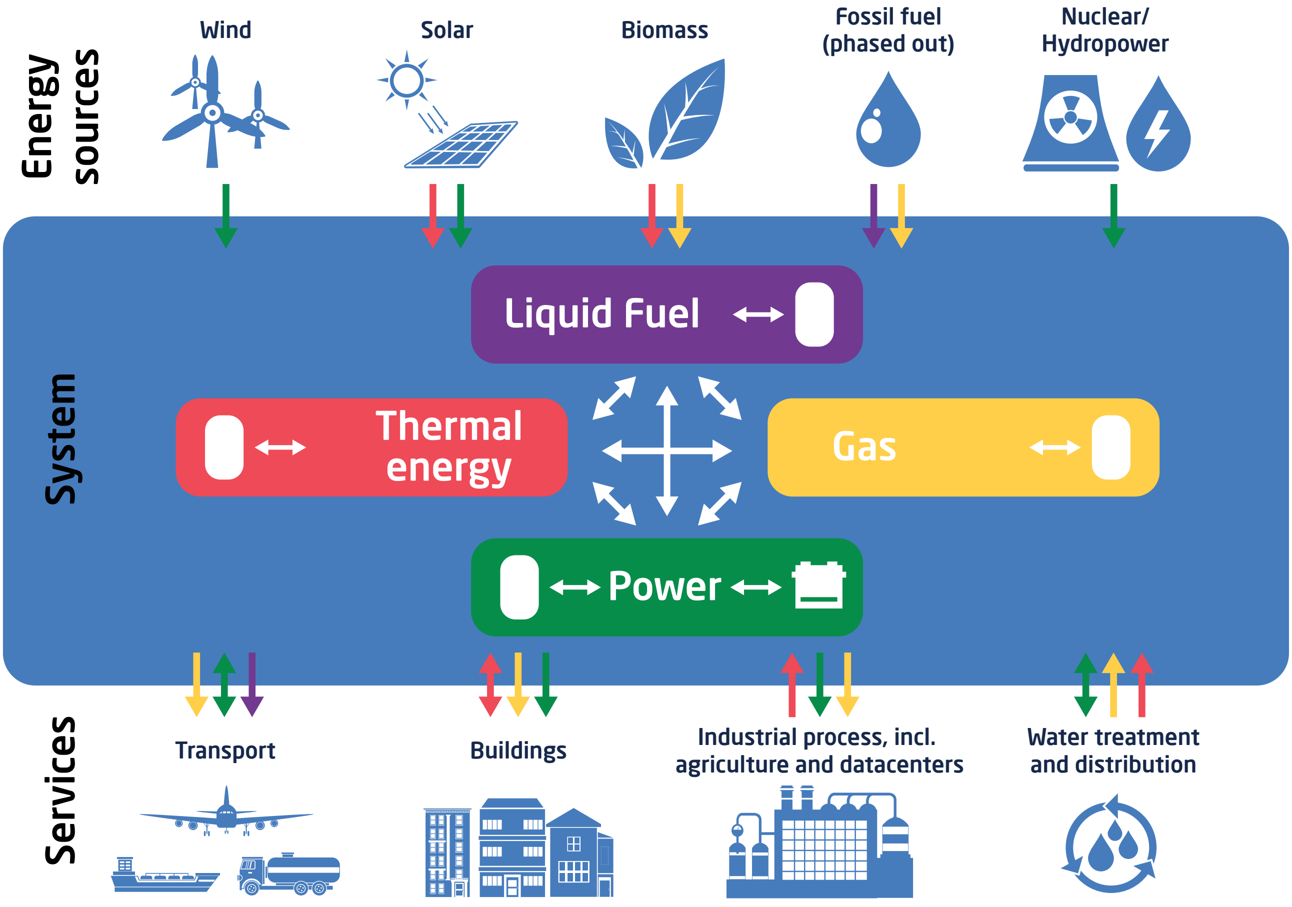
DTU Sector Development Report

Smart Energy Systems are the way forward



DTU Sector coupling model.

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PREFACE

Smart Energy Systems are the way forward

In this report, DTU presents an analysis of the research needs and framework conditions that can help to realize the potential Smart Energy Systems offer. The analysis has revealed that research into Smart Energy Systems, translated into business development, can make a major contribution to reducing CO2 emissions.

The analysis concludes with suggestions for necessary research in selected areas, and a set of recommendations that can help accelerate the development and use of new technologies and framework conditions. Six trade associations—the Danish Construction Association, the Danish Energy Association, the Danish District Heating Association, Danish Gas Technology Centre, the Confederation of Danish Industries/Energy, and (the Danish Association of Consulting Engineers—have contributed knowledge and input to the work.

The report offers constructive input to all players in the energy sector and other sectors. Obvious focus areas for action are transport, buildings, industrial processes (including in agriculture and data centres), and water treatment and distribution. These sectors must be integrated into Smart Energy Systems in the future, and help to strengthen the collaboration so that we can accelerate research and innovation in this area. This will be absolutely necessary in order to address the challenges entailed in these global goals: '7. Affordable and clean energy', '11. Sustainable cities and communities', and '12. Responsible consumption and production'. It is our hope that the report can help secure Denmark a position at the very forefront for many years to come.

We hope you enjoy reading the report!

Director Michael H. Nielsen, the Danish Construction Association

Research and Technology Director Jørgen S. Christensen, the Danish Energy Association

Deputy Director Kim Behnke, the Danish District Heating Association

Deputy Director Jan K. Jensen, Danish Gas Technology Centre

Sector Director Troels Ranis, the Confederation of Danish Industries/Energy

CEO Henrik Garver, (the Danish Association of Consulting Engineers

Director for Innovation and Entrepreneurship, Senior Vice President Marianne Thellersen, DTU

Smart Energy Systems are the way forward

Denmark's goal of a 70 per cent reduction in CO2 emissions by 2030 compared to the 1990 level can only be achieved through digitalization and integration between different forms of energy. We must also exploit the potential for CO2 reductions in sectors that are not normally viewed as part of the energy sector.

Countries and industries that manage to create cohesive and flexible energy systems will be the most successful and save costs in the transition to green energy, and in business development, export and job creation. The challenges and opportunities are particularly great for Denmark, as we have very ambitious goals for renewable energy, particularly in relation to technologies with variable energy production, such as wind power and solar cells.

Wind power, solar energy, biomass and other renewable energy sources are already competitive in relation to fossil energy—or close to being so. These technologies will form the backbone of the future energy system. But production from wind and solar power varies with changes in the weather. The energy system will therefore face a major dual challenge in the coming years. As the energy system becomes increasingly dependent on solar and wind energy, we will have a greater need for balancing. We have been able to handle this balancing in the past by raising and lowering production at combined heat and power plants and utilizing reserves. However, combined heat and power plants are being phased out, and foreign countries will increasingly use their reserves to balance their own energy systems, as these become more fossil-free.

In the future, balance must be maintained by shifting the focus from the former central units to all the units in society that can provide flexibility. Part of the challenge will therefore be to use analytics, artificial intelligence and IoT to ensure that there is balance between production and consumption, through much greater flexibility on the consumption side. For the Danish energy system, this means focusing on electric vehicles, buildings, district heating systems, the gas system, cooling systems and treatment plants.

Smart Energy Systems

'Smart Energy Systems' refer to cost-effective, sustainable and secure energy systems in which renewable energy generation, infrastructure and energy consumption are integrated and coordinated through energy services, active users and various technologies. However, this report deals only with digital technologies. The key players in this field are electricity companies, other utilities and a number of other companies, including wind turbine and solar power plant manufacturers and their suppliers. A number of IT companies are also active in the field.

Smart Energy Systems are essential to the development of sustainable energy systems, so that the world can achieve its goals of reducing greenhouse gas emissions and protecting the climate. Three of the UN's 17 global goals—'7. Affordable and clean energy', '11. Sustainable cities and communities', and '12. Responsible consumption and production'—address transformation of the energy system. The development of a Smart Energy System is thus a vital global agenda, and will be increasingly sought after for many years to come.

By 2030, the countries of the world are expected to increase their investment in energy solutions to USD 13,500 billion in order to meet their commitments in the Paris Agreement, which aims to protect the climate. A further USD 8,000 billion is expected to be invested in distributed intelligence, data analytics and communications technologies.

Great socio-economic advantages

The committee responsible for the electricity tariff reports, the Climate Council, the Energy Commission, the Danish Government's subsequent energy initiative and the new energy policy agreement for 2020 and beyond, all emphasize that now that solar and wind power have become competitive and the share of renewable energy in the system has grown, the main challenge in the future will be to ensure that renewable energy is used in a smart way, when it is available.[1] In addition to being vitally important to protecting the climate, this area offers great socio-economic advantages.

Cost-effective integration of fluctuating renewable power generation can be achieved by establishing coupled energy systems through digitalization, as well as big data analytics, artificial intelligence and cyber-physical systems, etc. This will make it possible to achieve a greater proportion of renewable energy with lower capacity costs (less grid expansion and less backup capacity).

Carbon emissions and harmful emissions have significant socio-economic costs. The effective control and reduction of these using sensors, filters, etc. will result in socio-economic benefits.

Smart Energy Systems will also allow broader utilization of transitions between energy forms and activation of the cheapest storage technologies—whether these be in central heat storage, external hydropower storage, district heating systems, buildings, batteries in electric vehicles, or gas-based storage. A portfolio of storage technologies is expected to lead to lower capacity costs compared to homogenous storage in each energy sector.

Digitalized energy systems may also provide a basis for better control, management and troubleshooting in manufacturing production processes. Value will be created here in terms of reduced energy costs, and more continuous production (control and monitoring) and flexibility in optimizing operations. Value can be created by improving general competitiveness in the manufacturing industry, as well as through export potential for Danish energy technologies, equipped with better control and management options. Savings can also be achieved through reductions in process and production times in manufacturing.

Two fundamental elements are involved in the digital transformation of the distribution grid. The first is that grid operators can better utilize existing capacity in the distribution grid, since by improving grid monitoring they can allow higher loads. The second is a cohesive system of measurements, forecasts and communication systems, aimed at monitoring grid loads and optimizing utilization.

In summary, Smart Energy Systems offer socio-economic advantages in three areas:

1. Achieving environmental goals at the lowest possible cost

2. Streamlining industrial production processes, thereby freeing up resources for investment and other consumption and increasing production competitiveness

3. Welfare gains through a wider product range/ new products that increase choice and comfort for consumers and offer new export opportunities

[1] "Vision for Smart Energy in Denmark", The Partnership Smart Energy Networks, Lea Lohse and Per Nørgaard
Danish Ministry of Climate, Energy and Utilities (2018): Energy agreement.

Four-level basic model

A basic model was developed during the sector development project (see Figure 1). This assumes that the development of Smart Energy Systems must take into account several levels.

The first level of the model consists of the goals the system has to fulfil. These will typically be goals related to the green transition, business development and a focus on consumer needs.

The next level describes the means to be used to achieve the goals. Keywords are flexibility, integration, optimization and automation.

The third level consists of supporting methods, technologies and framework conditions. Examples include the development of new technologies to mobilize flexibility and promote integration, and system architectures, control technologies, digitalization and frameworks for the utilities sector, and dynamic tariffs and charges.

Finally, it is necessary to have a fourth level describing how the system will handle cybersecurity, including the protection of private data, and general robustness.

The basic model is presented in Figure 1.

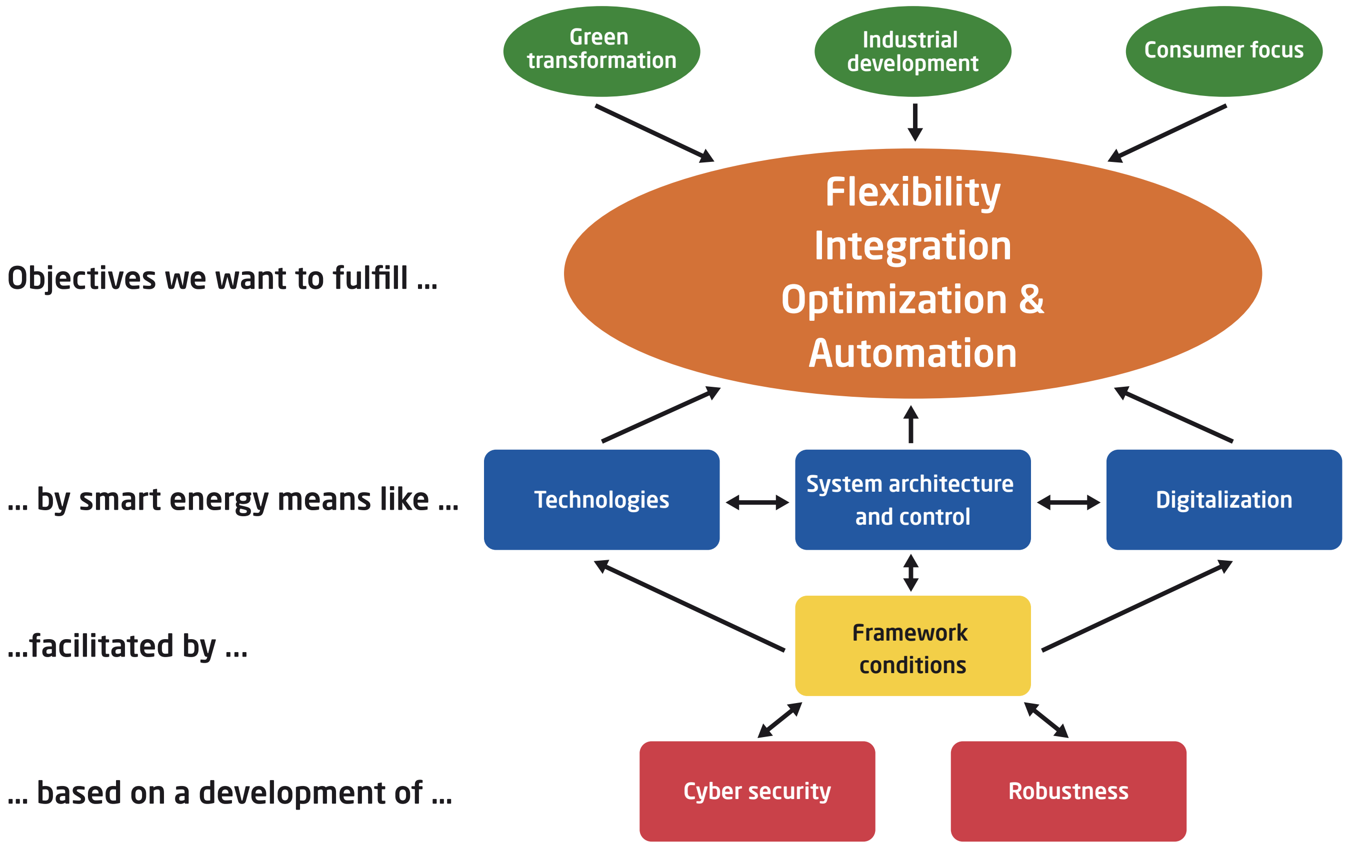

Figure 1. Basic model for Smart Energy Systems.

Sector coupling model

A sector coupling model was developed during the sector development project (see Figure 2). This assumes that the development of Smart Energy Systems must take into account several levels. The future energy system will be primarily based on fluctuating energy sources such as wind and solar power. The goals are to reduce CO2 emissions, and to use 100 per cent renewable energy. There will be different solutions depending on geography and current energy systems. The model illustrates the global energy system.

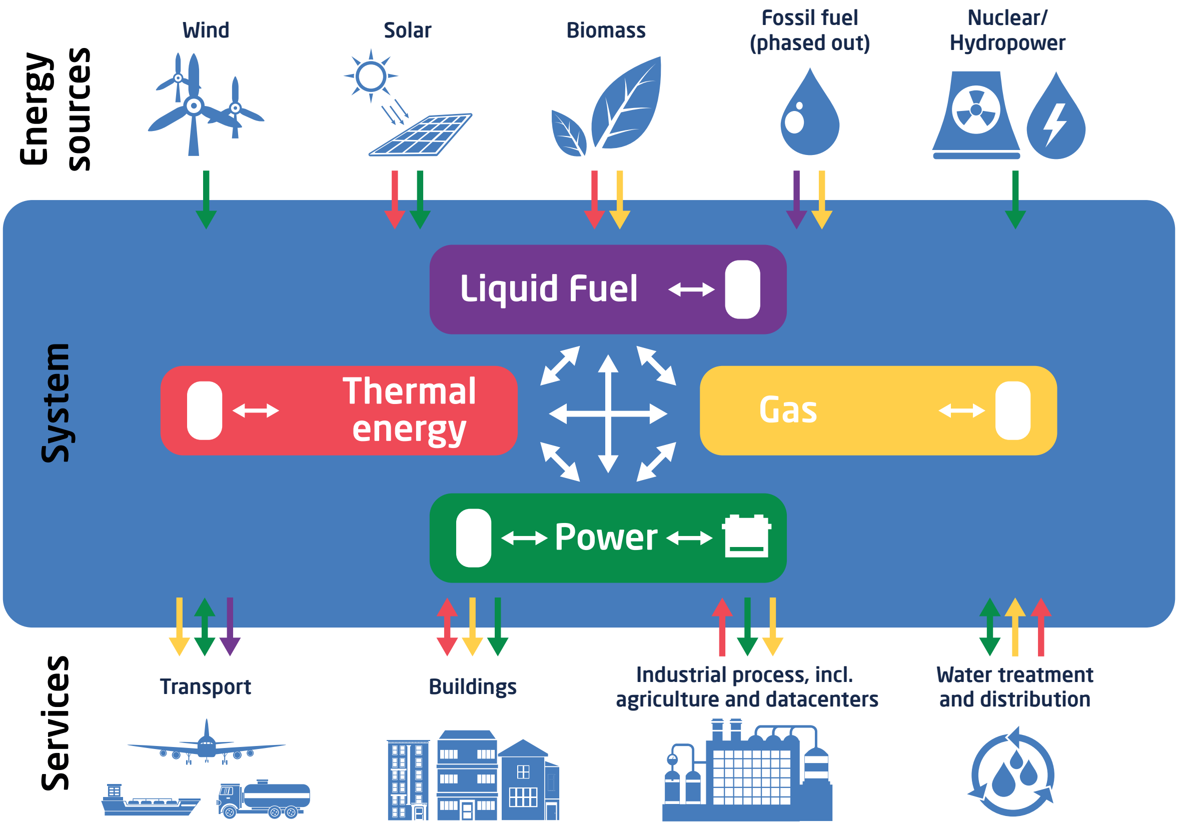

Figure 2. Sector coupling model.

Path to a 70 per cent reduction in CO2 emissions in Denmark

To achieve the goal of a 70 per cent reduction in CO2 emissions in Denmark by 2030, efforts will need to be significantly stepped up. At present, we have reduced CO2 emissions by 32 per cent compared to the 1990 level. This equates to a 1.1 per cent reduction per year. To meet the goal of a 70 per cent reduction in CO2 emissions by 2030, we must reduce emissions by 3.3 per cent per year from now on. In other words, we must implement the next stage of the green transition three times faster than the previous stage. The transition must be implemented in such a way that Denmark can maximize the benefit from the ambitious policy goals by focusing on flexibility based on digitalization and artificial intelligence, as alternatives to investments in cables and energy plants. At the same time, export companies must develop energy efficient and flexible solutions on the consumption side.

Achieving the 2030 goal will require greater direct electrification of areas such as heating, transport and industry. However, direct electrification is not in itself sufficient to achieve the 2030 goal. Further reductions can be achieved by using renewable energy electricity for Power-to-X.[2] Given the right framework conditions, it is believed that Power-to-X can provide flexible energy consumption that can support the necessary large-scale investment in solar power and especially in offshore wind power towards 2035.

According to the project calculations, reductions of 80-95 per cent in CO2 emissions could be achieved in six areas which account for a significant proportion of energy consumption (see Figure 3).

These six areas are:

1. Electric vehicle integration
2. Sector coupling between electricity and district heating
3. Buildings
4. Electrification and integration of industrial processes (including agriculture and data centres)
5. Sector coupling between electricity and gas, with the development of hydrogen technologies, Power-to-X and the production of liquid and gaseous fuels
6. Distribution and treatment of water.

[2] Power-to-X refers to the conversion of green power into hydrogen, for the subsequent production of green ammonia, green methane, etc. and other applications.

Case	Potential PJ reduction	Potential mio. CO2 reduction	Potential reduction relative to 2030 basic forecast (%)	Timehorizon for effect	Research needs
Case A - Integration of elctric vehicles - EVs and power grid	120	11.2	93%	0-15 year	Charging technology, user behaviour, netload, analytics, intelligent charging technology, fleet management tools, smart grid communication, flexibility services for netcompanies and service-based business models.
Case B - Sectorcoupling between electricity and district heating	21	2.5	89%	0-10 year	Need and potential for flexibility, dataplatforms, management and controlsystems, flexibility markets and products, analyses of need for regulation and value of flexibility.
Case C - Buildings	25	1.8	92%	0-25 year	Building flexibility characterization, regulation for the advancemetn of flexibility, management of heating and cooling systems, materials with better termal endowments, heating solutions that facilitate flexibility, personalized indoor climate, energy labeling scheme, methodologies for energy improvement activities, principles for design of buildings and cities for the green transformation.
Case D - Electrification and integration of industrial processes	20	3	73%	0-25 year	Potential for electrification, technical solutions for all temperature levels and capacities, effective heatpump facilities for all temperatures, heatpumps that apply natural and non-environmentally harmful refrigerants, hybrid solutions, digitalization, supply and capacity in the power system, solutions that both provide much flexibility, productivity and product quality, industry sector perspective in energy systemsanalysis.
Case E - Sectorcoupling between electricity and gas	-54	3.5	64%	10-25 year	Development of economically feasible electrolysistechnology, thermal gasification/pyrolysis, biological facilitations/fermentation, gasses that are the most effective energycarriers, value of flexibiilty, techno-economic benchmarking of different system layouts and technology choice, regulatory adjustability of various conversion technologies, flexibility by coupling Power-to-gas with other storage technologies.
Case F - Distribution and treatment of water	(Flexibility effect)	(Flexibility effect)	(Flexibility effect)	0-25 year	Drinking water: Pumping to water tower, potential in desaltification of sea water. Waste water: Various types of treatment plants, flexibility, potential for smart management of pumping stations, waste water tariffs and power tariffs in relation to sustainable management of water water systems.
In total - all 6 cases	142	22	83% for cases, (58% in total)	-	

Figure 3. CO2 reduction potential in six Smart Energy System cases, time horizon for effect and required research.[3] The calculations are based on the Danish Energy Agency's basic projections, and are estimates.

[3] Please note that biomass is considered to be carbon neutral, as assumed in the UN Convention. In reality, however, biomass is not always carbon neutral.

Sector coupling and Smart Energy Systems can facilitate potential CO_2 reductions. The total potential across the six cases is estimated to be 22 million tonnes of CO_2. By comparison, we need to reduce CO_2 emissions by 29.4 million tonnes compared to emissions in 2017 if we are to achieve the goal of a 70 per cent reduction by 2030. In other words, quite significant CO_2 reductions are achievable.

The following table (Figure 4) presents an overview of the six cases, their maturity based on various parameters, and their contribution to flexibility. Analyses performed in the sector development project show that the maturity in relation to realizing the potential varies, and that the cases have an implementation time of between 0-10 and 0-25 years. We therefore need to start these transitions immediately if we are to achieve significant reductions in CO_2 emissions by 2030. It will also be essential to focus on Smart Energy Systems in parallel, and on the necessary technical and structural changes in a number of sectors of society.

	Cases	Readiness of infrastruc-ture	Technological readiness	Readiness to Smart Energy System	Limitations by regulation	Readiness of market	Flexibility		
							Second	Hour and day	Season
	Def:	Deployment and function of necessary infrastructure to implement the case	Readiness of technology in relation to market development	Readiness to be part of a Smart Energy System or do we still need research, development, test and demonstration	Is it possible to implement the case with existing regulation?	Do we have a market pull to drive imple-mentation?	Ensures short term balance and security of supply of power grid	Creates daily flexibility to cope with variations in renewable power production	Creates seasonal flexibility, e.g. in terms of storage facilities
A	Integration of elctric vehicles - EVs and power grid	▼	▲	▼	▼	▼	▲▲ Charging and decharging can be managed at short notice	▲	▼▼
B	Sectorcoupling between electricity and district heating	▲	▲▲	▬	▼	▲	▲	▲▲	▲
C	Buildings	▲	▲▲	▬	▼	▼	▬	▲ Simple management makes it possible to switch energy supply off for several hours	▬
D	Electrification and integration of industrial processes	▲	▼	▬	▲	▬	▬	▲	▼▼
E	Sectorcoupling between electricity and gas	▲	▼	▬	▲	▼	▼	▲▲	▲▲
F	Distribution and treatment of water	▲▲	▬	▼	▬	▼		▲▲	▼▼

+2: ▲▲ =High maturity +1: ▲ = Low maturity 0: ▬ = Neutral -1: ▼ = Low immaturity -2: ▼▼ High immaturity

Figure 4. Maturity of the six Smart Energy System cases and their contribution to flexibility.

Recommendations for research and development

The overarching recommendation is that players in the energy sector, innovative digital companies and universities should jointly embark on much larger strategic initiatives for the development of cohesive Smart Energy Systems in Denmark and internationally. It is particularly important to recognize that flexibility needs to be shifted even more from production to consumption in the future, and obvious focus areas are therefore transport, buildings and industrial processes (including agriculture and data centres) and water treatment and distribution. Research should be conducted into aspects of the integration of energy technologies into Smart Energy Systems, in addition to research into individual storage and conversion technologies. The research efforts could be carried out in the planned new test zones, which aim to allow new and alternative framework conditions to be tested.

The focus is on research and development to be carried out today that can contribute to solutions by 2030, and lay the foundation for the solutions in 2050. It is therefore important to note that even the more short-term research should involve a 2050 perspective, so that the short-term investments will be aligned with the needs in the period between 2030 and 2050.

The recommendations for research and development are:

1) *Research into the development of platforms for sector coupling*

2) *Research into the development of methods and software to mobilize flexibility, including flexibility products*

3) *Research into tax structures that support flexibility and efficiency, and are fair to consumers*

4) *Research into tariff structures that support flexibility, while also ensuring economic efficiency and stability in the grid*

5) *Research into consumer-focused solutions and new business models that promote involvement and create value for customers*

6) *Research into how to ensure the robustness of decentralized and internationalized Smart Energy Systems*

7) *Research into the development of new models for optimizing investments and operations, specifically in a Smart Energy System context, and for calculating the socio-economic benefits*

8) *Improve access to data and enable innovation*

9) *Research into aspects related to the integration of energy technologies into Smart Energy Systems*

Recommendations on framework conditions and training, testing and demonstration, and innovation

The recommendations regarding framework conditions etc. are:

10) *Better framework conditions for utilities*

11) *The need for awareness of the green transition in other countries*

12) *Continuing education and awareness of interdisciplinary skills*

13) *Test and demonstration projects, localized needs and business models*

14) *Fund research into system aspects and into enablers of Smart Energy Systems*

INTERVIEWED COMPANIES, PUBLIC INSTITUTIONS AND AUTHORITIES, AND SECTOR ASSOCIATIONS

ICT companies:

Energy technology companies:

Construction:

Consultant engineering companies:

Utilities:

Public institutions and authorities:

Brancheforeninger:

Disclaimer: Representatives from the companies, universities and public institutions, and authorities listed above have been interviewed, but cannot necessarily be held accountable for the content of the report. Enquiries regarding the report can be addressed to Senior Executive Officer Mads H. Odgaard, maod@dtu.dk.

HCØ

Denmark celebrates the 200 year anniversary of Hans Christian Ørsted's discovery of electromagnetism

H.C. Ørsted discovered the link between electricity and magnetism in 1820. A direct line can be drawn from this scientific realization, via technical knowledge and industrial enterprise, to a fundamental and positive transformation of our society.

To this day, the link between electricity and mechanical power remains a key focus of research. Among the major challenges facing researchers is how to develop better batteries that will store the electricity we produce for a longer time—or how to establish carbon-neutral energy production on an even larger scale.

H.C. Ørsted epitomizes the inquisitive mind and is a present-day role model. He shows us that you can change the world if you are curious about nature. He was interested in nature's characteristics and performed an experiment where he saw something he did not expect to find. He investigated the unexpected phenomenon further and described it in such a way that others could reproduce his experiment. Thus, the discovery came out of his laboratory and influenced the entire scientific world.

Electromagnetism provides the scientific basis for a major proportion of electrotechnology—especially microwave technology.

Later in the 19th century, Ørsted's discovery of electromagnetism made it possible to demonstrate the electromagnetic waves that surround us today and which are used in countless ways for wireless communication—e.g. via mobile phones, radar, satellites, medical devices, and security systems. Technologies that continue to be researched to this day, and which provide the basis for a wide range of DTU's strengths.