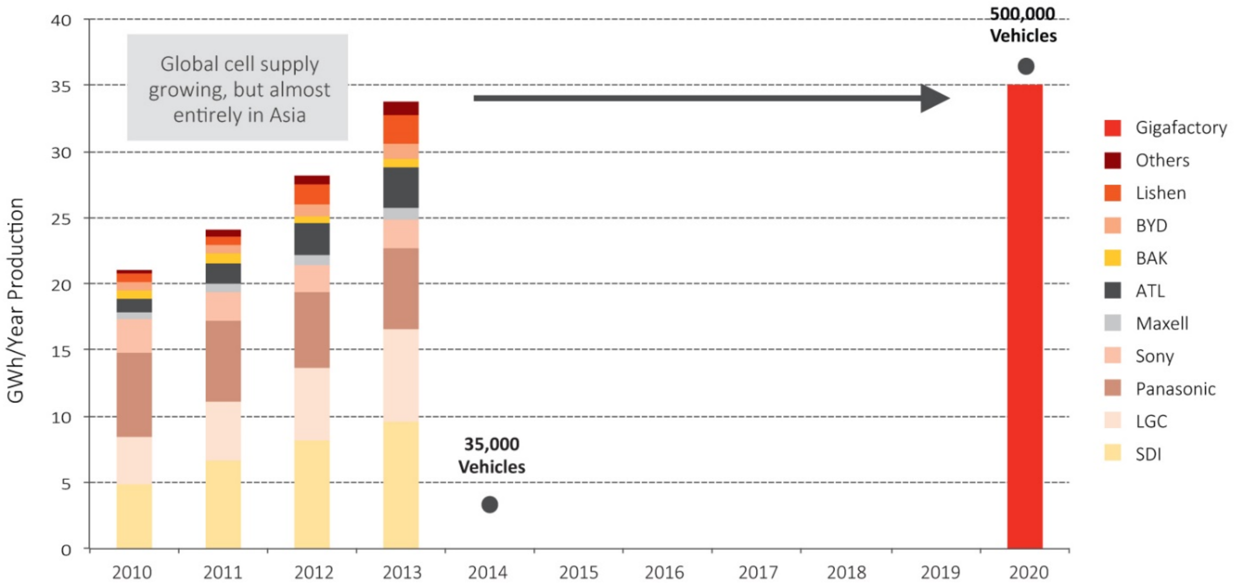
[24] Sunshift (2017) "Renewable Energy in the Australian Mining Sector". Retrieved from Arena: https://arena.gov.au/assets/2017/11/renewable-energy-in-the-australian-mining-sector.pdf

[25] "Gold Fields' "Granny Smith mine to install mega solar and battery power facility". Retrieved from aggreko: https://www.aggreko.com/en-au/news/2019/auspac-news/01-february/granny-smith-hybrid-facility

[26] QIC Red Paper *'Technology disruptions affecting infrastructure'*, 2016

[27] Frankel, D., & Wagner, A. (2017, June). *Battery storage: The next disruptive technology in the power sector*. Retrieved from McKinsey & Company: https://www.mckinsey.com/business-functions/sustainability/our-insights/battery-storage-the-next-disruptive-technology-in-the-power-sector

Figure 8: Planned 2020 Gigafactory production output to exceed 2013 levels[28]



With appropriate deployment across the grid, battery storage would enable more energy supply to be sourced from intermittent renewable sources such as wind and solar. This eliminates a key barrier to the broader deployment of renewable energy, unlocking new investment in the sector.

Highlighting the potential economic value of battery storage are the electricity prices in major markets which are increasingly approaching zero and even negative at times of significant wind and solar generation. In Australia, spot prices in the National Electricity Market (NEM) recently bottomed out at zero dollars per megawatt-hour for a five-minute period on June 30 and 31 of 2019 due to exceptionally strong generation from wind and solar generation assets along the east coast of Australia.

The near-term opportunities for infrastructure investors in supporting the deployment of battery technologies include:

- **Behind-the-meter energy storage –** These are energy storage devices co-located with distributed generation assets and positioned at the point of consumption which enables value to be captured from the time-shifting of energy generation, smoothing of intermittent renewable energy and avoidance of network and grid energy costs. These behind-the-meter battery investment programs are likely to create well-diversified and resilient asset portfolios with enhanced returns.
- **Smart metering and communications –** The integration of distributed generation and storage creates a powerful micro-grid system capable of clean, flexible and economic energy supply. Yet the full capabilities of such systems can only be realised with ancillary infrastructure enabling the capture and processing of energy relevant information. Smart meters, network sensors and load control devices that monitor and control energy flows are amongst existing such assets. These physical assets and platforms present further opportunities for infrastructure investors, particularly those already invested in distributed generation and/or storage platforms that can utilise these technologies to optimise the performance of their networks.

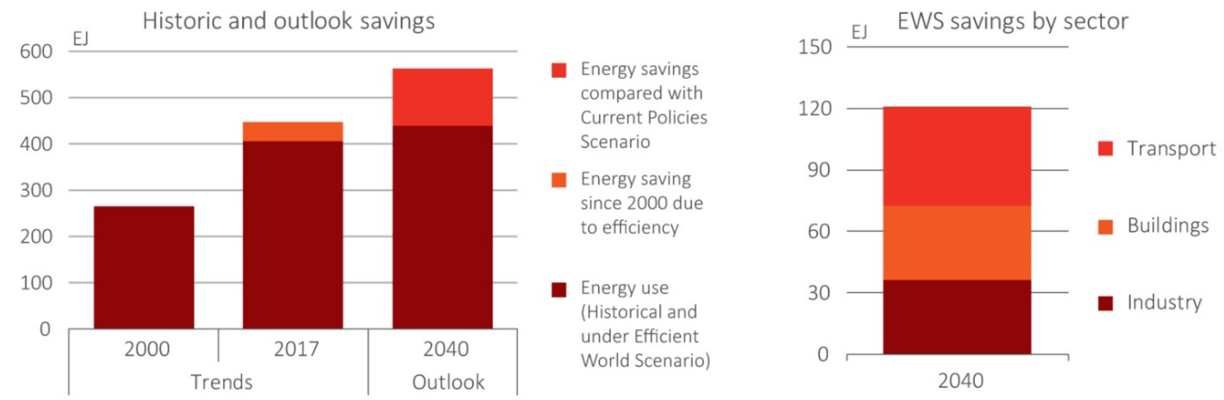
2.4 Energy Efficiency Technologies

The potential benefits from energy efficiency strategies have long been known to be significant. The International Energy Agency (IEA) estimates that since 2000, improvements in energy efficiency in the world's major economies offset more than one-third of the increase in energy demand. These efficiency gains saved

[28] Tesla. (2013). *Planned 2020 Gigafactory Production Exceeds 2013 Global Production.*

37 exajoules (EJ) of final energy use in 2017, equivalent to the final energy use of Japan and India combined. Final energy use, or final energy consumption, is the total energy consumed by end users such as households, industry and agriculture and excludes that used by the energy sector itself. Most of these savings were achieved in the industry (19 EJ), buildings (14 EJ) and transport (4 EJ) sectors. Under optimal policy settings, the IEA estimates that annual energy savings could reach ~120 EJ in 2040.[29]

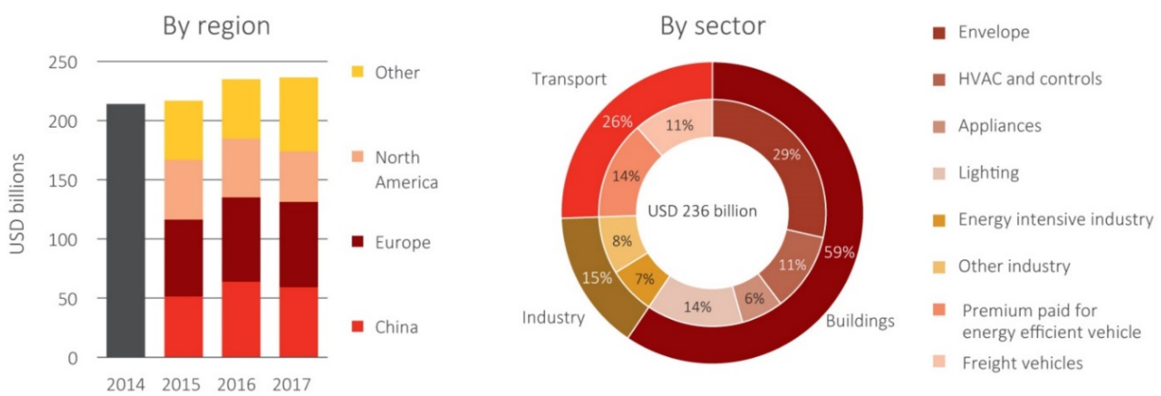
Figure 9: Historical and forecast global energy use and savings[30]



Note: One-third of the energy savings in 2040 are the result of current and planned policy settings (New Policies Scenario) and two-thirds from measures contained in the Efficient World Scenario. "Energy use" includes non-energy use (i.e. feedstocks), excludes energy supply.

The global incremental increase in investment needed to achieve the energy savings envisioned by the IEA averages around US$584 billion a year between 2017 and 2025, increasing to US$1.3 trillion between 2026 and 2040, as diminishing returns dictate that more expensive options are taken up in later years.[31]

Figure 40: Global energy efficiency investment by sector and region[32]



HVAC = heating, ventilation and air conditioning

[29] Market Report Series on Energy Efficiency (2018). Energy Efficiency 2018: Analysis and outlooks to 2040". Accessed IEA: https://webstore.iea.org/download/direct/2369?fileName=Market_Report_Series_Energy_Efficiency_2018.pdf
[30] ibid
[31] ibid
[32] ibid

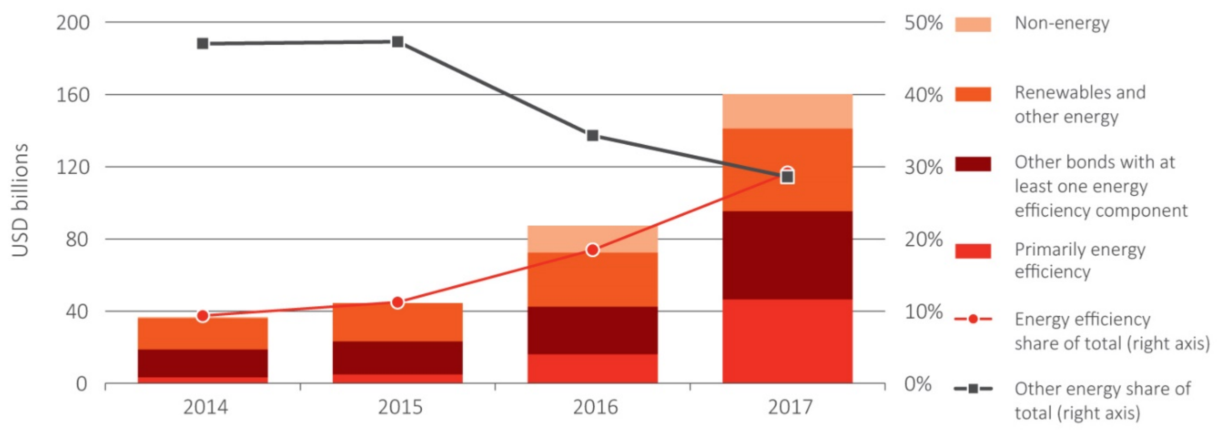
The buildings sector has been the dominant driver of energy efficiency investment globally, reaching US$ 140 billion (59%) of total investment in 2017.[33] This includes investments in more efficient building envelopes, heating and cooling, lighting and appliances.

As distributed generation is driving growth in energy efficiency, so too are technological advances and support for environmental sustainability. Over the past decade, decreases in the cost of efficient lighting, sensors and the proliferation of the internet has provided consumers with more granular data as to how they are consuming energy. This is in turn allowing consumers to be more proactive with mitigating their energy consumption.

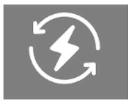
Utilities are further incentivising these changes in consumption behaviour by changing the way they bill for power. Rather than simply charging by amount of electricity consumed, many utilities globally are billing in more dynamic ways, such as charging commercial customers a fixed price based on the peak power they consume every month, or residential customers varying rates depending on the time of day. These dynamic billing rates increase the potential benefits from taking a more active role in a users' electricity consumption.

Global green bond issuance data demonstrates that companies and investors are rapidly recognising the opportunity presented by energy efficiency technologies. In 2017, the value of green bonds issued primarily for energy efficiency tripled from US$16 billion in 2016 to US$47 billion, overtaking green bonds issued for renewable energy for the first time (Figure 11).

Figure11: Global green bond issuance by use of proceeds (2014-17)[34]



2.5 Customer-led sustainability – Waste-to-Energy



Energy is the latest sector to participate in the transition to a circular economy which "makes, uses, reuses, remakes, recycles" unlike the traditional linear economy which operates by "take, make, use and dispose".

Waste-to-energy technologies may result in heat, electricity or fuel. These can be extracted from waste during thermal treatment which includes: burning, incineration, thermal oxidation, pyrolysis, gasification and plasma. Non-thermal treatments include anaerobic digestion and landfill gas capture.

Waste-to-energy has become increasingly attractive to investors as technology finds more efficient and effective ways to treat waste and social opposition to landfill has increased. It is estimated that investment in the organic waste industry is expected to grow about 11 per cent per year from US$800m in 2019 to

[33] ibid

[34] Climate Bonds Initiative, 2018

US$1,450 million in 2025.[35] At present, the OECD average is about 2.9% of total energy being derived from waste and bioenergy. Key global investments include:[36]

- In the EU (including UK) there are currently 507 facilities, each of which process between 250,000 and 500,000 tonnes a year (although some larger facilities can process 1.2 million tonnes a year);
- In the US, there were 77 waste-to-energy facilities as of 2016;
- In Australia, there are seven major waste-to-energy processing facilities which have been approved for future development.

See our prior red paper *Climate change: Building resilience in infrastructure* for further information.

3 CONCLUSION

Distributed energy and the move away from traditional, centralised energy systems is a key investment theme that QIC has been exploring in recent years. Its emergence as a new infrastructure sub-sector and expected future growth is underpinned by the four key megatrends: technological advancement; environmental sustainability; customer empowerment; and policy uncertainty. These trends, which are headwinds for traditional, centralised energy assets, are tailwinds for decentralised infrastructure deployment models.

We see investment opportunities across all segments of the energy supply chain, particularly in distributed generation with a focus on distributed solar and remote and off-grid generation. Standalone opportunities also exist for storage and ancillary supporting infrastructure, which when integrated with distributed generation assets and energy efficiency technologies, result in users adopting an interactive position where they both generate and store their own power. The public push for environmental sustainability over the last few years has also manifested in the growing adoption of renewable energy, low carbon technologies and waste-to-energy projects.

However, the most attractive distributed energy investment opportunities for infrastructure investors are those with embedded operating and growth capabilities within a platform structure, as this maximises value capture across asset creation and optimisation. Beyond this essential feature, infrastructure investors are likely to also be attracted to business models which: apply innovative and sustainable technologies to address specific customer needs; operate in markets where there is scope for significant growth (ideally across multiple markets); and generate economies of scale to deliver the "network effect" of resilience and optimised performance. Building such a platform requires efficient capital deployment into small-scale assets, which in turn requires experienced management with a proven track record and specialist expertise.

Distributed energy networks will be key to delivering essential, sustainable and cost-effective energy services to consumers into the future. However, investing in this sector requires an understanding of existing energy systems, the regulatory regimes applying, and the technological, social and political forces shaping its current evolution. Active infrastructure investors who can respond to this increasingly dynamic energy environment have the opportunity to lead the growth of distributed energy platforms and their important effect on the energy system of the future.

[35] Energy Insights by McKinsey. (2019). *Global Energy Perspective 2019: Reference Case.* McKinsey & Company.

[36] New South Wales Parliament Legislative Council. (2018). *'Energy from waste' technology.* New South Wales Parliament.

4 GLOSSARY

blackout:	Complete power loss affecting many electric users over a large area for an extended period of time.
brownout:	Controlled power reduction of loss of electricity to pockets of customers. Caused by lower quality power in which a utility reduces line voltage in order to deliver more electricity to meet increased demand.
C&I:	Commercial and Industrial
compressed natural gas (CNG):	Compressed natural gas which is methane stored at high pressure and can be used in place of gasoline, diesel fuel and propane.
exajoules (EJ):	A unit of power which is equal to one quintillion (10^{18}) joules.
gigawatt (GW):	A unit of power equal to one billion (10^{9}) watts.
Joule (J):	A unit of power which is the equivalent to one watt-second.
kilowatt hour (kWh)	A measure of electrical energy equivalent to a power consumption of 1,000 watts for one hour.
liquified natural gas (LNG):	Liquified natural gas is natural gas cooled down to liquid form for non-pressurised storage or transport.
load centres	Electric load centres serve as a “load” to the generators and “supply” power to the rest of the building.
megawatt (MW):	A unit of power which is the equivalent to one million watts and equal to 1,000 kilowatt hours (kWh).
petajoule (PJ):	A unit of power which is equal to one quadrillion (10^{15}) joules.
reciprocating engine	An engine in which one or more pistons move up and down in cylinders to create power. Most models of car engines and lawn mowers are two examples.
solar photovolataic (PV):	A technology which converts sunlight into direct current electricity through the use of semiconductors.
watt (W):	A unit of power and is defined as a derived unit of 1 joule per second and is used to quantify the rate of energy transfer.

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