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REPORT DECEMBER 2017

INFRASTRUCTURE FOR A CHANGING ENERGY SYSTEM

THE NEXT GENERATION OF POLICIES FOR THE EUROPEAN UNION

JOSEPH DUTTON, LISA FISCHER, JONATHAN GAVENTA

This report draws on a series of workshops on the future of EU energy infrastructure policy held in 2017. The authors would like to thank all participants from civil society, industry and European Commission for their input. The views in this report are the authors' alone.

About E3G

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EXECUTIVE SUMMARY

European energy markets, technologies, business models, geopolitics and political objectives are changing rapidly. The EU's approach to energy network infrastructure needs to keep pace. This requires reform to current delivery instruments and processes, including: aligning infrastructure policies with climate targets, updating definitions of energy security, broadening understanding of infrastructure boundaries and developing new tools to manage uncertainty.

Reassessing infrastructure needs

The transition of the EU energy system is both deep and rapid, driven by changes in technology, economics, policy constraints and consumer choice. Yet energy networks evolve more slowly: infrastructure investments are often capital-intensive, time-consuming to plan and construct, and once built have a lifetime of multiple decades. The infrastructure policy framework of today needs to be fully aligned with the transitions of the future. This paper reviews the macro-trends of the changing energy system and how the next generation of EU energy infrastructure policies can successfully adapt. These trends include:

> **Decarbonisation**: a shift in focus from marginal emissions reductions to a fully zero-carbon economy by mid-century limits potential for unabated fossil fuel infrastructure and requires investment to integrate renewable resources.

> **Decentralisation**: increasing generation and flexible demand resources at local level mean distribution grids are of increasing European significance.

> **Digitalisation**: advanced use of data, analytics and connectivity can reshape energy consumption and change the way energy networks are used.

> **Sector coupling**: electrification of heat and transport offers both a burden and an opportunity for power networks. New approaches will be needed to address the changing patterns of demand.

Realigning infrastructure and climate policy

New political commitments, such as the EU's 2030 targets and the ratification of the Paris Climate Change Agreement, will accelerate energy system change and impose stronger constraints on emissions. This has wide-ranging consequences for energy infrastructures. A failure to fully incorporate these aims into EU energy infrastructure policy would increase risks for network developers and market actors and raise the overall costs for the transition. A realignment is needed to incorporate EU 2050 climate goals into European infrastructure planning, to facilitate progressive ratcheting up of climate ambition, to respond to the increasing pace of technology change and to fulfil EU commitments to phase out fossil fuel subsidies by 2025.

Redefining energy security

As Europe's energy system evolves, the security threats it is exposed to are changing. On the basis of traditional definitions of energy security focused on physical supply, EU energy security in terms of physical supply has increased markedly and little new investment is needed on these grounds. Yet new security problems are emerging. To protect European citizens, EU infrastructure policies and funding instruments need to re-define energy security to include emerging issues such as adequacy of flexibility resources, the challenge of cyber security, and increasingly severe climate change impacts and extreme weather events.

Redrawing the boundaries of energy infrastructure

The integrated nature of modern energy networks is blurring the boundaries between infrastructure types. Increasingly interconnected transport, heat, digital and energy systems offer considerable opportunities but stretch the limits of the current regulatory framework. A modern approach to energy infrastructure needs to go beyond the traditional categories of pipes and wires. This includes: recognising demand-side resources as infrastructure; integrating planning and operation of gas and electricity networks; tapping into the demand flexibility potential from electrified heat and transport; and enabling multipurpose projects such as offshore grids.

Responding to uncertainty in the infrastructure transition

There is broad consensus that the macro trends of decarbonisation, decentralisation digitalisation, and sector coupling will lead to radical changes in volumes and flows of energy through European infrastructure networks. Yet the precise timing, location and nature of these changes are uncertain, and this uncertainty will remain endemic for the foreseeable future. Given the speed of change and long lead times for major infrastructure projects, decisions need to be taken before all of these uncertainties will be fully resolved. Instead, EU energy infrastructure policies and institutions will need to be re-tooled towards actively managing the uncertainties of the transition.

Way forward

The new challenges to Europe's energy infrastructure are increasingly recognised by actors across the system. Finding appropriate solutions will require re-tooling EU approaches to infrastructure planning, financing and institutional governance.

> **Infrastructure planning**: The EU's upcoming 2050 roadmap should include a new assessment of long-term infrastructure needs. This assessment should guide network planning scenarios and selection of Projects of Common Interest.

> **Financing**: We see no justification for continued EU budget spending on fossil fuel infrastructure post-2020, given the EU's international commitments on climate and on fossil subsidy phase-out. There is a strong case for the Connecting Europe Facility to be expanded, but to be broadened to a wider set of investments.

> **Institutions**: Changing infrastructure priorities should mean new roles and clearly defined objectives for the 'regional groups' that select projects of common interest. Beyond this, an EU-level foresight functionality is needed to help infrastructure planners keep pace with technology and economic change.

CHAPTER 1

REASSESSING INFRASTRUCTURE NEEDS

The EU energy system is undergoing a deep and rapid transition, driven by changes in technology, economics, policy constraints and consumer choice. Yet infrastructure networks evolve more slowly: infrastructure investments are often capital-intensive, time-consuming to plan and construct, and once built have a lifetime of multiple decades. The infrastructure policy framework of today needs to be fully aligned with the transitions of the future. This paper reviews the macro-trends of the changing energy system – including decarbonisation, digitalisation, decentralisation, sector coupling and uncertainty – and how the next generation of EU energy infrastructure policies can successfully adapt.

Why energy network infrastructure matters

The basic role of energy network infrastructure is to match demand and supply sources. As these fundamentals change, the shape of grids and networks must change too. If well-designed, energy network infrastructure is a key enabler for the transition to a clean economy. Inadequate or inappropriate infrastructure, by contrast, risks increasing the cost and slowing the pace of the transition.

Many infrastructure assets have a long operating life, meaning projects that are developed this decade will remain operational beyond 2050. Decisions over the short term will be manifested in physical infrastructure for many years to come.

Table 1: Operating life span of selected energy network infrastructure

Infrastructure type	Estimated operating life span
Gas transmission grid	80 years
High voltage AC transmission network	60-80 years (40 years for overhead lines)
Nuclear power station	60 years
High voltage DC (HVDC) interconnector	40 years
Gas-fired power station (CCGT)	30 years
Offshore windfarm	20 years

Sources: *EDF, EirGrid, Europacable, The Crown Estate, Dodds and McDowall (2013)* [1]

[1] EDF Energy (2015), **Couldn't we just build lots of gas-fired power stations?;** The Crown Estate (2013), **A Guide to UK Offshore Wind Operations and Maintenance;** Dodds, P, & McDowall, W. (2013), The Future of the UK Gas Network, *Energy Policy*, 60, 305-316; EirGRid, **The East West Interconnector**; Europacable, **Electricity Transmission of Tomorrow**

Current EU energy network infrastructure policy

The current generation of EU energy network policies were formed between 2009 and 2013. The 2009 **Third Energy Package** established two new organisations: the European network of transmission system operators for electricity (ENTSO-E) and for gas (ENTSOG). The ENTSOs conduct bi-annual **ten-year network development plans** (TYNDPs) as well as system adequacy assessments and are responsible for development of network codes.[2]

The Third Energy Package was followed by the **Trans-European Networks for Energy (TEN-E) regulation** in 2013. Its structure and 'priority corridors' were informed by the 2011 European Commission Communication on future energy infrastructure priorities[3].

This regulation set out the **Projects of Common Interest (PCI)** process, which was intended to speed up the planning and permitting process for vital cross-border infrastructure projects, primarily in in gas and electricity. It selects PCIs based on their alignment with 'priority corridors' and their ability to either enhance internal market integration, promote sustainability, increase security of supply or competition, i.e. drive down and harmonise market prices (*gas projects only*). The regulation requires member states to set up a 'one-stop-shop' for permitting.

Three PCI lists have been produced so far:

- **2013**: 248 projects – 107 natural gas; 132 electricity; 2 smart grids; 7 oil projects[4]
- **2015**: 195 projects – 77 natural gas; 108 electricity; 3 smart grids; 7 oil projects[5]
- **2017**: 173 projects – 53 natural gas; 106 electricity, 4 smart grids; 6 oil projects and 4 carbon dioxide transport projects.[6]

Changes in project categorisation, however, mean comparison between the lists is difficult: many of the gas projects have simply been clustered together rather than removed from the list.

[2] Regulation No 347/2013, **Guidelines for trans-European energy infrastructure**, Annex III

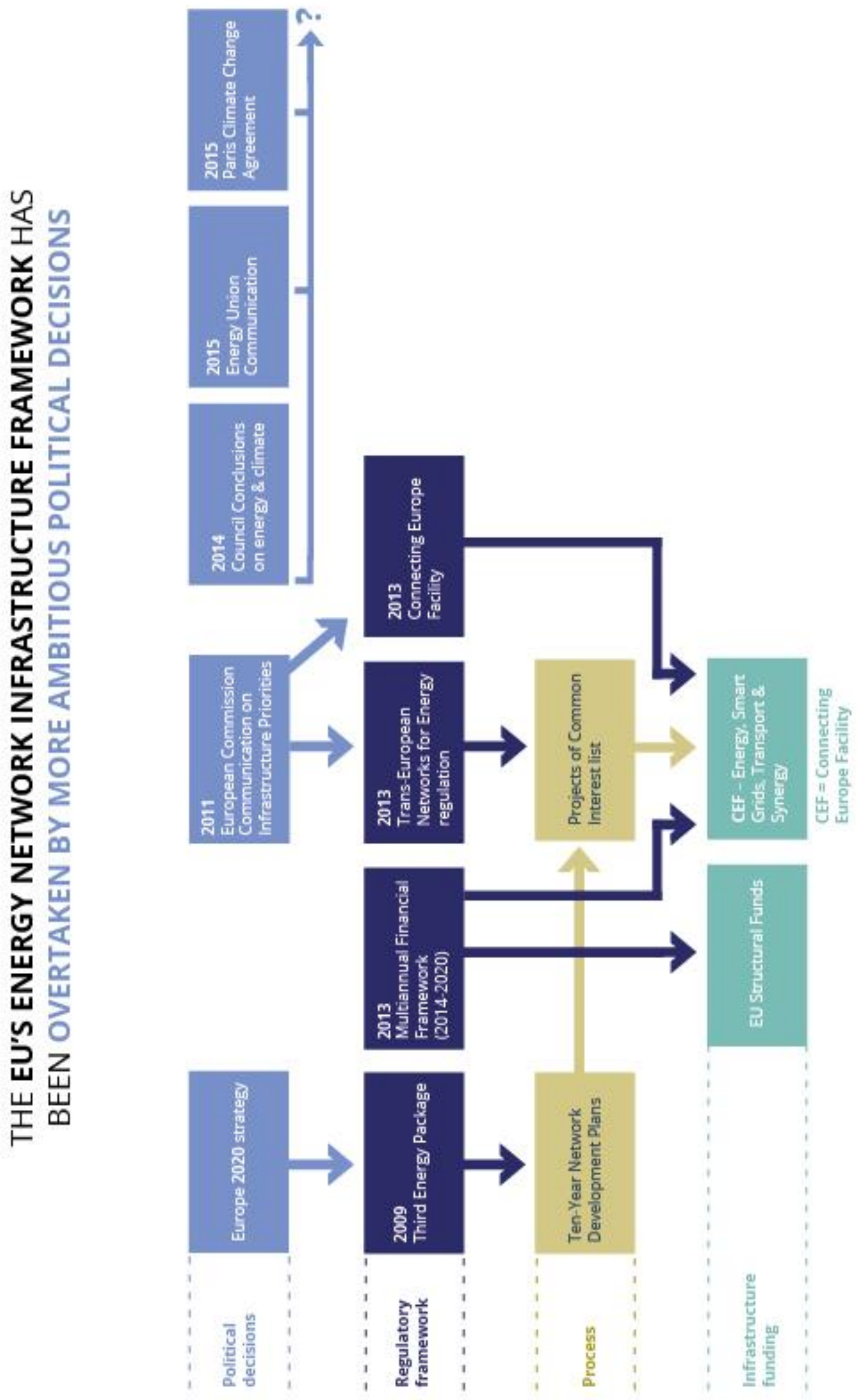
[3] European Commission (2011), **Priorities for 2020 and beyond – A Blueprint for an integrated European energy network**

[4] European Commission (2013), **First PCI list**

[5] European Commission (2015), **Second PCI list**

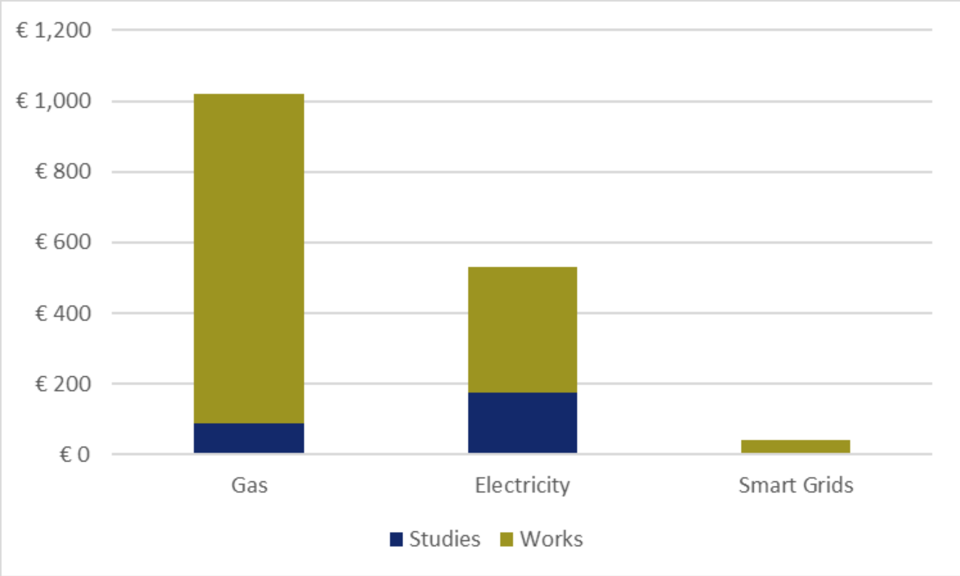
[6] European Commission (November 2017), **Third PCI list**

Figure 1: The EU's energy network infrastructure has been overtaken by more ambitious political decisions



Once projects are included on the list of PCIs they can apply for funding under the **Connecting Europe Facility** (CEF). This EU budget funding instrument was set up to "fill the missing links in Europe's energy, transport and digital backbone"[7]. Out of a total budget of €27.4bn for 2014-2020, €4.7bn are allocated for energy networks, of which €1.6bn has been spent so far. While the Connecting Europe Facility has supported studies and works for numerous PCIs, expenditure to date remains dominated by gas infrastructure projects.[8]

Figure 2: Summary of CEF expenditure to 2017, in €m



Drivers of a changing energy system

Since the EU's last major legislative revision on energy infrastructure in 2013, EU energy systems have continued to see deep and rapid change that is pushing the policy framework to its limits. The macro trends - deep decarbonisation, the rise of renewables, digitalisation, decentralisation and sector coupling – are briefly described below. Their wider implications, including the need to redefine energy security, redraw energy infrastructure boundaries and manage endemic uncertainty, are discussed in the chapters that follow.

Deep Decarbonisation

The EU's climate change objectives have moved from incremental to transformational. In 2015 EU greenhouse gas emissions were 22% lower than levels in 1990, putting the EU on track to meet its emissions reduction target of by 20% by 2020, and by at least 40% by 2030[9]. But to meet the Paris Climate Change Agreement goal of limiting global temperature increases to well below 2°C, the EU and other

[7] European Commission, **Connection Europe Facility website**

[8] European Commissions (2017), **Connecting Europe Facility Mid-Term Results**

[9] European Commission (2017), **Eurostat**

developed economies will need to pursue deep decarbonisation and reach net-zero emissions by mid-century.

This shift will have wide-ranging implications for EU energy infrastructure. The mid-century net-zero objective leaves little room for use of unabated natural gas or oil, while the role of electricity widens to decarbonise more sectors. Radical increases in renewable energy pose a system balancing challenge, with electricity interconnection acting as a key flexibility resource.[10] Efficiency measures deepen and energy demand becomes decoupled from economic growth. New vectors such as hydrogen and new infrastructures (e.g. for carbon capture, transport and storage) may also be needed. The challenge of reconciling Europe's infrastructure policies with its climate commitments are explored in Chapter 2.

Distributed generation and decentralisation

Distributed generation (or decentralised generation) is electricity that is either connected to the distribution network or is consumed on site by the generator. This typically takes place on commercial or residential properties, and has given rise to the idea of 'prosumers' – customers who simultaneously consume and produce electricity.

Distributed generation is viewed as crucial for decarbonisation, because the primary electricity source at this level is from renewables – notably onshore wind, solar (either rooftop or ground-mounted arrays), and small-scale hydro. Distributed generation also includes combined heat and power (CHP), battery storage, and demand response, as well as fossil fuel-based generation, such as small gas-turbines.

Increased self-consumption and generation and supply into the distribution network typically means demand for electricity from the transmission grid is lowered[11]. For example, in the UK peak electricity demand in the summer of 2017 was forecast to be almost 3GW lower than in 2014 – a fall of 7% – largely because of embedded generation, according to system operator National Grid[12].

The implication of this shift is that – despite being largely overlooked in EU-level policy frameworks so far – distribution networks and distributed resources are increasingly becoming infrastructures of European significance, as they shape energy flows across the rest of the system.

Digitalisation and smart grids

The use of data and computerised systems is not new in energy, with computerised systems common across infrastructure including electricity grid control rooms, power

[10] European Climate Foundation (2010), **Roadmap 2050**; E-Highway 2050 (2015), **Europe's future secure and sustainable electricity infrastructure**

[11] In some cases, the importance of the transmission network could increase if it is used to address localised supply and demand variations

[12] National Grid (2017), **Summer Outlook Report**

stations, oil and gas platforms, and refineries. But the transition to the new energy system, with high levels of renewables and distributed generation, requires a wider use of information and communication technology (ICT) in everyday operations, known as ‘digitalisation’.

The process is already underway in energy, but is less well-developed than in other industrial sectors. More support is needed to fully realise the benefits digitalisation can bring to energy suppliers and consumers. Digitalisation has three primary elements:

- **Data**: collection of digital information
- **Analytics**: the use of data to produce useful information and insights
- **Connectivity**: exchange of data between humans, devices and machines through digital communications networks[13]

The two-way communication between different elements of the network, and between electricity suppliers and consumers, allows grid operators to respond within real-time to supply and demand fluctuations.[14] And with more coordinated system operation, smart technologies can respond to local electricity supply and demand. This allows the development of smart grids, and the integration of the transport, building, and industrial sectors.

More broadly, digitalisation of energy end-use sectors such as industry, buildings, logistics and transport has the potential for deep changes to the way energy is consumed, with the potential for radical improvements in energy efficiency.[15]

Digitalisation has several implications for infrastructure policy. While digitalisation creates many benefits, it also leads to new security challenges - outlined in chapter 3. Communications networks, sensors, controls and software become central elements of energy infrastructure, going beyond traditional pipes and wires. This redrawing of infrastructure boundaries is explored in chapter 4.

Sector coupling

Sector coupling refers to the converging energy use of the three main energy consuming sectors of transport, industry and buildings. In Europe this process is primarily driven by decarbonisation: the electrification of transport, heating and – where possible – industrial processes lowers the consumption of fossil fuels and carbon emissions as the electricity generation becomes increasingly renewable.

The co-development of generation, distribution, and storage infrastructure across sectors can help to exploit synergies and avoid oversupply of infrastructure. For

[13] IEA (2017), **Digitalisation and Energy**

[14] Siemens, **Flexible grids for demanding challenges, Website** November 2017

[15] The IEA estimates widespread digitalisation could lead to 10 PWh of energy savings in Europe’s building sector by 2040. IEA (2017), **Digitalisation and Energy**

example, for electricity to become more distributed, the development of smart grids is needed – and a crucial element of smart grids will be smart meters and electric vehicle chargers.

This is expected to result in comparatively higher electricity demand, making it crucial that decarbonisation of Europe's electricity generation sector continues. Electricity from renewable sources can also be used to produce gases such as hydrogen (known as 'power-to-gas'), which could provide a lower-carbon alternative to natural gas in areas of the economy that cannot be easily electrified.

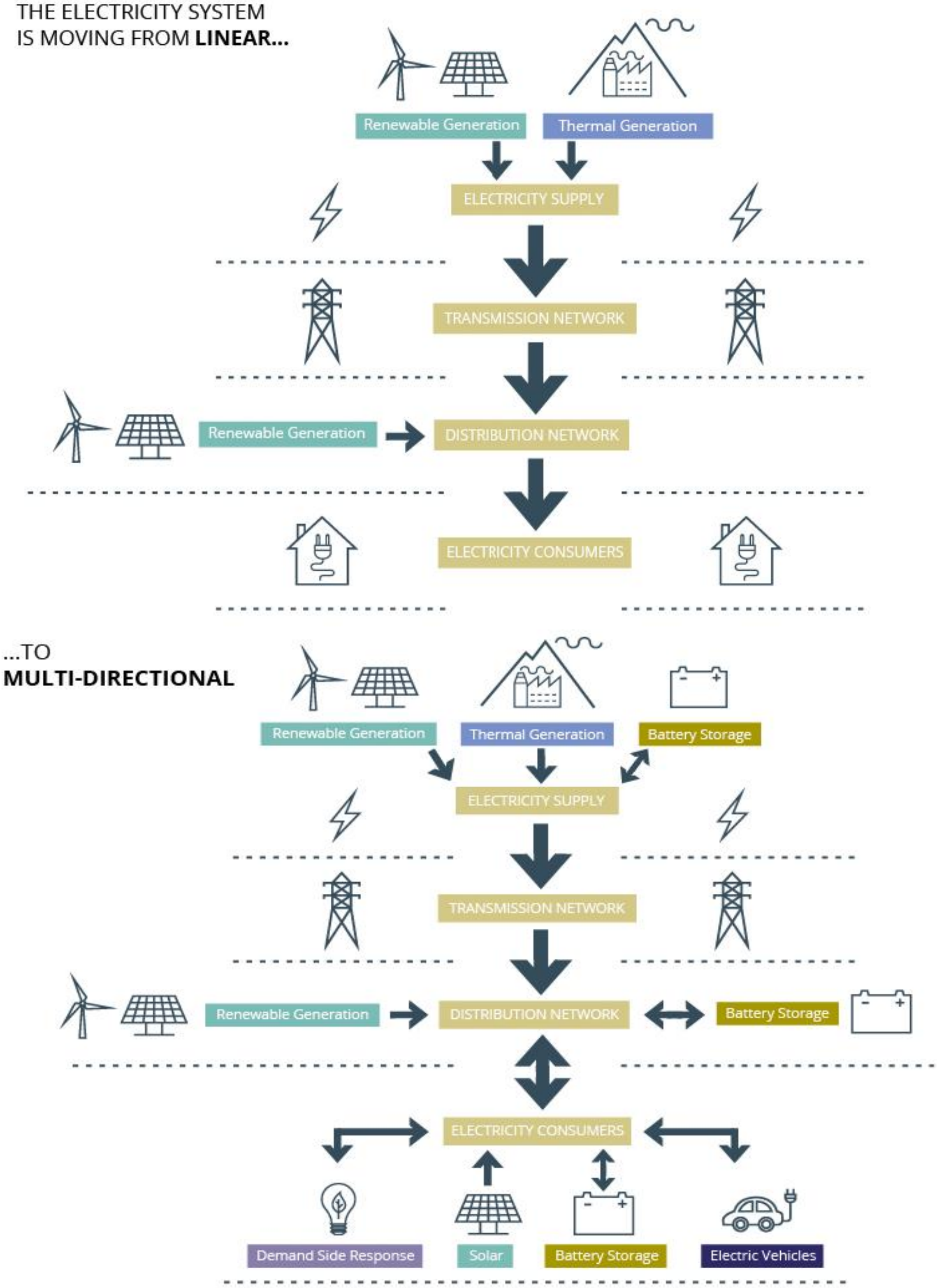
In the case of electric vehicles, the use of smart chargers means they can be automatically charged during periods of low electricity demand to help balance the system, or when it is cheapest for the consumer. Smart charging can combine several electricity sources, such as rooftop solar panels, battery storage and power from the grid. Using different supply sources at different times can also help level out the daily electricity load curve, making management of the grid easier for system operators.[16]

Smart chargers will ultimately interact with smart meters**,** which are the interface between consumers and the electricity network, relaying data on supply and demand. The EU created a smart meter task force in 2009 with the aim of replacing at least 80% of conventional meters with smart ones by 2020 – however, deployment has reached only 25%.[17]

Sector coupling has multiple implications for energy infrastructure policy. Electrification increases electricity and electric infrastructure needs – but can also act as a system resource to facilitate integration of renewable electricity. This multi-functionality blurs the boundaries between infrastructure types (explored further in chapter 4).

[16] Elexon (2015), **Active management of distributed generation**

[17] Acer (2017), **6th ACER Market Monitoring Report**

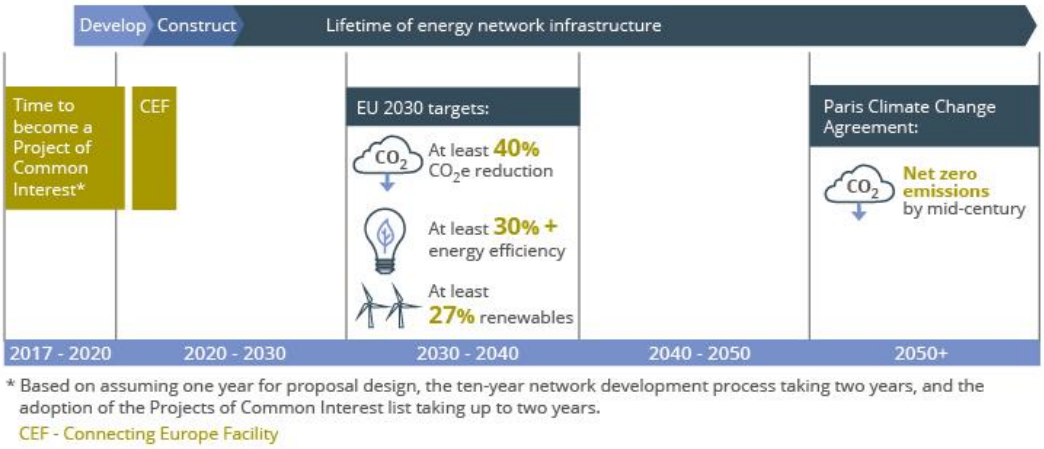

THE ELECTRICITY SYSTEM
IS MOVING FROM LINEAR...
Renewable Generation
Thermal Generation
ELECTRICITY SUPPLY
TRANSMISSION NETWORK
Renewable Generation
DISTRIBUTION NETWORK
ELECTRICITY CONSUMERS
...TO
MULTI-DIRECTIONAL
Renewable Generation
Thermal Generation
Battery Storage
ELECTRICITY SUPPLY
TRANSMISSION NETWORK
Renewable Generation
DISTRIBUTION NETWORK
Battery Storage
ELECTRICITY CONSUMERS
Demand Side Response
Solar
Battery Storage
Electric Vehicles

CHAPTER 2

REALIGNING INFRASTRUCTURE AND CLIMATE POLICY

New political commitments, such as the EU's 2030 targets and the ratification of the Paris Climate Change Agreement, will accelerate energy system change and impose stronger constraints on emissions. This has wide-ranging consequences for energy infrastructures. A failure to fully incorporate these aims into EU energy infrastructure policy would increase risks for network developers and market actors and raise the overall costs for the transition.

Figure 3: Today's regulatory framework shapes infrastructure to 2050 and beyond



EU climate objectives have changed since the current energy infrastructure framework was first introduced. The proposals for the 2013 TEN-E regulation were based on an infrastructure needs assessment performed in the 2011 communication "*Energy Infrastructure: Priorities for 2020 and beyond – A Blueprint for an integrated European energy network*".[18] This communication set out 'priority corridors' of infrastructure needs to 2020, on the basis of PRIMES 2007 energy system modelling (2009 update).

This infrastructure needs assessment is now badly out of date. Significant changes to the underlying parameters mean that the same exercise would come to very different

[18] European Commission (2011), **Energy Infrastructure: Priorities for 2020 and beyond – A Blueprint for an integrated European energy network**

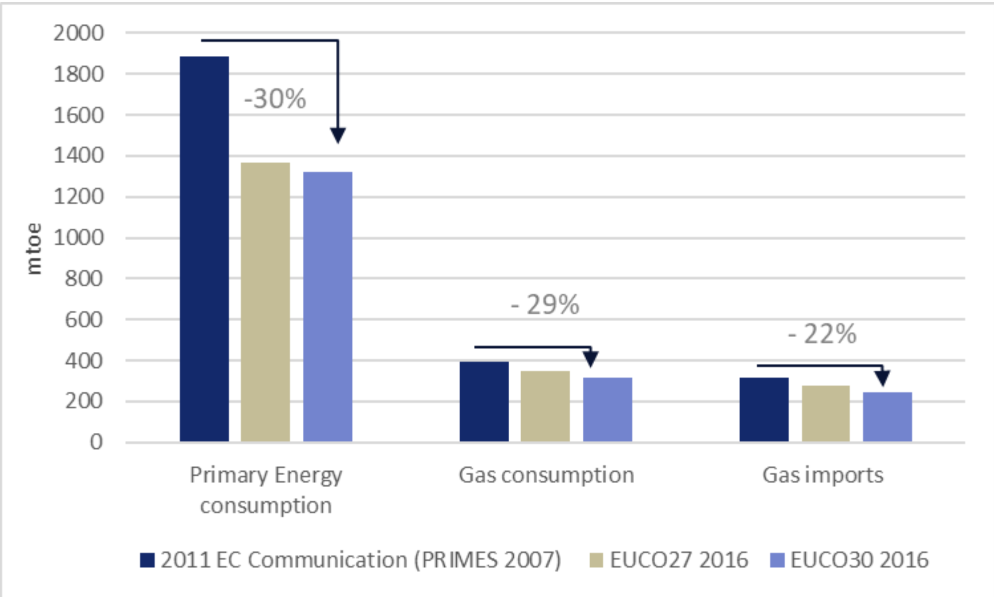
conclusions today. The intervening period has seen not only major changes to technology costs and potentials but also considerably stronger climate constraints.

EU 2030 targets change energy infrastructure needs

In 2014, the European Council agreed a set of **minimum** targets for the EU's decarbonisation until 2030.[19] They stipulated a target of at least 40% reduction in greenhouse gas emission until 2030 compared to 1990, at least 27% reduction in primary energy consumption compared to projections and an at least 27% share of renewable energy consumed. These targets may be revised upwards: the European Parliament is currently calling for 35% renewables and 40% energy efficiency for 2030, while the European Commission has tabled a 30% energy efficiency target for 2030.[20]

These targets reshape energy demand and energy infrastructure needs. The chart below shows the changes in energy demand projections between the 2009 PRIMES reference scenario for 2030 and the new EUCO30 scenario which incorporates a 30% energy efficiency target.

Figure 4: 2030 energy and gas demand projections fall with new EU 2030 targets



This lower gas demand reduces gas infrastructure needs. Analysis suggests that meeting the 30% energy efficiency target for 2030 could reduce the gas infrastructure investment needed for energy security by 74%.[21]

[19] European Council (2014), **Conclusions 24th October 2014**

[20] EURACTIV, **MEPs vote for stronger EU efficiency and renewable energy targets**, 28/11/2017

[21] Energy Union Choices (2016), **More Security, lower cost**

The Paris Climate Change Agreement means a deeper infrastructure shift

The Paris Climate Change Agreement, signed in late 2015 and ratified in 2016, means the infrastructure shift will need to go even deeper. The Agreement contains several important elements for EU energy infrastructure policy:

> **Net-zero emissions goal by mid-century:** Parties to the Paris Climate Change Agreement seek to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century" (Art. 4 (1)). This 'net-zero' goal gives a clear destination for long-term infrastructure planning: by the second half of the century the ultimate end point is to deploy the infrastructure needed for a zero-emission energy system.

> **Ratchet and review:** The Paris Agreement includes 'a ratchet and review mechanism' to increase ambition over time.[22] All nationally determined contributions, in the EU's case its 2030 targets, will need to become aligned with the temperature goal. Backsliding is not permitted. This means 2030 commitments may increase but not reduce. Infrastructure investments need to be tested against not only current targets but also against a potential increase in commitment levels.

> **Long-term strategies to avoid fossil fuel lock-in or 'stranded assets':** The Paris Climate Change Agreement requires parties to develop 'long-term low greenhouse gas emission development strategies' (Art 4 (19)), with submission by 2020 or before. The EU's long-term strategy (or 2050 roadmap) will offer an important tool for assessing the consistency of long-lived network infrastructure investments with EU climate goals.

> **Shifting financial flows and ending fossil fuel subsidies**: The Paris Agreement seeks to make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" (Art. 2 (1c)). The EU also committed to end "inefficient fossil fuel subsidies" by 2025, through the G7 in 2016.[23] Currently, the EU spends on average €4bn in fossil fuel subsidies through its budget, development and investment banks and funds – including financial support for gas infrastructure through the Connecting Europe Facility, the European Fund for Strategic Investments, cohesion funds and European Investment Bank lending.[24] This support will need to be phased out to meet the EU's G7 and Paris Agreement commitments.

> **A changing technological outlook:** Finally, the Paris Agreement includes national commitments by all countries, which will to lead to higher global deployment of low carbon technologies (renewable energy, efficiency measures, electric vehicles amongst others) and a more rapid learning curve than if Europe was acting in isolation. This accelerated learning curve affects technology cost and deployment assumptions for infrastructure planning. EU energy infrastructure models are

[22] Art. 4 (3) of the **Paris Climate Change Agreement**: "Each Party's successive nationally determined contribution will represent a progression beyond the Party's then current nationally determined contribution."

[23] **G7 Ise-Shima Leaders' Declaration (2016)**

[24] CAN-E, Green Budget Germany, ODI (2017), **Phase-Out 2020: Monitoring Europe's fossil fuel subsidies**

already struggling to keep pace with technology change: for example, the ENTSOs 2018 scenarios do not account for the sharp drop in cost of offshore wind experienced since 2015. New tools will be needed to ensure EU infrastructure planning remains robust to rapid technology change.

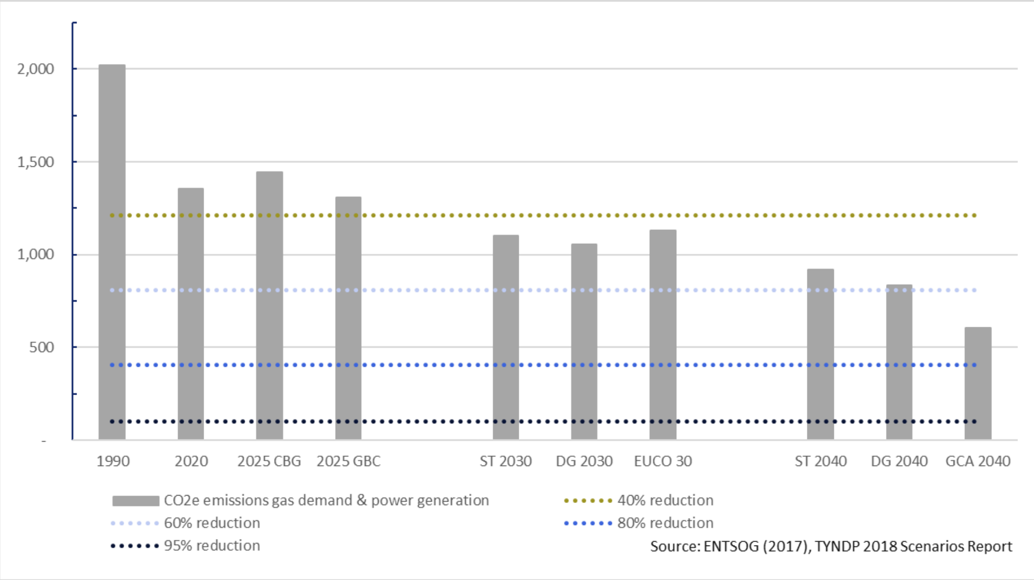
The current infrastructure framework is not yet Paris-compatible

The EU's energy infrastructure policies do not yet reflect the EU's Paris Agreement and other climate commitments. While important steps forward have been taken to make at least some of the ENTSOs' TYNDP scenarios consistent with EU 2030 targets, none of the scenarios have yet explored a Paris-compatible 2050 pathway.

The ENTSOs' most recent modelling still leaves a carbon footprint that exceeds 600 - 800mt CO_2e in 2040 from electricity and gas (or a 55-70% reduction on 1990 levels). [25] Considering that the energy sector is expected to decarbonise more swiftly than more challenging sectors such as industry and agriculture, this level of emissions is far from aligned with a net-zero pathway. A 'magic decade' of unprecedented change would be required in the 2040s to keep Europe on track.

The EU's 2050 climate roadmap – to be published by 2020 – will be an important moment to reassess long-term infrastructure needs.

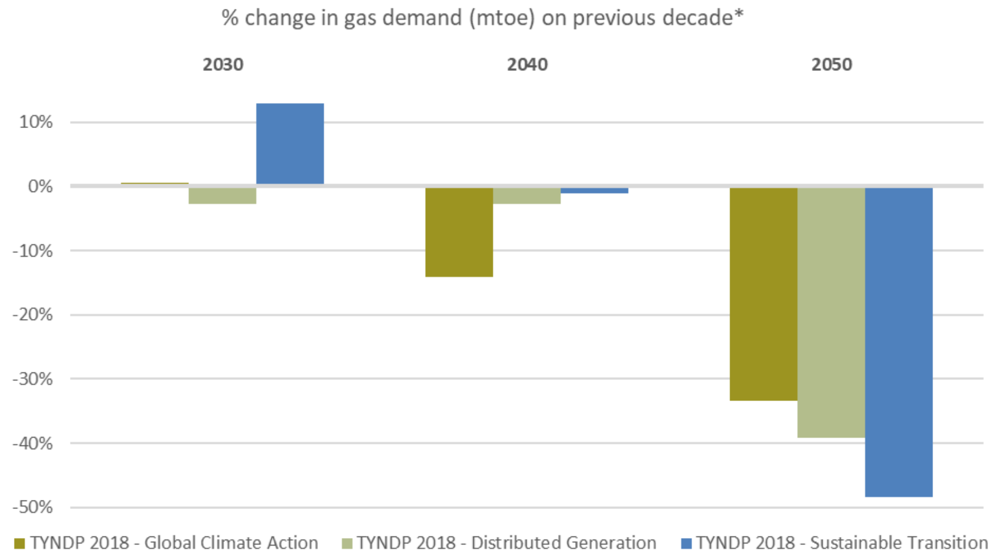
Figure 5: Electricity and gas sector CO_2e emissions and reductions (mt CO_2 equivalent)



2020 Expected Progress	2025 Coal before Gas	2025 Gas Before Coal	Sustainable Transition 2030	Distributed Generation 2030	EUCO 30 European Commission	Sustainable Transition 2040	Distributed Generation 2040	Global Climate Action 2040

[25] ENTSOG (2017), **TYNDP 2018 scenario report**

Figure 6: The 'magic decade': Current industry projections assume a delayed transition away from gas



* **Source**: Up to 2040: TYNDP 2018; 2050: EU 2050 roadmap.
Compliance with the Paris Agreement would likely require further cuts in gas demand (in the absence of CCS).

CHAPTER 3
REDEFINING ENERGY SECURITY

As Europe's energy system evolves, the security threats it is exposed to are changing. As existing risks are brought under control, new challenges are emerging. To protect European citizens, EU infrastructure policies and funding instruments need to re-define energy security to address new challenges to the energy system including flexibility resources, cyber security and climate change impacts.

(Re)defining energy security

Current energy security policies focus heavily on safeguarding the physical supply of energy. This includes coal, natural gas, oil, biomass, and nuclear materials for electricity, but also petrochemicals for transport. In this context, energy security forms one part of the 'energy trilemma' alongside energy equity and environmental sustainability.[26]

The European Commission released its 2014 energy security strategy to "ensure a stable and abundant supply of energy for European citizens and the economy". It was developed in response to the 2006 and 2009 Russian gas supply disruptions, as well as general concerns about gas import dependency levels (69% in 2015). [27]

EU energy security policies have evolved to contain a hotchpotch of overlapping objectives. In the gas sector, for example, targets include:

> **The N-1 criterion**: the network must be able to withstand the (temporary) loss of the biggest asset on the network.

> **Three supply sources**: the European Commission has suggested an objective of all member states having access to gas from three different supplier countries. Liquified natural gas (LNG) is only counted as one source despite providing access to multiple sources.[28]

> **Access to LNG**: the EU's LNG strategy sets an objective of all member states having access to LNG, either directly or via other member states.[29]

> **Stress tests**: As part of the 2014 Energy Security Strategy, the EU assessed the ability of the gas market to maintain supply in the context of a complete halt of

[26] World Energy Council (2016), **World Energy Trilemma – Defining Measures to Accelerate the Energy Transition**

[27] European Commission (2014), **European Energy Security Strategy**

[28] Commissioner Arias Cañete, **Speech at the Gas Infrastructure Europe 13th Annual conference**, 23 April 2015

[29] European Commission (2016), **EU strategy for liquified natural gas and gas storage**

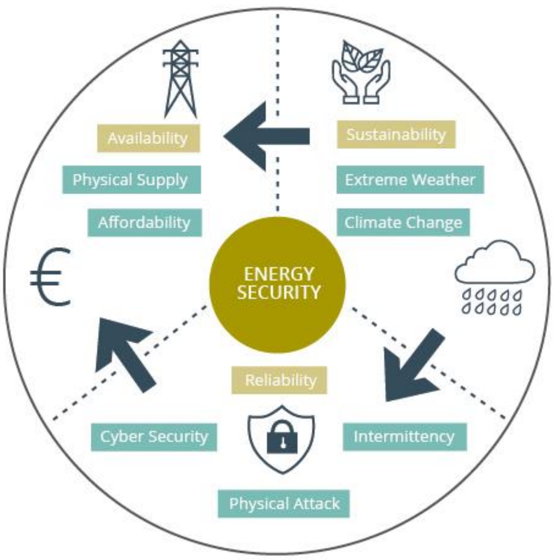
Russian gas imports to the EU or a disruption of Russian gas imports through the Ukrainian transit route, for a period of 1 to 6 months.[30]

The EU has made considerable progress on energy security according to these standards. A recent study demonstrated that existing infrastructure is largely already sufficient to ensure Europe is resilient to a range of shocks including extreme cold and a prolonged disruption of gas supply from Ukraine (with the exception of some specific problems in Southeast Europe).[31] The European Commission has assessed that by "by 2022/25, Europe should achieve a well interconnected and shock resilient gas grid" as a result of projects already underway[32].

However as currently framed, EU energy security objectives may not be a reliable guide for infrastructure investment needs. The current formulations underplay the role of the demand-side in managing exposure to security challenges. They neglect the integrated nature of the energy system and the interaction between gas and electricity networks. They lack attention to probability and to value at risk, which are key concepts for risk management strategies in other fields.

As the EU's energy system continues to change, a more comprehensive definition of energy security is needed to guide infrastructure priorities and investments. Beyond securing physical supply of energy, this new definition should address the value of demand-side and flexibility resources, reflect the integrated nature of the energy system and respond to new security challenges, such as climate risk and cybersecurity. These new energy security risks are highlighted below.

Figure 6: A more comprehensive definition of energy security



[30] European Commission (2014) **European Energy Security Strategy**

[31] Energy Union Choices (2016), **More Security, lower cost**

[32] European Commission (2017), **Communication on strengthening Europe's energy networks**

Spotlight: Cyber security and energy infrastructure

Digitalisation has increased the risk of cyber-attacks and disruption to systems. Energy system-level security has focused on the physical supply of energy, while for power stations and the grid it has been on securing the immediate physical environment. But as more processes become digitalised and infrastructure is integrated, the risk to the wider system increases.

In recent years there have been several high-profile cyber-attacks, notably the 2017 WannaCry and Petya attacks targeting businesses and governments globally.[33] The energy sector has also experienced targeted attacks to disable systems or collect operational information. In Ukraine in 2015 the hacking of three electricity distribution companies resulted in a six-hour blackout for 230,000 people, while the following year an attack took offline a fifth of the electricity supply in Kiev.

The use of data and computerised systems in system management is not new, but these operations were typically carried out using 'decentralised management systems' (DMS). These are self-contained and isolated from other parts of the network, using a so-called 'air-gap'.

The threat level from cyber-attacks has increased for two reasons: firstly, the digitalisation of operations and management means the energy system is more susceptible to attack because there are more entry points for cyber attackers. Secondly, systems that were previously operated in isolation as a DMS are increasingly interconnected with the rest of the system via the internet, making 'air-gapping' harder to implement. Different nodes of production and consumption are becoming increasingly interconnected, meaning attacks can spread.

Investments in cyber-security measures, however, can be difficult to fund. Unlike investments to guard against physical disruption (for example new pipelines or power lines), cyber security investments are less tangible. The costs of software, expert advice and computing upgrades may not always be fully met either by regulated tariffs or EU investment. Ultimately, an EU-wide legislative framework for cyber security measures may be needed, alongside a unique investment facility for cyber security infrastructure, so it is not in competition with other sectors seeking infrastructure investment.

[33] Financial Times, **Petya attack raises fears of escalation of global cyber arms race**, July 2017

European Commission response: cyber security directive

In 2016 the European Commission adopted the Directive on security of network and information systems (NISD), which will come into force in 2018. This sets out the legal framework for addressing cyber security, and sets out a series of requirements for member states including the establishment of designated cyber response teams and national authority, and formal cooperation among member states. Key sectors which have a heavy reliance on ICT – including energy – will be required to notify authorities of serious incidents.

ENTSO-E has proposed creating a new network code for cyber security to ensure that transmission system operator security systems conform to a standardised set of requirements. This is particularly important in view of how interconnected member states' electricity systems are. In 2017, ENTSO-E signed a memorandum of cooperation with the European Network for Cyber Security on developing cybersecurity regulation, practices, and standards for Europe's power transmission system.

Spotlight: Extreme weather from a changing climate

Weather events present short-term risk to infrastructure, while long-term climate change alters structural energy trends. Climate change-related weather risk has increased in recent years and will continue to rise in the future[34]. This poses a critical threat to thermal electricity generation infrastructure in three principle ways: higher air temperatures, water cooling ability (*higher water temperatures and reduced availability*); and flood risk. Changing weather patterns will also affect electricity generation from renewables.

Higher air temperatures

Higher air temperatures and warmer weather pose a threat to the power generation sector as they reduce the efficiency of electricity generation. The efficiency of coal and gas fired plants falls by 0.8-1% for every 1°C rise in the air temperatures. Warmer air contains less oxygen, therefore reducing the efficiency of burning fuel to generate heat for the turbines.[35] At a network scale, electricity grid efficiency falls by 1% for every 3°C of temperature increase.[36] Efficiency also falls if cabling and components expand under warmer conditions, while transformers in substations are also less efficient with higher air temperatures.

Water: higher temperatures and reduced availability

Thermal power generation from fossil fuel or nuclear plants requires large volumes of water for creating steam to drive turbines that generate power, and for the cooling of

[34] United States Environmental Protection Agency, **Climate Change Indicators**

[35] European Commission (2011), **Investment needs for future adaptation measures in EU nuclear power plants and other electricity generation technologies due to effects of climate change**

[36] Drax, Blog: **What hot weather means for electricity**, August 2017

machinery. The warmer the temperature of water used for cooling is, the longer it takes to cool down in cooling towers. This reduces the efficiency of the power station and reduces output. Warmer ambient conditions can also raise the temperature of water sourced from rivers, lakes or the sea that is needed for cooling, making it too warm to be used.

The use of water in thermal power plants also exposes them to the risk of low water levels in rivers, as a result of reduced rainfall or drought. Equally, low levels of rain or winter snow fall can reduce river flow rate for hydro-electric plants. This affects EU member states in different ways, as power stations are located in different areas: for example, all nuclear power stations in the UK are located on the coast, while in France the majority are situated on rivers.

Flooding

Flooding of infrastructure can occur in different ways, including: fluvial (i.e. rivers); tidal; groundwater; surface flooding; sewers and drains; and reservoir failure[37]. These threaten infrastructure in different ways; for example, electricity substations are at more risk from flooding than overhead transmission lines. But when taken together, they pose significant risk to the whole electricity system. Generation infrastructure is at high risk from flooding as thermal plants are situated next to rivers of bodies to access water for cooling.

Electricity distribution and extreme weather

Weather-related supply disruptions are more frequent than technical failures, cyber or physical attack, and geopolitical disputes – with the latter typically seen more with oil and gas than electricity.[38] The scale of their impact greatly varies. Most of events affect only a small number of people, but they can also lead to much larger and more widespread electricity outages. For example, in 2012 superstorm Sandy in the US cut power supply to over 8.5 million people; in the UK over 1.5 million people lost power during a storm in October 1987, while flooding in 2007 cut off electricity supplies for over 500,000 people.

Extreme weather events do not affect the different levels of the network equally. More disruption occurs on the distribution network than the transmission or generation level. This is because distribution networks are more prone to damage from high winds, falling trees and localised flooding, and there is also a higher number of distribution assets.

The EU distribution network totals close to 1 million km, but the transmission network is just under 500,000 km (including both AD and DC connections). In planning, less resilience is built in to the distribution level because of the relative size of the network and the cost to securitise it. The disruption for consumers is also typically lower during each event.[39]

[37] Evans, Lawrence, Brindley (2016), **National Grid Flood Resilience Programme**, Water Projects Online

[38] Banks, Ebinger (2010), **The Geopolitics of Electricity**, Brookings

[39] House of Lords Science and Technology Select Committee (2015), **The resilience of the electricity system**

Managing climate-related infrastructure risks

When considering the risk that climate and extreme weather pose to energy security, it needs to be established which parties are responsible for assessing climate risk – be it institutional actors, regulators, or project and infrastructure developers.

Policy development at an institutional level should include climate impact scenarios in project modelling and infrastructure forecasts. The risk of weather events and climate change to infrastructure is already part of contingency planning and insurance for companies in the energy sector and governments; however, the frequency and magnitude of these is set to increase. This increase in extreme weather events – not just in average temperatures - should be reflected in modelling and planning carried out by institutional actors such as ENTSO-E and ENTSOG.

CHAPTER 4

REDRAWING THE BOUNDARIES OF ENERGY INFRASTRUCTURE

The integrated nature of modern energy networks is blurring the boundaries between infrastructure types. Increasingly interconnected transport, heat, digital and energy systems offer considerable opportunities but stretch the limits of the current regulatory framework.

The 2013 TEN-E regulation focused on a specific set of infrastructure types: high voltage power lines above 220 kV and cables above 150 kV; electricity storage connected to high voltage lines; 'smart grid' technologies; gas and oil pipelines, storage and LNG terminals; and carbon dioxide transport infrastructure for carbon capture and storage.

As Europe's energy system evolves, the ecosystem of energy infrastructures is becoming more diverse. A broader set technologies and techniques can replace or complement traditional infrastructure investments – including energy efficiency and demand flexibility, system integration between gas and electricity, sector coupling of heat and transport, and multipurpose projects that combine interconnection and generation assets. A broader conception of 'infrastructure' is needed.

Demand-side resources are infrastructure

Demand-side resources (including energy efficiency and demand response) can directly replace infrastructure need and offer additional benefits to consumers. The EU will benefit from improved energy security through less dependence on imports or timely domestic production. Customers can save twice - lower network charges on their bills because the distribution company avoided or reduced the scope of costly network investments and co-benefits from energy efficiency such as improved health and comfort.[40]

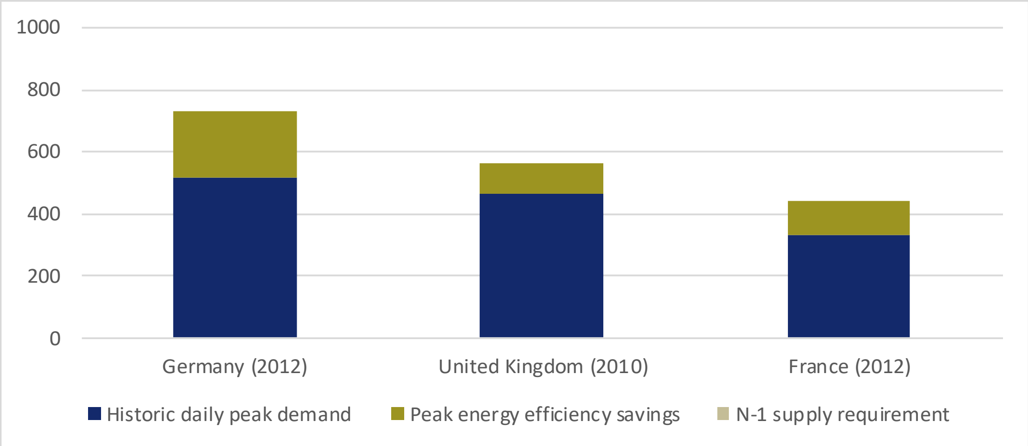
Energy efficiency and demand-side management are already shaping EU infrastructure needs. The International Energy Agency finds that energy efficiency has been an effective tool to maintain a high level of energy security in Europe - it estimates that Germany's historical peak daily gas demand in 2012 would have been 41% higher without energy efficiency measures. France and the United Kingdom

[40] EURACTIV (2017), **The future of network regulation: Let's pay consumers to support the grid**, 25/09/2017

would not have met the EU's security of supply indicator (n-1) with current supply infrastructure without energy efficiency measures since 2000.[41]

Figure 7: Historical peak daily gas demand and energy efficiency savings in selected European markets (million m³)

Source: IEA (2017), Energy efficiency at crossroads



In many instances, the business case for energy efficiency or demand-side flexibility will be as strong or stronger than additional grid or gas network infrastructure. Demand-side investments have been successfully used to defer or eliminate the need for new network investment.[42] However at European level, there is currently no requirement to evaluate projects against potential demand-side alternatives – meaning the potential benefits of 'efficiency as infrastructure' will be missed.

Gas and electricity are not separate networks

A further opportunity comes from integrating the planning and operation of electricity and gas grids. Co-optimising gas and electricity networks can reduce gas network investment needs by up to half, as re-dispatching electricity can address gas security problems.[43]

Recently, the ENTSOs have moved to a joint scenario development for the TYNDP. This is an important first step in developing a more efficient understanding of our network needs. However, the models used still show significant shortcomings according to the Agency for Cooperation of European Energy Regulators (ACER) in "assessing potential competition and synergies of electricity and gas infrastructure

[41] International Energy Agency (2017), **Energy Efficiency at Crossroads**

[42] For case studies, see RAP, E3G et al (2016) **Efficiency First: from principle to practice**

[43] Energy Union Choices (2016), **More Security, lower cost**

developments" and "cross-sectoral influences of gas and electricity projects" and they lack the ability to translate gas market developments into infrastructure needs. [44]

Gradual progress in terms of integrating modelling needs to be translated into integrated decision making. Gas and electricity projects of common interest are still evaluated separately in the TEN-E regional groups. A move to joint assessments will be needed to maximise the synergies between electricity and gas and minimise the risk of overcapacity. The forthcoming EU gas market design proposals offer a further opportunity to maximise the synergies between gas and electricity networks.

Electrification of heat and transport can become a burden or resource

Sector coupling including the electrification of transport and heat is increasingly pursued as a means of decarbonising wider sectors of the economy. Depending on the approach taken, electrification will either be a challenge for Europe's energy infrastructure or a resource.

In transport, for example, the rise in electric vehicles is expected to increase electricity demand, while reducing consumption of petrol and diesel. The European Environment Agency projects that electric transport could represent 4-5% of EU power demand by 2030 and 9.5% by 2050, compared to 0.03% in 2014.[45]

The use of 'passive charging' alone would put new pressures on the electricity network by increasing demand at peak times. This could lead to requirements for new power generation capacity and distribution grid upgrades to handle the additional load. The European Environment Agency estimates an additional electrical capacity of 150 GW will be needed to charge electric cars if only passive charging is used.[46] Passive charging could lead to larger challenges in countries with weak distribution grids, once electric vehicles go beyond 10% of the fleet.[47]

By contrast, other analysis shows that if all electric vehicles used smart charging, the peak load would remain stable, even in a 100% electrification of cars scenario. The utilisation rate of the electricity grid improves by around 14% (due to higher demand off peak), leading to lower grid tariffs per unit.[48]

Sector coupling requires a more integrated approach to infrastructure planning. However, transport and energy priorities in the Connecting Europe Facility appear out of step. Transport projects only qualify for CEF support if in accordance with the TEN-T regulation of 2014. The priority list in this regulation does not include smart charging

[44] ACER Opinion (2017) on **"THE ENTSOS' DRAFT CONSISTENT AND INTERLINKED ELECTRICITY AND GAS MARKET AND NETWORK MODEL"**
[45] European Environment Agency (2017), **Electric vehicles and the energy sector - impacts on Europe's future emissions**
[46] European Environment Agency (2017), **Electric vehicles and the energy sector - impacts on Europe's future emissions**
[47] Öko-Institut, TNO, Trinomics, Transport & Mobility (2016), **Electric mobility in Europe – Future impact on the emissions and the energy systems**
[48] Eurelectric (2015), **Smart charging: steering the charge, driving the change**

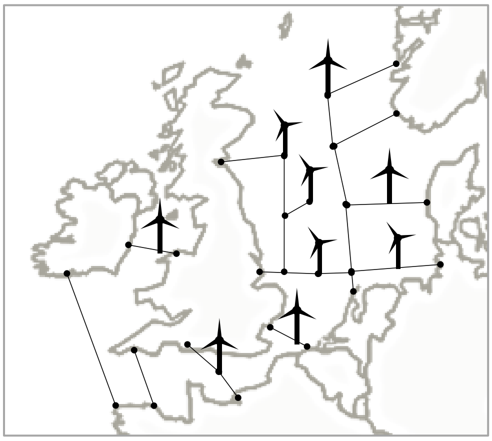
explicitly. Without an update of these priorities, it is difficult to reflect recent fast technology developments, such as the increasingly fast uptake of electric vehicles.

As a result, only around 2% of CEF transport money are dedicated towards the CEF objective of deploying sustainable and efficient transport.[49] CEF 'Synergy' projects (aimed at contributing to both energy and transport priorities) have struggled to be realised as they have to fulfil multiple sets of criteria, and only half the budget for the first call was spent.[50]

Accommodating multi-purpose infrastructure – the example of the North Seas Grid

The EU benefits from optimal conditions for offshore wind, thanks to strong winds and areas of shallow water depth largely concentrated in the North Sea. Ten countries have signed a Memorandum of Understanding at the beginning of this decade declaring their intention to work together to harness this large renewable energy potential[51].

Figure 8: Illustrative North Seas offshore electricity grid



An integrated approach to offshore electricity grid development in the North Seas lead to €25-€75 billion savings in operation and network investment costs as well as €3.4-€7.8 billion in generation investment costs, lowering average cost of electricity production by 0.8-2.2 €/MWh. However, if each country develops its own renewable power supply and network infrastructure independently from their neighbours, there will be no possibility for offshore wind generators to directly dispatch electricity to different markets other than that of the connected country.[52]

[49] European Commission (2017), **The Connecting Europe Facility: Mid-term results**

[50] Ibid, €22.1m out of €40m.

[51] Memorandum of Understanding (2010), **The North Seas Countries' Offshore Grid Initiative**, the UK signed it in 2016.

[52] Imperial College London, E3G (2014), **Strategic Development of North Sea Grid Infrastructure to Facilitate Least-Cost Decarbonisation**

The North Seas offshore grid concept is also a challenge for the regulatory regime, which treat generation and interconnection separately, and were not designed to support multipurpose infrastructure. For example, although the North Sea offshore grid has been designated a ‘priority corridor’ in the TEN-E regulation, it is not clear that the Connecting Europe Facility would be able to invest in projects that combine offshore wind with interconnection due to project selection rules.

CHAPTER 5
RESPONDING TO UNCERTAINTY IN THE INFRASTRUCTURE TRANSITION

The macro trends of decarbonisation, digitalisation, decentralisation and sector coupling outlined in previous sections will lead to radical changes in volumes and flows of energy through European infrastructure networks. The precise timing, location and nature of these changes remain uncertain. Given the speed of change and long lead times for major infrastructure projects, decisions need to be taken before the uncertainties will be fully resolved. Instead, EU energy infrastructure policies and institutions will need to be re-tooled towards actively managing the uncertainties of the transition.

This section outlines the major uncertainties facing EU electricity and gas network planning and tools for their management.

Uncertainties facing electricity networks

An expanded and integrated European electricity grid is a common feature of many decarbonisation scenarios.[53] Variable renewable energy is easier to integrate when smoothed out over a larger area, and greater interconnection enables renewable generation to be sited in the most productive locations.

Nevertheless, there are major uncertainties facing network planners on future electricity infrastructure needs. These include:

> Volumes and profile of power demand, particularly related to electrification of transport and heat (which increases electricity demand) and take-up of energy efficiency and digitalisation technologies (which lowers demand).

> Location and type of generation and other resources, particularly including timing and extent of distributed/demand-side technologies.

These factors will shape grid investment, with significantly higher investment needs for new capacity in high renewable energy / heavily centralised / high demand scenarios, compared to high renewable energy levels in more distributed and low demand scenarios.

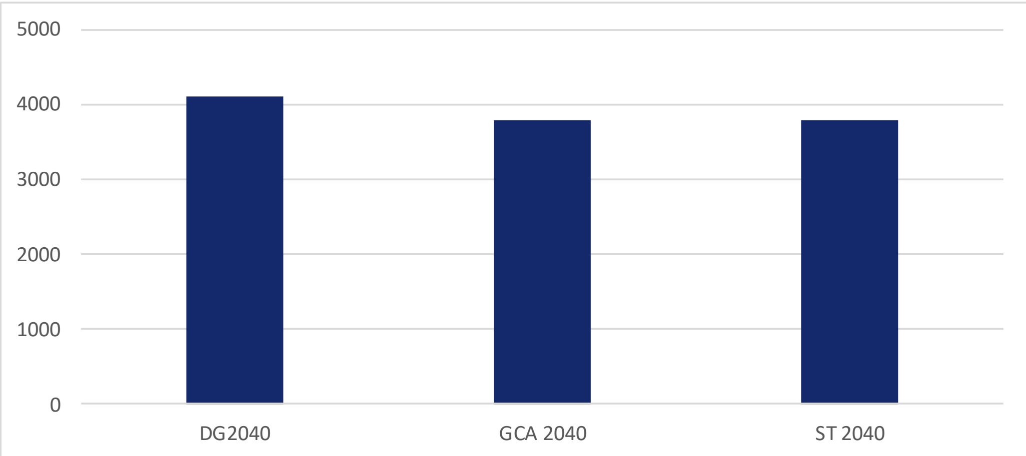
[53] Examples include: European Climate Foundation (2010), **Roadmap 2050**; E-Highway 2050 (2015), **Europe's future secure and sustainable electricity infrastructure**

However, the decision point for choosing between pathways in the electricity sector has not yet been reached, so there may be value in keeping options open. Current electricity grid infrastructure has not kept pace with the development of renewables and the move to an integrated European market is suboptimal even for the current system. Analysis suggests that significant new transmission investment is still economically desirable in a 'small and local' scenario – although considerably less than in a centralised 100% renewables scenario.[54] This means that many investments will be low regret.

Uncertainties in future energy system developments are typically managed by scenario analysis. ENTSO-E and ENTSOG produce multiple scenarios to inform their Ten-Year Network Development Plans, to reflect different storylines about the future.

Yet this scenario process may be underselling the full extent of uncertainty facing EU power systems. In the most recent ENTSO-E and ENTSOG projections, the scenario with the highest power demand in 2040 is only 8% higher than the scenario with the lowest. This would imply the uncertainty range on power consumption for 2040 is lower than the volatility experienced over the past decade.

Figure 9: Electricity demand in 2040 – ENTSO scenarios (TWh, TYNDP 2018 scenarios)



Part of the challenge is that current consumption and generation patterns are no longer reliable guides to the future: significant technological and social disruption is likely. Current transmission system operators cannot be expected to have full clarity on how these trends will materialise.

The ENTSO-E and ENTSOG scenario development processes are commendably open to external stakeholder participation, but the range of stakeholders who find the time and inclination to participate remains relatively narrow, with limited participation from 'new energy' actors.

[54] E-Highway 2050 (2015), **Europe's future secure and sustainable electricity infrastructure**

This points to the need for a strengthened 'foresight' analysis as an input into scenario development, drawing on state of the art assessments of technologies both within and outside the power sector, and assessing more granular demand data from distribution system operators. The need for this strengthened foresight analysis is not unique to network planners: it is a function that would also strengthen European Commission modelling for impact assessments and the development of National Energy and Climate Plans. As a result, it would make most sense to task the Joint Research Council or a new European Energy and Climate Observatory to fulfil this function.

Uncertainties facing gas networks

Gas networks share the same uncertainties as electricity, but the challenge is even more stark. Meeting Paris Climate Change Agreement objectives for moving to a net-zero economy means phasing out unabated fossil gas by mid-century – within the lifetimes of new infrastructure planned now. Yet the exact pathways of the transition are uncertain and – as with electricity – disruptive technologies and business models are likely to change gas infrastructure utilisation even over the near term.

This changes the role of EU infrastructure policy: it is no longer solely about ensuring sufficient infrastructure provision, but rather about securing an orderly transition as the role of gas changes.

From growing the network to managing decline

A core function of EU infrastructure policy has been to identify and accelerate development of new priority infrastructure, particularly those needed for security of supply. This is among the key roles of the Trans-European Networks – Energy (TEN-E) framework and the development of Projects of Common Interest, as well as funding under the Connecting Europe Facility.

In the gas sector, however, the necessary infrastructure to ensure security of supply is nearly complete, and further investment needs for market integration are limited.[55] This raises questions about the future role of the PCI list and Ten-Year Network Development Plan into the 2020s and beyond.

At the same time, declining gas demand will put new pressure on EU gas networks. As gas usage falls in the context of a decarbonizing economy, eventually parts of the network will be costlier to maintain than to decommission. However, decommissioning individual lines will have consequential impacts for the rest of the network. The question of who pays for network infrastructure will become increasingly challenging as fixed costs are shared across a smaller number of remaining customers.

[55] European Commission (2017), **Communication on strengthening Europe's energy networks**

This means a changing role for ENTSOG and TYNDP process: not only developing new network infrastructure but monitoring sustainability of existing infrastructure and planning an orderly transition.

What role for 'alternative gas'?

A further uncertainty is the potential of 'alternative gas' pathways, including use of biogas, synthetic gas and hydrogen, to enable a continued role for gaseous fuels even in a low carbon system.

Types of alternative gas

Biogas: Methane produced from organic matter (e.g. farm and sewage wastes) through a process known as anaerobic digestion. Can be injected into conventional gas grids.

Hydrogen: Hydrogen is a flammable gas that can be sourced in multiple ways, but there are two principal modes of bulk production:

Electrolysis: Electrolysis involves using electricity to split water into hydrogen and oxygen. It can be renewable if the electricity used in the process comes from renewable sources ('power-to-gas').

Steam Methane Reformation (SMR): SMR chemically converts methane (natural gas) to hydrogen. If excluding the cost from capturing the CO_2e emissions (CCS) it is the most economical way to produce bulk hydrogen.

Advocates of these options point to several potential benefits:

> They may allow continued utilisation of existing gas infrastructure (largely a sunk cost), and could provide the potential to avoid or defer upgrades to electricity transmission and distribution infrastructure.

> They provide an alternative option to full electrification in the heat sector.

> Hydrogen can play an important role in decarbonising industrial applications.

> Producing hydrogen through electrolysis and storing it in the gas network can act as a form of electricity storage and make use of 'excess' electricity.

While there has been considerable speculation about these potential options, the evidence base remains thin.[56] A full assessment of implications for EU gas infrastructure has not yet been performed.

[56] For useful summaries, see: Policy Connect and Carbon Connect (2016), **Next steps for the gas grid**; Sustainable Gas Institute (2017), **A greener gas grid – what are the options?**

In the near term, 'alternative gas' will compete against unabated fossil gas. If it succeeds, this could mean considerable changes to gas market flows resulting from a different geography of production. Hydrogen produced from electrolysis is likely to be produced close to large renewable generation sites or imported from regions rich in renewable energy resources (Iceland, MENA). Biogas will be produced on a distributed basis and predominantly consumed locally, although some gas transmission system operators are investigating the potential for biogas in local distribution networks to feed in to transmission networks.

As a result, even a high share of alternative gas will not necessarily mean all current and planned gas infrastructure will continue to be utilised. In particular, major pipeline and LNG import infrastructure could be jeopardised by a combination of substitution by domestically-produced alternative gas and lower overall demand.

There are major uncertainties still facing the development of alternative gas:

> The production of biogas faces resource availability constraints. Use of crop-based bioenergy resources rather than agricultural wastes would risk competing with food production. In Germany for example, two thirds of sustainable biogas potential is already in use.[57]

> Future costs are uncertain but current costs are considerably higher than fossil gas.[58] Cost competitiveness against alternative options in the power and heat sector cannot yet be determined.

> Lifecycle emissions of alternative gas is also a concern in the context to the move to a net-zero emissions system by mid-century. The upstream production emissions of the natural gas used to produce hydrogen from steam methane reformation – even when used with CCS – may be incompatible with a fully decarbonised system.

> The potential for using existing infrastructure is also uncertain. In the case of hydrogen, upgrades to gas infrastructure may be needed because of the different physical properties of the gas. Widespread use of biogas could require investment to allow distribution networks to feed into transmission networks (the reverse of current configurations).

> Consumer acceptance is a further uncertainty in the case of a switchover to hydrogen, as all gas boilers and appliances in a given network would need to be replaced from the moment the switch takes place.

> Finally, speed of deployment is also a critical uncertainty. ENTSOG scenarios point to alternative gas sources representing less than 10% of gas consumption by 2040, with some in the industry projecting a faster rollout.

[57] Fachagentur Nachwachsende Rohstoffe (2015), **Biomassepotenziale von Rest- und Abfallstoffen**

[58] Sustainable Gas Institute (2017), **A greener gas grid – what are the options?**

Given the challenges facing decarbonisation of heat and transport, there is value in developing and testing options including hydrogen.

However, given the uncertainties involved, at this stage a potential future switch to hydrogen or other alternative gas sources should not be used to justify continued investment in new fossil gas infrastructure.

Instead, further evidence on both the technical and policy pathways for decarbonised alternative gas sources is needed. This includes larger-scale demonstration projects to build better evidence on costs and feasibility, and more sophisticated deployment scenarios assessing potential supply routes and volumes – including gas infrastructure implications.

On the policy side, a more credible pathway for the transition from fossil gas to decarbonised gas is needed before alternative gas sources can be expected to play a significant role. Options to be explored include an escalating carbon tax on fossil gas (to prioritise decarbonised sources) and a target phase out date (of 2050 or sooner) for the transition from fossil gas to decarbonised gas to be completed.

CONCLUSIONS
THE WAY FORWARD

The new challenges to Europe's energy infrastructure are increasingly recognised by actors across the system. Finding appropriate solutions will require re-tooling EU approaches to infrastructure planning, financing and institutional governance.

This paper has outlined the infrastructure implications of the macro-trends of decarbonisation, decentralisation, digitalisation and sector coupling. These implications include the need to realign infrastructure policies with EU climate objectives, update our approach to energy security, redraw the boundaries of infrastructure categories and develop tools to manage endemic uncertainty.

The European Commission's new communication on "Strengthening Europe's Energy Networks" recognises these challenges. It argues "well interconnected and integrated trans-European grids are indispensable for making the energy transition a success"; highlights the importance of sector coupling, digitalisation and demand flexibility; and signals a change in priority from gas infrastructure investment to electricity interconnection and smart grids. Reforms are now needed to put this change of emphasis into practice.

The current policy landscape offers important opportunities to instigate reform. As part of the Future of Europe process, the European Commission is developing a communication on the Future of EU Energy and Climate Policy to 2025, to be published in early 2018. Proposals for the EU's post-2020 multi-annual financial framework, including the future of the Connecting Europe Facility, will be published in May 2018. Work will soon begin on a new EU 2050 roadmap to set out how the EU can fulfil its Paris Agreement commitments by mid-century.

Infrastructure planning

EU energy infrastructure planning must become more closely aligned with EU climate commitments and with the changing nature of the energy system.

> The current tools and the processes associated with the TEN-E regulation need to be updated to align infrastructure planning with the Paris Climate Change Agreement and Europe's climate strategy. The EU will develop a new 2050 roadmap by 2020, as part of its Paris Agreement commitments. This will set out scenarios and pathways for decarbonising the European economy. In parallel to this exercise, **a new assessment of EU infrastructure priorities for a delivering a net-zero energy system by mid-century should be conducted, and should steer the selection of future Projects of Common Interest and Connecting Europe**

Facility spending. The 2050 roadmap and net-zero objective should also be built in to the ENTSOs scenarios for Ten Year Network Development Plans.

> Energy security has typically focused on physical supply, but it needs to be conceptualised in a more comprehensive manner. **Definitions of security of supply in infrastructure planning should be reassessed, incorporating changing electricity and gas demand patterns.** Although physical supply remains important, climate change and the risk posed by extreme weather events should have a more prominent role in infrastructure planning. Cyber security and protecting digitalised operations also needs to have a prominent position in how energy security is reconceptualised.

> The risk of weather events and climate change to infrastructure is already part of contingency planning and insurance for companies in the energy sector and governments; however, the frequency and magnitude of these is set to increase. **Climate impact scenarios – including risk of extreme events – should be incorporated into infrastructure priorities and project evaluations**, and reflected in modelling and planning carried out by actors such as ENTSO-E and ENTSOG.

> The rapid pace of the energy transition results in endemic uncertainties that makes long term investment decisions more challenging. **European energy infrastructure planners need to consider a wider range of scenarios** to understand the spread of risk, and develop tools to assess the value of different investments in the face of uncertainty.

Financing

Financing flows should be channelled towards the low carbon infrastructure of the future.

> The European Union has committed to phase out fossil fuel subsidies by 2025, and projects already under development are adequate to meet gas security needs. We see **no case for EU budget funding for fossil fuel infrastructure post-2020**. The EU's next multiannual financial framework should make this commitment clear.

> The integrated nature of modern energy systems challenges the boundaries of traditional infrastructure definitions. **The Connecting Europe Facility should be continued and expanded in the next EU budget period, but broadened to cover a considerably wider range of infrastructure investments**. Priorities include integrated offshore grid projects combining offshore wind generation and interconnection and smart charging infrastructure for electric vehicles.

> Demand flexibility and demand reduction can directly replace the need for new infrastructure investments. **Candidate projects for Connecting Europe Facility support should be evaluated against demand-side alternatives, and demand-side investments should be eligible for support under the Connecting Europe Facility where they replace the need for new network investments.**

- Smart grids are crucial for decarbonisation and placing the consumer at the heart of the energy system. However, smart grid investment falls through the cracks in current EU infrastructure policy, with only a handful of projects selected as Projects of Common Interest. **Decisions are needed on whether to fundamentally reform the PCI and CEF systems to strengthen support for smart grids, or whether a separate regime for smart grid support is needed instead.**
- Securing sufficient investment for new energy security challenges is a priority, as the investments needed do not conform to traditional infrastructure types. **A review should be conducted of whether current regulatory arrangements and funding instruments are adequate to incentivise investments in cyber security, climate resilient infrastructure and flexibility resources.**

Institutions

Institutional roles and responsibilities need to adapt to keep pace with the changing energy system.

- The current framework for assessing projects of common interest is based on a set of 'priority corridors' that no longer represent the most pressing challenges facing Europe's energy system. **The regional groups approach for assessing projects of common interest should be refreshed on the basis on a new infrastructure needs assessment**. In particular the regional groups should be based on a clear set of objectives, integrate assessment of gas and electricity projects and consider demand-side alternatives.
- **A more coordinated picture of the drivers of demand should be developed, including through bridging the institutional gap between distribution and transmission system operators.** The largest shifts in energy infrastructure are observed at distribution level, having knock-on impacts on transmission networks. A formal institutional link between data collection and planning between both system levels will enhance planning accuracy.
- Finally, **the rapid changes in European energy markets and technologies point to the need for a strengthened foresight function at European level**, to develop a consistent outlook for potential energy system changes. This role could be delivered either through the Joint Research Council or through a new European Energy and Climate Observatory. This foresight function would help guide network planning scenarios and EU energy infrastructure policy more broadly.