

Introduction—Smart Grids: Design, Analysis and Implementation of a New Socio-technical System

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Self-Managing And Reliable Transmission electric grids—SMART Grids. According to many sources on the internet, including his own LinkedIn page, Andres Carvallo, “Energy Maven and Smart Grid Godfather”, defined the term SMART grid on March 5, 2004” (Carvallo 2015). Johannes Kester (Chap. 12 in this book) found an older source. In a less bombastic manner, Khoi and colleagues defined SMART Grids as:

The Self-Managing and Reliable Transmission Grid (SMARTGrid) is seen as the future of protection and control systems. It is an automated system of monitoring, control, and protection devices that improves the reliability of the transmission grid by preventing wide-spread break-ups (Khoi et al. 1997).

Beyond Carvallo’s bravura and claims to precedence, there are more intriguing aspects to the term SMART Grid. ‘Self-Managing’ hints at an engine without a driver. Such a techno-fix is expected to help create a sustainable society without addressing questions like ‘whose society?’ and at ‘which levels of welfare and well-being within that society?’ This version of smart grids doesn’t pause to ask: Will there be equal access for all—in the spirit in which the electricity grid was rolled out in Western countries in the last century—or will smart grids create new social stratification through differential access to energy? Given the way the social is excluded from such definitions, it is not surprising that a number of publications

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on smart grids see the consumers and prosumers as the main obstacles to success. They are externalities and unknown factors in the equation. Not in this book.

In the run up to the preparation of this volume, we have noted again and again how the dominant paradigm in the literature on smart grids insists on the economic road to socialisation: pro- and consumers can be pushed into the desired directions by creating economic incentives. The pro- and consumers are expected to behave like a *homo economicus*, a rationally operating agent who attempts to maximize utility as a consumer and economic profit as a producer. There is also a *homo politicus* and a *homo ethicus*, with corresponding non-economic modes of reasoning, decision-making and behaving. These different dimensions are relevant for families, communities, nations, religions, and societies, and important also for firms, bureaucracies, armies and governments. All are part of complex socio-technical systems, and there is no single stimulus, economic or otherwise, that can bring about change.

If smart grids aim to contribute to a more sustainable production, transportation and use of energy *by design*, its ‘self-management’, ‘reliability’ and ‘transmission’ need to incorporate factors it has ignored so far. This book intends to open a window into that direction by merging a variety of approaches of smart grids. As such it builds on the four-year experience of the interdisciplinary Groningen Energy Summer School, run by the University of Groningen and Globalisation Studies Groningen (GSG). This School unites staff and Ph.D. students from a wide range of academic disciplines in one programme: engineers, lawyers, chemists, sociologists, physicists, philosophers, economists, geographers, psychologists, political scientists, historians, geologists and computer science experts. Over the course of two weeks, they try to incorporate the best of each other’s expertise into their own. The Ph.D. students have to present each other’s work: a lawyer needs to come to grips with algorithms that run distribution systems, or an engineer needs to understand how speech acts create social realities. This book as a whole represents that practice. The individual chapters, however, reflect the expertise of the authors. Some of them combine various disciplines, but the true transdisciplinary exposure of this book is the added value created by the sum of its parts. To strengthen this we have added Points for Discussion to each chapter, emphasizing the broader context, and helping readers from other fields understand the relevance of a particular kind of expertise for larger questions about smart grids. It is our hope that this book will be an instrument to rethink the boundaries of smart grids as a concept, making it more inclusive and reflexive, and therefore more adequate for shaping a sustainable energy future.

In the course of our discussions, participants often quipped about the relative smartness (or dumbness) of smart grids. Whether the system is seen as smart or not depends on how you define smartness, but also on how the problem that smart grids are meant to solve is defined. While this varies across regions and systems (see Beaulieu, this volume), two main framings of the problem dominate debates about anticipated problems with reliable supply of electricity to consumers, especially households, but also industries. The first focuses on how to incorporate and balance the often fluctuating production of renewable electricity into the grid. The second

has to do with managing infrastructures and coping with the increasing electricity demand of societies, in particular peak demand. In both cases the answer is expected to come from ICT, by adding a layer of digital information to the operations of the grid and to the management of supply and demand. These starting points emphasize technology, but do so in relation to an existing infrastructure. Furthermore, the solutions proposed, even the most narrowly technological, always involve a suite of technologies (Shove 2007) rather than a single device. There will be no single ‘killer app’, but clusters of new technologies and practices. Solutions will necessarily be multiple and heterogeneous, if only because technological change involves the merging of the software of ICT and the hardware of energy infrastructures. The chapters in this book will further more demonstrate how transformations of infrastructures and technologies are intrinsically tied to social, economic, institutional and legal changes of our energy system. Furthermore, these changes will take place in a context where the very nature of ‘energy’ is shifting. In a near future, we may see transformations as far-reaching as the recent digital revolution, and the very concept of energy may be moving, from the provision of Kw/h to the provision of energy services.

In the first part of this volume, various approaches to changing energy systems are set out. Marco Aiello and Giuliano Andrea Pagani (Chap. 2) focus on energy distribution and the role that information and communication technology (ICT) can play. After a brief overview of the current role of ICT in energy distribution systems, they discuss the consequences of bi-directional energy flows. The electricity meter has to transform in such a way that it can help to predict energy consumption and can deliver a real-time view of both production and consumption anywhere in the distribution grid. They conclude that the current energy systems have to deal with two different constraints. Whereas ICT research and development must deal with a material infrastructure that is highly constrained by physical laws, power systems research and development faces the challenge of having to decentralize its operations and to make room for decision-making by more active end-users.

These decentralized decision refer to the new roles for consumers and prosumers in the grid. The passive and active roles of energy users are analysed by a research team of the Eindhoven University of Technology, led by Geert Verbong (Chap. 3). The authors develop a quadrant with four typical roles: users can be passive or active enablers of potentially sustainable innovation and they can be passive or active ‘barriers’ to such innovation. There can be organised protest to change or there can be organised grass root innovation projects, and anything in between. They conclude that there is a need for user-centred business models that enable desired roles, for which they sketch out a research agenda.

In Chap. 4, Ellen van der Werff, Goda Perlaviciute and Linda Steg put forth further psychological dimensions to analyse active roles of energy users. Using a review of psychological studies, they identify factors that stimulate so-called ‘smart energy behaviour’ by individuals and households. Little is known about how different incentives for smart energy behaviour affect each other. Both positive and negative spill-over effects are noted, leading to the ‘enabler’ or ‘barrier’ roles

discussed in the work of Verbong and colleagues. The processes underlying these effects deserve more attention. Policies stimulating smart energy behaviour need to be aware of people's values, which the authors operationalize in four types: hedonistic, egoistic, altruistic and biospheric sets. The final point in this chapter points to the bridge between psychological and societal dimensions: addressing the biospheric values of individuals appears most effective, provided this is combined with a conducive context, including perceived distributive fairness and trust in the parties involved.

Part 1 ends with Anne Beaulieu's epistemological analysis of smart grids (Chap. 5). Confusion about the nature of new energy systems and the role of smart grids therein is not merely a matter of the developmental stage of the new technologies and their application. Beaulieu discusses the roles of definitions, not by providing an authoritative once-and-for-all definition, but by demonstrating their function in the development of smart grids. "Definitions put forth a reality, foreground and background, include and exclude, assign active and passive roles," she argues. These diverse realities are described in terms of three functions: promissory work, creation of objects and boundary-work. This analysis provides insight in the power of framing inherent in definitions of smart grids, as well as very concrete tools for working across definitions, as is often the case in interdisciplinary work.

In the second part of *Smart Grids in Global Context*, we move from design to control and regulation of smart grids. In seven chapters technical, legal, economic, and societal aspects are discussed. Hassan Farhangi (Chap. 6) kicks off with an analysis of cybersecurity. Smart grids will existentially rely on ICT, and thus get on board the broad agenda of cybersecurity, running from software vulnerabilities for (e.g., hacking or data misuse) to hardware vulnerabilities of its material infrastructure for (e.g., sabotage, bombings or natural hazards). Farhangi moves beyond the general issues by investigating the cyber vulnerabilities in the British Columbia Institute of Technology (BCIT) Smart Microgrid. He analyses it as a potential site for cyber warfare, and concludes that, in face of attack scenarios on critical infrastructure, massive investments in cyber defence are unavoidable.

Part 2 ends with Johannes Kester's Foucauldian approach of the structures and practices that are empowered by the security dimensions of smart grids. "A smart grid is about the delivery *of* power, but there is power *in* and *behind* a smart grid as well," he argues in Chap. 13. He agrees with Farhangi that smart grids are essentially not about electricity but about the infrastructure to deliver it, and, he adds, its owners and operators. Although the smart grid seems to liberalize individual choices about production and consumption, the centralization of information in the energy system may very well move society into an opposite direction. Companies and governments will achieve new powerful positions in the new structures, for better or for worse. The chapters in-between these two analyses of how smart grids will shape vulnerabilities and power (in all sense of the word) further detail the dynamics of control, regulation, privacy and flexibility currently being designed.

Chapter 7, by Bao Nguyen, Desti Alkano and Jacqueliën Scherpen, discusses how demand response regulation can be embedded in the market structure of the Universal Smart Energy Framework (USEF). Using distributed model predictive

control (MPC) methods, they calculate how the balance between demand and supply can be optimized. Additionally they analyse how innovative storage options like Power-to-Gas can be successfully integrated into the system. With such integration, the electricity grid and the gas grid become physically intertwined. The next step would be to incorporate pricing mechanisms in the system, which are discussed in more detail by Machiel Mulder in Chap. 8.

Mulder focusses first on the present tariff-regulatory frameworks, which were mainly designed to stimulate competition and lower prices for consumers. Environmental and sustainability concerns were not part of the equation. Can they be sufficiently adapted to trigger network operators to make the desired investments to support a shift in the energy sector from a fossil-fuel based to a renewable-based industry? Provided the right circumstances in the wholesale and retail markets, Mulder is optimistic about one form of tariffs: yardstick regulation, a form of price-cap regulation. Experiences in the Netherlands are positive. Productive efficiency can be achieved without negative effects on the performance of the networks.

Energy prices and demand response regulation intend to balance the demand behaviour. But how much unpredictability can the energy system cushion itself? In Chap. 9, Sebastian Trip and Claudio De Persis take on the problem of frequency regulation in power grids in the presence of unknown and uncontrollable generation and demand. They formulate the problem of frequency regulation as an output agreement problem for distribution networks. This is a clear case in which the exchange of information between parts of the grid can lead to new approaches to its control. When the grid also becomes a communication network, new solutions become possible.

Another incentive for studying various aspects of social and technological balancing potentials comes from a game changer in energy transition, which is expected from the massive use of electric vehicles, and electric transportation more generally. Together with distributed renewable energy sources, they add to the balancing problems noticed so far. In Chap. 10 Chris Develder, Matthias Strobbe, Klaas De Craemer and Geert Deconinck investigate demand-response strategies that will be needed to avoid peaks and support balancing in the energy systems. In two case studies they discuss the options for load flattening: the smart grid regulates the charging of electric vehicles, thereby reducing peak demand and moving it away from the present base load peak around 6 pm. The second case shows how the electricity demand of electric vehicles can be used to prevent over-voltage problems caused by irregular electricity supply from renewables. The chapter goes on to investigate three types of algorithms that can be used in these cases: centralized, distributed and aggregate and dispatch algorithms. In terms of scalability and optimality, the distributed algorithms perform best, be it in theory. The authors end by elaborating various simulation tools for further testing.

If Develder and colleagues seek a better interaction between mobility needs and the grid, Lukszo and Park Lee put forth a radical concept, a near fusion of mobility, grid and energy production. They present the ‘car as power plant concept that links mobility needs of drivers, the actual immobility of passenger vehicles that are

stationary (parked) most of the time, and the need for flexible energy production. They review the feasibility in technical, organisational, economic and social terms of this use of fuel-cell powered cars, which has the potential for create a decentralised and ‘detachable’ energy production system.

Chapters 7–11 show that an optimally functioning electric smart grid profits from optimal data sharing and communication. Compared to the classical grids, the uncertainties in supply and demand are many. The more is instantly known about fluctuations or malfunctions, the more sophisticated the algorithms can become, and thus the higher the reliability of the system. This is clearly in the interest of society. Yet, as always, there is a downside: potential misuse of the data. Farhangi (Chap. 6) mentions the commercial interest in knowing consumer behaviour. Kester (Chap. 13) elaborates the more general problem of a society moving from the spectre of ‘Big Brother is Watching You’ (a centralized tyranny) to the nightmare of ‘Many Little Sisters Are Watching You’—an image developed already in 1997 by Manuel Castells. These new forms of power are hard to control. The least we can do is provide legislation that helps to protect people from misuse.

Jonida Milaj and Jeanne Pia Mifsud Bonnici take up one dimension of this challenge in Chap. 12: how does privacy relate to law enforcement use of smart meter data? They investigate this in the context of the European Union and sketch a sobering overview of the existing shortcomings in European legislation. Simultaneously, the literature on the technical and engineering aspects of smart meters shows how tempting it will be for law enforcement agencies to exploit this source of information. Much can be detected from detailed knowledge of a household’s electricity use, building a clear profile of a suspect, without the suspect’s awareness. But mass surveillance can also be supported by using smart meter data. The EU aims at 80% smart meter use by 2020, but the legal safeguards established thus far by the laws, case law and the doctrine for both service providers and law enforcement authorities do not address the intrusive nature of smart meter data analysis.

In spite of (or should we say: in the face of?) such unsettled aspects of introducing smart grids, many experiments are initiated. Part 3 of this volume takes stock of the lessons learned so far. The authors are reporting field experiences in the Netherlands (Chaps. 14, 15 and 17) and in Denmark (Chap. 16).

Bas van Vliet, Joeri Naus, Robin Smale, and Gert Spaargaren (Chap. 14) present a sociological research agenda to guide existing pilots. They focus on the emerging energy practices in smart energy systems, which they call e-practices. By elaborating Social Practice Theory, they show that existing e-practices at the household level are much harder to change than is often assumed. They are routinized and reflect implicit sets of norms, values and principles which are difficult to address. Specifically relevant is to stop viewing a household as a closed entity or unitary actor. Instead it is “a set of different yet interdependent sub-systems that fulfil specific domestic tasks”, including various human agents. This approach is used to analyse interviews with householders in a trial among 45 Dutch households, energy providers and consumer organisations, and survey and interview data on household involvement in two local energy cooperatives. They conclude that the changes in e-practices that did occur redefined the relationships within and between

households and providers. These changes are the outcomes of complex systems, however, and are therefore equally complex to steer, just as expected.

Petra de Boer and Nynke Verhaegh (Chap. 15) report the results of smart grid demonstration projects in The Netherlands, set up by a conglomerate of public and private actors in the energy sectors. They conclude that in these small scale projects, smart grids have been working well in balancing demand and supply in grids with renewable distributed resources. Yet, in line with the previous chapter, they emphasize the basic dependence on the cooperation by consumers and prosumers. On average the motivation of participants in small projects is high. The challenge therefore is to scale up the experiments.

Chapter 16 by Mikkel Baun Kjærgaard, ZhengMa, Emil Holmegaard and Bo Nørregaard Jørgensen, brings us back to the more technical side of bringing smart grids to practice. The first half of the chapter focuses on field tests to improve the capacity of data collection. The second half focuses on the visualization of this data. To this end the research team has set up a *micro-grid living lab* in Vejle (Denmark), aimed at collecting energy data sets covering renewable energy sources, commercial and industrial buildings and their occupants. The project focuses on commercial and industry buildings and involves five companies. Visualisation of the processed data helps to identify domain characterisations, which helps to improve decision support tools, using the merits of instant data collection by smart grids.

Carina Wiekens (Chap. 17) reports on end user research in PowerMatching City II. This is a leading Dutch smart grid project, involving 40 households. As also described in Chap. 15, two energy services were developed jointly with the end users: Smart Cost Savings, and Sustainable Together. This allowed them to build a sustainable community at lowest energy costs. Did they? Well, to some extent. Using self-produced energy appeared to value higher than following the most efficient strategy for saving energy. This seems to contradict a second conclusion that feedback on costs was preferred over feedback on sustainability. Apparently, self-production triggers other values. It also seems that in certain cases, end users “prefer automatic and smart control, even though manual control of appliances felt most rewarding”. In face of the major challenge noted in Chap. 15, one of Wiekens’ conclusions may be especially crucial to effecting change: “we found that experiences and behaviours were fully dependent on trust between community members, and on trust in both technology (ICT infrastructure and connected appliances) and the participating parties.” If this is the case, scaling up smart grid projects to city-levels and transnational levels will put a heavy burden on the societal cohesion of our multicultural societies.

But perhaps it can also work the other way around: discovering the merits of functional cooperation in (partly) distributed smart grids might give end users something else to discuss than their class, gender, age, racial or religious differences. In the end, the global concerns highlighted by the sustainability discourse might overshadow such societal cleavages. Smart grids would then become a project to shape our future, and not only a solution to an infrastructural challenge. Dialogue and collaboration between disciplines are essential. Our hope is that this volume will be a potent tool to develop the variety of knowledge and interaction

needed to build this future. The transformational experiences of the authors and participants in the Groningen Energy Summer School reinforce our trust that this is achievable.

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