



Towards a European Smart Energy System

ICT innovation goals
and considerations

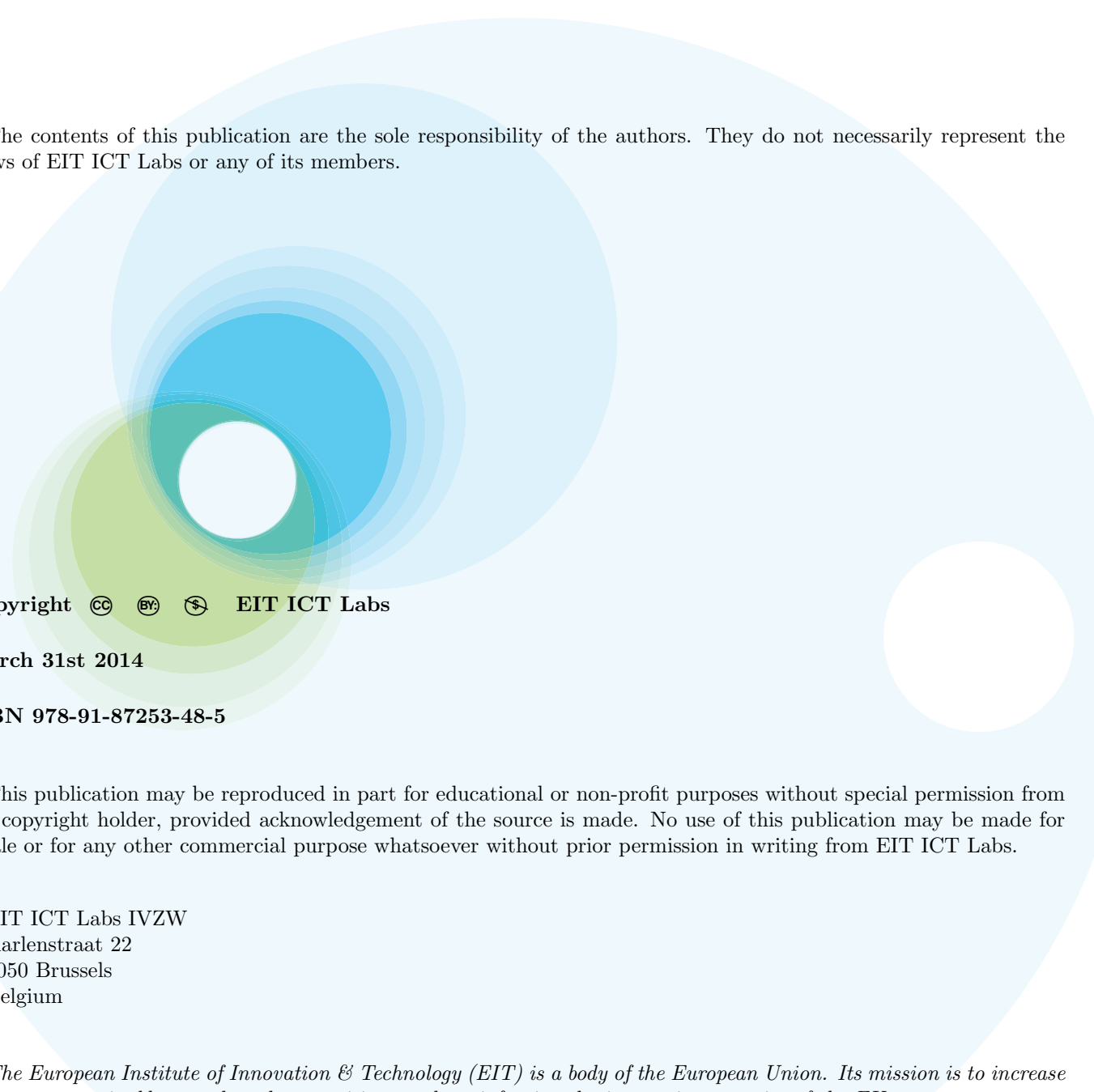


Felix N. Claessen
Han La Poutré
(Eds.)

Abstract

The EU-driven integration of European energy systems and the development of a Smart Energy System involves many key players. The success of a European Smart Energy Systems relies heavily on the development of well-designed ICT solutions in all related sectors. Because such ICT solutions should be well aligned, ICT innovation goals are needed that have the support of key European players and consortia.

To this end, Round Tables have been organised by EIT ICT Labs from 2013 onwards, in which key players in the European energy sector establish a common vision on and align forces in the development of a European Smart Energy System. We reflect and build upon these discussions to formulate a joint input to the European goals on ICT and Smart Energy Systems, and for the innovation activities of EIT ICT Labs.



The contents of this publication are the sole responsibility of the authors. They do not necessarily represent the views of EIT ICT Labs or any of its members.

Copyright © EIT ICT Labs

March 31st 2014

ISBN 978-91-87253-48-5

This publication may be reproduced in part for educational or non-profit purposes without special permission from the copyright holder, provided acknowledgement of the source is made. No use of this publication may be made for resale or for any other commercial purpose whatsoever without prior permission in writing from EIT ICT Labs.

EIT ICT Labs IVZW
Aarlenstraat 22
1050 Brussels
Belgium

The European Institute of Innovation & Technology (EIT) is a body of the European Union. Its mission is to increase European sustainable growth and competitiveness by reinforcing the innovation capacity of the EU.

EIT ICT Labs is a pan-European education and research-based innovation organisation founded on excellence. The mission of EIT ICT Labs is to drive European leadership in ICT innovation for economic growth and quality of life. EIT ICT Labs is a Knowledge and Innovation Community of the European Institute of Innovation and Technology. By linking education, research and business, EIT ICT Labs empowers ICT top talents for the future and brings ICT innovations to life. The ecosystem is characterised by an open and collaborative way of working with partners representing global companies, leading research centres, and top ranked universities in the field of ICT. Since 2010, EIT ICT Labs is consistently mobilising talents, ideas, technologies, investments as well as business across Europe and beyond. For more information, visit www.eitictlabs.eu.

Centrum Wiskunde & Informatica (CWI) is the national research institute for mathematics and computer science and part of NWO, the Netherlands Organisation for Scientific Research. The mission of CWI is to conduct pioneering research in mathematics and computer science, generating new knowledge in these fields and conveying it to society, especially industry.

Contents

1	Introduction	5
2	Background	6
2.1	An integrated European energy system	6
2.2	EU recommendations	6
2.3	The role of ICT and market design	7
3	A European system of systems	9
3.1	Chances for new ICT solutions	9
3.2	Open questions and ICT challenges	10
3.3	A general wish list towards legislators	10
4	Markets for smart grids	12
4.1	Roles within new organisational designs	12
4.2	Organisational designs for smart grids	14
4.3	Challenges for ICT	15
4.4	Wish list for further alignment	17
5	Integrating new ICT services for big data management	19
5.1	The value of big data	19
5.2	New services made possible	20
5.3	Obstacles for deployment	22
6	Making the most out of different energy carriers	23
6.1	When to use a mix of energy carriers?	23
6.2	Barriers to business case development	24
6.3	Next steps in ICT development	25
	Acronyms and abbreviations	26
	References	27

SES Round Table project coordination and lead

Felix N. Claessen ^(2,3,4) and **Han La Poutré** ^(1,2,4)

Centrum Wiskunde & Informatica (CWI), Amsterdam

SES Round Table committee 2013

The Round Table committee of the Smart Energy Systems Action Line of EIT ICT Labs was formed by the following members in 2013:

Heiko Lehmann ^(1,4) and **Christian Huder** ⁽¹⁾

Telekom Innovation Laboratories

Co-chairs of the 1st Berlin Round Table (July 8th 2013) – Decentralized Energy Provisioning

Co-authors of Chapter 3 – A European system of systems

Felix N. Claessen ^(2,3,4) and **Han La Poutré** ^(1,2,4)

Centrum Wiskunde & Informatica (CWI), Amsterdam

Co-chairs of the Amsterdam Round Table (November 29th 2013) – Markets for Smart Grids

Co-authors of Chapter 4 – Markets for smart grids

Alexey Baraev ⁽³⁾ and **Daniele Miorandi** ⁽³⁾

CREATE-NET

Co-chairs of the Trento Round Table (December 4th 2013) – Big Data for Smart Energy Systems

Co-authors of Chapter 5 – Integrating new ICT services for big data management

Thomas P. Mahr ⁽⁴⁾ and **Ariane Sutor** ⁽¹⁾

Siemens

Co-chairs of the 2nd Berlin Round Table (December 12th 2013) – Multimodal energy systems

Co-authors of Chapter 6 – Making the most out of different energy carriers

SES Round Table participants*

Jan van Aken ⁽²⁾

Fabio Bellifemine ⁽³⁾

Massimo Bertoncini ⁽³⁾

Andrea Bombana ⁽³⁾

Andrea Bondi ⁽³⁾

Paul Boonekamp ⁽²⁾

Alberto Bridi ⁽³⁾

Giuseppe Carrara ⁽³⁾

Davide Franceschini ⁽³⁾

Michele Gubert ⁽³⁾

Onnen Heitmann ⁽⁴⁾

Paulien Herder ⁽²⁾

Clemens Hoffmann ⁽⁴⁾

Maarten Hommelberg ⁽²⁾

Klaas Hommes ⁽²⁾

Nicolas Höning ⁽²⁾

Frans Koene ⁽⁴⁾

Christoph Lange ⁽⁴⁾

Michael Metzger ^(2,4)

Randolf Mock ⁽⁴⁾

Giacomo Poderi ⁽³⁾

Cristiano Quaciari ⁽³⁾

Bram Reinders ⁽²⁾

Tullio Salmon Cinotti ⁽⁴⁾

Manuel Sánchez Jiménez ⁽²⁾

Jochen Schäfer ⁽⁴⁾

Yannis Velegrakis ⁽³⁾

Frits Verheij ⁽²⁾

Robert Weiss ⁽⁴⁾

Alessandro Zorer ⁽³⁾

Acknowledgements

With special thanks to:

Udo Bub ^(1,2,4)

EIT ICT Labs

Node Director of the Berlin Node

*The contents of this publication do not necessarily represent the views of individual Round Table participants.

¹1st Berlin Round Table (July 8th 2013) – Participants undisclosed

²Participants of the Amsterdam Round Table (November 29th 2013)

³Participants of the Trento Round Table (December 4th 2013)

⁴Participants of the 2nd Berlin Round Table (December 12th 2013)

1 Introduction

Felix N. Claessen and Han La Poutré

Worldwide, the activities and views on future Smart Energy Systems (SES) are dispersed, and no clear global or European directions are present. Governments, industry, and society agree that future power generation should be approached in a sustainable fashion. To this end, sustainable energy resources such as wind, solar, heat, and biomass are more and more used in our energy system. However, these resources are intermittent in their power generation. In addition, devices for transportation and heating become electric and more environmental friendly, like in the form of electric vehicles and heat pumps. But at the same time, these put a stress on the electricity system by their intense power consumption. So, it is widely agreed that our overall energy system should change, in order to deal with the above goals and developments. However, the development of our energy system, including its future actors and their roles, is highly uncertain. These depend on developments in a wide range of disciplines and sectors that are involved in or are interconnected with the energy system, such as power technology, ICT, governance and regulation, social norms and behaviours, business and business roles, markets, and, of course, the economy. Many scenarios for developments of our energy system can therefore be envisioned, and the future remains highly uncertain.

Currently, companies and governments but also academia are still looking at other players with respect to how to proceed in acting, developing, and investing in SES. What is needed to advance the coordinated and smooth introduction of SES are short-term and longer-term approaches, positioning, and visions. Dispersed or even adverse developments have to be reduced in size, and business opportunities have to become more clear and with more stable expectations.

In order to obtain a European common view and approach, EIT ICT Labs has started organising Round Tables involving a broad range of key experts in the field

of SES, from industry, politics, and academia. The results of the first four Round Table meetings, held in 2013, are reflected and built upon in this report. The Round Tables aim to contribute to a common understanding of challenges and strategies in business development, investments, and R&D, in order to enable future coherent and synergetic eco-systems of business, government, and academia. The four Round Tables in 2013 were organised around the topics of decentralised energy provisioning, markets for Smart Grids, ICT services for big data management, and integrated systems for various energy carriers. The Round Tables aim especially at ICT challenges, but also largely address other essential challenges and problems intertwined with ICT challenges for SES. Examples of other important challenges lie in the areas of business roles and governance roles.

The Round Tables and this document may be valuable to potential users and actors in SES as well as to society, in different ways. Bottlenecks, opportunities, and challenges are detected and addressed in order to come to an operational, stable, and profitable SES. This can lead to a better coordination of business and research investments, where common grounds and visions are more readily available. It will also help to understand the market needs and help to derive new activities in the field of SES. This could lead to new research, development, and test projects, within EIT ICT Labs or in general, as well as to new business and governance initiatives on the road towards a fully fledged Smart Energy System.

How to read this report We advise the reader to first read Chapter 2, which frames the development process of the European energy system and provides a background for our focus on ICT innovation. Chapters 3 to 6 correspond to the Round Tables organised in 2013 and can be read independently, depending on the interest of the reader.

2 Background

Felix N. Claessen and Han La Poutré

The Round Tables are set out to examine what ICT innovation is needed for Smart Energy Systems (SES). Here, we frame the development process of SES in a European perspective. Various European consortia have been set up within the last decade, bringing together, for example, national regulators, energy industries, system operators, market operators and ICT developers. Discussions between these consortia are facilitated by the EU within various projects related to SES, as well as within the European Institute of Innovation & Technology (EIT). These activities lead to both regulatory recommendations to and by the EU, and to new ICT innovation goals for academia and industry.

2.1 An integrated European energy system

For two decades, the European Commission has worked on the development of an integrated European energy system. Three main goals are associated with this [1]:

1. Security of supply, by enabling international access to a more varied mix of energy resources.
2. Competitiveness, by having lower energy prices due to economically efficient generation.
3. Sustainability, by enabling export of renewable energy surplus to other countries across Europe.

A number of policy measures have been taken by the European Commission in order to attain these goals, such as unbundling, infrastructure integration and market integration. Unbundling of infrastructure and trade has been progressively regulated by the EU since 1996 through liberalisation, requiring vertically integrated utilities to sell off their infrastructure to regulated system operators. European integration of infrastructure has been supported by the Trans-European Energy Networks programme since 1995, financing transnational infrastructural projects. Furthermore, new European bodies such as ACER, ENTSO-E and ENTSO-G have been created for cooperation between regulators and transmission system operators (TSOs), which are given mandates to provide blueprints of the necessary European energy infrastructure in the future [2]. Finally, European integration of markets is driven by energy market operators through market coupling across European regions (Figure 1). Market coupling deals with the harmonisation of market mechanisms, such that barriers for international trade are taken down, leading to increased competition and lower energy prices. This process is ongoing; price coupling within North Western Europe, for example, has been launched in February 2014 [3].

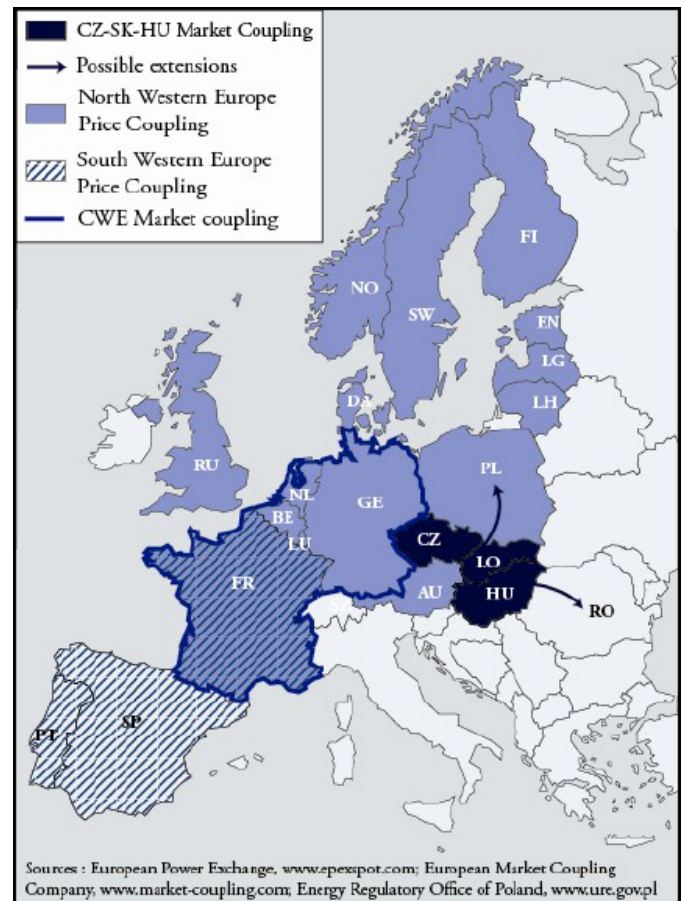


Fig. 1. Major European market coupling initiatives [1].

2.2 EU recommendations

Roll-out of sensors On the HV grid, a lot of real-time data on the status of its components is already available, but little information is available on the LV grid. This information is needed to create new business roles.

A relevant document in this context is a report on the status of the European roll-out of smart meters [4]. At least 17 member states proclaim a 100% roll-out by 2020, and 7 member states also target a 100% gas meter roll-out by 2020. This yields 200 million electricity meters and 35 million gas meters, corresponding to a 70% EU coverage, which compares to the EU directive of 80%. The roll-out is estimated to cost around 45 billion euro. A cost-benefit analysis is in progress, but has not yet been reported.

Distribution system operators (DSOs), instead of commercial parties, should be responsible for managing the data from smart meters, because the grid data is a monopoly and needs to be regulated. Furthermore, privacy and security concerns need to be addressed, as the LV

data can relate to small and medium enterprises (SMEs) and residential customers.

Recommendation process The Joint Research Centre (JRC) compiles scientific input on current European developments within the field of Smart Energy Systems, for consultation of the European Commission. Besides the aforementioned report on the roll-out of smart meters, additional research by the JRC on developments within the European distribution system and the energy retail sector is ongoing.

The European Commission does not envision one single specific design of our future energy system. Instead, recommendations follow from ongoing discussions on a European level, facilitated by the EU. To this purpose, the EU has set up the Smart Grids Task Force (SGTF) in 2009, in which expert groups from European organisations within the energy industry (such as ENTSO-E and EDSO), and organisations within the digital technology industry (such as Digital Europe) were asked to identify challenges, come up with synergies, and set out recommendations. Three design cases for our future energy system have followed from the SGTF discussions, which the European Commission has reported [5]. These cases essentially open up new discussion topics, within both the energy and ICT sectors, around three main pillars:

1. Increasing the level of distributed flexibility in demand and supply, by installing more electric vehicles (EVs), storage options, distributed energy resources (DER), including renewables, etc.
2. Setting obligations of DSOs and TSOs to plan, build and maintain communication systems, in order to create incentives for grid innovations.
3. Creating local incentives to provide the full potential of distributed flexibility to the grid, by setting up new market places and retail tariffs.

The second and third pillars in particular connect with ICT challenges and market design, on which we have organised several Round Table meetings. Three specific EU recommendations closely connect to these discussions [6]:

Institute new local markets *“With the increase in distributed generation, new energy market places will have to be promoted, contributing to a further optimisation of the system. These market places might require additional rules than the ones which are in place today in the wholesale market. The structures in the markets will start to reflect more and more the increasing decentralised character of the power system and balancing, clearing and settlement will have to react to this development by opening [up] to smaller participants. It can be expected that an increasingly flexible formation of energy prices and ancillary services (both on the time scale and in the spatial extension) as well as increasingly flexible grid tariffs will ultimately be required to deliver the full potential of Smart Grids.”*

Work towards pan-European market coupling

“The trading activities [i.e. wholesale markets as opposed to vertically integrated utilities] are responsible for the economic optimisation of the European generation “portfolio” since the first market openings in Europe. In order to best cope with short-term intraday changes in generation patterns and congestion at the same time, it would be helpful to introduce a common implicit auctioning (“market coupling”) intra-day platform which allows continuous wholesale power trading across Europe and to incentivise TSOs to further develop and harmonise the capacity calculation systems. Beyond that, the demand side response framework and implementation should be developed, that will allow the best use of the most effective measures at the customers’ side also to contribute managing the intermittency of e.g. wind power.”

Adapt to prosumer customers *“The emergence of more dynamic energy pricing being offered by suppliers/retailers to consumers is expected. These products may vary the price offered based on time-of-day or day-of-week related to the cost of electricity on the marketplace at that time. This would bring many benefits, but also a higher complexity for the supply of standard customers both with regard to making an adequate offer for supply and with regard to billing. Steps should also be taken to ensure that low income and vulnerable consumers are not adversely affected by the new tariff structures. Retail suppliers will be more and more confronted with supplying customers that produce some of their electricity as well. The management of such customers will be a challenge but at the same time an opportunity for retail suppliers or other service providers. As stated above, a change of standard load profiles will be needed for customers that actively manage their demand. These new load profiles / flexibility measures should help retail suppliers to optimise their procurement from the energy market.”*

2.3 The role of ICT and market design

ICT has several parts to deal with within the above perspectives; e.g., that of infrastructure for ICT-based services on the one side and that of the services implemented by ICT on the other side. Regarding the latter, this especially deals with ICT solutions for demand side management, for energy and power management services, and for markets and auctions. The development, not only of ICT solutions, but also of energy technology and business, is a process in which two questions alternate—what is needed and what is possible—which creates two-way streets.

ICT in market design Design of markets has always been a typical discipline of economics and other sciences that use markets. However, in recent years, this area also has become a discipline of computer science and ICT development, since in order to have a well-functioning ICT implementation, the design of market mechanisms should, for example, allow for:

- **Computability:** software agents in the market, as well as the allocation mechanism in the markets, need to be able to compute solutions and decisions (in limited time). Since computational possibilities are limited (both in practice and in theory), this lays new constraints on the design of markets.
- **Stability:** for example, issues such as high-frequency trading, large numbers of (learning) bidding agents, market mechanisms not well chosen for the application domain, as well as possibly identical bidding software at various agents (taking, in various situations, the same decisions at the very same moment), all require substantial care in order to avoid instability or

extreme behaviour of markets.

- **Scalability:** in order to deal with large numbers of players, the market should be scalable (remaining computable even when dealing with many agents).

ICT innovation The following chapters focus on individual properties of the energy system and corresponding business opportunities and ICT challenges. Some immediate, general challenges for ICT and markets already follow from the EU recommendations. This document can serve as an input for defining ICT innovation goals that match business demand and regulatory requirements of Smart Energy Systems.

3 A European system of systems

Heiko Lehmann and Christian Huder

Chapter authored by and based on the Round Table co-chaired by Heiko Lehmann and Christian Huder (Deutsche Telekom) [7].

The European energy system can be seen as a system of systems in which regional, national and international subsystems for energy trade, energy transport and electricity network balancing interact. As we discussed in Chapter 2, there is on the one hand a trend to harmonise this existing heterogeneous European landscape of national systems, and on the other hand newly emerging subsystems of local/regional trade in which actors such as prosumers and aggregators interact with existing systems for (inter)national energy trade and regional network balancing. In light of the importance of having a well-functioning European energy system, we must ask ourselves what we can do to integrate such new subsystems smoothly, securely and economically.

In order to answer this question, we first give an overview of what kind of new actors we can expect to become part of our existing energy system (Section 3.1).

We then give an overview of open questions and challenges for ICT concerning the increasing complexity of the European energy system (Section 3.2).

Finally, we present a wish list by key players for a smooth transition to a Smart Energy System (Section 3.3). These requests refer primarily to the development of new market designs and legislative concepts rather than technical concepts.



3.1 Chances for new ICT solutions

Various parties within our energy system, such as system operators, retailers and regulators, are attributed with specific roles. Most of these parties use ICT solutions, which imparts a high level of automation to their functioning within the energy system. An immense diversity of ICT solutions in the energy sector already exists for such things as distribution management, markets, client databases, building management, and so on.

The developments discussed in Chapter 2 provide opportunities for new or adapted roles, and for new ICT solutions that support these roles. For example, increasingly frequent occurrences of brief periods with very low (or even negative) energy market prices, due to the overcapacities of renewable energy at certain times, lead to economical opportunities for services such as resource portfolio management and forecasting. Furthermore, the growing impact of distributed energy resources provides opportunities for new service companies such as aggregators.

It has been argued that the costs associated with such new services should not significantly hold back their uptake. For example, the financial contribution by the end customer for the necessary upgrade of the distribution grid has been estimated by the German Energy Agency to be

a fraction of a euro cent per kWh [8]. A comparison with current subsidies for renewables shows that an upgrade of the distribution grid may not pose a financing problem for Smart Energy Systems.

Customer categories During the current process of development and innovation of ICT solutions, we can already distinguish several categories. These categories can be characterised by the actor that these ICT solutions target as a future customer. Table 1 lists such actors by their roles within the energy system. Although many ICT solutions are already available, most of these potential actors currently only exist within experimentation in test beds. Whether or not the actors in Table 1 will (co-)exist depends on the context in which they are used. As no market design is yet in place for the trade of decentralised energy, it is often unclear how energy systems (specifically the local and regional subsystems) will turn out, and what interoperability or other requirements new ICT solutions will face.

It is often unclear what interoperability or other requirements new ICT solutions will face.

Table 1. Some categories for potential customers of new ICT solutions within a Smart Energy System.

Actors	Purpose of ICT solutions
Local market operators	Organising energy trade within a section of the distribution grid.
Microgrid operators	Resource optimisation within a microgrid.
Aggregators	Turning the flexibility in consumption and production of local customers into a significant ancillary service.
Storage operators	Controlling local energy storage and selling ancillary services to other parties.
Data managers	Security services, big data management, service level agreements (for example, concerning availability and latency of data), etc.

3.2 Open questions and ICT challenges

Round Table participants still face many open questions that cannot be clearly expressed as concise requests to a certain party, but instead reflect a sought-after fundamental clarification, either from research or from high-level (preferably international) “project management”.

Organisational questions Some questions relate to fundamental systemic research, where technological aspects coincide with economics. For example, questions relating to the use of generators or storage options: Under which conditions is it preferable to briefly shut down generators or to store energy? How and at which times should such actions be taken? No textbook answers are available that deal with the systemic degree of freedom of distributed energy resources. Current research tends to deal with technological issues whereas a complete techno-economic picture is still elusive.

A complete techno-economic picture is still elusive in current research trends.

Other questions relate to roles, rights and responsibilities in future scenarios. For example, questions relating to the control over resources: Which control options will reside with the DSO? Are there control mechanisms that should be avoided? How do we ensure a level playing field for commercial parties? And so forth. Data management in particular is a recurring theme, with questions like: Who will be in charge of centralised data management? Which data are needed? Who analyses? Who runs controls?

Investment challenges While many questions relate to mostly short-term dynamics in various future scenarios, the Round Tables have also frequently led to discussing the investment challenges in a transition phase towards a new energy system: How can a unified infrastructure be designed and implemented when the investments need to be done by different and independent parties? In Germany, for example, subsidies have led to a dramatic uptake of renewable DER by end customers. Under current regulation, prosumer customers are exempt from the electricity fees by an amount that is related to their self-consumption. As a consequence, the total volume of renewable power that needs to be subsidised increases while at the same time the proceeds from grid electricity fees shrink. This paradox may be viewed as a result from early legislation. Its clearing-up in a consistent and convincing manner would demonstrate the political capacity to act in the German energy transition.

Needed legislative concepts In summary, it can be stated that legislative concepts lag far behind the technically available concepts. The general problem of having many locally managed energy resources that effect the energy system on a large scale is unsolved in a fundamental way. Some kind of combination of hierarchical and market-based control seems to be needed to manage a large number of local resources efficiently, but neither academia nor grassroots best practices have come up with a convincing blueprint so far.

Efficient resource management may come from some kind of combination of hierarchical and market-based control.

3.3 A general wish list towards legislators

As a result of the Round Table discussions, several requests were formulated addressing both national and European legislators. These requests differed widely with respect to their precision. In the following, we order the participants’ wish list from the most general to the most concrete ones:

- The willingness of e.g. the German grid watchdog (*Bundesnetzagentur*) to dialogue should increase. This is most effectively enabled by clear government mandates.
- Investments must be secured by long-term legislation. However, this may also have side effects, for example, the guaranteed long terms for feed-in compensation for photovoltaics in Germany may keep German electricity prices high for the foreseeable future.
- Installation and operation of a centralised communication platform for the power grid is demanded. From diverse market forces such a structure cannot arise. Here, strong government action is mandatory.

- More research projects and experimental platforms are needed. These should be exempt from regulation and legislation to a reasonable extent for a limited period of time in order to meaningfully test new solutions and set-ups.
- Local balancing markets should be created. Regional pricing is expected to boost the installation of renewables.
- New market roles must be defined, especially in the ICT realm which is expected to shadow the existing physical grid. A prominent example of such a market role is the aggregator.
- In Germany, the smart metering debate needs to be broadened: Whereas today the prevailing arguments circle closely around the cost case of smart metering, the future chances of, say, the communication gateway between prosumers and companies are largely neglected. This debate needs to be restarted.

In conclusion The pattern of this wish list is surprisingly clear: A trusted legislative framework is needed which can be relied upon to safeguard imminent investments and nurture innovative solutions while, at the same time, encouraging research and development.

4 Markets for smart grids

Felix N. Claessen and Han La Poutré

Chapter authored by and based on the Round Table co-chaired by Felix N. Claessen and Han La Poutré (CWI) [9].

A second Round Table has been organised to discuss possible organisational designs, market designs and corresponding ICT designs for smart grids. Such designs could provide a consistent framework for the further development of business models and legislation. A clear formulation of organisational designs will enable companies and researchers to construct scenarios. In turn, this will enable them to align research and strategies. The Round Table focused on organisational designs for the electricity network, and in particular on the role of markets and traders in these designs. What different market designs are envisioned by key actors in the electricity market sector, what challenges do they entail, and can they co-exist within an organisational design? We focus here on roles and challenges for ICT, but these in fact closely connect to several legislative issues, particularly concerning the roles of aggregators and system operators.

In order to address such issues, we first discuss where the need for innovative solutions is placed within the current organisational design of most national electricity systems in Europe (Section 4.1). In particular, we address the role of aggregators and their possible relationships with other actors, and the changing roles of DSOs and residential customers.

We then discuss two organisational designs for smart grids based on the works of different consortia, which could provide frameworks for the introduction of new ICT solutions (Section 4.2). These designs correspond to two distinct concepts of aggregators as envisioned by different key players in the European electricity sector.

Subsequently, we discuss the roles and challenges for ICT and regulation related to market design, addressing mechanisms such as markets for balancing and congestion management, and markets for trading electricity (Section 4.3).

Finally, we present a wish list by key players for further development of market designs for a European Smart Energy System, which includes a top-down approach using simulation platforms as well as a bottom-up approach through test bed experiences (Section 4.4).



4.1 Roles within new organisational designs

As a starting point for discussing new organisational designs, we present the current organisational design of most national electricity systems in Europe. Figure 2 shows the most important roles in this design, where each role can represent multiple actors. We visualise the organisational design as two hierarchical systems overlaid on the physical grid: one system for trading electricity and one system for trading reserve capacity and network capacity (meant for balancing and congestion management, respectively). Here we use the term *capacity market* to represent a market-based mechanism for trading reserve capacity, balancing capacity and network capacity.

Three side notes to this visualisation are the following:

1. In many European countries, the role of TSO is intermingled with the role of capacity market operator. In some cases, the TSO operates the capacity market and is the sole buyer of reserve capacity; in other cases, the TSO still uses bilateral instead of market-based contracts for buying reserve capacity. In all cases, the TSO is the sole owner and seller of network capacity on the transmission level.
2. To trade on the electricity market, any actor is required to become a balance responsible party (BRP) itself or appoint an existing BRP to be responsible on its behalf on the capacity market. BRPs must ensure that their consumption/production in real time

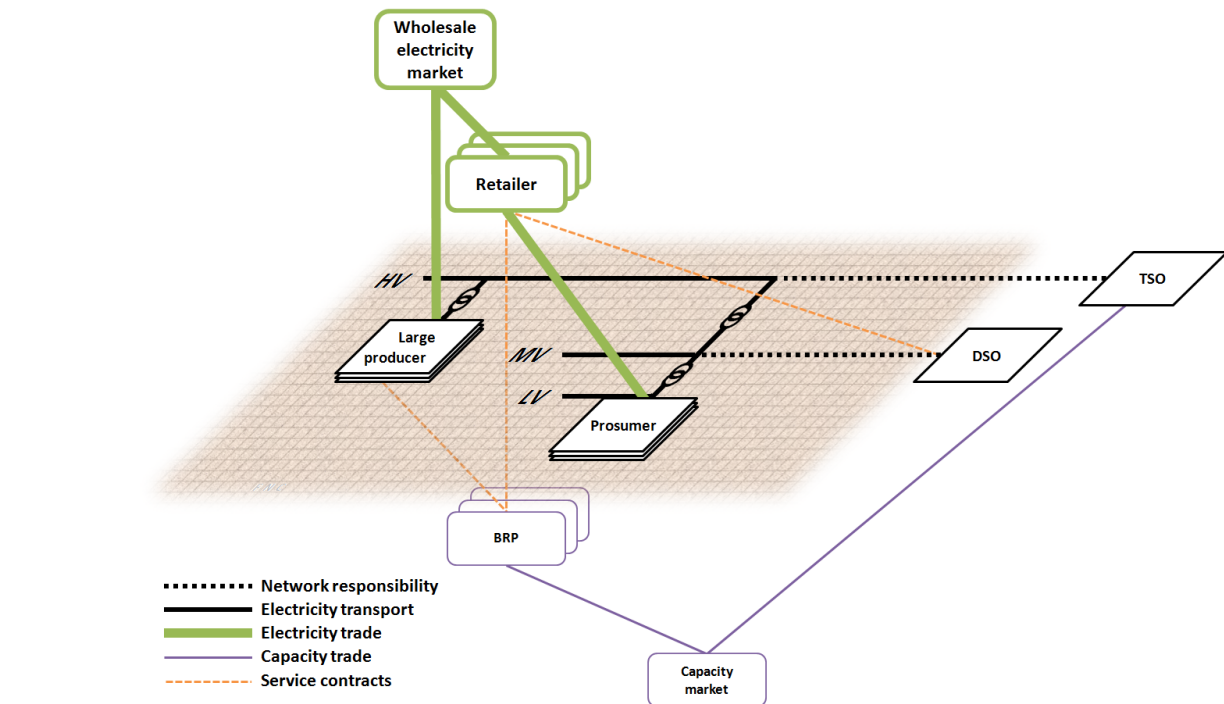


Fig. 2. Main elements and links of the current organisational design of most national electricity systems in Europe. The physical network is shown on a grid, with electricity trade relationships on top and capacity trade relationships underneath. Multiple retailers exist within a given distribution grid, each of which is or has appointed a balance responsible party (BRP) on the capacity market. The latter is achieved through service contracts. Service contracts are also used by the DSO to charge prosumers for the allocation of distribution network capacity; for small prosumers this is mediated by their retailer.

is equal to their planning; any mismatch between their planning and their realisation has to be resolved by buying balancing capacity, either through bilateral contracts or through the capacity market.

3. Retailers usually operate within many distribution networks, and also electricity markets are not inherently constraint to a certain section of the grid. On the other hand, capacity markets do relate to a specific section of the grid, most often a national transmission grid.

The reason for wanting new organisational designs at all is that, in the near future, we expect to need new mechanisms for balancing and congestion management on the distribution grid as well. This development is fostered by two trends—the increasing amount of distributed renewable generation and the possibility of shifting consumption and/or production—which induce a demand and supply of ancillary services on a local level where congestion problems are occurring. New organisational designs for Smart

organisational designs for Smart Energy Systems therefore focus foremost on mechanisms on the distribution level. New balancing mechanisms should be able to deal with many actors in near real time. This requires mechanisms that can take fast deci-

sions and deal with volatile behaviour, i.e. dynamic mechanisms. Such mechanisms are already used for transmission grids, and similar types of mechanisms might be used for the distribution grid as well.

Aggregators It is in this context that the role of aggregator is supposed to appear. In a most general description (though still in the context of smart grids), an aggregator is an entity that collects the flexibility of local prosumers (i.e. their ability to adjust their demand or supply), aggregates this flexibility to create a significant ancillary service, and offers this service to other parties. However, it is not yet clear what the aggregator role will exactly entail and what its relationship will be with other parties.

For one, an aggregator has several alternatives for creating incentives to local prosumers. It may ask them to be somewhat flexible in their demand through, for example, the use of price signals, prioritisation of resources, or tariff contracts. Also, its primary interest is yet undefined: will an aggregator be interested in making money (i.e. a commercial party) or will it merely be a facilitator for the aggregation of ancillary services, by operating a market mechanism (i.e. a local energy market). Furthermore, an aggregator may trade directly on the wholesale market, or offer its aggregated ancillary service to DSOs, TSOs and/or BRPs. A clear positioning of the aggregator role is a central issue in any organisational design for Smart

Energy Systems, and various possibilities have been discussed in the Round Tables and the literature [10, 11] (see Section 4.2).

DSOs Importantly, the existence of an aggregator does not immediately imply that congestion problems in the distribution grid will be solved; this task remains with the DSO. But as more dynamic mechanisms are involved in managing consumption and production within the distribution grid, their role is expected to change, leading to a growing conflict concerning the independence of the DSO. On the one hand, the role of DSO should be conceptually separated from that of commercial parties. Otherwise, the DSO would become a market player with a natural monopoly over the infrastructure. On the other hand, the costs associated with a DSO's responsibilities—of developing, operating and maintaining the infrastructure—need to be balanced by network fees, paid by users of that infrastructure. Current pricing methods are quite static, in the sense that DSOs only have to read a customer's meter once a month, at most.⁵

When local congestion becomes a more dynamic problem (involving many local intelligent decision-makers), more dynamic mechanisms may be necessary for allocating network capacity. Different dynamic congestion mechanisms exist, such as dynamic grid tariffs, advance capacity allocation and distribution grid capacity markets [12]. By using such mechanisms, the DSO can effectively become a market player. This leads to the following trade-off: as

the level of allowable price dynamics increases, the DSO is better able to resolve congestion, possibly at the expense of becoming a more active market player. If the DSO could set extreme prices, it would be able to manage congestion perfectly, but it would also be a very active market player; it would effectively

DSOs should engage in the discussion with governments to examine which regulated pricing concepts are allowable.

be able to operate resources directly, such as by shutting down wind turbines or operating its own storages. If it would have no control over prices whatsoever, it would not be a market player, but it would also not be able to resolve congestion; it could merely inform the network's users on the network's limits. Both of these are extremes of the aforementioned trade-off and are not recommended.

The most supported dynamic mechanism for congestion management is a market mechanism, facilitated by the DSO, that finds proper congestion prices. For the most part, clear requirements for the mechanism's design are unresolved. The Round Tables suggest that such a mechanism should at least be non-discriminatory and transparent, where transparency indicates a comprehensible mechanism that other actors find stable, learnable and engageable [13].

For now, the dynamic pricing of network capacity by DSOs is a particularly grey area, in which they traditionally refrain from participation due to legislative concerns. However, the need to think of out-of-the-box solutions is growing, and DSOs should engage in the discussion with governments to examine which regulated pricing concepts are allowable.

Customers Small but numerous actors such as SMEs and residential customers may be involved in new types of contracts with aggregators, regardless of what new mechanisms will exactly be incorporated in the energy system. Although these contracts are between customers and aggregators, they may be mediated by retailers, similar to how in many cases retailers currently mediate the bill of system operators for the use of their networks.

The Round Table participants identified two clear EU recommendations regarding the customer-aggregator relationship.

1. The European Commission is against mandatory control of residential flexibility. This includes demand response via centralised control (i.e. external control of resources behind the meter), whether in the form of shifting device functionality over time, changing temperature settings or controlling storage options. Only incentives through premiums are desired, including financial bonuses and novel services, which should be enabled by a free market. Importantly, experiences from ongoing smart grid test beds show that, currently, adequate incentives to consumers are provided by apps and services, more than prices.
2. It should be the DSO's task to handle the real-time data from residential smart meters. This data should only be shared with those commercial parties that the consumer decides to share it with. If no data is chosen to be shared, the existing market roles could remain in place and business would be as usual. That is, residential customers will remain under contract with a retailer and may decide to miss out on certain premiums. Preferably, residential customers would have a home energy management system installed, which could allow better control over the information flow.

4.2 Organisational designs for smart grids

A clear positioning of the aggregator role is essential in new organisational designs for smart grids. Generally, the Round Table participants recognise two views concerning the role of aggregators: one view is that the aggregator is a commercial party; the other view is that the aggregator is a local energy market. Here we describe two corresponding organisational designs, based on the works of different consortia [14, 15] and the Round Table discussions. Open

⁵Customers today are priced an amount per kW capacity, either for the maximum electrical power that they can possibly draw (the size of their connection) or for the maximum electrical power that they have actually drawn over a relatively long time period (monthly or annually). In addition, they may be priced per kWh for transport losses. Frequent readings are not necessary for any of the above.

questions relating to several of the roles and interactions in these and other organisational designs are addressed in Section 4.3.

In Figure 3a, aggregators are considered to be a new type of retailer to which prosumers can offer their flexibility. Prosumers can choose whether they want to sign an energy contract with a traditional retailer or with a commercial aggregator. In this organisational design, multiple aggregators will exist within any given distribution grid, and balancing and congestion management within the distribution grid will remain a responsibility of the DSO. In order to deal with multiple aggregators in a dynamic and fair way, the DSO itself will require a more dynamic mechanism for balancing and congestion management, which should be non-discriminatory and transparent; for example, a capacity market for specific sections of the distribution grid. One possibility is that aggregators acquire local capacity through their service contract with a BRP. Similar to traditional retailers, aggregators would be able to trade on the wholesale market, and would therefore be required to become a BRP themselves or appoint an existing BRP to be responsible on their behalf on the capacity market of the transmission system. Here a similar concept could be possible for the distribution system: to be able to have dynamic contracts with prosumers, an aggregator would be required to become a BRP themselves or appoint an existing BRP to be responsible on their behalf on the local capacity market of the distribution system.

Another organisational design defines the aggregator as a local market on which prosumers can offer their flexibility (Figure 3b). Such a local market corresponds to a given (section of the) distribution grid, and could provide a means for the implementation of balancing and congestion management by allowing a DSO to influence local market prices under regulated conditions [15]. This would add a fourth system state (yellow) to the traffic light system used by DSOs, allowing a local market mechanism to perform congestion management. The system states (and corresponding traffic light colours) would then become:

- Normal Operation (green): the DSO takes no action as no congestion occurs
- Congestion Management (yellow): the DSO uses network capacity pricing to urge the local market to resolve congestion
- Graceful Degradation (orange): the DSO directly controls resources to resolve congestion
- Power Outage (red): the DSO deactivates network areas

When the local market is not able to resolve congestion, the DSO takes over, either by influencing local prices or by enforcing direct control. The market operator itself would have a natural monopoly over transaction and par-

ticipation fees and, as such, should also be regulated.

In both designs, the aggregator collects the flexibility of prosumers to generate a significant ancillary service for the transmission network. In Figure 3a, these ancillary services can be provided to an aggregator's BRP within their service contract and traded onwards to other actors on the transmission capacity market; in Figure 3b, the ancillary services can be bought on the local market by BRPs and traded onwards to other actors on the transmission capacity market. As we mentioned earlier, the TSO has a large influence on this transmission capacity market, as it is usually the sole buyer of reserve power (from peak load power plants and aggregators) and the sole seller of balancing power (to BRPs). It has been suggested that the economic efficiency and the transparency of network balancing would increase if the capacity market would become two-sided; instead of a TSO, an independent market operator should mediate the trade of ancillary services [14]. BRPs can then construct their own bids on the capacity market to reserve sufficient power to cover their expected imbalance, and the TSO can bid to reserve sufficient power to ensure network reliability; any BRP that failed to reserve enough power itself is required to compensate the TSO.

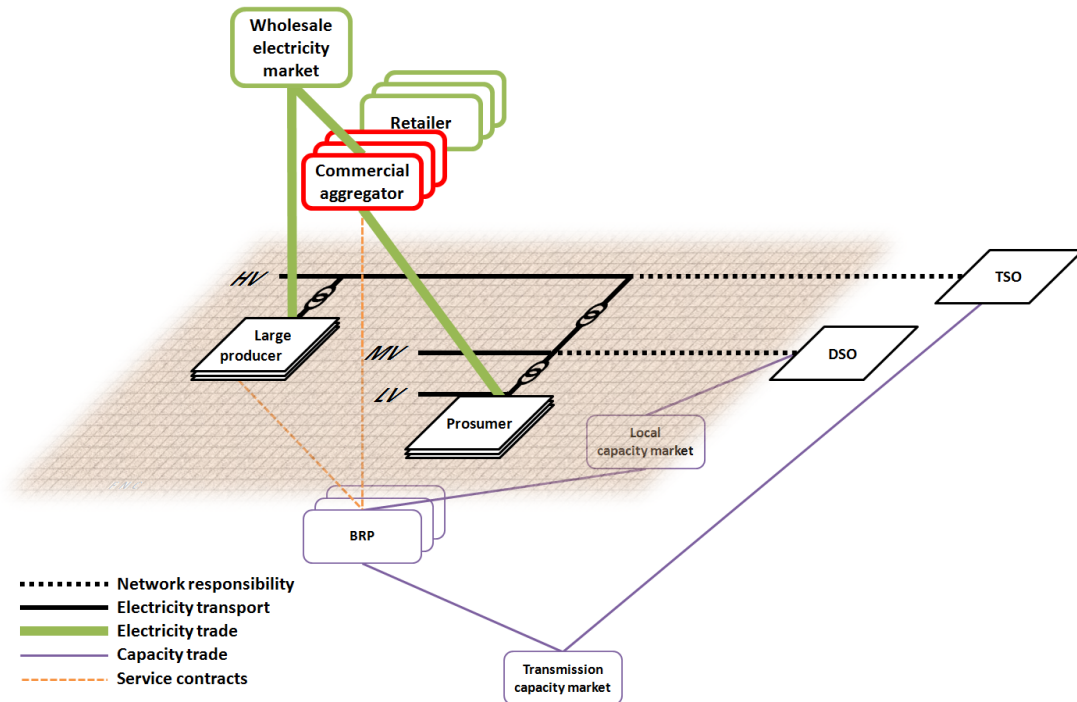
4.3 Challenges for ICT

Important issues related to ICT as well as regulation arise from the organisational designs described in Section 4.2, and the considerations in Section 4.1 and of the EU (Section 2.2). We first present some general issues on organisational designs for smart grids, following up with specific issues relating to market design. This concerns the rules of market mechanisms, the computational software to compute the allocation of electricity or network capacity (or other traded goods), and the decision software in the agents for bidding, scheduling, or dealing.

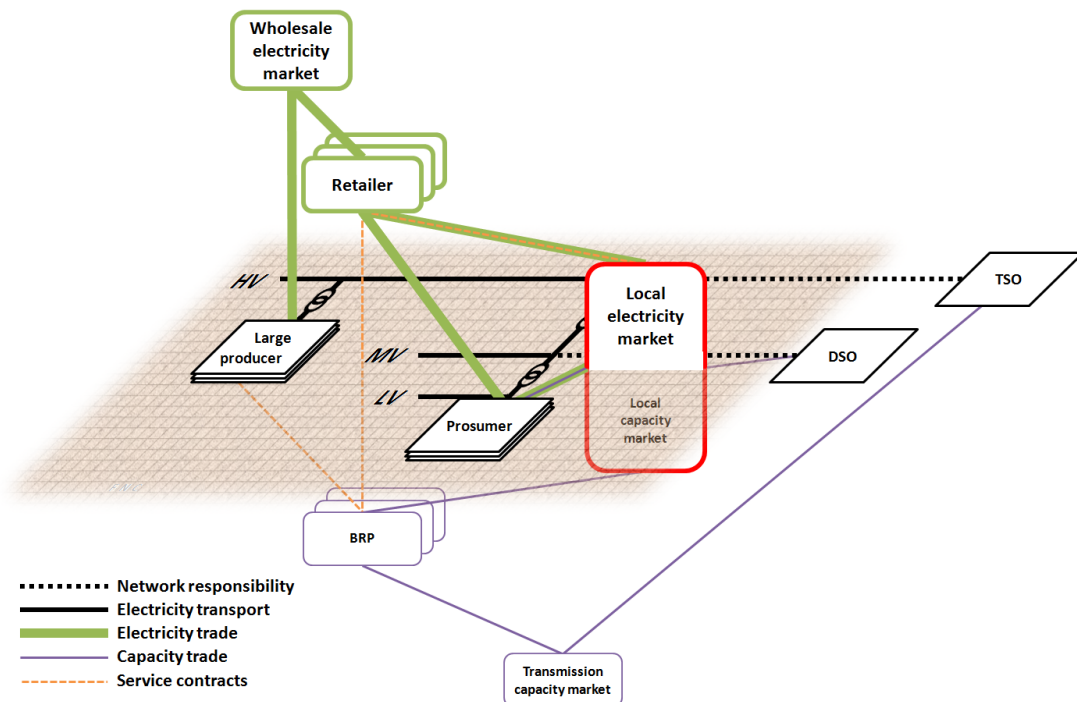
Organisational designs Regardless of whether an aggregator uses a market-based pricing mechanism or sets prices itself, it has to deal with various factors outside its control. In both models, tree-like organisational structures with decentralised markets appear, i.e. hierarchies of markets. Such structures can scale well without increasing the amount of required communication costs too much. So, market mechanisms are required that operate well in such a system of systems. For example, the aggregator can use a market mechanism towards its prosumers, but at the same time pose as a player in other markets such as a wholesale electricity market or a capacity market.

Robust ICT solutions should take into account their interactions with other mechanisms.

Robust ICT solutions should take into account the other mechanisms with which they interact, in terms of their planning, the availability of price information, predictions of prices and loads, etc.



(a) Main elements and links of an organisational design with commercial aggregators (red). The physical network is shown on a grid, with electricity trade relationships on top and capacity trade relationships underneath. A local capacity market is one of the possible solutions for allocating distribution network capacity amongst a number of aggregators that may be operating within a given section of the distribution network. A commercial aggregator may offer ancillary services on the transmission capacity market through its service contract with a BRP.



(b) Main elements and links of an organisational design with local markets (red). The physical network is shown on a grid, with electricity trade relationships on top and capacity trade relationships underneath. In this design, the local market is the aggregator, and only one aggregator operates within a given section of the distribution network. The DSO may be allowed to influence local market prices in case of congestion. The aggregator provides opportunities for BRPs to avoid imbalances on the transmission network. The aggregator can consist of a platform for electricity trade between retailers and prosumers, or for capacity trade between BRPs and prosumers, or both, and may have additional service contracts with e.g. retailers.

Fig. 3. Possible organisational designs for the electricity system within a European Smart Energy System, based on [14, 15] and the Round Table discussions.

In addition, a DSO may interfere with the pricing mechanism of the aggregator. This requires effective mechanisms, for example, to add prices on top of the market price, or may even call for alternative market mechanisms. At the same time, fairness towards (vulnerable) users should be taken care of.

Furthermore, SMEs and residential customers that operate resources such as storages may (indirectly) act on both (local) electricity markets and capacity markets. Market mechanisms should facilitate this, and appropriate decision software for such actors then needs to be available.

Market mechanism design Many organisational designs for smart grids include local markets for trading electricity or capacity at a distribution level. The local market operator can be the DSO or an independent party, but in either case it appears that the mechanism design of local markets should be regulated. Here we state some specific challenges for their design.

Market mechanisms can be used to trade electricity (ahead of time or near real time), reserve capacity and network capacity. Both commercial aggregators and individual prosumers may be charged through local market mechanisms. Mechanisms should be stable, non-discriminatory,

Market mechanisms should be stable, non-discriminatory, transparent, scalable, predictable and fair.

transparent, scalable, predictable and fair towards (vulnerable) parties, possibly satisfying additional contract constraints. Furthermore, prosumers should not suffer from local circumstances like having large dominating players in the

neighbourhood. This can lead to maximum tariffs, (fixed) price ranges, an emphasis on the incorporation of ahead markets, and so on.

Other challenges concern the influence of the DSO. For such mechanisms based on markets or on dynamic price tariffs set by the DSO, the net profit for the DSO should be limited, controlled, or even naught, to help avoid that the DSO becomes a market player. Mechanisms like nodal pricing could be effective.

Markets may need to satisfy additional requirements; for example, different local settings may dictate different market mechanisms, contract types, and/or tradeable products, in order to effectively deal with the specifics of local production and consumption. In addition, the level of risk that is acceptable for users of the system (prices, costs, availability of

electricity) puts requirements on the design choices for the market mechanism. Both relate to market and system stability, as well as to the quality of service towards individual

users. Nevertheless, standards for ICT and markets need to be available to allow for EU-wide businesses and operations, where local market mechanisms can vary within the boundaries of these standards.

Tradeable products and decision software Trading may occur either between prosumers and commercial aggregators, or amongst prosumers (through local markets). In the former case, new types of contracts can become important; e.g. in (sub)systems where a commercial aggregator uses dynamic prices, time-of-use pricing or multi-part tariffs. In both cases, prices for electricity, reserve capacity and network capacity may become valid for timeslots as short as 5 minutes.⁶ This calls for appropriate market mechanisms, bilateral contracts, pricing schemes, and such, that allow for frequent and fast trading. But it especially also calls for new tradeable products such as block orders (electricity for a number of consecutive timeslots) or even for combinatorial orders (electricity for a free combination of timeslots). In addition, different trade opportunities may be required, also in local markets, such as long-term contracts, day-ahead contracts, intraday contracts, and reserve capacity contracts.

Pricing in short timeslots necessitates block orders and combinatorial orders.

As a consequence, decisions—such as for bidding, scheduling or market allocation—can become much more complex. Market mechanisms should therefore be designed that allow decision making with a low computational complexity. The decision software should also be able to handle the uncertainty in electricity and capacity prices; and, vice versa, markets should be designed to reduce this uncertainty as much as possible, e.g. by designing ahead markets for congestion. In addition, software for predicting congestions could be effective here, in order for BRPs to pro-act, where prediction of external factors like the weather could be important. Software based on user and network data could be used for such congestion predictions, as well as for assessing the current state of the network. The DSO should facilitate this and will need ICT solutions to transfer the relevant data (from smart meters and network sensors) to others, while satisfying privacy constraints. Finally, ICT solutions might be developed that contain all data about real-time power consumption behind the meter. Such solutions would only require real-time dynamic prices as input to smart meters; aggregated costs over a longer period would suffice as output. This would require certified and verified smart meters.

4.4 Wish list for further alignment

Developers of new ICT solutions should be aware of the context in which their product will be placed, and a consistent framework is desired in that sense. Also, players

⁶Trading on shorter timeslots would interfere with primary regulation. On the other hand, practical limitations of currently installed metering infrastructure may result in longer timeslots of 15 minutes.

in the energy sector should be aware of the possibilities of ICT in terms of both its opportunities and its limitations. Development of business, energy technology and ICT are two-way streets. The organisational designs for smart grids and considerations presented here could help align ongoing research and innovation in new ICT solutions. Possibilities and requirements for ICT are already displayed in Section 4.3. Additionally, key players in the energy sector maintain their support of projects based on simulation platforms and test beds, and continue to share their experiences to promote further alignment between them, which helps to further address the challenges for ICT and regulation.

Concerning the various regulatory challenges encountered in the Round Table discussions around new organisational designs, temporary regulatory exemptions for test beds may help establish a new organisational design for Smart Energy Systems. For example, in a transition phase to a new organisational design, regulators may allow a DSO to construct, operate and benefit from new ICT infrastructure. In such a situation, a DSO is acting as the first aggregator. After the transition phase, the DSO should step back to let commercial parties take over. Past experiences point out that such temporary exemptions may greatly catalyse the development of Smart

Energy Systems.

Simulation studies are another tool to show the benefits of Smart Energy Systems that incorporates innovative ICT solutions for energy management. Many key players and consortia, for example, within the Experience Labs and European Virtual Smart Grid Lab projects of EIT ICT Labs, have developed their own simulation platforms to demonstrate or validate specific ICT solutions. Some platforms focus specifically on new market designs for Smart Energy Systems (see boxed text). Developers of such market simulation platforms, often academic, may benefit from a closer collaboration between key players in the electricity market sector, such as policy makers, system operators and traders, and vice versa.

Besides addressing challenges for ICT and regulation, projects based on simulation platforms and test beds are also expected to show the value cases for different actors. Interested actors include DSOs and new companies—not just aggregators, but also companies that offer such services as forecasting and data analysis. The value case for DSOs is often not positive on a purely economical basis, but other benefits do occur. Also, having a combination of “smart” projects within a given area may be synergetic. Still, it remains hard to determine the overall costs and benefits of a DSO’s participation in smart grid projects.

Market simulation platforms

Some researchers use simulation platforms to assess new mechanisms within an energy system, addressing two main branches of economical theory: game theory and mechanism design. In particular, the widespread establishment of wholesale electricity markets and the ongoing coupling of balancing areas within Europe has inspired many researchers to develop multi-agent simulation platforms for studying different aspects of the electricity system’s organisational design [16]. Such platforms typically focus on trading and balancing on the transmission level (e.g., AMES [17], EMCAS [18], MASCEM [19] and OPTIMATE [20]).

For assessing mechanisms in a smart grid, simulation platforms should focus on the aggregator role and on balancing and congestion management on the distribution level. The Power TAC platform [21] focuses on the game-theoretic decision making of aggregators, without balancing or congestion management and with a fixed market and organisational design. A full multi-agent perspective is taken in the Market Garden platform [16, 22], which includes modular mechanisms for all parties in the electricity network involved in the planning of trade and network balancing. This enables researchers to construct and validate different market and organisational designs in different scenarios of DER uptake and in any physical network layout, both on the distribution and the transmission level.

5 Integrating new ICT services for big data management

Alexey Baraev and Daniele Miorandi

Chapter authored by and based on the Round Table co-chaired by Alexey Baraev and Daniele Miorandi (CREATE-NET) [23].

The direct value of new ICT solutions is still unclear for many parties, and there is a tendency to wait for value cases to be derived from simulation studies or test beds, before fully committing to investments in ICT solutions. On the other hand, many parties have already taken steps towards the integration of new ICT solutions, for example, by rolling out smart meters and making exploratory bilateral agreements for analysis of the data. But why is the integration of new ICT solutions (even those that are ready) happening at such a slow pace? Besides the investment risk, it has to do with the nature of the data. The data can be characterised as being big, in terms of volume, velocity and variety, which has several implications explored in this chapter.

In order to address these issues, we first discuss some of the data's characteristics, and present some experiences with new ICT solutions for managing big data (Section 5.1). Particularly in countries with an advanced roll-out of smart meters, system operators are encountering new opportunities.

We then discuss the roles and challenges for ICT concerning big data gathering and analysis (Section 5.2). The availability of data opens up a demand for new services, for which new ICT solutions are needed. Such solutions will have to deal with various technical limitations of the data. Furthermore, we address the incentive gap for system operators to invest further in smart ICT infrastructure.

Finally, we present three obstacles that hinder the deployment of ICT services for big data management (Section 5.3). These obstacles relate to market design, standardisation of data exchange and to regulation of data access (privacy).



5.1 The value of big data

As the complexity of the energy system increases (in terms of both infrastructure and operations), system operators are faced with the need to access data for taking informed (in many cases automated) decisions. Advances in electronics, telecommunications and computing are making it possible to monitor and control both the power grid infrastructures as well as the system's end points (i.e. where energy generation and consumption take place) in near real time.

The question now becomes: is dealing with lots of data a novelty for system operators? Generally speaking, that is not the case. It has been estimated that in the US only, utilities have more than 200 PB of data stored. Yet, the data that will be generated in smart energy systems are different. They are big data. Not just because of the sheer size in terms of space used for storing them, but because they are different in the 3V dimensions:

Volume The rate at which data to be managed by energy operators grows is very high, with estimates in the range 10%–40% year over year [24].

Velocity Traditionally, most of the data collected was used for billing (end-points) or ex-post analysis in case of failures (infrastructure). In both cases the data could be analysed on a very large time period (of the order of months or more). On the opposite, some type of smart grid data should be processed in near real time, e.g., data from phasor measurement units to control balance in LV/MV subsystems.

Variety The data to be managed now comes from a variety of sources, with some of them being provided by external parties (e.g., weather forecasting data for predicting the production from renewable DER) and some of them being unstructured or partially structured (e.g., mobility data from traffic sensors).

For these reasons, there is a high potential for the usage of big data tools, techniques and analytics in the energy sector. Energy companies could leverage on big data for two main objectives:

- Optimising the efficiency of their operations, resulting in a better service to end users and significant increases in efficiency, effectiveness and economy.
- Providing new added value services to energy consumers, increasing the company's margins while enhancing the robustness and dependability of the underpinning infrastructure.

For ICT companies with knowledge and expertise in big data, energy represents a promising opportunity. We are talking about a market estimated already at more than 2 billion dollars in 2013 [24], and growing at a compound annual growth rate of approximately 65%.

System operators have already been experimenting with analysing the new data from smart meters and phasor measurement units. Their experiences show a clear pattern: such big data analysis is not their core business, and the expertise from third parties is sought.

System operators' experiences Being able to measure, in real time, the power flows through the network allows system operators to improve the network's reliability. The Italian TSO, for example, has run a pilot project [25] aimed at automatically monitoring and detecting energy losses on the national power grid. Their solution leverages on two distinct data bases from which data is pulled and analysed. The experience gained with the project was considered valuable and showed the technical feasibility of such an approach.

In Italy, where smart meters have already been rolled out, DSOs are granted new opportunities from the available data as well. In one case, a regional DSO was successful in testing the data acquisition on production output in real time. However, technical incompatibility problems limited its ability to effectively take advantage of the data to adjust the generation from traditional sources.

Some Round Table participants have collaborated with universities and research centres in the area of data acquisition and analysis. They rate the results as positive, but the work is not complete and further steps are needed to turn the outcomes into standard practice.

Hard-to-handle data Currently, most operators simply collect the data that they are not able to analyse due to a lack of instruments. The annual growth of the data's

System operators seek third party ICT solutions, and possibly services, for analysis of the data.

volume is in the order of terabytes, and according to the experience of system operators the pace of data acquisition is accelerating: 90% of the available data has been collected in the past 2 years. A non-negligible

part of such data is unstructured, requiring data analysis tools that are not currently in use. Most operators have already experimented with data collection, processing and application of the results. Some operators have dedicated teams that work with data collection and management, others have automated the data processing. Notwithstanding the obtained experience in data management, the operators admit that they need to acquire third party solutions and possibly services.

Customer relationships Another observation relates to the required communication, i.e. finding appropriate ways of communicating and engaging with customers. The Round Table participants offered examples of a number of communication solutions, while agreeing that the utility industry inherited certain weaknesses that are typical for companies with a recent monopolistic history—weak customer relationships. ICT could play a key role in enabling a more effective communication with end customers. Our findings concerning an appropriate organisational design (Chapter 4) may help to address this challenge.

ICT could play a key role in communication between DSOs and customers.

5.2 New services made possible

Resource portfolio management With the available data, several types of services can be provided by ICT solutions, for example, those services relating to the integration of renewable DER. System operators in charge of certain network segments are interested in knowing both the future and the real-time (or near real-time) generation levels of any connection to their segment, as well as its energy mix. One of the challenges is that the structure of the reported data may vary from segment to segment, as it depends on the profile of the generation facilities in each reporting segment.

In the end, operators are interested in obtaining at least two separate indicators from this data: generation from renewable resources and generation from traditional resources. By knowing the actual energy mix the operators plan to regulate the production by favouring the generation from the renewable resources. Although this monitoring solution is desired by operators, it is not yet available.

For determining future generation levels, the industry requires prediction services for the output from renewable resources. This depends on a number of factors that are influenced strongly by season, the time of day, and weather conditions. Some operators have studied the influence of particular weather conditions on the energy production and rated the applicability of the results as extremely relevant.

DSOs are interested in knowing the real-time and future energy mix.

Network management Other services relate to network operation in terms of efficiency and reliability. By employing appropriate data collection and management technologies, operators wish to identify and quantify the losses in the distribution network. The existing methods are associated with excessive costs.

By combining data it would be possible to optimise O&M costs and grid reliability.

Big data technologies could also prove valuable in long-term asset management of single components in the grid's infrastructure. By combining data about a single component (such as location, date of production, date of installation, maintenance) with network-level parameters (such as network stress) and external parameters (such as weather conditions, for example, wind speed and cloud coverage) it would be possible to optimise the operation & maintenance costs, while taking proactive actions to reduce the risk of failures/blackouts.

Interaction with customers and retailers Finally, system operators require services relating to customer interaction. Most operators are publicly owned companies, and thus the regulator might in the future require them to justify their costs clearly and provide certain operational data to consumers. Related to this, operators wish to assess the risk of customer claims due to breakdowns with outages, for which they require reliable data on the precise reason and geographical location of both the breakdown and subsequent damages.

Moreover, operators will require additional services for demand side management solutions, depending on their role within the organisational design of the electricity system. With the current generation of smart meters, prosumption data could be read every 15 minutes. Yet, for most prosumers attached to the LV subsystem, readings occur only monthly at most, and, due to the prevalence of long-term tariffs and the lack of demand response, merely for billing purposes. The readings are a responsibility of the DSO. If it would decide to read the data more frequently, the regulator is expected to require the DSO to expose the aggregated data (on the state of the network) to all commercial retailers, in order to maintain a level-playing field on

For most prosumers attached to the LV subsystem, readings still occur only monthly at most.

the market. The DSO would incur substantial investment and operational costs for the ICT infrastructure, whereas a substantial part of the emerging benefits are expected to go to retailers, such that DSOs are unlikely to cover the costs. This points to a clear incentive gap for investments in ICT infrastructure within the current organisational design of the electricity system, which comes in addition

to the policy barriers faced by DSOs, discussed earlier in Chapter 4. If the relevant ICT solutions arrive, operators are willing to consider them, but the majority of operators insists that a precise analysis of costs and benefits is necessary.

Technical aspects Using this kind of data to improve the operating efficiency in the energy industry is a new development; many technical aspects are not evident and some of them require additional research.

The reporting interval, for example, warranted several discussions in the Round Table sessions. Participants stated their interest in various intervals, such as 1 minute, 5 minutes and 15 minutes. It has been argued that 1-minute intervals would interfere with primary and secondary regulation, which is undesired.⁷ 5-minute intervals would not interfere with those, and would have two further advantages (with respect to a 15-minute interval): a system advantage and a user advantage. For the system, it would be more economical because it would allow the system operator or market parties to take over from secondary regulation much faster (secondary regulation is less economically efficient); and for a flexible prosumer, it would be less cumbersome to shift demand for 5 minutes than to shift it for 15 minutes. However, the consensus opinion depends largely on the technical limitations of the current generation of rolled-out smart meters, which have a reporting interval of 15 minutes. It is a value that some operators already use for data collection (for example, in Italy, in particular for customers attached to the MV grid). Going beneath a 15-minute granularity (at least for end points) would require an extensive re-deployment of technology, which is not feasible for economic reasons.

Going beneath a 15-minute granularity for end points is currently not feasible.

Another technical issue that ICT solutions will have to handle is the non-responsiveness of meters. Operators already face this issue in field trials. The percentage of non-responding meters is normally small; nevertheless, they have to be identified and handled automatically.

Finally, our participants agreed that lagging standardisation slows down the introduction of data-based solutions. High prices of new equipment and software is an additional negative side effect of the weak standardisation. In reality, proprietary solutions from several of the largest suppliers typically become standards de facto. New companies have to follow them, which increases their costs and, as a result, the price of the end product.

⁷Real-time imbalances are regulated by different control systems on different timescales. Primary regulation involves resources that can immediately respond to imbalances. Secondary regulation involves resources that take over the imbalance control from primary regulation on a second to minute timescale. Finally, tertiary regulation takes over from secondary regulation to provide more economical control, and to optimise the available reserve capacity for managing imbalances.

5.3 Obstacles for deployment

ICT services for big data management have been identified as promising technology that could have a major impact for all actors in the energy value chain. From an ICT perspective, the necessary building blocks for creating such services are already available and have reached a rather good level of stability and maturity. Yet, in order to unleash the potential of big data, a number of actions are needed in terms of both regulation and standardisation of data formats and interfaces. Three main obstacles have been identified by energy companies as slowing down the adoption and deployment of big data techniques.

1. Each actor has little incentive to expose energy data to other actors. The energy data is fragmented across the energy chain, and those that could benefit from the availability of data are, typically, not the ones that have access to it. When data exchange does take place, it is usually due to a well-defined action by regulators. A holistic framework for the governance of energy data is seen as a key enabler for the take-up of big data in energy. A mechanism for pricing the data may contribute to a solution.
2. The lack of well-defined and widely adopted standards for energy data creates lock-in situations for energy companies. In some cases, it turned out that system operators were not able to have a unified perspective on their own data due to the incompatibility between standards used by different vendors and technology providers. A standardisation action is required to ensure that also innovative high-tech SMEs and startup companies can enter the market for big data services for Smart Energy Systems.
3. There is a need for some answers surrounding the discussion on privacy and access to data. As some energy data (in particular those related to consumption) are to be considered personal information, it is subject to European and national laws on data privacy. Additionally, some of the energy data is to be considered confidential in nature, and system operators will not share it as it might provide intelligence to competitors. There is a tension between regulators and energy operators in terms of what data should be made accessible to whom. These issues are typically dealt with at the national level; a European set of golden rules would be welcome.

6 Making the most out of different energy carriers

Thomas P. Mahr and Ariane Sutor

Chapter authored by and based on the Round Table co-chaired by Thomas P. Mahr and Ariane Sutor (Siemens) [26].

Our energy system consists of different energy resources and carriers (such as gas, heat and electricity). The interconnection of these resources offers great opportunities to improve overall energy efficiency. However, the interconnection also increases the complexity of energy systems, in addition to the complexity due to the variety of their subsystems discussed in Chapter 3. The value of using a certain mix of energy carriers is related to specific local settings, in terms of climate, market structure, on-site industries, etc. Well-designed new ICT solutions should be able to take into account all relevant energy carriers, conversion options and data. In this chapter, we identify opportunities for technology and carrier combinations, focussing especially on power-to-heat/cold and power-to-gas conversions.

First we explore the general benefits of combining different technologies and energy carriers, taking a macro-economical perspective to recognise possible business cases for hybrid energy systems (Section 6.1). The various conversion options face a number of technical challenges that business models should address.

We then present some barriers identified by key players that hinder the detection and validation of business cases, relating both to regulatory issues and the availability of relevant data and tools (Section 6.2).

Finally, we recognise some next steps to be taken in the development of new ICT solutions for hybrid energy management (Section 6.3).



6.1 When to use a mix of energy carriers?

Generating electricity from renewable energy resources is key for a sustainable future energy supply. However, major challenges arise, mainly due to the fluctuations in wind and solar generation. To ensure that there is enough renewable energy available even at times when consumption peaks, many renewable generators are needed. This may lead to a temporary surplus of renewable energy at times when there is less consumption, especially in the form of electricity.

Two major approaches may be pursued to make use of excess electricity. One approach is to store it by converting it to a different energy carrier, such as potential energy (pumped-storage hydroelectricity), pressure (compressed air energy storage) and chemical energy (batteries, hydrogen and natural gas). While all of these storage solutions involve major conversion losses, hydrogen has the best potential for storing large amounts of energy using existing infrastructure.

Another approach is to replace the demand for other energy carriers, such as heat and natural gas. An energy system in which these energy sectors are coupled can be referred to as a multimodal or hybrid energy system. Such systems can become a key factor in achieving higher over-

all energy efficiency. Nevertheless, managing the required interactions between different energy carriers is not trivial.

Benefits of hybrid energy systems Hybrid energy systems have at least two types of benefits:

1. Hybrid systems can combine the pros of different energy carriers, for example, in terms of transportability and storability. Electricity can be transported almost immediately and with high efficiency, but cannot be stored. Heat cannot be transported due to large heat losses, but can be locally stored for some time in order to act as a buffer. Gaseous fuels can be stored for long periods and can also be transported, but much slower as electricity. Hybrid systems help to eliminate these cons, while combining their pros. For example, by converting excess electricity that cannot be stored as such.
2. Hybrid systems can reduce problems such as congestion, network imbalances and inefficiencies, by compensating one technology's weakness by another's strength. Photovoltaic (PV) units, for example, generate more electricity during summer, while combined heat and power (CHP) units generate more electricity during winter, when heat demand is higher. Because

sunlight and heat demand are anti-correlated, a combination of PV and CHP units may be complementary on a seasonal timescale. Another example relates to the problem of congestion. For large wind farms, transport is often a challenge due to unavailable network capacity. Converting electricity into hydrogen or methane may provide an alternative for electricity transport.

Regarding the overall structure of the future grid, the electricity grid is expected to be needed everywhere, since the fast transport capabilities of electricity will be useful for short-term balancing of microgrids. The gas grid is expected to provide a useful alternative for electricity transport, and the heat grid is expected to play a local role.

Power to heat / Power to cold Heat accounts for a much higher share of the final energy consumption (54%) than electricity (24%) in Germany.⁸ Consequently, sustainable heat supply is a key factor in meeting the challenges associated with the reduction of CO₂ emissions and the scarcity of fossil fuels. Power to heat (and power to cold) provide energy conversion options to do so.

Power-to-heat/cold technologies include heat pumps, resistance heating devices and refrigerators, which each have their pros and cons. Heat pumps are considered a

suitable option in microgrids—also from an economic perspective as they have a return on investment within five to seven years. Resistance heaters may become widely used for energy conversion for district heating.

Heat storage overnight is ques-

tionable, as it may not be the best option for reaching a system's objectives in terms of absorbing excess energy with the highest possible efficiency, which often implies consuming as much as possible locally.

Economic feasibility is a key issue for power-to-heat conversion. Thermal storage devices are usually more economical than electrical storage. This contributes to the merit of power-to-heat conversion with excess energy from renewable energy sources. However, it also depends for a large part on the specific context in which such a conversion is used.

So far, we have neglected power-to-cold solutions; though these could also function as a buffer, just as power-to-heat solutions, but in other countries, for example, in the United Arab Emirates where about 70% of the overall energy consumption is used for cooling buildings; and in China, where an increase in the number of households with air conditioning systems (from less than 1% to 62% over a period of 13 years) has led to regular blackouts in peak times [28].

In brief, power-to-heat and power-to-cold solutions enable shiftable demand on a minute-to-hour timescale,

working like a buffer for fluctuating renewable energy generation.

Power to gas Power to gas describes the concept of converting electricity into a gaseous fuel such as hydrogen or methane (methane is a substitute for natural gas). Power-to-gas systems have the potential to play a key role in bulk storage of excess electrical energy, since gaseous fuels can be converted back to electricity using highly efficient gas-fired power plants and distributed CHPs. Additionally, gas can be used directly in the traffic sector, providing a fuel that is almost as clean as the energy it is generated from.

However, power-to-gas systems also face a number of technical challenges. Especially their placement is important regarding the proximity to at least 4 ingredients: renewable electricity generation (in order to reduce transmission losses), gas storage, bottlenecks in the network's transport capacity, and the possibility to sell by-products such as heat and oxygen. Additional challenges depend on whether electricity is converted to hydrogen (A) or to methane (B):

- (A) Power-to-hydrogen conversion has a higher efficiency than power-to-methane and does not involve carbon if e.g. used as fuel. Transport of gaseous hydrogen would require upgraded pipelines. Therefore, proximity to hydrogen demand or appropriate transport infrastructure needs to be considered.
- (B) Power-to-methane conversion is fully compatible with the existing natural gas infrastructure and with many chemical processes, and is suitable for the mobility sector, albeit with a lower well-to-wheel efficiency compared to hydrogen. For power-to-methane conversion, a high-purity CO₂ source is required (eliminating the atmosphere as a source). Therefore, proximity to such a source needs to be considered. The required CO₂ can, for example, stem from the exhaust of future gas-fired balancing plants, from concrete production or from anaerobic fermentation of bio-fixated carbon hydrates.

6.2 Barriers to business case development

The future success of hybrid energy systems and conversion technologies depends on the emergence of a suitable and economically feasible business model. It remains an open question for utilities and industry to select and pursue the most promising business case scenarios. As of now, nobody has been

Power-to-gas solutions can play a key role in bulk storage of excess electricity.

Nobody has yet been successful in identifying a dedicated market strategy for the longer term.

⁸This is also true worldwide, for which the shares are 47% for heat and 17% for electricity [27].

successful in identifying a dedicated market strategy that would last for five to ten years and could thus sustain itself in any of the scenarios in question. Two barriers that hinder the development of robust business cases have been identified:

1. Not all relevant data is currently available. For business case calculations of hybrid energy systems it has been suggested that the currently used profiles of heat and electricity demand are not suitable. Standard load profiles are based on assumptions valid for more than ten thousand end customers and may therefore not be applicable for planning on a small scale.
2. Regulation on certain issues is not entirely clear (yet), and the many changes in regulation create uncertainties for all utilities and industry partners (e.g., the German Renewable Energy Act and the current change in the German government policy). For example, it is an open question whether it will be possible for utilities to operate power-to-heat and power-to-gas systems together and use the same data basis (e.g. from smart meters) from a legislative and regulatory perspective.

Both of these reasons may have a large effect on the analysis of costs and benefits, since the market for energy conversion applications and the energy market itself are both highly competitive. All business cases can only operate on a small margin, which makes it hard to derive the correct entry strategy as a basis for new startups. Both further research and regulation are required.

6.3 Next steps in ICT development

Besides the joint analysis of all conversion options in Smart Energy Systems, the development and deployment of a suitable ICT infrastructure is needed. This requires clear definitions for the interactions between various actors, and requirements for the interoperability between their energy management systems (e.g. between home energy management systems operated by prosumers and building management systems run by businesses). According to [29]:

“Having a substantial amount of renewable energy sources [...] in a distributed setting requires such [hybrid] systems to be connected in an intelligent and more dynamic way than today. Optimising the operation of the integrated power and heat infrastructure requires access to operational context information from a large number of network nodes from both the demand side and the supply side. The way to satisfy such needs is to have a bottom-up approach rather than a top-down architecture. Intelligent agents at the level of individual devices and multi-agent systems organised in a distributed software architecture are particularly suited to this kind of application.”

Especially for energy management systems on a microgrid level, self-learning systems may become important. Prototypes for hybrid energy management systems are currently under development, for example, within the Hybrid Energy Grid Management (HEGRID) project of EIT ICT Labs. A close collaboration between ICT developers is desired to ensure the interoperability of different management systems.

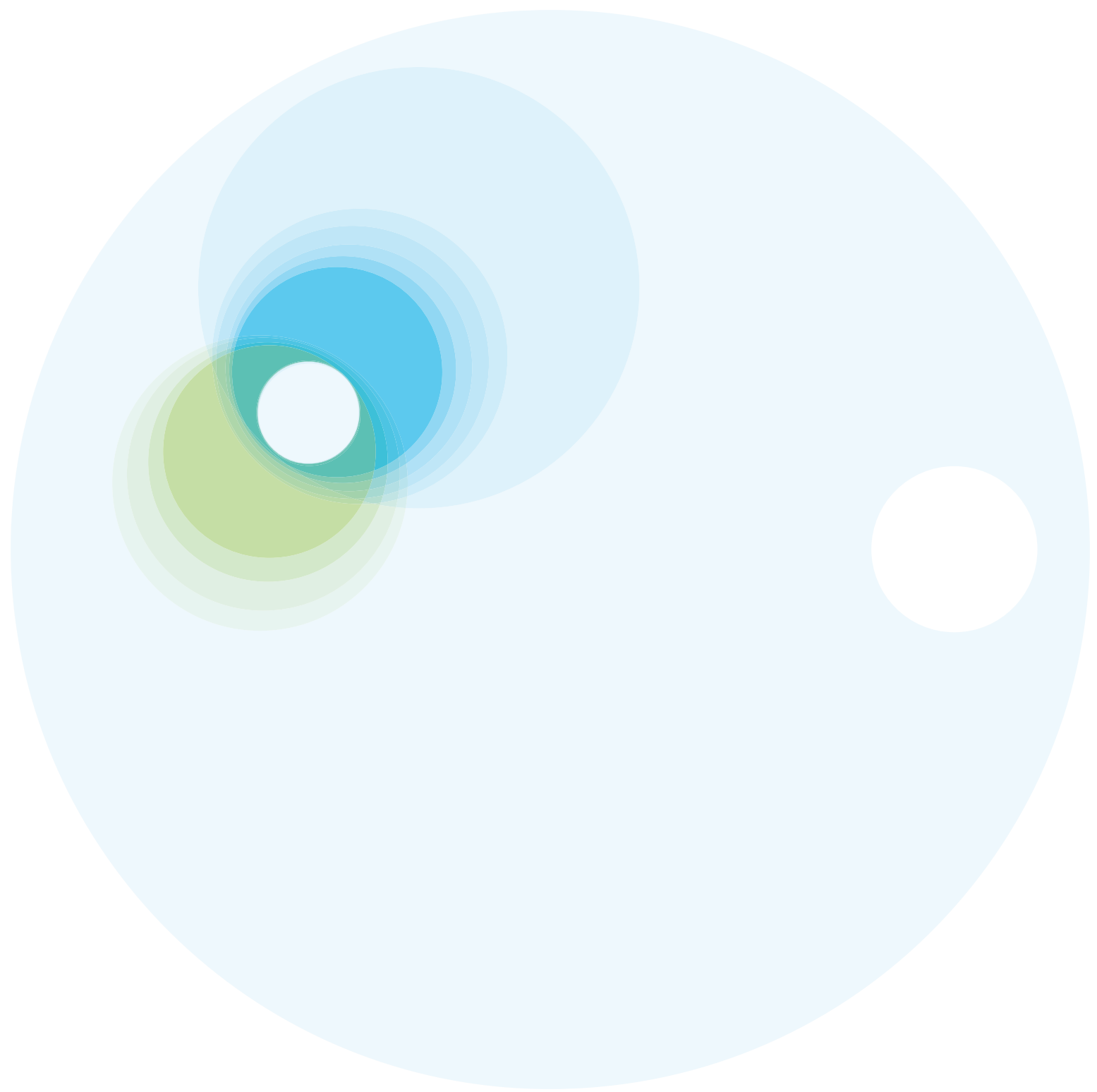
Acronyms and abbreviations

ACER	Agency for the Cooperation of Energy Regulators
BRP	Balance Responsible Party
CHP	Combined Heat and Power
CWI	Centrum Wiskunde & Informatica
DER	Distributed Energy Resources
DSO	Distribution System Operator
EDSO	European Distribution System Operators' Association
EIT	European Institute of Innovation and Technology
EIT ICT Labs	One of the EIT's Knowledge and Innovation Communities with a focus on the use of ICT in our future society
ENTSO-E	European Network of Transmission System Operators for Electricity
ENTSO-G	European Network of Transmission System Operators for Gas
EU	European Union
EV	Electric Vehicle
HV	High Voltage
ICT	Information and Communication Technologies
JRC	Joint Research Centre
LV	Low Voltage
MV	Medium Voltage
O&M	Operation and Maintenance
PV	Photovoltaics
R&D	Research and Design
SES	Smart Energy Systems
SME	Small or Medium Enterprise
SGTF	Smart Grid Task Force
TSO	Transmission System Operator

References

- [1] A. Palle; Regional Dimensions to Europe's energy integration. Oxford Institute for Energy Studies, ISBN 978-1-907555-83-1; 2013.
- [2] European Commission; Energy 2020—A strategy for competitive, sustainable and secure energy; 2010.
- [3] Nord Pool Spot; North-Western European Price Coupling (NWE). Press release available at: <http://www.nordpoolspot.com/How-does-it-work/European-Integration/NWE> [accessed 13 February 2014]
- [4] V. Giordano, F. Gangale, G. Fulli, M. Sánchez Jiménez, I. Onyeji, A. Colta, I. Papaioannou, A. Mengolini, C. Alecu, T. Ojala, I. Maschio; Smart Grid projects in Europe: lessons learned and current developments. Technical report, Joint Research Centre (JRC) of the European Commission; 2011.
- [5] EU Commission Task Force for Smart Grids; Expert Group 3: Options on handling Smart Grids Data. EG3 First Year Report; 2013.
- [6] EU Commission Task Force for Smart Grids; Expert Group 3: Roles and Responsibilities of Actors involved in the Smart Grids Deployment. EG3 Deliverable; 2011.
- [7] H. Lehmann, C. Huder. 1st Berlin Round Table – Decentralized Energy Provisioning. Deliverable for the Smart Energy Systems Action Line (EIT ICT Labs), Telekom Innovation Laboratories, Berlin; 2014.
- [8] Deutsche Energie-Agentur (dena); dena-Verteilnetzstudie – Ausbau- und Innovationsbedarf der Stromverteilnetze in Deutschland bis 2030; 2012.
- [9] F.N. Claessen, H. La Poutré; Amsterdam Round Table – Markets for Smart Grids. Deliverable for the Smart Energy Systems Action Line (EIT ICT Labs), Centrum Wiskunde & Informatica (CWI), Amsterdam; 2014.
- [10] J. Ikäheimo, C. Evens, S. Kärkkäinen; DER Aggregator Business: the Finnish Case. Research report VTT-R-06961-09; 2010.
- [11] F.N. Claessen, N. Höning, B.J. Liefers, P.A.N. Bosman, H. La Poutré; Organising Smart Energy Systems: Classification, Scenarios and Simulations. Deliverable for the Smart Energy Systems Action Line (EIT ICT Labs), Centrum Wiskunde & Informatica (CWI), Amsterdam; 2012.
- [12] R.A. Verzijlbergh; The Power of Electric Vehicles – Exploring the value of flexible electricity demand in a multi-actor context. Ph.D. dissertation, TU Delft; 2013.
- [13] N. Höning, H. La Poutré; Designing comprehensible self-organising systems. Proceedings of the 4th IEEE International Conference on Self-Adaptive and Self-Organizing Systems (SASO), IEEE Computer Society, pp. 233–242; 2010.
- [14] E-Price project final report. Available at: <http://setis.ec.europa.eu/energy-research/content/price-based-control-electrical-power-systems> [accessed 10 February 2014].
- [15] Universal Smart Energy Framework (USEF) developed by the Smart Energy Collective (SEC). Available at: <http://tki-switch2smartgrids.nl/projecten/universal-smart-energy-framework> [accessed 11 February 2014].
- [16] B. Liefers, F.N. Claessen, E. Pauwels, P.A.N. Bosman, H. La Poutré; Market Garden: a Simulation Environment for Research and User Experience in Smart Grids. Manuscript submitted for publication; 2014.
- [17] H. Li, L. Tesfatsion; Development of Open Source Software for Power Market Research: the AMES Test Bed. Journal of Energy Markets, Vol. 2, No. 2, pp. 111–126; 2009.
- [18] V. Koritarov; Real-world Market Representation with Agents. IEEE Power and Engineering Magazine, Vol. 2, No. 4, pp. 39–46; 2004.
- [19] I. Praca, C. Ramos, Z. Vale, M. Cordeiro; MASCEM: A Multiagent System that Simulates Competitive Electricity Markets. IEEE Intelligent Systems, Vol. 18, No. 6, pp. 54–60; 2003.
- [20] A. Weber, V. Rious, M. Saguan, J.-M. Glachant, J.B. Gil, E.R. Puente, L. Kitzing, P.E. Morthorst, S.T. Schröder, J.-Y. Bourmaud, J.-M. Coulondre; OPTIMATE – a Modeling Breakthrough for Market Design Analysis to Test Massive Intermittent Generation Integration in Markets. Proceedings of the 9th International Conference on the European Energy Market (EEM); 2012.

- [21] W. Ketter, J. Collins, P. Reddy; Power TAC: A Competitive Economic Simulation of the Smart Grid. *Energy Economics*, Vol. 29, pp. 262–270; 2013.
- [22] F.N. Claessen, N. Höning, B. Liefers, H. La Poutré, P.A.N. Bosman; Market Garden: A Scalable Research Environment for Heterogeneous Electricity Markets. *ERCIM News* 92, pp. 25–26; 2013.
- [23] A. Baraev, D. Miorandi; Trento Round Table – Big Data for Smart Energy Systems. Deliverable for the Smart Energy Systems Action Line (EIT ICT Labs), CREATE-NET, Trento; 2014.
- [24] Pike Research LLC; Smart Grid Data Analytics. Market report; 2010.
- [25] E.M. Carlini, C. Quaciari, S. Neri, A. Distefano; Progettazione ed implementazione di un sistema automatizzato per il calcolo del reale livello di perdite d’energia sulla Rete Elettrica Nazionale. Proceedings of the annual conference of the Italian Electrical Association (AEIT), Palermo; 2013.
- [26] T.P. Mahr, A. Sutor. 2nd Berlin Round Table – Multimodal energy systems with the integration of different utility providers for electricity, heat and gas. Deliverable for the Smart Energy Systems Action Line (EIT ICT Labs), Siemens, Berlin; 2014.
- [27] D. Elzinga, L. Fulton, S. Heinen, O. Wasilik; Advantage Energy – Emerging Economies, Developing Countries and the Private-Public Sector Interface. International Energy Agency (IEA); 2011.
- [28] M.A. McNeil, V.E. Letschert; Future Air Conditioning Energy Consumption in Developing Countries and what can be done about it: The Potential of Efficiency in the Residential Sector. Lawrence Berkeley National Laboratory; 2008.
- [29] P. Booi, V. Kamphuis, O. van Pruissen, C. Warmer; Multi-agent control for integrated heat and electricity management in residential districts. 4th International Workshop on Agent Technologies for Energy Systems (ATES), a workshop of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS), Minnesota; 2013.





ISBN 978-91-87253-48-5



9 789187 253485

Cover illustration from Shutterstock