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Abstract

Digitalisation is the innovative use of information and communications technologies, in particular the large-scale rollout of smart devices and sensors, and the use of big data collection and analysis. In the context of meeting the energy savings targets of the European Union and improving the energy efficiency of its buildings, this Joint Research Centre Technical Report looks at the technologies, opportunities and challenges presented by digitalisation for heating and cooling. The report provides real-world examples and highlights key policy initiatives and research projects.

Digitalisation in heating and cooling has received less attention than digitalisation in other areas, such as household appliances or transport. Yet heating and cooling accounts for around half of final energy consumption. Therefore it is essential to better understand the potential of digitalisation for these end uses, and the technologies with most relevance, in order to develop appropriate policies and prepare the ground for new investment.

By analysing the available literature, it is shown that there is a significant opportunity for energy savings and other benefits. However, there is also a possibility that energy savings might not be as large as expected, for example due to the energy consumption of digital technologies themselves, and there are important risks to be anticipated in other areas (privacy, cybersecurity, the digital divide, etc.). New policies – both energy and digital – could mitigate those risks and ensure that the best technologies and business models prevail.

1 Introduction

This JRC Technical Report provides an overview of technologies, challenges and opportunities associated with digitalisation for heating and cooling, along with real-world examples and policy initiatives. Until now, digitalisation in heating and cooling has received less attention than digitalisation in other areas, such as appliances or transport. Yet heating and cooling is vital for comfort at home and at work, and (although the report focuses mainly on buildings) process heat represents about two-thirds of industry energy demand. Moreover, and perhaps more importantly, energy systems are increasingly interlinked. Therefore it is essential to better understand the potential of digitalisation for heating and cooling, and the technologies with most relevance, in order to develop appropriate policies and prepare the ground for new investment.

1.1 What is digitalisation?

Digitalisation is the innovative use of information and communications technologies (ICT), in particular the large-scale rollout of smart devices and sensors, and the use of big data collection and analysis (Table 1). It can be used to optimise flows of heating and cooling, for example in response to prices and demand, as well as to reduce costs and enable new services.

A **smart meter** is an electronic device that records data on energy consumption and communicates it to suppliers for monitoring and billing. More advanced models enable two-way communication between the meter and the supplier, sometimes wirelessly. According to Recommendation 2012/148/EU, which covers smart meters for electricity and gas, they should update frequently enough to allow the information to be used to achieve energy savings, and they should enable consumer participation, particularly when paired with advanced tariff schemes. Similar devices exist for district heating and cooling. Under the revised Energy Efficiency Directive (EED, Article 9c), a transition to remotely readable meters and heat-cost allocators (radiator-mounted devices for metering individual apartment buildings) is required to be completed throughout the EU no later than 2027.

IoT (Internet of Things) is the ever-growing network of physical devices and objects that feature an IP address for Internet connectivity, and the communication that occurs between those objects and other Internet-enabled devices and systems. It allows remote devices to be easily monitored and controlled by facilities managers or households via smartphones or tablets.

IoT can allow households to remotely control their heating and cooling equipment, for example by combining temperature data with a set monthly budget. On the supply side, a key application for many IoT platforms is to use sensor and machine data in conjunction with analytical software to optimise reliability, increase availability and reduce operating costs. Solutions range from simple software packages to much more expensive IoT platforms.

IoT is closely related to **big data and cloud computing**. IoT collects data and takes action based on specific rules, cloud computing stores the data and big data analytics enables processing, interpretation and decision-making. In combination, they merge the physical and virtual worlds, creating **smart** environments.

The large volumes of data generated from equipment, machines and people, along with dramatic increases in computational power, are allowing machines to learn and become intelligent, in some cases surpassing human analytical capabilities. **Artificial Intelligence** (AI) is the ability of machines and systems to acquire and apply knowledge and to behave intelligently (OECD, 2016). It can indicate any technology (software, algorithm, set of processes, robot, etc.) that is able to function appropriately with foresight of its environment (EPSC, 2018).

Digitalisation provides significant opportunities for innovation, new business models, and smart products and services. In addition, new heating and cooling technologies could emerge that would be enabled and amplified by digitalisation. For example, clothes and other textiles could be redesigned to incorporate heating and cooling, which would be a radical shift from space heating to human comfort, with huge potential for energy savings (Futures CoLab, 2018).

Table 1. Elements of digitalisation for heating and cooling

<table>
<tr><td rowspan="2">Benefits</td><td colspan="2">Energy transition (energy bill savings, climate change mitigation, reduced air pollution), greater comfort and new services, innovation and competitiveness, improved policymaking</td></tr>
<tr><td>Decarbonisation (energy savings, renewable energy)</td><td>Decentralisation (distributed energy; district energy; smart buildings, communities and cities)</td></tr>
<tr><td>Barriers</td><td colspan="2">For households: need for expert knowledge, multiple changes and customisation
For housing developers: risk of delivering obsolete technology</td></tr>
<tr><td>Drivers</td><td colspan="2">Cost reduction > New revenue streams > Platforms > Distributed ledger technologies (Blockchain)</td></tr>
<tr><td rowspan="7">Components</td><td colspan="2">Mobile apps, notifications, dashboards, gamification, integration services, etc.</td></tr>
<tr><td colspan="2">BIM, BEMS, GIS, Big data analytics, AI</td></tr>
<tr><td>Data storage</td><td rowspan="2">Cloud</td></tr>
<tr><td>IoT hub, external data sources</td></tr>
<tr><td colspan="2">Controls and equipment, smart HVAC, DHC, water heaters, interconnection, network control</td></tr>
<tr><td colspan="2">Smart meters, sensors, drones</td></tr>
<tr><td colspan="2">Fixed and mobile broadband networks (3G, 4G, 5G)</td></tr>
<tr><td rowspan="3">Frameworks</td><td colspan="2">Cybersecurity</td></tr>
<tr><td colspan="2">Interoperability and standardisation</td></tr>
<tr><td colspan="2">Policies on privacy, data ownership and social impacts</td></tr>
</table>

BIM = Building Information Modelling, BEMS = Building Energy Management Systems, GIS = Geographic Information Systems, AI = Artificial Intelligence, IoT = Internet of Things, DHC = District Heating and Cooling, HVAC = Heating, Ventilation and Air Conditioning.

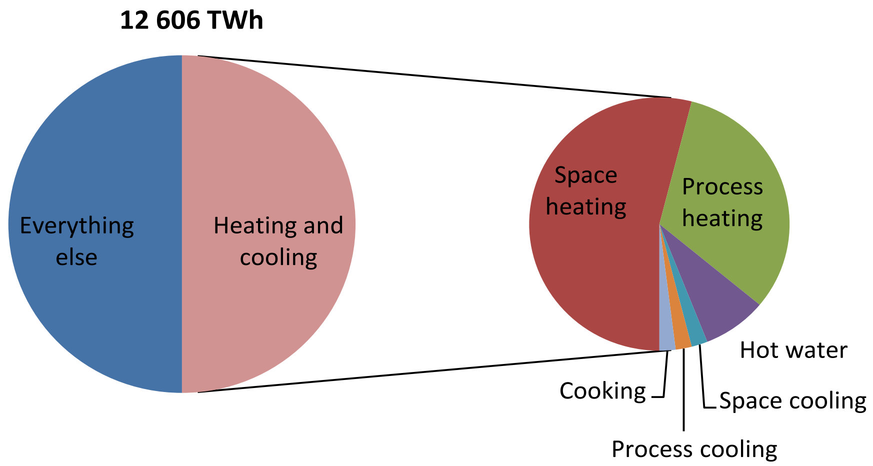
1.2 Why is it important for heating and cooling?

Heating and cooling is the largest end use of energy Europe. According to the latest available data, it is responsible for around 50 % of final consumption (Figure 1).[1]

[1] Final energy consumption is the energy that users purchase in order to enjoy a service such as heating or cooling.

Although cooling only accounted for 3.8 % of final energy in 2018, demand throughout Europe is expected to rise rapidly and is already quite significant in a few Member States (Nowak, 2018).

Figure 1. The other half: Final energy in the European Union by end use, 2015

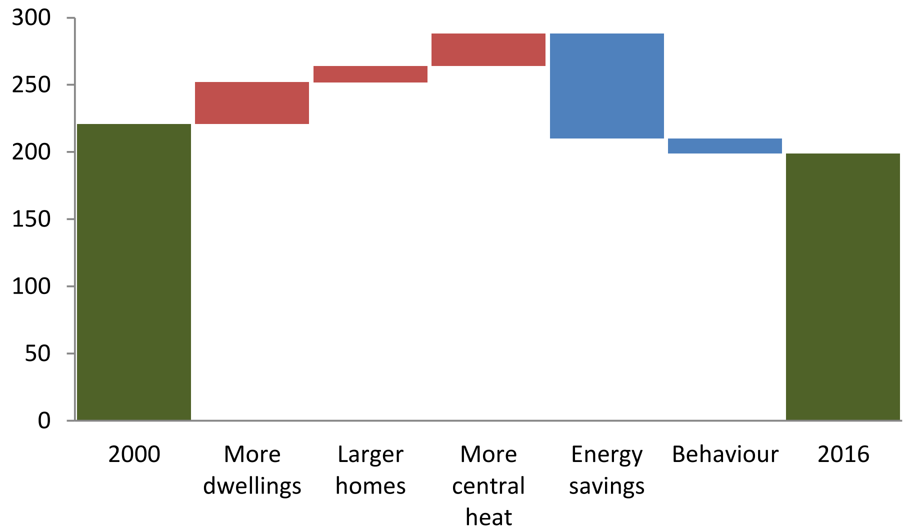


Source: HRE, 2018.

Buildings are responsible for around 80 % of final energy consumption for heating and cooling in the EU. Adoption and enforcement of building codes and deployment of more efficient equipment have improved the energy intensity of heating and cooling, offsetting other factors (Figure 2), but the energy intensity of heating per unit of floor area is still high, in part because of the cold climate. Also, although building energy codes in Europe are ahead of other world regions, about 75 % of the existing stock dates from before such codes were implemented.

In recent years however, progress seems to have ground to a halt: weather-corrected heating energy consumption has been quite flat since 2010 (Thomas, 2018). Energy renovation is not happening fast enough (the annual rate needs to increase to 2-3 % from 1.2 % today (Fabbri, 2017)) or deep enough (typical improvements in the 10-12 % range are insufficient and below the cost-effective potential) (IEA, 2016a). Moreover, average heating and cooling equipment efficiencies are still far below Best Available Technology.

Figure 2. Household energy consumption for space heating (normal climate) in the European Union (Mtoe), 2000-2016



Source: ODYSSEE, 2018.

Digitalisation is an opportunity to increase the share of heating and cooling demand met by a wide range of renewable energy sources. About 19 % of Europe's heating and cooling consumption is met by renewable energy (mostly solid biomass) (EEA, 2018). That share has been rising over time but slowly, and slower than the share of renewables in electricity overall. Technologies using renewables to deliver heating and cooling in buildings can be deployed in individual units of small capacity or in DHC in larger capacities. However, their penetration is very low despite being promoted by energy efficiency and renewables policies that increasingly include dedicated heating and cooling measures.

The Heat Roadmap Europe project showed that heating and cooling can be decarbonised affordably with existing technologies and that doing so would save primary energy too, allowing renewable energy capacity to be better used and reducing pressure on power-sector infrastructure (HRE, 2018). However, radical change is needed and digitalisation can be part of that change.

Digitalisation reduces the overall cost of decarbonisation by optimising operations, planning and business models, and by connecting producers of heat and cooling, users, local stakeholders and energy markets (Rothballer, 2018). It contributes to changes in energy market design and is a driver of smart buildings, smart communities, smart cities, distributed energy and district heating and cooling (DHC).

Yet in many buildings today, control is limited to a room thermostat at most. And even when thermostats are programmable, many building users do not know how to do so, or choose not to. There is still low awareness of the benefits of digitalisation for heating and cooling, or even that the technologies are available. In many cases, there is also a lack of good distribution, installation and service support.

Barriers include the need for expert knowledge, accumulation of multiple (albeit low-cost) changes, and customisation. For households, in terms of disruption and the length of intervention required, digitalisation falls somewhere between a lighting upgrade and the addition of insulation (Olsthoorn et al., 2017). For housing developers, the time to plan and build houses can be long (around five years), so the risk of delivering obsolete technology is a further barrier.

2 Smart buildings

There are applications of digitalisation for heating and cooling in design and planning, across production, distribution and use, and in the development of smart energy systems that integrate multiple sources of heat and cold. This report focuses mainly on buildings and in particular residential buildings, which account for 75 % of floor space in Europe (Pavel and Blagoeva, 2018). However, much of what is discussed is also relevant for the service sector and small- and medium-sized enterprises (SMEs).

At the design stage, a growing number of simulation tools are available to improve understanding of the interaction of the building components that contribute to energy demand. In particular, the Building Information Modelling (BIM) approach creates what can be called a "digital twin", recreating the entire building with all its systems on a computer and then simulating, testing and correcting it (Siemens, 2018). The first two parts of a new International Organization for Standardization standard were published in January 2019, providing a framework for managing information through collaborative working using BIM (ISO, 2019).

A low-cost first step is regular feedback (e.g. via smart meters, in-house displays, energy bills or emails). However, several studies show that it is hard to engage households in energy issues (de Beaufort et al., n.d.), especially if the information received is not clear, action-oriented and timely or frequent enough. The revised EED (Article 10a and Annex VIIa) lays down new, clearer and strengthened rules on the billing and consumption information to be provided to the final user of thermal energy supplied from collective sources.

There are far fewer systems on the market that go beyond basic information and visualisation to carry out advanced analytics. Building energy management systems (BEMS) combine software with smart thermostats and sensors to anticipate behaviour and use weather forecasts and energy prices to predict demand and manage heating and cooling. The aim is to optimise energy consumption and maintenance (with remote monitoring replacing some inspection visits), enable demand response, and improve comfort and environmental quality.

BEMS have been around for a long time but improvements in sensors and control technology, and the use of computers, have made them increasingly sophisticated and reduced costs. Increasingly, systems can be interlinked, for example by using sensors embedded in smart lighting to tailor heating and cooling. Systems can be managed by algorithms with minimal input from humans, or by authorised users on smartphones. AI can greatly enhance the potential by balancing energy saving and user-customised comfort.

As regards individual items of equipment, air conditioning for example can be improved using variable-speed drives (VSDs) and optimisation of controls (IEA, 2008). VSDs can modulate blower fans and pumps based on actual demand for heating and air conditioning. Some have a built-in controller based on a set of programmed instructions, others need an external controller. Other relevant technologies include switchable vacuum insulated panels, switchable mirror film on windows, automatic shades, integrated cooling of ICT equipment and integrated control of clean room conditions (BIO et al., 2008).

2.1 Examples

Temperature monitoring and heating control solutions are provided by many companies, e.g. Siemens or Centrica (Hive Active Heating). In the longer term, voice-activated home assistants such as Amazon's Echo or Google Home aim to be the single interface for home energy systems, with the utility as the enabler.

LeanHeat from Finland (46 % owned by Danfoss) provides smart building control and maintenance based on IoT and AI, in 80 000 apartments so far (LeanHeat, 2018). They claim 10-20 % energy cost savings for building owners with smart heating control, and up to 30 % savings in technical maintenance costs.

WattTime incorporates software in smart thermostats that adjusts the amount of electric heating and cooling (e.g. on-off cycles of air conditioners) according to the availability of renewable energy using real-time data from power-grid operators.

Tado is a smart thermostat and air conditioning control startup headquartered in Munich with total funding of USD 102 million since 2011 (Techcrunch, 2018). It plans to add proactive boiler maintenance, via data its app collects and analyses, and a network of 40 000 heating engineer partners. Longer term, Tado aims to benefit energy management overall, including at the grid level, through partnerships with local utilities (pilots are underway) that enable its customers to opt in to demand-response schemes so that a home's heating and cooling systems are used outside of peak times where possible. This could be as simple as turning the heat down slightly without it being very noticeable or heating the home a little ahead of time. This can make a tangible difference to grid stability. Tado's sales are around half to households and half to businesses, with investors including E.ON and Amazon (which has also invested in ecobee, another smart thermostat company).

BeeBryte is based in France and Singapore and provides automatic control of heating and cooling equipment based on weather forecasts, occupancy, usage and energy prices. It claims up to 40 % savings, using algorithms, cloud computing and IoT, and predictive analytics.

The "adapterm" service offered by the energy services company Techem uses temperature measurements from sensors in individual heat-cost allocators in apartment buildings with central heating to control and optimise flow temperature and operation (Techem, 2019).

The smart heating service offered by Fourdeg in Sweden takes into account the local weather forecast, number of open windows, number of occupants and characteristics of each room (Gunnarson and Melin Hamber, 2018). Heating is operated wirelessly using thermostatic radiator valves and gateways, compatible with other IoT devices and building automation.

Among other functions, the Trecobat smart home app developed in France can be used to improve maintenance. It would allow a heat pump to send an alert whereby the customer receives either a tutorial by text message or an appointment for a technician to intervene (Chauvot, 2018).

The Cosy system by the company geo is an electric heating management system for the Nordic market with advanced controls, including integration with Nord Pool Spokt Market and potential for peak lopping (smartEn, n.d.). Tiko Energy Solutions provides smart home energy systems in France and Germany that connect residential and SME storage assets to make a large-scale virtual battery, raising finance through the sale of primary balancing power to the electricity grid (Hill, 2018). Finally, Voltalis is another example from France of a company providing a demand-response solution free of charge by selling flexibility to wholesale electricity markets.

In Amsterdam's The Edge building, intelligent ventilation systems and connected LEDs are responsive to real-time data from sensors or occupant commands. This allows lighting levels, humidity and temperature to be adapted to building-user preferences, while also improving energy efficiency. In addition, the data is shared with occupants, enabling employees to locate workspaces that match their thermal comfort needs (Bloomberg in IEA, 2017a).

Sello is a shopping centre in Finland with 24 million visitors per year (smartEn, n.d.). Sello has been working with Siemens since 2003 and uses a cloud platform to monitor and optimise its ventilation units, room sensors and lighting. The results include better air flow, 680 MWh in electricity savings and 800 MWh of district heating.

3 Heat pumps

A heat pump transforms low-temperature heat from the air, water or the ground, or from waste heat, into high-temperature heat. Heat pumps are used to heat and cool buildings, as well as for some industrial applications needing low-temperature heat.

Heat pumps are particularly appropriate when both heating and cooling are required in the same location and they can be four to five times more efficient than condensing gas boilers (IRENA, 2017). In the EU, heat produced by heat pumps counts as renewable, subject to certain energy performance requirements. The overall environmental impact can be improved even further relative to fossil alternatives through continued progress in decarbonisation of the electricity grid and uptake of alternative refrigerants.

The European heat pump market grew every year from 2013 to 2017. More than 11 million heat pumps had been installed by the first half of 2018, with sales of 1.11 million units in 2017 alone (Nowak, 2018). About 85 % of homes in Austria and 45 % in Germany use heat pumps (IRENA, 2017); with both countries having offered special electricity tariffs for heat pump owners.

Heat pumps can be connected to storage in three ways (Nowak, 2018):

- a water tank can store domestic hot water and a second tank can store heat or cold for later distribution;
- if equipped with floor or wall heating, the thermal mass of a building can be used to shift demand;
- a battery can be used to run the heat pump at night.

In the first two cases above, the system provides a "thermal battery" to the grid: electricity is used in times of surplus to heat up the storage or the building core. In times of supply shortage, the stored energy is distributed to maintain comfort. Heat pumps therefore provide load-shaping and load-shifting services. In the third case, a battery increases the independence of the system. While battery storage is still expensive, costs are rapidly coming down.

A heat pump system with thermal and battery storage can provide heating and cooling for several hours or even a few days without needing grid electricity. This will help move demand off peak, and appropriate business models would make that economically advantageous. Demand-shifting will also probably be cheaper than maintaining reserve power plants or building new power generation and distribution infrastructure.

Digitalised heat pumps need sensors providing temperature data, access to weather data (in particular solar irradiation), access to electricity price signals, intelligent controls that can understand the thermal behaviour of the building and user comfort requirements; and smart controls that can use all that data to optimise the service (Nowak, 2018).

In the long term, individual heat pumps should supply the majority of demand in low heat-density areas (typically detached houses outside towns and cities) (HRE, 2018). However, heat pumps are also increasingly used in DHC. Starting from a few hundred kW, they can reach capacities of several MW – sufficient to supply a city like Helsinki or Stockholm. Combining central and decentralised heat pumps with energy grids and storage will provide flexibility and stability to the electricity grid in the most efficient manner (Nowak, 2018).

3.1 Examples

Currently, the largest installation of this kind is the Katri Vala heating and cooling plant in Helsinki: five large heat pumps use wastewater and the return line of the district heating grid as energy sources; they can generate 90 MW of heating and 60 MW of cooling. In addition, buildings serve as solar collectors and waste heat from ventilation processes is fed into the grid (Nowak, 2018). The GreenHP project analysed the load-shifting potential of heat pumps for Germany (www.greenhp.eu).

4 District heating and cooling

DHC systems are a major contributor to emissions reduction and primary energy savings in several Member States. They consist of networks of insulated pipes, pumps, energy sources and end users. Heat exchangers transfer heat from a district heating network to a building's own heat and hot water systems, while return water is pumped back to the heating plant. District cooling uses the same principles.

There are more than 6 000 district heating systems across Europe and many cities and regions envisage a growing role for them in their energy plans; some are also looking at district cooling, which is much less widespread as it requires more specialised conditions and more complex design (Euroheat & Power in IEA, 2016a).

Modern DHC is inherently flexible in terms of source, size and load. Although currently dominated by fossil fuels such as coal and gas, it can use any fuel including excess heat that is currently being wasted, renewables (solid biofuel, solar and geothermal) and co-generation. Each network develops according to local circumstances and adapts to continuous innovation such as digitalisation.

District heating could cost-effectively meet at least half of heating demand in 2050, up from 12 % today, with large-scale heat pumps and other proven technologies providing heat from renewable sources (HRE, 2018). An important advantage of DHC is that HVAC systems in buildings can be simpler and easier to install, reducing maintenance costs, freeing up space and improving safety (Nguyen and Hoang, 2018). Increasing the share of district heating in combination with cheap thermal storage, heat pumps and co-generation can help stabilise the electricity grid as well (Rothballer, 2018).

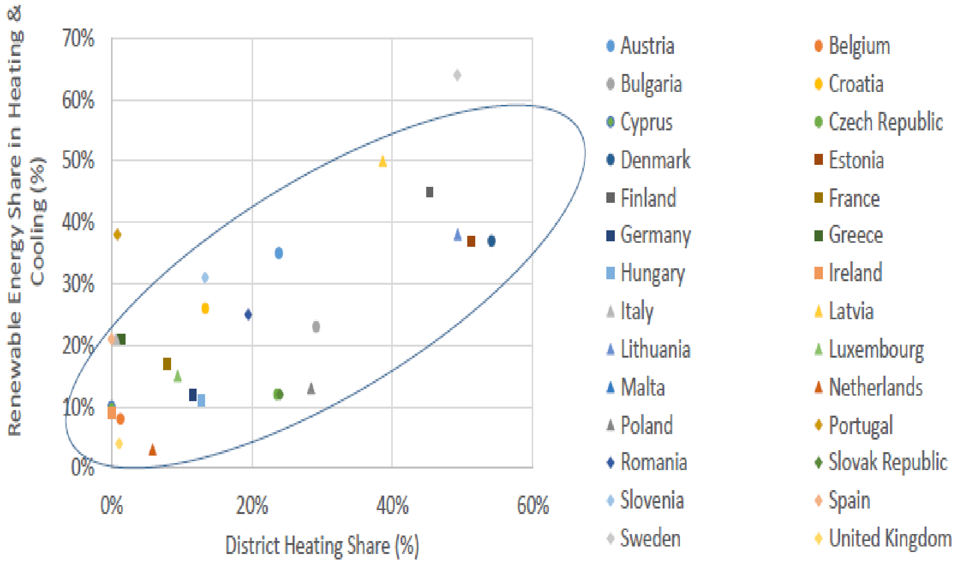
DHC can become more efficient, intelligent and cheaper thanks to automation and other digital technologies that enable data management relating to temperatures, flows, pressure and leak detection (de Beaufort et al., n.d.). Under the revised EED, meters in DHC networks installed or replaced as of 25 October 2020 will have to be remotely readable, and any meters already installed will have to be rendered remotely readable or replaced by 1 January 2027. While this requirement was introduced to provide better and more frequent consumption information to customers, it will also open up new opportunities for network operators in terms of optimisation, leak or fault detection, etc. (see for example Staerk, 2016).

Smart DHC network controllers would help manage demand, enabling more dynamic control of system temperatures, which would reduce heat loss and therefore primary energy demand. Buildings would communicate with each other and with energy production and distribution systems, to continuously exchange information about which energy sources are available and learn to make the system more efficient over time (STORM, 2018). Smart optimisation and control technologies as well as IoT would also enable better co-operation with service providers and equipment manufacturers.

4th generation DHC is characterised by low-temperature heat supply, integration of ambient, waste and solar heat as well as district cooling, heat recycling, power-to-heat flexibility of co-generation, storage systems and intelligent control systems (continuous real-time monitoring). In countries where DHC has been in place for a long time, 4th generation systems are moving beyond concept stage towards design and implementation. The enhancements of 4th generation technology may be necessary in order for Nordic district heating networks to maintain viability as a long-term low-carbon solution (IEA, 2016b).

New district heat technologies offer several important advantages. First, energy efficiency is improved both on the production and distribution sides. Second, because of the lower supply temperatures, the co-generation power-to-heat ratios can be raised, distribution losses reduced, and renewable heat sources easily integrated. Finally, the system as a whole provides more flexibility in both electricity and heat supply – important for integrating renewables (Figure 3).

Figure 3. Renewables and district heating: Shares by Member State



Source: Vad Mathiesen, 2018.

Accessible and still largely unexploited opportunities lie in the recovery and reuse of low-temperature heat from urban sources such as transport systems, shops and offices, wastewater networks, data centres, harbours, rivers, lakes, seawater and electrical substations. For example, waste heat recovered from sewage systems in urban areas with more than 10 000 inhabitants could cover 5 % of total heat demand (ReUseHeat, 2018), and could provide heating and cooling through individual systems as well as DHC. Only a limited number of small-scale examples are in place in the EU today.

4.1 Examples

InDeal offers a platform for real-time energy consumption data-gathering via intelligent meters; identifying buildings' heating and cooling needs depending on energy efficiency, energy consumption and type of building; predicting short-term and long-term weather conditions and forthcoming need for heating and cooling; monitoring and control of the level of energy storage; 24/7 monitoring; and minimising heat losses via novel pipe design solutions and innovative insulation materials (InDeal, 2018).

TEMPO includes three elements: a supervision platform for detection and diagnosis of faults in district heat substations, visualisation tools and a smart network controller to balance supply and demand and minimise the return temperature (follow-up to the STORM project) (TEMPO, 2018).

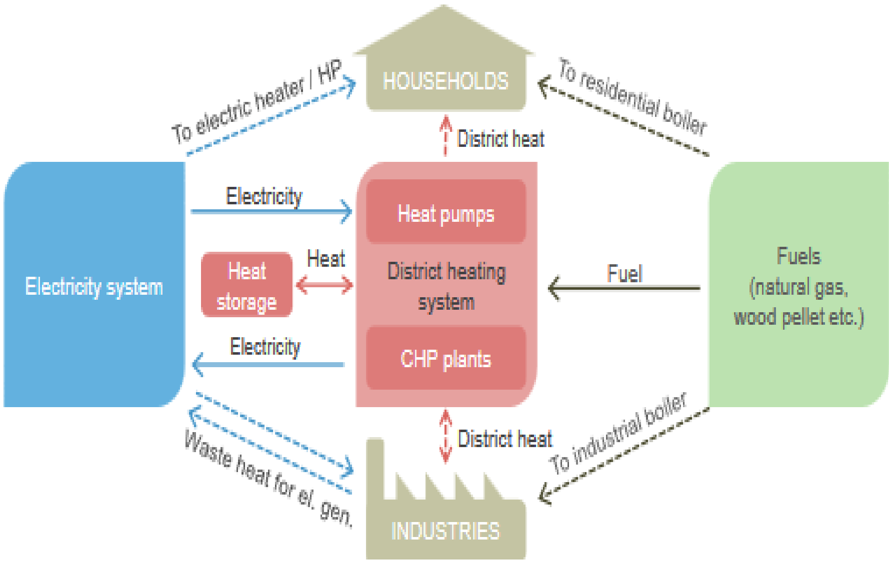
CELSIUS covers the full spectrum of planning, implementing and optimising new and existing smart infrastructure solutions for heating and cooling. COOL DH aims to find ways of using low-grade waste heat in energy-efficient buildings by optimising low-temperature district heating, including by enabling prosumers and better network layout and control (COOL DH, n.d.).

Other relevant EU research projects include RELaTED (ultra-low temperature), THERMOS (address-level energy system maps, to enable public authorities and other stakeholders to rapidly and cheaply upgrade, refurbish and expand heating and cooling systems), and FLEXYNETS (intelligent DHC networks where the substations are replaced with heat pumps and networks serves as low-temperature storage).

5 Smart energy systems

In a smart energy system, electricity, heat and gas networks are co-ordinated to identify synergies and achieve an optimal solution for each individual sector as well as the overall system (Lund, 2015). The large volumes of data produced by smart meters and other digital technologies could be used to predict heating and cooling flows, spot inconsistencies and check for leaks or losses. AI could control distributed production assets to optimise local resources and minimise overall cost.

Figure 4. Integration of heat and electricity systems



Source: IEA, 2017b.

CHP = Combined Heat and Power. CHP, or co-generation, is the simultaneous production of electricity and heat, both of which are used. In other words, excess heat generated by the production of electricity can be reused in individual buildings, industrial facilities or cities served by district heat networks (ReUseHeat, 2018).

Energy storage technologies can capture energy during periods when demand or costs are low, or supply exceeds demand, and surrender it when demand or energy costs are high. Storage benefits customers, system managers and companies and can be applied from the household level to the utility scale. Depending on the size, thermal storage can be up to 100 times cheaper than electricity storage (Lund et al., 2016); collective storage can be orders of magnitude cheaper than individual household storage. There are storage technologies available for short-, medium- and long-term applications and with varying returns on investment. Technologies include pit, cold water, underground, residential hot water heaters with storage, ice, molten salt and thermochemical storage.

With a smart energy system, a 100 % renewable energy system in Europe is technically possible without consuming an unsustainable amount of bioenergy (Connolly et al., 2016). This is due to the additional flexibility that is created by connecting the electricity, heating, cooling and transport sectors, which enables renewables penetration of over 80 % in the electricity sector. The scenario costs approximately 10-15 % more than business as usual but since it is based on local investments instead of imported fuels, it creates around 10 million additional direct jobs in the EU.

5.1 Examples

The EU project HEAT4COOL demonstrates integrated heating and cooling solutions complemented by heat pumps and renewable energy sources at building and district scales. It includes an online design tool that combines a set of HVAC technological solutions including renewables and BEMS with data from real buildings to predict the performance of a variety of retrofit solutions; and the architecture for a Self-Correcting Intelligent Building Energy Management System (HEAT4COOL, 2018).

STRATEGO was an Intelligent Energy Europe project that supported local authorities in developing enhanced heating and cooling plans. It has been succeeded by Heat RoadMap Europe, which is mapping and modelling the heating and energy systems of 14 Member States (those that use the most heat) to develop new policies that ensure the uptake of efficient, sustainable and affordable heating and cooling solutions.

6 Electrification

Most of today's energy network infrastructure will still be operational in 2050 so there is a clear rationale for sector coupling to create smart energy systems as described in the previous chapter; in the longer run, there may be choices to be made between managing multiple networks and operating only one extended power grid (EC, 2018).

Electric heating has been common in France for decades but has recently received renewed attention there and in other Member States in the context of decarbonisation. The use of electricity for heating and cooling can make a significant contribution to emissions reduction. However, electrification will only be viable if power generation can continue to decarbonise, increase output and adapt to building consumption patterns, and if distribution networks strengthen and digitalise. ACEEE considers "beneficial electrification" that which reduces total energy, costs and emissions, and sees it as a form of energy efficiency as well (Nadel, 2018).

Electrification has its own drivers and has always progressed more quickly than broader energy consumption. It may even be the only option when there is no access to a gas network or no possibility of district heat. In the industry sector, the demand for digitalisation, automation and advanced robotics often leads to fossil fuels being replaced with electricity.

On average, only 37 % of EU consumers are equipped with smart electricity meters, which is well below the 80 % non-binding objective agreed by Member States for 2020 (ACER in Simon, 2019). Sweden, Finland and Estonia have fully deployed smart meters but fixed network data collection on an hourly or daily basis is still in the early stages in most other Member States.

In France, 15 million smart meters have been installed so far (about one household in three) but progress has been slower than planned. Delays have also been encountered in the UK, with 11 million smart meters installed out of 46 million (Which? in Press Association, 2018), and some early adopters already having to upgrade to a newer model. Other countries have not yet started – Ireland for example is beginning to roll out smart meters in 2019, with smart services set to become available from 2021. Italy instituted time-of-use pricing after it rolled out smart meters in 2011 but experienced only modest customer load-shifting because of a small price difference and substantial growth in solar PV (Hale et al., 2018).

Smart meters and digitalisation enable automation of controllable thermal loads such as air conditioners, heat pumps or electric water heaters. Key technologies include building management solutions, digitally controlled thermostats and remote-control pumps that can make subtle changes in intensity. Automatic curtailment of consumption can be based on predefined signals sent by the transmission systems operator (TSO) or the aggregator. Demand response should have only a limited effect on daily life and while particularly relevant for commercial centres or large industrial sites, can achieve meaningful scale when aggregated for the residential sector (IEA, 2016c).

For now, demand response is mostly restricted to large industry – Finland, France and the United Kingdom are the only Member States with commercially open demand-response markets. Interest is growing but large-scale deployment of demand response will require the development of automated solutions.

6.1 Examples

The "Real Value" European project studies the potential to electrify more of the heating load in aggregated, small-scale residential uses by introducing power-to-heat storage devices that can provide flexibility to the grid. Companies such as Brenmiller Energy provide heat storage for district heating and industrial power-to-heat. The DR-BOB project aims to demonstrate the benefits of demand response for blocks of several buildings at universities, hospitals and a technology park (EASME, 2018). Finally, the

Horizon 2020 project SABINA aims to exploit synergies between electricity and heat networks through the optimisation of electricity use for cooling and heating purposes.

7 Business models

In the past, digitalisation of heating and cooling was driven by a simple business case to reduce costs. For example, smart meters help reduce commercial losses from unregistered or non-paying customers, while apps allow customers to more easily sign up and pay bills. Digitalisation has been an opportunity for suppliers to optimise assets, integrate distributed renewables and reduce operating costs.

This first generation of digitalisation however, did not create a universal, interconnected space and more importantly did not offer radically new services or customisation. In the future however, digitalisation will be driven as much by desire to create new revenue streams as to reduce costs. The second generation will be characterised by the fusion of advanced technologies and the integration of physical and digital systems. It is set to profoundly transform business models and processes, and lead to the creation of smart products and services.

Energy systems are moving towards digitalisation, decentralisation and decarbonisation. In buildings, ongoing energy efficiency improvements and a warming climate could lead to declining heat demand, while heatwaves of greater intensity, duration and extent could lead to increased cooling demand. Comfort requirements are also increasing, meaning people are more likely to turn on cooling systems in hot summers and to turn up the heat in cold winters (a particular opportunity for heat pumps) (Nowak, 2018). These trends also increase the need for further integration of heat and electricity systems (see Chapter 5).

One way for companies and policymakers to respond to such changes is to develop new business models and offer comfortable indoor climate as a service, rather than selling kWh. In that way, energy efficiency improvements would not necessarily represent a financial loss.

Some energy businesses are beginning to transform into software-enabled service platforms, providing everything from equipment design through operations and maintenance tools to BEMS and smart district energy. In strategy terms, they are choosing Innovate rather than Fight (against uptake of renewables) or Flight (divestment) (Green and Newman, 2017). Energy-service companies (ESCOs) or similar businesses could provide comprehensive energy packages such as smart controls combined with heat pumps and renovation measures, aimed at delivering energy savings across a range of end uses.

Software can also be used to show how a heating and cooling system will behave before it is installed, helping to stimulate investment. And there may also be implications for heat-cost allocation in apartment buildings.

Large corporations have legacy business to protect, and so may be reluctant to expand funding of disruptive technologies such as platforms that would enable transactions related to self-produced energy or decentralised storage. Disintermediation of energy trading represents a risk to the business model of centralised utilities. In electricity, the rise of distributed generation will reduce wholesale demand, forcing utilities to raise charges, which will further accelerate adoption of distributed generation, inducing what has been called a utility death spiral, with poorer or more vulnerable consumers charged higher tariffs too (Asensio et al., 2018) (see also section 12.6).

However, digitalisation improves the utilisation rates of assets, offering an alternative to building or upgrading network infrastructure. And digital technology is expected to increase the prospect of energy efficiency participating in electricity markets by enabling energy savings generated by ESCOs or utilities to be traded. This is starting to happen, particularly in the United States.

The development of multi-vendor ecosystems will be a key factor in how fast digitalisation proceeds. The companies that develop and control these systems will play a major role in the energy sector.

7.1 Heat pumps

The dominant business model in the heating sector today is to manufacture a boiler and sell it to a customer via a wholesaler or installer. Value is created by manufacturing, installing and maintaining the product as well as by providing the energy to operate it.

For larger capacity heat pumps in apartment buildings, offices and district heating systems, a different business model is already in place today. Based on a service model, the end user pays for the delivery of heating and cooling. This approach is now becoming feasible for aggregated heat pumps or even individual units, thanks to digitalisation (sensors, computing power and access to high-speed data networks).

With a redefined value proposition, the offering is no longer a physical product but a package consisting of hardware, software and support in terms of planning, financing, insurance, maintenance, etc. Heating and cooling becomes a service that the user enjoys and pays for, while the service provider takes ownership and is also responsible for system design and operations. Optimising design, monitoring operations and providing timely maintenance leads to reduced operating cost and thus optimised profit (Nowak, 2018).

Business models are even conceivable in which heating or cooling would be offered against a flat payment or for free. Value would instead come from:

- access to data on user behaviour;
- the use of the system for electricity grid-balancing purposes (demand response);
- the achievement of a better building class with related savings;
- CO_2 emission-free heating that would benefit from savings on the payment of a carbon tax;
- particulate emission-free heating: there may eventually be penalty payments or usage restrictions on combustion technology giving an advantage to technologies free of CO_2 or particulate matter emissions at the point of use;
- cost-efficient deployment of CO_2-neutral technology in another part of the world, benefiting from transfer mechanisms or other monetary benefits (similar to the former Clean Development Mechanism).

A service provider would integrate all the necessary steps from system design to integration, add the necessary sensors and control systems and be the direct link to the end user, in return reaping all the benefits from the system. In this way, the workings of the heating and cooling system would no longer matter to the user, as long as the required function is provided. Such an approach could have far reaching effects on the brand value of the current market leaders and on their ability to set high prices for their products.

Any of these new value propositions could be offered by existing actors but it is expected that new players will take an active role in their development, in particular those with access to sensors and digital technologies (e.g. the Google Nest thermostat). Similarly, large utilities could commercialise their knowledge of large-scale roll-out of products and services. Having access to user data already could be a headstart for those players.

7.2 District heating and cooling

The trends of decreased heat demand in buildings and competition from heat pumps are a challenge to district heating companies and co-generation. For example, Helsinki Energy has announced that they will not replace large co-generation plants (IEA, 2016b). Coverage of homes in Helsinki is close to 99 %, so without new customers, energy efficiency improvements will reduce heating loads. Even a 1 % reduction in district heat demand per year is an issue given the long lifetimes and structural characteristics of district energy infrastructure.

Digitalisation can support the development of new business models for DHC by allowing district energy companies to offer more diversified products and services. The offerings would be highly automated and standardised, while at the same time personalised using software. As a result, the companies would become more service-oriented.

7.3 Examples

The Horizon 2020 project MAGNITUDE (www.magnitude-project.eu) aims to develop business and market mechanisms, and support co-ordination tools to provide flexibility to the European electricity system, by enhancing synergies between electricity, heating and cooling, and gas systems.

Bristol Energy has become the first energy supplier in the UK to trial selling heat as a service, rather than kWh. The trial is backed by the government through Energy Systems Catapult. Customers can buy a Heat Plan that includes a fixed monthly cost tailored to their home and habits (Energy Systems Catapult, 2019).

In Germany, manufacturers of solar thermal systems have provided potential customers with online sales platforms for heating systems with or without solar energy; clients could provide information online about their desired heating system and then receive an offer directly from the system supplier, bypassing the installer (REN21, 2017).

Large-scale pilot projects are ongoing in Denmark (www.ic-meter.com) to test novel meters and digital solutions to perform heat-cost allocation that integrates indoor environment parameters.

8 Communities, cities and regions

The fact that heat and cold are produced and consumed locally, combined with a general trend towards decentralisation of governance, means that regional, municipal and local levels are often involved in infrastructure planning. At the same time, long-term investments are necessary, which engages higher levels of governance.

Cities often have jurisdiction over zoning and building codes, business licensing, transport planning and, in many cases, local distribution networks. In Denmark for example, municipalities play the key role in heat supply planning.

It is estimated that 75 % of EU citizens will live in cities in 2020, increasing to 84 % by 2050 (ReUseHeat, 2018). The main focus of decarbonising the urban energy supply is heat – electricity benefits from greater flexibility and more policy options as electricity is easier to transport via transmission lines. The density and diversity of urban energy demand also offers valuable opportunities for integrating electricity, heat and buildings.

In particular, DHC in cities can be a cheap and efficient solution for reducing emissions and primary energy demand by accommodating renewable sources and excess heat. The key is to plan, co-ordinate and implement over a long enough period to engage stakeholders and allow for capital investment planning (IEA, 2016a).

The REMOURBAN project includes the following goals on optimisation of existing DHC (Muñoz Rodríguez et al., n.d.):

- Minimise the investment costs in the generation plant by optimising using simulations of energy demand together with real data. Back-up boilers from the original generation system could be maintained to supply peak loads.
- Increase the efficiency of the system by at least 5 % and reduce district energy consumption by adapting energy distribution and production to end users' real demand, for example by using a variable flow pumping system.
- Adapt the operating conditions to real heat needs by control strategies to adjust various parameters such as the supply temperature and the flow rate.
- Integrate a smart centralised control and monitoring system that ensures that the system responds to the demand. This measure optimises the energy balance between the network and the substations.
- Achieve appropriate co-ordination of generation, distribution and energy exchange control strategies in order to anticipate the response to variations in demand. The substations constitute a connection point between the overall optimisation strategies for the generation and distribution levels and end-user demands.

Digitalisation of energy can also be an important part of the blueprint for smart **regions**. It can be particularly relevant to coal- and carbon-intensive regions in transition. Both regions and cities are major enablers of digital transformation, by bringing together local resources and mobilising everyone concerned.

Renewable energy sources, distribution networks and storage capacity are increasingly seen as local resources that need a community approach. Local **communities** are well placed to identify local energy needs, take appropriate initiatives and bring people together to achieve common goals.

Energy communities collaborate to develop smart energy and foster greater use of renewable and distributed sources, with the aim of reaping economic, environmental and energy security benefits. Digital technologies can be understood as enablers of energy communities, along with technical innovation in distributed renewable energy technologies and social innovation in governance. Digitalisation helps communities to manage and control these assets, giving them an interest in running and maintaining them.

There are around 3 000 energy communities across Europe, of which around 1 000 are in Germany and 400 in the Netherlands (Koirala et al., 2018). The number is increasing as more and more local communities engage in generating, conserving, sharing, consuming and exporting energy locally thanks to recent developments such as the implementation of suitable policies, cost reduction of renewables, emergence of ICT and IoT as well as environmental awareness and community objectives such as self-sufficiency, resiliency and autonomy.

Digitalisation can enable community energy storage (CES). CES stores excess local heat that cannot be consumed locally when produced and makes it available later when it is needed. For example, the energy community of Feldheim (Germany) has added it to its technology mix (Koirala et al., 2018). Stored energy can be used for various purposes depending on local conditions such as resource availability and consumption patterns. In this way, it enables matching of local renewable energy supply to local energy demand. It not only allows higher penetration of local generation such as renewables but also facilitates energy sharing and self-consumption. At the same time, CES can provide energy services to neighbouring communities as well as larger energy systems.

Digitalisation is also a potential way to reduce the cost of new Nearly Zero Energy Buildings, by shifting the focus from individual buildings to entire settlements. This brings economies of scale into play, together with sharing and management of energy loads across individual buildings.

Regulation in Europe is evolving to respond to and facilitate these trends. Citizens and communities also need to be provided with the capacity to become knowledgeable participants and to participate effectively in the formulation of energy policy.

8.1 Examples

aspern Seestadt is a new urban centre in northeast Vienna due for completion in 2028. It encompasses whole system research, three smart buildings (equipped with solar thermal, heat pumps and thermal storage) and 111 households equipped with a smart home app (aspern Seestadt, 2018).

Kalasatama is a smart district of Helsinki, connected to district heating and cooling. The area also hosts TelecityGroup's data centre using seawater for cooling and providing heating for houses in Helsinki (Smart Kalasatama, 2018).

Schoonschip is a floating residential neighbourhood of 47 households in Amsterdam North that hopes to become the most sustainable urban development in Europe. A smart grid will be implemented and each house equipped with local photovoltaic (PV) production, battery storage, solar collectors, thermal storage, a smart heat pump and other smart-grid ready appliances.

The much larger Bijlmer Bajes development includes local renewable generation systems based on PV, wind and biogas; large-scale centralised battery systems; smart heat pumps combined with an aquifer thermal storage system; and intelligent co-ordination of local supply and demand via an energy management system (Spectral, 2018).

The European Innovation Partnership for Smart Cities and Communities has 4 600 partners and 370 commitments in 31 countries. It aims to deliver scale, acceleration and impact through common solutions, an integrated approach and collaboration. It focuses on energy, ICT and transport.

The Digital Cities Challenge is another example of a European Commission initiative to help cities achieve their digital transformation ambitions.[2] It provides free advice from experts to 15 cities across Europe (www.digitallytransformyourregion.eu).

[2] See http://ec.europa.eu/growth/industry/policy/digital-transformation_en.

Smart cities projects funded under Horizon 2020 include: GrowSmarter (including open district heating using waste heat, district heating rings and smart local thermal districts), REMOURBAN (including optimisation of existing DHC and low-temperature district heating), Triangulum, REPLICATE (including district heating system), Smarter Together, SmartEnCity (biomass district heating and district cooling using residual heat), Sharing Cities, ESPRESSO (smart cities information systems), MySMARTlife, Ruggedised (smart thermal grid) and +CityxChange.[3]

The Smart Specialisation Platform for industrial modernisation is a tool to combine smart specialisation and inter-regional co-operation to boost industrial competitiveness and innovation. All EU regions with their clusters and industrial partners are encouraged to take part and a partnership in a new thematic area can be proposed by any EU region or group of regions.[4]

The Pan-European Thermal Atlas (part of the Heat Roadmap Europe project) provides information on heating and cooling demand densities, renewable energy sources and excess heat in order to empower decision-making processes. It can facilitate dialogue and help enable heat synergy regions – regions in which urban and rural areas combine their renewable energy potentials and excess heat sources beyond their borders in order to optimise energy infrastructure and make it as sustainable as possible (Rothballer, 2018).

The ZERO-PLUS project is constructing four pilot demonstration settlements that will each save at least 16 % of the normally expected building costs by using mass-produced technologies and integrating them into a system that is optimally designed according to the local climate (EASME, 2018).

[3] See cityxchange.eu.
[4] See s3platform.jrc.ec.europa.eu/industrial-modernisation.

9 Case study: Blockchain

Distributed ledger technologies save transactions in a shared data structure (blockchain). New transactions are added to the end of the chain, with each block referencing the previous one. A smart contract is code that executes or enforces a predefined agreement using blockchain once specific conditions are met (though it is usually not legally binding without separate contractual agreements) (WEC and PwC, 2018).

Public blockchains remove intermediaries and trusted third parties. Modifications are visible to all and transactions cannot easily be altered or deleted. However, blockchain cannot verify the accuracy of external data, only what is contained in the blockchain itself. Blockchain isn't necessarily better than traditional databases in all cases, but it is particularly useful in low-trust environments (WEC and PwC, 2018).

Blockchain and smart contracts can theoretically be used for almost any decentralised service, though few or no reliably operational examples exist (House of Commons, 2018). Transaction costs in terms of time and energy consumption (see Chapter 10) have limited the scope of services offered by public decentralised blockchains so far.

Blockchain for energy thus is also still in the early adoption phase and has not yet made a commercially tangible impact, changed business models or enabled a clear shift to decentralisation. Meanwhile, distributed energy resources have achieved high levels of penetration without blockchain in countries such as Germany and Spain (WEC and PwC, 2018).

That said, in order to facilitate the transition to renewable heating and cooling at the scale needed, a range of transaction technologies enabling storage, trading, demand forecasting and management, will need to be integrated into new, intelligent systems. Blockchain could help knit such technologies and systems together, thus becoming a core part of distributed heating and cooling resources and DHC (PwC, 2018).

Systems based on blockchain have the potential to help solve data management challenges, reduce transaction costs, error and fraud, and help empower households and energy communities. They can enable households to become producers as well as consumers of heating and cooling, and to play a more active role in storing and managing it. Smart contracts to support this automatic and distributed exchange would make energy markets more efficient and resilient. That would reduce the need for new heating and cooling infrastructure and make greater use of existing assets.

Box 1. Potential applications of blockchain for heating and cooling

Decentralised utility systems at scale: Platforms could collate distributed data on energy resources (e.g. from smart sensors in households), enabling more informed decision-making regarding system design and resource management. This could include peer-to-peer transactions, with blockchain managing contracts for energy flows and instant payment, allowing households to become producers with minimal reliance on authorities.

Sustainable finance: Blockchain-enabled finance platforms could increase access to capital and unlock potential new investment in projects – from retail-level investment in infrastructure to blended finance to charitable donations for developing countries. There is potential to expand traditional financial accounting to capture social and environmental capital and for a shift from shareholder to stakeholder value (tokenisation or crowdsale) – through automated smart contracts, blockchain makes it possible to raise finance for an asset that directly represents an ownership stake, incentivising locally owned renewable energy projects, e.g. WePower and 220 Energia in Estonia (JRC, 2018a).

Carbon (and other environmental) markets: Authentification and trading of renewable energy credits, certificates of origin, emissions trading or energy efficiency certificates based on actual production or savings. Blockchain could be harnessed to use cryptographic tokens with a tradable value to optimise existing markets for carbon (or other substances) and create new opportunities for carbon credits. For example, tracking renewable energy certificates is among the first applications of the Energy Web Foundation platform (Orcutt, 2017).

Enhanced traceability in supply chains: By creating unique and trusted digital identities and allowing all users to work with a common ledger, blockchain can track ownership, increasing certainty of the origin of assets and energy. Traceability enables more sustainable production, logistics and consumer choice, which could drive behaviour change and contribute to the circular economy.

Asset agency: Through unique and trusted digital identities, blockchain can enable assets such as batteries or other smart home equipment to participate directly in markets without the need for a human intermediary, co-ordinating energy purchase and use with a network, increasing efficiency, decreasing overall energy costs and extending lifetimes.

Automation of data collection for sustainability monitoring, reporting and verification: Helping companies manage, demonstrate and improve their performance while enabling consumers and investors to make better decisions. This could drive more accountability and action, as it provides a more complete picture of risk and reward profiles.

Data sovereignty: By creating unique identifiers for asset owners, assets and the data produced by those assets, blockchain could create direct data ownership and selective permission, allowing for better customer data management and privacy.

Distributed cybersecurity: Through distributed ledgers and consensus mechanisms, blockchain aims to ensure that there is no single point of failure for network control systems, increasing robustness to certain types of cyber-attack.

Increased market access: With smart contracts automating many of the functions necessary to bid, settle and participate in markets, blockchain can help open up energy markets to smaller participants.

Secure transactions: Facilitating faster payment cycles and streamlined account management.

Optimised and resilient network management: Using blockchain-enabled sensors and controls. For example, maintenance and repair activities of service providers could be stored in a blockchain, enabling accountability and payments using smart contracts (dena, 2019).

Blockchain-based land, corporate, civil and asset registries.

Waste-to-energy blockchain solutions.

Sources: PwC (2018), McKinsey (2018) and Henly (2018), unless otherwise specified.

Blockchain could be particularly useful for DHC. Today, DHC is based on transactions between one company and many customers. However, blockchain could play a role if transactions among customers of different companies started to occur (Gunnarson and Melin Hamber, 2018).

A study in Sweden identified 32 relevant applications of blockchain for district heating (Table 2). The two deemed to have the most potential were 1) to ensure the quality of metering and maintenance, and 2) to create a common heat production system for district heating companies. However, it is recognised that standardisation is key and that additional policies, technologies or infrastructure may be necessary in order to create value from a blockchain solution (Gunnarson and Melin Hamber, 2018).

Table 2. Potential applications of blockchain in district heating

Procurement and suppliers	Fuel-origin tracing and supply-chain tracking Shared fuel procurement programme for district heating companies Smart contracts with suppliers
Production and sustainability	Common heat production system for district heating companies Improved trading of carbon credits Calculation and visualisation of production climate impact Customer influence over environmental decisions and sustainability
Distribution and properties	Quality of metering and maintenance Extended load control management for customers Transition towards smart and automated properties Individual measurement and charging for owners and co-operatives
Excess heat suppliers	Dynamic control of the temperature delivered
Customer relations	Smart contracts with the customers Customer payment system with more transparent prices Optimised sale of heat where several intermediaries are involved Client profiles
Data storage and IT security	Machine-to-machine communication among production, distribution and customers Confidentiality and integrity of data Improved AI systems
Administration and communication	Signing, storing and sharing of documents Checking of supplier certificates and handling of company certificates Simplified communication among stakeholders Verification of digital accounting documents
Finance and asset management	Management of owner shares in facilities Facilitation of investment in the district heating sector Asset management
Ecosystem	Unified system for communication, agreements, permit management Visualisation of a property's heat life-cycle for customers by its waste, measuring how much heat could be generated Connection of society infrastructure systems
Market structure	Facilitate an open marketplace for heat trading Manage integration of heat and electricity systems

Source: Gunnarson and Melin Hamber, 2018.

9.1 Examples

In 1Q2018, energy-related blockchain projects attracted USD 359 million in investment (Buchmann, 2018). As of March 2018, there were 122 organisations involved in blockchain for energy and 40 deployed projects (Metelitsa, 2018). The EU is a leader in blockchain in general and far ahead of the United States when it comes to blockchain demonstrations and expertise (Henly, 2018). It is also home to more blockchain initiatives in the energy sector than any other world region. However, use cases for the energy sector that have advanced beyond proof-of-concept are rare, in particular for heating or cooling (Table 3).

Table 3. Blockchain-for-energy initiatives in Europe with potential relevance to heating and cooling

Name	**Type**	**Website**	**Status**
SAIEX Tokens	Initial Coin Offering from Saiterm for an infrared heating product; based on Ethereum	https://ico.saiterm.com	Crowdsale ongoing
Enerchain	Execution of bilateral trade of physical electricity and gas within Europe, managed by Ponton, in partnership with E.ON, Engie, Statkraft, Vattenfall and others	https://enerchain.ponton.de/index.php	Proof of concept phase complete
Energy Web Foundation Blockchain	Base-layer infrastructure dedicated to the energy sector; based on Ethereum; with the Rocky Mountain Institute and major European oil companies. Proof-of-authority mechanism (less energy-intensive).	energyweb.org	In production
Household-Supplier Energy Market	Peer-to-peer electricity trading	https://gtr.ukri.org/projects?ref=EP%2FP031838%2F1	2017-2019
cryptoleaf	Crowdfinancing green projects	www.cryptoleaf.io/	First projects expected available for funding 1Q2019
Offis	Power systems intelligence, standardised systems engineering and assessment, automation, communication and control, simulation and agents in multiple domains, data integration and processing	www.offis.de/en/applications/energy.html	Proof of concept completed
NestEgg	Crowdfunding	nestegg.eu	Startup

DEFENDER	Security and resilience of electricity infrastructure	defender-project.eu	Ongoing research
Solarchain	Smart grid platform	www.sunchain.fr	Proof of concept
PowerToShare	Peer-to-peer trading and information services platform	www.powertoshare.eu	Startup
Fortum	With three research partners and nine companies, part of the BOND project in Finland. Optimises heating consumption by taking forecasts and electricity prices into account.	www.fortum.com	Founded 2016
CGI & Eneco	Uses Tendermint blockchain for decentralised trading in heat. Pilot running in the heat network that connects the Port of Rotterdam to the city.		Prototype, founded 2017
OLI Systems	Residential and commercial buildings are equipped with OLI boxes that optimise the use of electricity and heat. Electricity produced can also be shared with neighbours and tenants.	my-oli.com	Founded 2016

Source: Various including Illinois Blockchain Initiative (Blockchain in Government Tracker), EU Blockchain Observatory Forum (Blockchain Map) and SolarPlaza.

The European Commission is monitoring this area closely and organises regular workshops with experts to explore how blockchain can help meet the Energy Union objectives. The launch of the EU Blockchain Observatory and Forum in February 2018 has enriched the discussion on the opportunities and challenges of the blockchain ecosystem.[5] Also, 24 European countries have signed a declaration on the establishment of a European Blockchain Partnership, with a view to developing a blockchain infrastructure that can enhance value-based, trusted, user-centric digital services across borders within the Digital Single Market. The Partnership will be a vehicle for Member States to exchange experience and expertise, and prepare for the launch of blockchain applications.[6]

The European Parliament’s Industry Committee has agreed a motion for a resolution on "Distributed ledger technologies and blockchains: building trust with disintermediation". The resolution, voted on by the full Parliament in October 2018, emphasises the need to safeguard trustworthy blockchain decentralisation and calls upon the European Commission to explore the possibility of creating an EU-wide, highly scalable and interoperable network that makes the technology available to European citizens. The challenge with these EU-level initiatives is to create a framework of legal and institutional certainty that would facilitate the development of scalable, efficient and high-impact decentralised solutions to social innovation challenges arising from blockchain applications (Kritikos, 2018).

[5] See http://europa.eu/rapid/press-release_IP-18-521_en.htm.

[6] See https://ec.europa.eu/digital-single-market/en/news/european-countries-join-blockchain-partnership.

10 Energy consumption

The majority of digitalisation trends will lead to an increase in overall energy consumption, particularly electricity (INSIGHT_E, 2016). However, digitalisation of the energy sector itself, in particular heating and cooling, could prove an exception. Beneficial digitalisation is when the energy savings outweigh the direct energy consumption. Digital technologies have great potential to help achieve energy savings through more efficient delivery of heating and cooling and by supporting users to reduce or shift loads, saving money while safeguarding or improving comfort and indoor air quality.

Rebound effects could offset some of the energy savings brought about by digitalisation. Firstly, improved affordability could lead to increased consumption of heating and cooling. Second, there may be greater use of energy for the technology itself, including standby functions. Thus, the technical potential may exceed the energy savings actually achieved (Sanguinetti et al., 2018). However, part of this is due to new services and improved comfort levels, which can be considered non-energy benefits. Moreover, part of that improvement in comfort can be considered "catch up" rather than waste (Noesperger et al., 2017).

There are also important pitfalls to anticipate and avoid in promoting digital technologies. To take a high-profile example, speculative crypto-assets use more energy per euro generated than mining copper, platinum or gold – even before cooling is taken into account (Krause and Tolaymat, 2018).

Efforts to restrain the energy consumption of blockchain more generally (including for heating and cooling as described in Chapter 7) involve more efficient mining (new chips, servers and cooling systems such as immersion in liquid) and alternative consensus mechanisms such as proof-of-stake. However, efficiency gains are quickly eaten up, while alternative mechanisms are still being developed (e.g. Ethereum is only due to transition to proof-of-stake within the next five years) and could lead to problems of security and centralisation (Roubini, 2018).

In fact, any digital technology can benefit from becoming more energy efficient even at early stages of development, and energy consumption is an important consideration in assessing the benefits of digitalisation more generally. In that sense, energy efficiency is the best fuel for digitalisation.

A scenario approach is useful given the uncertainty in the potential net effect of digitalisation on energy consumption. In one recent study, the shift towards smart products and services (automation) is estimated to result in additional energy savings in 2050 of 5 % in an "Efficient" scenario and -11 % (i.e. lost energy savings) in an "Inefficient" scenario (Fraunhofer ISI, 2019). For heating and cooling in buildings, building automation and interconnection of appliances *increases* energy demand by 10 % in the Inefficient scenario but *reduces* it by 5 % in the Efficient scenario.

10.1 Buildings

Energy efficiency and digitalisation in buildings can reinforce each other. While a building is being renovated, there is an opportunity to achieve additional gains from digitalisation. Similarly, installation of digital technologies is an opportunity to implement energy efficiency measures at the same time – though energy savings are rarely the primary objective. In addition, energy efficient buildings are more suitable for technologies such as heat pumps that enable greater digitalisation.

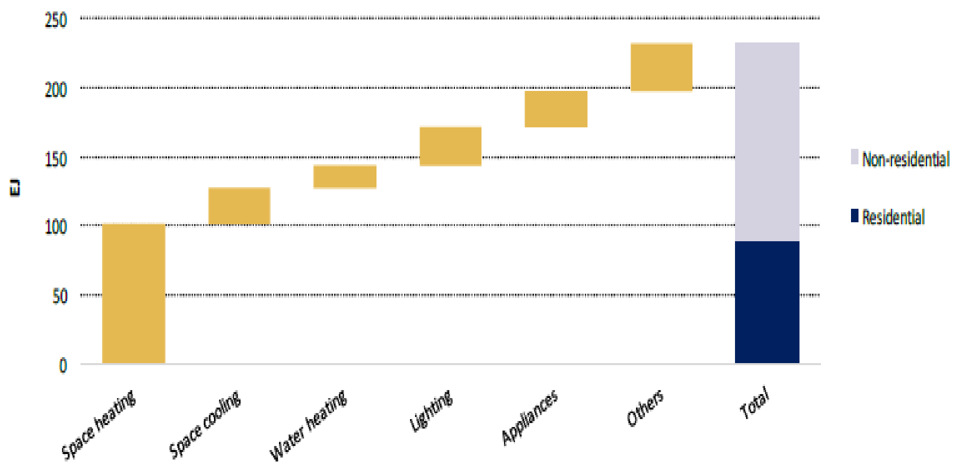
These two complementary aspects – renovation and modernisation of buildings – drove the revision of the Energy Performance of Buildings Directive (EPBD), which entered into force in 2018. The revised EPBD includes additional measures in favour of digital and smart technologies in buildings: for instance, targeted requirements for the installation of self-regulating devices and building automation and control systems, and the establishment of a new instrument to rate the smart readiness of buildings: the Smart Readiness Indicator for buildings.

Savings from basic digitalisation (smart meters, visualisation) are likely to be modest. One review for the UK found that a reduction of just 2-3 % might be expected, although savings might be higher in Member States that have significant cooling loads (House of Commons, 2016).

Digitally controlled lighting, HVAC, security and home appliances offer greater savings and the number of homes using them is projected to grow from 8.5 million in 2016 to 80.6 million in 2021 (ESPC, 2018b). At the same time, alliances are emerging whereby smart home platforms incorporate both home energy management and non-energy related devices. This amplifies the value of smart home technology for consumers but also makes it difficult to anticipate the net energy impacts. Smart home products adopted for non-energy benefits, or integrations with other smart home technologies that consume but do not help manage energy, might just as easily result in net energy consumption increases (Sanguinetti et al., 2018).

While savings for traditional energy efficiency products (e.g. A-rated appliances or LED bulbs) can be calculated through technical testing, the savings of a smart home product depend on how it is used and such savings can vary widely. In the United States, Energy Star-certified smart thermostats save on average 8 % of heating and cooling bills and can also function as a demand-response resource (Relf et al., 2018). Nest, a leading manufacturer of smart thermostats, reports drops in electricity bills of 10-12 % for heating and about 15 % for cooling. Extending the concept to large commercial buildings, an integrated system that manages cooling, heating and lighting could help reduce energy consumption by as much as 50 % (Ramamurthy and Jain, 2017). Widespread adoption of such digital technologies, in particular smart thermostats and sensors, could cut energy use in buildings worldwide by about 10 % by 2040, with the largest gains in heating and cooling of non-residential buildings (IEA, 2017c).

Figure 5. Heat first: Cumulative energy savings in buildings from widespread digitalisation, 2018-2040



Source: IEA, 2017c.

In the EU, the optimisation of technical building systems (not taking into account savings from the replacement of heat generators) can lead to average energy savings of 30 %, with a range of 14-49 % (Schramm et al., 2017). The "Get the basics right" scenario presented in Table 4 includes no-regret measures with low investment and short payback periods. The ”High performance” scenario includes a set of advanced measures (mainly building automation and control systems).

Table 4. Results of optimising technical building systems at EU level

	Emissions reduction, 2030 ($MtCO_2$)	**Primary energy saving, 2030[3] (Mtoe)**	**Energy cost savings per year (EUR billions)**	**Investment cost per year (EUR billions)**	**Payback (years)**
Get the basics right[1]	61	27	2.8	5.6	2.0
High performance[1, 2]	126	58	5.2	24.8	4.8

[1] Not considering the business-as-usual scenario with an impact of 30 $MtCO_2$ and 13 Mtoe in 2030. [2] Includes the impact of Get the basics right. [3] Optimised technical building systems implemented in 47 % of the EU building stock until 2030.

Source: Schramm et al., 2017.

Importantly, optimisation of technical building systems can deliver quick savings, avoiding lock-in and reducing cumulative emissions. Therefore, the speed of optimisation needs to increase – renovation rates of technical building systems could be in the range of 3-4 %, which would be three times the current renovation rate of buildings.

The revised EPBD promotes the optimisation of technical building systems through two main sets of provisions: inspections of heating, air conditioning and combined heating, air conditioning and ventilation systems (Articles 14-15) and establishment of requirements on the overall energy performance, proper installation, appropriate dimensioning, adjustment and control of technical building systems (Article 8).

The rollout of advanced metering infrastructure creates an opportunity to derive additional value from utilities' energy efficiency programmes by obtaining more timely and more granular estimated impacts (Kupser et al., 2017). Digitalisation is also key to the development of high-quality thermal models to predict building behaviour. The benefits of such models are expected to amount to 5-70 % of energy savings and 10-40 % of peak power savings (JRC, 2018a).

Digitalisation can also facilitate deep renovation by analysing and customising information on existing building systems, enabling holistic approaches such as building renovation passports. Building passports support building owners with personalised information on their renovation options and a long-term renovation roadmap resulting from an energy audit. They present all the expected benefits of renovation along with a logbook and a repository of information on energy consumption (using smart meter data) and production, and finance opportunities.

10.1.1 Examples

The IMPRESS project brings together reconfigurable moulding (RM) techniques, 3D laser scanning and 3D printing technology and embeds them in a cloud-based BIM model that incorporates all stages of the building process from design, construction and installation through to operation. Its Online Management Platform allows all team members to collaborate and plan the project based on a shared model (EASME, 2018).

Similarly, the BIM4EEB project under Horizon 2020 will encourage renovation by developing a set of BIM tools capable of a) supporting designers in the planning phase, b) allowing construction companies to efficiently perform the work, and c) providing service companies with attractive solutions for building retrofitting. The toolset will be tested during the renovation of three buildings (IERC, 2019).

Building passports are being implemented in France (the *carnet numérique* is mandatory for new buildings since 2017 and will be for any property transaction by 2025 (Sebi et al., 2019)), Belgium (Flanders) and Germany (Fabbri, 2017). There are also one-stop shop services for renovation in France (Energies POSIT'IF), Denmark (BetterHome) and other Member States that include digital (online) tools. One-stop shops have been advocated by the European Commission through the "Smart financing for smart buildings" initiative and through the "new" EPBD as part of the Directive 2018/844/EU (Boza-Kiss and Bertoldi, 2018).

In Flanders, every resident can connect free of charge to an online platform using an electronic identity card or an app. This platform encourages users to improve their building's energy performance by providing an overview of various characteristics of the property and comparing it with neighbours. From January 2019, the site recommends a roadmap and an overview of the available tax incentives (Armand, 2018). The EPBD provides a framework for Member States to introduce such programmes.

The Request2Action Intelligent Energy Europe project aimed to stimulate retrofit action in the residential sector by using big data tools to make retrofit data (from Energy Performance Certificates) available in new and dynamic ways. Companies, distributors, providers and investors could use such tools to spot areas with good potential. Visualisation of data could be aggregated, e.g. for 500–1 000 buildings or by postcode, in order to avoid door-to-door selling and address data privacy concerns. However, interest from the small companies (1-5 employees) that dominate supply chains in many Member States seems to be low. Such actors tend to operate in small geographic areas and base their leads on word-of-mouth or local advertising rather than data analysis (Costanzo et al., 2017). The EU project 4RinEU is also developing tools and methodologies for deep energy renovation (see 4rineu.eu/results).

10.2 Data centres

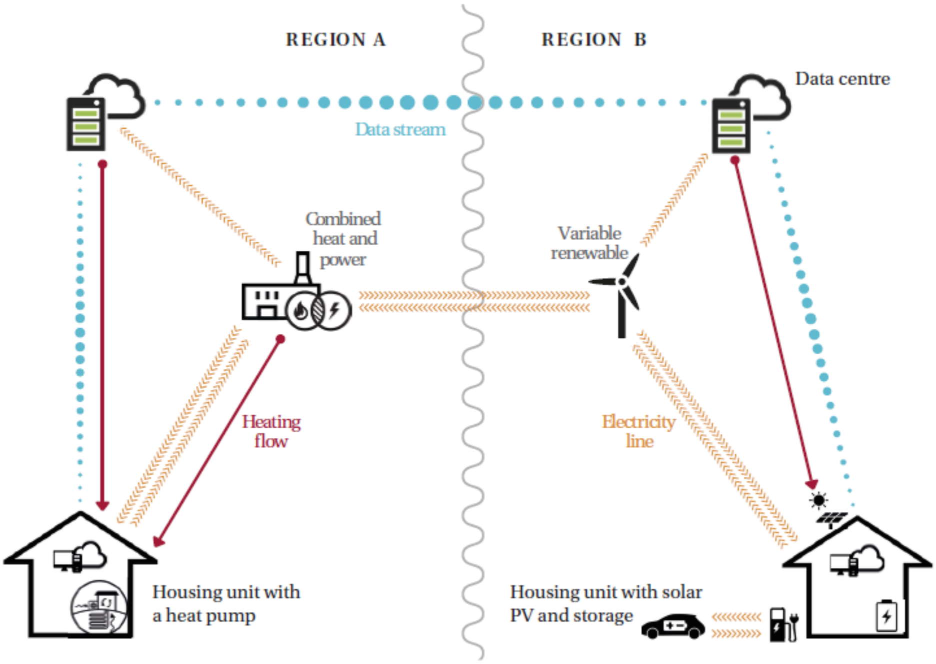
Data centre energy consumption in the EU (the second- or third-largest market in the world) was estimated in 2014-2015 at 43-49 TWh, i.e. between 1.5 % and 1.8 % of EU total consumption. If data transmission by broadband operators and end users is included, that estimate doubles (Craglia et al., 2018).

Data centres themselves are a constantly growing source of waste heat and could thus play a role in smart energy systems (Figure 6). A medium-sized data centre with 1 MW of IT load releases 3 700 MWh of thermal energy per year. If heat is not used, it must be removed anyway to avoid damage to the equipment. The cooling system represents up to 40 % of data-centre energy consumption (ReUseHeat, 2018).

Efforts are underway to power data centres with more renewable energy, restrain their electricity consumption and use the resulting heat. Efficient cooling solutions include outdoor air, evaporative cooling and free cooling from nearby water sources. More efficient servers and other equipment are also important as well as more efficient software.

It is important to note however that although there have been major advances in energy efficiency for large data centres, that is not yet the case for small and medium centres, which account for more than 50 % of the electricity consumption of the sector (Vasques et al., 2017). Also, other environmental impacts also need to be addressed more robustly than today. For example, heat pumps, air conditioning units, electric furnaces, electric centralised heating units, dehumidifiers, and monitoring and control equipment are all sources of e-waste that are set to grow in coming years (Baldé et al., 2017). The ICT sector should feature more prominently in climate strategies and, conversely, environmental sustainability should be a key issue in digital strategies.

Figure 6. More data, more heat: Coupling of electricity, heating, transport and data



Source: Vad Mathiesen, 2018.

10.2.1 Examples

In Ireland, Amazon designed and installed an energy centre as part of its planning approval for a data centre near Dublin. A non-profit company is being set up to manage the supply heat to nearby homes in what is set to be Ireland's first data centre-based district heating system. The project will also receive funding from the EU HeatNet programme, a fund for schemes that reduce CO_2 emissions in Europe's northwest (McMahon, 2018).

Data centres can also be retrofitted to recover excess heat, as is being shown in Stockholm by Digiplex. It has signed a deal with Stockholm Exergi to provide heat to the local district heating system (Data Centre Dynamics, 2018).

The EU Code of Conduct on Energy Efficiency in Data Centres has been adopted voluntarily by more than 350 data centres in Europe (Craglia et al., 2018). It promotes data centre energy efficiency best practices and monitors energy consumption (Avgerinou et al., 2017). There are also many EU research projects that can be relevant to improving the environmental sustainability of data centres (Table 5).

The use of data centre heat resulting from blockchain has been studied for example for the Hyrsylä Co-housing project in Lohja (Finland) using heat from crypto-asset mining (Nguyen and Hoang, 2018). The model can also be applied in the agriculture sector for greenhouses, as seen in UnitedCorp's use of geothermal air exchange (UnitedCorp, 2018). The bitcoin miner Heatmine in Canada is going one step further and experimenting with a network of decentralised mining machines connected to homes and businesses. In a pilot at a greenhouse for strawberries, heating costs were reduced by 75-100 % (Kirkwood, 2019).

Table 5. Selected FP7 and Horizon 2020 projects with relevance for data centres

FP7		H2020		
Efficiency of an individual data centre	*Renewables, heat reuse, smart grids*	*Public procurement*	*Measuring environmental efficiency*	*Bringing more energy efficient and integrated data centres to market*
EUR 12 million	EUR 18 million	EUR 5 million	EUR 0.4 million	EUR 6 million
CoolEmAll	RenewIT	EURECA	ICTFootprint	CATALYST
All4Green	GreenDataNet			BodentypeDC
Fit4Green	Dolfin			
GAMES	GENiC			
	DC4Cities			
	GEYSER			

Source: Based on Mihaylov, 2018.

11 Other opportunities and challenges

There will be many benefits to digitalising and decarbonising heating and cooling: energy savings (see Chapter 10), reduced operating costs (thereby reducing exposure to fuel prices), greater resilience, better service quality, new markets for local heat sources, local job creation and improved industrial competitiveness, and mitigated environmental impacts including improved air quality (Rothballer, 2018).

However, the positive impact of digitalisation is accompanied by destabilising effects on some aspects of economic and social life. These include up-front costs, privacy and data protection, fairness and impacts on vulnerable groups such as the fuel poor, elderly or those less adept with ICT.

European citizens see digitalisation and automation primarily as an opportunity but call for investment in better and faster Internet services as well as effective policy to accompany changes in areas such as employment, privacy and personal health. The more people are informed or use technologies the more they are likely to have a positive opinion of them and to trust them (Eurobarometer, 2017).

11.1 Privacy and data

While traditional systems have collected user data on a planned basis, for example on a fixed date each year, new smart meters allow data to be collected at least hourly. Wide deployment of demand-response and smart-grid technologies brings with it an increase in the granularity and amount of data collected.

A central challenge is to properly collect and handle these data. Smart meter data are sensitive and fall under data protection laws. However, there are also anonymised, non-sensitive data being produced.

A healthy market for digitalisation will require some level of access to consumer and distribution data, such that companies can pursue the most valuable opportunities. Too much regulation could hinder the development of digitalisation for heating and cooling. This requires finding a balance, with the objective of forming an efficient, dynamic and open market (REN21, 2017).

Data protection (including notably the requirement in some cases that personal data be anonymised or deleted) is covered by the General Data Protection Regulation (GDPR), which entered into application in May 2018.

The Article 29 Working Party has concluded that smart meter data is considered personal data and therefore covered by the GDPR (Schelle Jensen, 2018). The Danish Energy Agency and Department of Justice have looked into whether into whether a legal basis for processing smart meter data can be found in Article 6, i.e. to the extent that such processing is in the public interest (e.g. to save energy) or for the purposes of legitimate interests (e.g. improving energy efficiency). They concluded that under certain conditions, district heating operators need not request consent from customers to read remotely readable meters more frequently than required for billing purposes (Danish Energy Agency, n.d.).

The decentralisation inherent in blockchain (all transactions can be seen by others) makes it difficult to interpret some GDPR rules. Compliance is therefore to be assessed by use case and application rather than for the technology as a whole (EU Blockchain Forum, 2018). Some systems now provide encrypted and private transactions.

11.2 Cybersecurity

In a more complex system, operators must protect information systems, detect potential attacks, and respond and recover from any incidents. In order to address this, it is important to develop a common understanding of cybersecurity threats, and a common response framework for operators.

The European Commission is reviewing the EU Cyber Security Strategy and developing a comprehensive strategy on how to reinforce the operation of the 2016 Directive on security of network and information systems (NIS Directive) in the energy sector (JRC, 2018a). ENISA, the EU Cyber Security Agency, assists Member States in the implementation of the NIS Directive and supports public and private stakeholders to enhance the security and resilience of their smart infrastructures and services and delivers trainings to enhance their capabilities.

Blockchain has the potential to make cyberattacks less likely, by giving digital identities to electronic equipment (Simon, 2018). On the other hand, it may itself be vulnerable to centralisation: a dominant player would be a critical failure point. Given that whoever controls mining also controls the protocol, this decides which transactions are deemed valid. If the majority of the hashing power decides for or against a change, it is nearly impossible for other users of the network to oppose this decision. In the case of Ethereum, for example, 61 % of the average weekly capacity is in the hands of just three miners (Kritikos, 2018).

Some newer blockchain projects hardcode decision-making processes into the software in the form of smart contracts, a method called on-chain governance (Kritikos, 2018). Also, the introduction of open-source patents such as the Blockchain Defensive Patent Licence is expected to encourage mining entities to grant their mining patents under a mutually defensive licence. That would prevent any single consortium from obtaining the ability to launch majority attacks, given the fierce competition to obtain patents that allow faster and more efficient mining (Kritikos, 2018).

11.3 Standardisation and interoperability

ICT standards are essential to interoperability (compatibility between systems) and competitiveness. Standards and interoperability are preconditions for the uptake of digitalisation for heating and cooling. No technology works in isolation and data from different sectors can help to optimise the energy system as a whole, so it is crucial to think holistically.

Missing standards for heat meter interfaces hamper the remote reading of data. Standardisation and regulation of remote metering in the electricity sector is far ahead of the heat sector (de Beaufort et al., n.d.).

The Communication on ICT Standardisation Priorities proposes to speed up the standard-setting process by focusing on 5G, IoT, cloud, cybersecurity and data technologies. It builds on the European Multi-Stakeholders Platform on ICT Standardisation, the Rolling Plan for ICT Standardisation and the Annual Union Work Programme for European Standardisation (Europa, 2018).

A key participant in European work on standards for digital interoperability in energy is the European Committee for Standardization-European Committee for Electrotechnical Standardization (CEN-CENELEC), which brings together the national standardisation bodies of 34 European countries and includes industry stakeholders, consumer representatives, trade unions and environmental groups. Recent areas of work include the development of standards for electricity and telecommunications networks, energy management systems, data formats for electronic invoicing and digital skills.

The Smart Appliances Reference Ontology (SAREF) is a common interoperability language for home appliances to exchange energy- and product-related information with any energy or building management system or entity.

The JRC Smart Grid Interoperability Laboratory was inaugurated in November 2018 in Petten. It will test the interoperability of market and research solutions, promote the use of a common interoperability testing methodology, network with other European laboratories and research centres for common initiatives, and disseminate the results of testing campaigns.

11.4 Economic activity

Investment in digitalisation of the energy sector (including smart meters, home energy management systems, distribution automation and other categories) is estimated at almost USD 60 billion in 2017 and projected to rise to USD 80 billion in 2025 (Curry, 2018). The global market for data analytics in the energy sector reached more than USD 3.5 billion by 2Q2017 (Gifford and Willuhn, 2018). Revenue from the sale of connected smart thermostats and their software and services is projected to reach USD 1.1 billion in 2025 (Navigant Research in IEA, 2017c).

Current estimates suggest a shortfall of EUR 155 billion of the total EUR 500 billion investment needed to meet the Commission’s 2025 internet connectivity objectives. Furthermore, lack of advanced computing systems impedes Europe's success in the data economy. Also, as underlined by the Commission’s communication on AI for Europe, there is currently a gap in investment in AI between the EU and competing economies of more than EUR 10 billion per year (European Parliament, 2019).

In Germany, the market for energy management services, software and technology has been growing significantly and service suppliers expect further dynamic growth (Flegel et al., 2017). The market volume of around EUR 0.2 billion is driven by the expansion of smart metering and remote services, along with improved opportunities derived from demand-side management and renewable energy.

Energy tech start-ups attracted EUR 5 billion in 2017 in venture capital and private equity (ESPC, 2018b). The cleantech sector in general has historically seen high risks and low returns to such investment. However, digitalisation can improve that situation: energy-oriented early-stage deals for software companies have been twice as likely to exit successfully and half as likely to dissolve as deals for hardware companies (IEA, 2017d). Likely reasons include the efficiency gains from enhanced productivity and reduced costs unlocked by automation, remote controls, marketplaces and other forms of software. In addition, the average software deal requires about half the capital of the average hardware deal, thereby enabling increased diversification for investors. Since 2015, the increase in corporate investments in new energy technology companies has been driven by the ICT sector (IEA in ESPC, 2018b).

There has been a strong trend worldwide towards greater corporate procurement of renewable electricity and companies are also set to play a leading role in deployment of renewable heating and cooling (see for example the Renewable Thermal Collaborative in the United States with members Cargill, City of Philadelphia, L'Oréal USA, Mars, Procter & Gamble, Kimberley-Clark and General Motors [7]). Such approaches are also an opportunity for digitalisation.

11.5 Skills

Reskilling is essential to help workers cope with the changes required by the energy transition and ensure a positive economic impact. Various funding mechanisms could play important roles in this, such as the recently launched Coal Regions in Transition Platform, Cohesion Policy funds, the European Social Fund or InvestEU. The European Parliament has also proposed an Energy Transition Fund to help regions green their economies (Morgan, 2018).

Already 90% of jobs require at least a minimum level of digital skills, and demand is growing for digital specialists (European Parliament, 2019). However, 37 % of the EU labour force has an insufficient level of such skills. In addition, nearly half of EU businesses are not implementing strategies to reskill their workforce.

The European Digital Platform for construction is intended to facilitate the uptake of digital tools such as BIM and support the digital evolution of the sector (JRC, 2018a). In

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[7] See www.renewablethermal.org.

addition, the BUILD UP Skills initiative, co-ordinated by EASME, was set up in 2011 to boost the continuing or further education and training of craftsmen, other onsite construction workers and systems installers (JRC, 2018b). There may be a need to focus future BUILD UP Skills support on digital technologies as well.

11.6 Social impacts

Energy poverty is a structural deficit in the accessibility and affordability of energy. It is caused by a combination of factors such as high energy bills, low incomes, poor energy efficiency, inadequate housing tenure and quality of energy supply. Around 9-11 % of the EU population is not able to heat their household adequately at an affordable cost (EU Statistics on Income and Living Conditions in Asensio et al., 2018).

Digitalisation of heating and cooling can help address energy poverty by reducing energy demand and spending. Using a smart thermostat is cheaper than insulating a building envelope. Digitalisation can therefore be a more attractive option for low-income households than more expensive measures. However, there is also a significant cost associated with digital technologies, and perhaps more importantly a risk of lock-in to sub-optimal measures or shallow renovation.

The European Commission has highlighted the increasing relevance of energy poverty (Asensio et al., 2018). As reflected in the Guidance document on Vulnerable Consumers, smart meters are an opportunity to empower consumers and promote integrated options. However, there is also a risk that digitalisation of heating and cooling could exacerbate digital divides, such as that between urban and rural areas, and introduce new types of inequality.

It is demanding and tiring to tackle uncertainties and learn how to use building technologies and contact professionals for support (Isaksson, 2017). Some (perhaps wealthier) households could react to digitalisation by opting for greater convenience and comfort (and increased energy consumption), while other (possibly less wealthy) households could face constant nudges to change their behaviour and reduce energy consumption.

Digitalisation for heating and cooling could also have gender impacts. The ERA-Net Smart Grid Plus-funded project MATCH found that it is often men that are most interested and engaged in new digital technologies and the efforts of monitoring and planning (Christensen et al., 2017). In extreme cases, giving control over thermal comfort, lighting or security to one member of the household could exacerbate situations of domestic abuse.

Finally, the digital divide applies to organisations as well as people. Larger companies exhibit much greater uptake of digital technologies than SMEs, and more traditional industry sectors such as construction also lag behind (European Parliament, 2019).

11.7 Digitalisation for policymaking

Digitalisation can improve the policymaking process in various ways, notably the collection and publication of more timely and better quality energy statistics. Digitalisation provides opportunities to analyse data on a much more disaggregated basis and enable the effects of policy interventions to be more easily tracked (Thomas, 2018).

All levels of governance can use data and a better sense of building energy needs to shape policy decisions and prioritise energy efficiency. Data can also play a critical role in targeting the right stakeholders to increase adoption, the more manageable market segments and the most critical areas for action.

For example, this could include near real-time statistics on power generation, or better information on biomass through geospatial imaging of forests. There is even potential to use satellites and drones to identify energy efficiency potential; for example, the

European Space Agency, E.ON and Astrosat plan to use satellite imaging data to create heat maps and identify areas in the UK where energy efficiency improvements are most needed (Eco-Business, 2018).

Digitalisation can also lead to greater use of market-based instruments for energy efficiency by making metered savings feasible in more circumstances; increased use of metering will ensure more accurate measurement of savings at the individual project level (IEA, 2017e).

Finally, digital energy labelling provides several advantages. For example, the Digi-Label project funded under Horizon 2020 develops and initiates the roll-out of an extended digital version of the European energy label (Dütschke et al., 2017).

12 Research and innovation

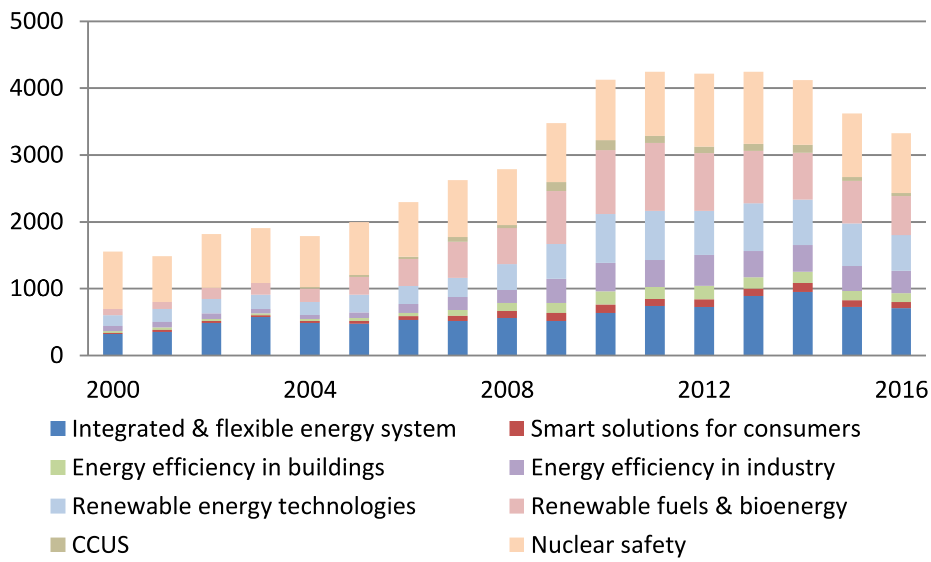
Europe needs a world-class research and science strategy. Public sector research plays a pivotal role in technology development and, just as importantly, nurtures many of the skills needed (OECD, 2016). Sufficient investment is therefore important.

The innovation progress of solar-assisted water or space heating systems and heat pumps has been estimated as "lagging but viable", while progress of DHC with renewables is "not viable at current pace"; meanwhile, information on advanced smart heating and cooling is "currently not available" (Cornell University et al., 2018). Among other areas, technology breakthroughs are still needed in high-temperature thermal storage and smart storage in general, though research is under way to bring capital costs down (OECD, 2016).

Further research is needed to improve understanding of the opportunities for co-generation and DHC in an increasingly dynamic, integrated energy system with various actors and energy sources (IEA, 2016a). There is also a need for more research into the impacts of digitalisation on emissions mitigation scenarios for the EU (INSIGHT_E, 2016).

Public research and innovation investment in digitalisation for heating and cooling has not yet been estimated but is likely to be very low. The categories "Smart solutions for consumers" and "Integrated and flexible energy systems" below are probably the most likely to contain digitalisation research but also contain much research that does not involve digitalisation, or only partly. Patent activity in these two categories has been increasing but is still behind the rest of the world.

Figure 7. Cool on funding: Public research and innovation investment in the EU, 2016 (EUR millions)

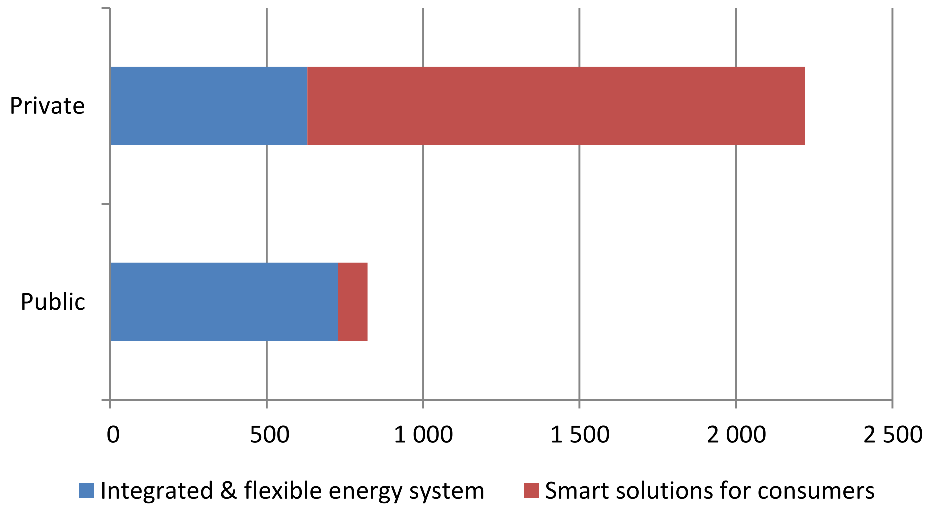


Source: Based on Pasimeni et al., 2018.

Notes: Public investment as available in the IEA RD&D Statistics database, for codes relevant to the Integrated SET Plan Actions. Public investment does not include funds from EU framework programmes or other funding instruments at EU level.

The data suggest that private research may tend to focus more on solutions for consumers, whereas public research may have more of a system-level emphasis. However, it is important to note that the data sources and typologies are different, so the comparison below can only be an indicative one.

Figure 8. Public systems, private solutions: Research and innovation investment in the EU, 2015 (EUR millions)



Source: Pasimeni et al., 2018.

Notes: Public investment as available in the IEA RD&D Statistics database, for codes relevant to the Integrated SET Plan Actions. Public investment does not include funds from EU framework programmes or other funding instruments at EU level. Private investment as estimated by JRC SETIS.

12.1 Examples

Under the current multiannual financial framework, digitalisation is financed through several programmes and instruments, the biggest being Horizon 2020. The European Commission proposes to spend about 16 % of the next round of Horizon 2020 funding on "Climate, Energy and Mobility". For the period 2021-2027, EUR 8.7 billion will be on offer for energy networks and EUR 3 billion for digital networks (Euractiv).

The European Commission has also proposed a new Digital Europe programme with a budget of EUR 9.2 billion to shape and support the digital transformation of Europe's society and economy (European Parliament, 2018). Of that, EUR 2.5 billion is to go to AI, EUR 2 billion to cybersecurity and EUR 700 million to digital skills. Digital Europe is the first ever funding programme dedicated to digital transformation.

The EU strategy on Digitising European Industry aims to financially support research and innovation, for instance via Horizon 2020. The contribution of the Energy Challenge is matched by a contribution from the ICT part of Horizon 2020 within two topics, "Interoperable and smart homes and grids" and "Big data solutions for energy". In addition, the Energy Challenge contributes to the Focus Area "Boosting the effectiveness of the Security Union" with the topic "Cybersecurity in the Electrical Power and Energy System" (JRC, 2018a).

Horizon 2020 cannot solve the challenges of digitalisation on its own. It is only by facilitating co-operation and triggering the creativity of businesses and innovators that the impact of digitalisation can be maximised. The SET Plan, supported by its Strategic Energy Technologies Information System (SETIS), is crucial in this respect: many of the targets and Implementation Plans that industry, research organisations, Member States and the European Commission have defined address digitalisation. The group working on smart solutions for consumers has for example agreed to look at reference architectures for generic digital platforms and at specific requirements for the energy sector (JRC, 2018a). Also, a new European Technology Platform on Renewable Heating and Cooling is being set up under the SET Plan with Horizon 2020 funding.

13 Conclusion – towards beneficial digitalisation

13.1 Energy policy initiatives

For buildings, the first priority should be to reduce the need for heating and cooling to the extent possible, in particular through renovation, better building design (solar shading, orientation, window size, efficient appliances and lighting, etc.) and urban planning. Efficient equipment is also important, although it should be a secondary priority (IEA, 2016a). There is also what has been called "getting the basics right": individual room temperature control and dynamic hydronic balancing delivered by equipment installed at the riser pipes or directly at the radiators; such technical solutions are well proven and offered by multiple suppliers at relatively low cost (Osojnik et al., 2017.

Digitalisation enables greater integration of heating and cooling with other sectors and uses of energy (transport, power generation, etc.). Energy policy should therefore focus not only on developing the market for individual technologies but on combinations of technologies, the interplay with on-site renewables and on managing the building's usefulness within a smart energy system (including district energy) (Schramm et al., 2017). For example, DHC has the capacity to incorporate several technology solutions (co-generation, industrial waste heat, heat pumps, solar thermal, off-peak or seasonal thermal storage, etc.). When paired with building efficiency measures, integrated solutions can reduce life-cycle costs for both buildings and the DHC networks themselves.

The Clean Energy for all Europeans measures push innovation in the direction of energy efficiency, demand response and small-scale generation, and aims to create markets for this increased flexibility. The package facilitates self-consumption and energy communities, strengthens the rules for metering and billing of thermal energy – especially for DHC and apartment buildings with collective heating systems – and mandates the gradual roll-out of remotely readable heat meters by 2027.

Article 8 of the EPBD aims to minimise energy use of technical building systems through better installation, adjustment and control (Schramm et al., 2017). For example, the text requires new buildings to be equipped with self-regulating devices, and existing buildings when heat generators (e.g. boilers) are replaced. The revised Directive also requires the European Commission, in consultation with stakeholders, to establish an optional common European scheme for rating the smart readiness of buildings, i.e. capacity to use ICT and smart technologies to adapt operation to the needs of the occupant and the grid and to improve its energy efficiency and overall performance. The Smart Readiness Indicator will raise awareness among building users and customers of the benefits of digitalisation and of the smart functions with the most impact, and will encourage investment in building modernisation.

The Connecting Europe Facility supports the development of trans-European networks in energy, digital services and transport. One of its key priorities is to enable synergies across those sectors so it is therefore a key instrument in promoting digitalisation for heating and cooling.

At Member State level, Germany launched a programme in 2017 that offers grants of up to 60 % of investment cost for new, innovative heating and cooling networks based on at least 50 % renewable heat. Similar support is available in France under the *Fonds chaleur* programme (IRENA, IEA and REN21, 2018). France has also made it possible for third-party aggregators to shift energy loads without needing the agreement of energy suppliers (UN Environment and IEA, 2017).

Policy and planning at all levels should also take into account the multiple benefits of heating and cooling technologies. Under the revised EPBD, renovation strategies are supposed to include "an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality".

Finally, the energy consumption of digitalisation needs to be considered alongside its potential benefits for decarbonisation and decentralisation. In order to ensure beneficial digitalisation, there is a need to assess energy consumption and to promote the uptake of more energy efficient technologies.

13.2 Digital policy initiatives

It is important to move from national digital markets to a single one, just as it is important to integrate national energy markets. There are synergies between the Energy Union[8] and the Digital Single Market in stimulating joint investments and coherence in regulatory frameworks, common standards and interoperability.

The European Commission has launched several initiatives as part of the Digital Single Market Strategy to tackle obstacles to big data and digital platforms.[9] The European Cloud Initiative aims to strengthen Europe's position in data-driven innovation. The Digitising European Industry initiative sets out a vision of IoT based on a thriving ecosystem, a human-centred approach and a single market. The Commission also assesses various legal and technical obstacles to the free flow of data and defines measures to address them; for the digital economy to flourish, data needs to be accessible and reusable across borders, and by different organisations and sectors. This work needs to continue as technological progress accelerates; in particular in the areas of data, AI and cybersecurity, and on uptake and skills (European Parliament, 2018).

Denmark for example has a Digital Strategy 2016-2020 adopted by the national, regional and local governments (IEA, 2017b). One of its focus areas is efficient utilities, highlighting the need for open and high-quality data, including on production and consumption of heat, as well as underground infrastructure such as district heating. Since 2013, energinet.dk, the TSO, gives extensive access to its data on the web, while several digital pilot projects are ongoing in smart cities, local grids and at commercial sites.

A co-ordinated plan on AI was agreed with Member States, Norway and Switzerland in December 2018; in addition to creating an enabling environment, it aims to build global regulatory norms and frameworks that ensure that AI develops in a human-centric and ethical way (Craglia et al., 2018). Finland and France have their own AI strategies and are building their capacity, with other Member States to follow.

The AI4EU project launched in January 2019 includes eight industry-driven pilots that will demonstrate an AI-on-demand platform. An AI4EU Ethics Observatory will be established to ensure respect for human-centred AI values. Sustainability will be ensured via the creation of the AI4EU Foundation, whilst the results will feed a new and comprehensive Strategic Research Innovation Agenda for Europe.

13.3 Standardisation and interoperability

Policymakers and companies need to ensure that equipment and devices are able to provide and receive information using open source or compatible software to allow for interoperability with other equipment, building management systems and energy networks. Inadequate interoperability and harmonisation of technology are obstacles to sector-coupling solutions such as power-to-heat. Standards can also improve interfaces and ergonomics, making products more user-friendly (IEA, 2017c).

The EU can not only lead in some or many technology and service innovation fields but also export its approach to system and market design. The EU "can set global standards for big data, artificial intelligence and automation", according to Jean-Claude Juncker in the 2018 State of the European Union. The large internal market and EU leadership in

[8] See https://ec.europa.eu/commission/priorities/energy-union-and-climate_en.
[9] See http://ec.europa.eu/digital-single-market/.

technologies and climate policy are an opportunity to promote European values and interests around the world, while the urgency and pace of the energy transition will impel all countries to adopt proven models for hardware, software, engineering, governance, legal frameworks and business models.

13.4 Research and innovation

Europe needs ambitious strategies for the rapid deployment of digital technologies. Continued support for R&D is needed, pushed by tighter minimum energy performance standards and pulled by market incentives and other policies.

Competition exists not only in technical solutions, but also business models, platforms and standards. First-mover advantage can make the difference between success and failure. Supporting emerging technologies therefore requires looking beyond R&D to appreciate the company and industry dynamics that contribute to their success.

13.5 Other opportunities and challenges

Digitalisation involves changes in technologies, services, standards, business models and socio-economic factors. These changes will affect energy companies, markets and infrastructure, households, and public authorities at all levels (including energy communities). Changes will be seen in the adoption and integration of new technologies but also in institutions, updated legal frameworks for privacy and cybersecurity, and jobs and skills.

Innovation requires a supportive regulatory framework and policies in order to develop and compete. Fully decentralised heating and cooling solutions will require sufficient regulation to encourage adoption and ensure the security and integrity of software, the ownership and control of intellectual property, and the trading of resources.

Yet policymakers also have a duty to anticipate threats and take action. Risks associated with digitalisation include technology lock-in, social exclusion and market oligopolies. This calls for an inclusive, anticipatory governance of technological change that includes assessments of costs and benefits and active shaping of development pathways (OECD, 2016).

In particular, strategies for digitalisation of heating and cooling need to be designed around people, taking care not to widen the digital divide or result in unwanted "gamification" of daily life. Technologies must be accessible and affordable to all, including renters, SMEs and low-income households, which may require specific support or skills initiatives. Data privacy and cybersecurity risks must also be addressed.

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List of abbreviations and definitions

1Q	first quarter
AI	Artificial Intelligence
BIM	Building Information Modelling
BEMS	Building Energy Management Systems
CES	community energy storage
CO_2	carbon dioxide
DHC	district heating and cooling
eceee	European Council for an Energy Efficient Economy
EED	Energy Efficiency Directive
EPBD	Energy Performance of Buildings Directive
EUR	euros
FP7	7th Framework Programme
GDPR	General Data Protection Regulation
GIS	Geographic Information Systems
HVAC	heating, ventilation and air conditioning
ICT	Information and Communications Technologies
IoT	Internet of Things
LED	light-emitting diode
JRC	Joint Research Centre
kWh	kilowatt-hour
Mtoe	million tonnes of oil-equivalent
MW	megawatt
MWh	megawatt-hour
n.d.	not dated
NIS	network and information systems
PV	photovoltaic
TSO	transmission system operator
USD	United States dollars
VSD	variable-speed drive

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