A Note on System Integration to Support a Renewable Energy System

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1 Introduction

Modern energy paradoxes

The transition to an energy system largely based on renewable energy sources (RES) is one of the greatest challenges of our time. Advances in RES technologies in recent years have led to sharp cost-reductions and, in concert with government support schemes, a marked growth of the installed RES capacities worldwide. At the same time, troublesome signatures of typical RES characteristics are now becoming more visible in the operation of power systems. Although the German Energiewende has known significant successes, questions have been raised about its cost-effectiveness. While the installed wind and solar capacities in some European countries have grown phenomenally, CO₂ emissions have hardly decreased due to lower coal prices and a simultaneous increase in coal generation. The cost of solar power has fallen to competitive levels much more rapidly than foreseen, but many traditional electricity producers across Europe find themselves in an existential crisis.

These are examples of friction in the energy system: the system shows itself not to be fit to accommodate the amount of RES needed to achieve our 2050 decarbonization targets yet. One could argue that these result from new technologies being forced on the old, fossil fuel based energy system paradigm, which resists change. The main RES integration challenges relate to their fundamental characteristics¹: variability and uncertainty. These RES characteristics, often summarized in the notion of intermittency, cause friction - technical, operational, financial - when integrating them in the energy system.

¹Biomass is clearly an exception to this. We will further elaborate on its role in following sections, but in sketching the context of this document we assume that wind en solar based RES will play a large role in the energy mix.
Flexibility is key

The key to effectively deal with these aspects lies in the rather broad notion of flexibility\textsuperscript{2}. Recent discussion papers by Eurelectric [2] and EDSO [3] seem to indicate that there is a wide consensus on flexibility as a key prerequisite for a new RES based energy system. In several studies, see e.g. [1] and [4] for overviews on this, four forms of flexibility are identified: flexible generation, storage, demand response and interconnection.

The energy system, however, is clearly more than a collection of interlinked technologies, it is also a collection of market sectors and the rules and regulations that govern them, together referred to as the institutions of energy systems. Markets on which energy is traded, legislation and (financial) interests form the essential boundary conditions for use of the technological system, while they shape decisions on strategy, development and (dis)investment. Furthermore, we note that behavioral and societal aspects, too, belong to the institutions of the energy system. Moreover, they may prove to be of crucial importance to the success of the energy transition.

System integration

The energy system can thus be viewed as a system where technology and institutions are inexorably intertwined, as a socio-technical system consisting of several interconnected sub-systems. In the context of this document, energy system integration can thus be defined as follows:

\textit{The process of jointly shaping the technical and institutional sub-systems in a way that supports the transition to a renewable, affordable and reliable energy system.}

In this paper we will argue that next to numerous technological challenges, the main challenge lies in reforming our energy system, both on the technical and on the institutional level, in a way that makes it fit for the massive integration of RES. In particular, we contend that a system integration approach to meet this challenge is a promising way forward.

Scope and structure of the paper

The European 2050 decarbonization goals are clear about the fact that huge emission reductions in all sectors (power, industry, transport, agriculture, etc) need to be realized [5]. For the power sector, the emissions constraints turn out to be the most stringent, and by 2050 a virtually CO\textsubscript{2} free sector must be achieved. Simultaneously, carbon reductions in transport and heating will require a shift towards electricity as their main energy carrier - a notion generally referred to as electrification. These considerations justify an important limitation of scope of this document: we will mainly focus on the integration of RES in the power system. This does, however, not mean that we do not recognize the important transition challenges in, for example, the chemical industry, transport and the agriculture sector and the potential of natural gas, bio-fuels

\textsuperscript{2}In [1] flexibility is defined to \textit{"express the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise"}
and hydrogen to meeting those challenges. Rather, we acknowledge the width and complexity of the energy system, but we deliberately choose to focus on the power system RES integration challenges to illustrate the system integration approach that we propose.

The paper is organized as follows. Following from the definition of system integration given above, we will first discuss the main technological issues associated with the RES integration challenges. After that we will elaborate on the interrelations of the institutional sub-systems, and their relation with the technical system. We conclude by summarizing the most important elements of this paper and outlining the main challenges and opportunities.

2 Flexibility from a technical point of view

The four forms of flexibility identified in the previous section will be the central technological themes that are addressed in this section\(^3\). We will sketch some developments, technological challenges and opportunities, but we emphasize that the overview is far from complete. At the end of this section we highlight a number of interdependencies of the different technical sub-systems we consider. These interdependencies, together with the relations between the technical and the institutional sub-systems that are discussed in the next section, are key to understanding the value of the system integration approach.

2.1 (In)flexibility from the supply side: Solar and wind vs. conventional and biomass

The most widely distributed renewable energy sources for electricity generation today are photo-voltaic solar energy, wind energy and biomass. As noted earlier, the main RES integration issues are largely due to the variable and uncertain nature of wind and solar energy. It should be noted, however, that despite the intermittent nature of wind and solar irradiance, there exists some flexibility of wind and solar energy output in the form of curtailment. In some instances it may be the least cost option to curtail RES production, but the environmental performance of the system decreases by curtailment.

Conventional coal-fired and nuclear thermal power plants have been built to run steadily at their most efficient operating point and provide base load to the power system; their flexibility is limited. Modern gas fired power stations, on the other hand, combine high efficiency with short ramp-up - and ramp-down time, making them natural complements of variable RES technologies. Due to these renewed requirements, current research in coal plant design focuses on making them more flexible, using storage vessels to store water at high temperature and pressure.

Nevertheless, a high-RES power system by definition lowers the use of fossil fuels. Several studies have shown, however, that even in high-RES scenarios, gas fired power may be a cost-efficient complement to wind and solar. For example, in \([6]\) it is shown that gas fired back-up plants used to overcome pan-European RES ‘droughts’ may, from a system point of view, be cost-effective even if they

\(^3\)For completeness we include solar and wind generation in the discussion of flexible generation technologies, though they obviously are not what is commonly understood to be flexible generation.
are run with very low capacity factors. Nonetheless, recovering capital costs of such plants, may be problematic in current market settings and additional incentives remunerating their flexibility may be required. Furthermore, when emission constraints become ever more stringent towards a 100% CO$_2$ free energy system, additional measures such as CCS may be needed.

An alternative to fossil fuel fired back-up plants are bio-fuel based back-up plants. In medium-term projections, see e.g. the scenario outlook as aggregated by ENTSO-E [7], the role of biomass generation is, however, still modest. Within the available capacities, though, biomass and/or biogas may become important fuels for the flexible generation units complementing the RES based portfolios. Furthermore, biomass may have a more important role as a replacement of fossil based raw materials for the chemical industry as well as fuel for the transport sector.

2.2 Large scale energy storage

Energy storage is an enabler for upholding the electricity supply in a society increasingly driven on electricity generated by intermittent renewables. Using electricity directly is most efficient, but the electricity supply should be available and reliable throughout the year. The range of power system applications where storage could be important is long and diverse\textsuperscript{4}, with different requirements to e.g. energy capacity, power capacity and response time. For example, the relevant time scales range from microseconds (e.g. power quality, frequency response) to months (seasonal storage). No single technology will thus be superior for all intended applications. Because storage can play such a key role in RES based energy system, it forms one of the central research challenges related to RES integration, and at the same time it is a business opportunity of great proportions.

For typical daily fluctuations associated with variations in demand and RES production, the currently most economic and widely used form of large-scale energy storage is pumped hydro storage. Its potential seems, however, unlikely to cover the enormous storage required in future high RES scenarios. As they are largely compatible with decentralized energy systems, battery storage is seen to have great potential. Indeed, there have recently been numerous interesting developments in laboratories, and battery production is growing. Nonetheless, the costs, performance and lifespan of commercially available batteries need to be enhanced further to play a key role in high RES energy systems.

Nevertheless, battery storage is unfit for the seasonal storage that will be needed to overcome longer periods with low RES output. Most notorious are so called ‘wind droughts’ in winter, when solar generation is at its lowest. Such events can last for a few weeks, requiring huge energy quantities to overcome\textsuperscript{5}. Furthermore, with the ongoing electrification of transport and heat, the future electricity demand will increase too, thereby altering the needs and viable options for storage, see e.g. [10].

It remains unclear what seasonal storage technologies will be feasible. Storage technologies that are seen as potentially viable for seasonal storage ap-

\textsuperscript{4}In [8], for example, 28 different applications for storage in power systems are identified

\textsuperscript{5}Depending on assumptions on cross-border network capacities and the amount of wind and solar curtailment, seasonal storage needs for a pan-European electricity system can be as large as 10% of the current European annual electricity use, see e.g. [9].
Application include pumped hydro, compressed air and flow batteries, but their technical potential may not be enough to cover all future storage needs. Chemical storage using hydrogen, ammonia, methane or methanol are again under scrutiny, as they provide a means to store large-quantities of RES. New system concepts around long-established conversion technologies are being explored to improve cycle efficiency, flexibility and reduce costs. Some of these can be categorized under the wider Power-to-Gas concept. Alternatively, though not necessarily relating to RES based electricity generation, seasonal thermal energy storage may be a cost-efficient complement to fulfill heat demand.

2.3 Flexibility from the demand side: smart grids and demand response

Demand response\(^6\) (DR) can loosely be defined as electricity demand that can be shifted in time to anticipate or react to certain signals. Traditionally studied appliances suitable for DR\(^7\) are non-time critical loads like refrigeration and climate control systems or washing machines. With the expected electrification of transport and heating, i.e. the advent of electric vehicles and heat pumps, two potentially very large sources of flexible demand are emerging. Physically, DR is closely related to energy storage. In fact, many forms of DR is energy storage because energy is stored in electro-chemical form (EV batteries), in heat (heat pumps), or in ‘cold’ (refrigeration)\(^8\) DR has may have an energetic advantage over energy storage because no extra conversion losses are incurred. This may, on the other hand, be at the cost of lower convenience levels for consumers, less flexibility than in the case of storage and higher thermal losses in the case of heating and cooling systems.

Current research focuses on technical issues, such as planning and optimization algorithms to schedule flexible demand, but also on behavioral challenges as the value of DR will to a large extent depend on people’s willingness to participate. Furthermore, hierarchical and distributed control schemes are relevant areas under investigation because the large number of appliances makes it computationally infeasible to consider them individually. Another potentially interesting approach are local ‘markets’, where energy and network capacity are being traded on the community level by autonomous agents.

2.4 The networks: interconnection and distribution

Originally, national transmission networks were built to interconnect different power systems for backup and reliability. Over time, cross-border interconnects were established, too. With the ongoing process of creating of an internal European electricity market and pan-European level playing field, the function of

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\(^6\) In recent years, the terminology on this theme has mostly converged to demand response. Alternative descriptions include demand side management, (direct) load control and (adaptive) load management.

\(^7\) The idea of demand response is far from new. Advanced control schemes interacting with spot-prices of electricity of e.g. air-conditioning systems have already been described extensively in the early 1980’s\(^[11]\). Even decades before that, many countries had some form of direct load control on water storage heaters.

\(^8\) As a fundamental difference with energy storage in the conventional use of the concept, one may note that in demand response, energy is not stored with the purpose of converting it back to electricity.
the network and the cross-border interconnects increasingly has become an economic one. Today, routinely, large volumes of electricity are transported from where it is produced at lowest cost to where it is needed most.

When transmission and interconnect capacity is sufficient, any surplus from RES generation can be exported, instead of being dispatched to national markets at low or even negative prices. Indeed, it has been advocated that a pan-European electric ‘super-grid’ could aggregate the RES production of the continent, rather than those of a country. On a pan-European scale the result would be a much smoother and more regular RES production profile.

In parallel to the trend of strengthening the pan-European transmission backbone is the increase in importance of the regional distribution networks. Not only is a large part of RES production embedded at this distribution level, but so may two of of the important sources of flexibility: storage and demand response.

On both network levels we see important research efforts. At the electrical engineering side new hardware equipment, like flexible AC transmission system devices, high and low voltage DC grids and power electronics are being developed further. New network planning tools are also being studied, both on transmission and distribution level. Here it is essential to develop tools capable of handling uncertainties: we must now design the grid that will transport the renewable energy of the future, while we do not know yet exactly where the large RES production centers will be. New, efficient tools in network flow modeling are essential input to such planning algorithms.

2.5 Interdependencies between technical sub-systems

The four technological themes discussed above are related in many ways. We highlight a few of this dependencies here, but we emphasize that many more exist.

Controllable system operation assets shift from transmission towards distribution level. Crucial system operation functions like frequency and voltage control currently are provided by large generation units, to some extent fully automated, to some extent actively controlled by TSO signals. When the amount of large generation units will decrease, or when large generation units are more often off-line because of temporary RES surpluses, these essential system functions need to be taken over by other sources of flexibility: DR, storage and flexible generation units will increasingly have to provide these types of services. Furthermore, flexibility provided by increased interconnection implies that the flexibility in neighboring nodes will become available too. This new way of controlling the system is technologically very challenging, but encouraging approaches are being developed, see e.g.[12]. Furthermore, it would obviously constitute a major paradigm change in the technical operation of the power system, and, as a consequence, it will require new rules, regulation and grid codes to enable it.

Interrelations between different flexibility sources. Demand response, storage and interconnection all belong to the important sources of flexibility that are needed in a high RES energy system. The first two can be regarded
as inter-temporal arbitrage (shifting energy between different points in time), while the latter could be classified as inter-locational arbitrage (shifting energy from one location to another). Because these two forms of arbitrage are both forms of flexibility that address the same problem of dealing with the variable nature of RES, they are intuitively considered as substitute technologies: when there is enough storage, the need for interconnection capacity decreases. In the very high RES penetration scenarios that will need to materialize to achieve emission targets, this may, however, be a flawed reasoning, as was shown in [13].

The key in understanding this apparent paradox lies in the observation that inter-temporal arbitrage, i.e. storage and demand response, need transmission capacity to provide access to it. For example, if interconnection capacity from North-West and Central Europe to Norway is very limited, its pumped hydro capacity will be of little value. For high RES penetrations, the value of the interconnector thus increases with a larger storage capacity in Norway, and vice versa. Hence, the reasoning that local demand response or storage can replace the needs for increased transmission capacity in Europe does not necessarily hold. It will depend very specifically on the exact volumes and production profiles of RES, the additional generation mix and the other sources of flexibility in the system.

3 Markets and rules designed for RES integration

In this section we elaborate the interplay of technology and institutions. To this end, we extend our discussion from technological issues and the technical sub-system to the energy markets, rules and regulations – the social sub-system – that govern the operation and development of the energy system. We first discuss the shortcomings of the current system when it comes to a massive RES integration, and then we highlight some important interdependencies between different technical and social sub-systems. This complex interplay between technology, market and regulation is the main rationale for the system integration approach that we propose in this paper.

3.1 New technologies need new rules

While the technical energy system as we know it today has been shaped in the last 50 years, the social subsystem we see today is the result of the process of unbundling and liberalization that (only) started in the 1990’s. Some even contend that the liberalization is still ongoing, as the ensuing adaptation and transition is still unfolding.

We now focus mainly on the electricity system, which has, however, many similarities with the gas system. A central role in power systems is played by the spot-market\textsuperscript{9}: a market place where energy can freely be traded between producers and consumers, that are usually represented by retailers. A number of additional markets and mechanisms are needed to deal with the characteristics that make electrical energy a peculiar commodity: intra-day markets and balancing markets make sure that uncertain demand and supply are matched

\textsuperscript{9}Also referred to as \textit{wholesale market} or \textit{day-ahead market}. 

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in real-time. Capacity based reserve markets, ancillary services (frequency and voltage control) and transmission congestion management further enhance the reliability of the power system. The central tenet of this system, though, is that the conventional, controllable, fossil fuel based generation capacity is providing the majority of this energy. Marginal generators set the electricity price; all generators that are dispatched under this price collect revenues they need for capital cost recovery. Together, the generators provide the additional system functions required for system stability and security. It is this picture that is rapidly changing however, with the ongoing advent of renewable energy sources.

RES, in principle, have a marginal cost of zero. According to the merit-order logic underlying our electricity markets, when RES production exceeds demand, the resulting electricity price will be zero for all generators\textsuperscript{10}. Not only will RES generators receive no revenues, but no conventional generators will be on-line to provide the essential system services either. Clearly, the system must be organized differently when the RES shares grow to the levels required to meet 2050 emission targets. If the sources of flexibility discussed in the previous section are to take over the essential system functions, they need to be remunerated appropriately. In this context it worth noting, that the meaning of ”appropriately” may require re-consideration of the relevant techno-economic characteristics of the system, i.e. what technical aspects constitute the main value and cost drivers.

3.2 Complexity and interdependencies: system integration

In this section we highlight a selection of interactions between different subsystems of the energy system. This non-exhaustive list illustrates the increase in complexity of a RES based energy system and emphasizes the approach of system integration that we propose.

Demand response for RES integration should be aligned with network management. Demand response causes flexible loads to be scheduled in a way that correlates with RES production. The resulting load profile will be characterized by high demand peaks, as all flexible loads react on more or less the same RES production profile - an effect also referred to as load clustering. This can be a desired effect when the RES are embedded at the distribution network itself, like the case of rooftop PV, because generation peaks are locally absorbed by DR. When RES are, however, mainly embedded at higher network levels (e.g. large wind parks), the energy has to flow all the way down to the responsive demand at distribution network. This may lead to high network load peaks that, in turn, cause costly network reinforcements [14]. A coordination mechanism is thus needed to align the network capacity, RES production and demand volumes and location by market signals. Such a mechanism, essentially a form of congestion management, is common on the transmission level, but its extension to the distribution level is a new feature that results from the increased RES penetration and the role of demand response. Current research

\textsuperscript{10}In fact, due to a lack of flexibility in the current system, negative wholesale prices are being observed more frequently. They can be seen as the price that large, inflexible generators are willing to pay to avoid temporary shut-downs.
focuses on the exact design of such a mechanism, either price based or capacity based, and its practical implementation. The enabling IT infrastructure will be a crucial component of such a systems, which translates to a range of business opportunities on the cross-section of the IT and energy sector.

**Flexibility, financial incentives and CO₂ policy.** In the current market structure, the power system is operated from a profit maximization or cost minimizing point of view\textsuperscript{11}. This implies that additional flexibility will be employed to steer the system further towards the minimum cost operating point. In a situation where the generation capacity with the lowest marginal cost is simultaneously the most polluting, like in portfolios that include coal and lignite, this boils down to using the flexibility to keep coal plants running, thereby saving expensive start-up costs and fuel costs of the more expensive gas plants. This results in the paradoxical situation that in a mixed portfolio with RES, gas and coal, the availability of extra flexibility leads to higher emissions. In practice, we already observe signatures of this phenomenon. German coal and lignite plants keep running, while wind and solar generation is exported abroad. Without these exports, these plants would be forced to experience many more shut-downs, and the more flexible and cleaner gas plants would be more favorable. A higher CO₂ price where coal and gas would switch places in the merit order would remedy such effects.

**Carbon policy and RES support schemes** The EU-ETS system has been labeled the EU’s main instrument for energy transition. The carbon price has been very low because there has not been real scarcity in emission rights. This is due to shortcomings and inherent flaws in its design, and too many rights issued and banked, a situation which has been exacerbated by the financial crisis which stalled electricity production growth\textsuperscript{15}.

RES support schemes (public funding for new RES generation capacity) ceteris paribus reduce the demand for CO₂ rights. This will lead to lower carbon prices, which benefits the most polluting generators. Effectively, a part of the public funding in clean generation capacity goes directly to the pockets of polluting generators, and emission reduction achieved may be much lower than anticipated. Hence, if public money is invested in clean generation capacity, the equivalent amount of CO₂ credits should be taken out of the market. This examples illustrates one of the many complexities surrounding CO₂ policy, and justifies further research to alternative CO₂ pricing mechanisms, such as carbon taxation\textsuperscript{16}.

**International harmonization of energy policies** Market coupling brings economic advantages by efficiently matching production and demand across national borders. This means, however, that certain effects of national energy policies are also ‘transported’ across the border. In Germany, the large RES potential has been realized with the help of the feed-in tariff, and renewable energy producers are effectively not subject to the rules of the market. In the Netherlands, however, RES production is to be traded on the electricity market like any other form of electricity generation. So when a German wind surplus is lowering wholesale prices in the Netherlands, the Dutch wind producers will

\footnote{\textsuperscript{11}Under the assumption of perfect competition these can be shown to be equivalent.}
collect much lower revenues. The spatial correlation of wind energy production, i.e. when it is windy in the Netherlands, it is, on average, also windy in Germany, enhances this effect. German wind energy producers are protected by the feed-in tariff, but the Dutch wind energy producers are not. This example illustrates that an internal European energy market with different national energy policies may have adverse effects.

**Making variable RES work in a market setting**  The fact that most energy systems in the Western world are market based, liberalized systems, means that the task of switching to a RES based system may even be harder than in a vertically integrated and centrally planned system. It means that the rules of the markets must be designed such that the adequate investment signals are given, and simultaneously, that the operation of resulting portfolios happens in a cost-efficient, clean and reliable way. In the above it has already been demonstrated that a system centered around the spot-price as we know it today is unlikely to adequately fulfill these tasks. Some elements of today’s organization, may, however be more suitable for the new challenges. The cascade of day-ahead, intra-day and balancing markets will likely play a central role as it naturally deals with the uncertainty of RES \(^{12}\). But the flexible resources that will become essential for reliable system operation, cannot only be rewarded on a MWh base anymore, and instead should be rewarded appropriately for the service they are delivering: providing the option of delivering a service when needed. Capacity based mechanisms are good candidates for remunerating flexible resources at value and providing enough incentives for investment. Furthermore, new markets where different types of flexibility products can be traded could be useful complement to the capacity based mechanisms.

**Social acceptance and a renewed perception of the energy system**  In addition to the technical changes and the restructuring of the markets and regulations, a whole renewed public perception of the energy system may be needed. One could classify this at as a required change on the social level. Currently, the continuous availability of cheap energy is a matter of course. When production of energy will be largely driven by fluctuating weather conditions, it seems inevitable that stronger energy price fluctuations will be the result. While such price volatility may currently be perceived as very undesirable, it is not unthinkable that some day it will be socially accepted, like is the case for many other commodities with volatile prices. People may adapt to it, and become used to plan their EV charging or washing clothes on those days when energy prices are expected to be lowest. Comfort, utility (in the economic sense of the word) and energy costs may be weighed more carefully.

For energy intensive industries, too, this situation may actually offer opportunities. Instead of designing industrial production process to run 24 hours per day against a reduced electricity tariff, one could think of designing a flexible plant that runs only when energy is available at very low prices. Such societal changes might create more price-elasticity of energy demand, which will have a dampening and stabilizing effect on the system.

\(^{12}\)An important premise for this mechanism to work properly, of course, is that RES, like any other generation source, need not be shielded from this type of market discipline - as is the case in countries where feed-in tariffs without balance responsibility for the RES producers are in place.
4 Concluding remarks

Important additional issues  In this paper we have sought to highlight a number of aspects that we consider important in the light of system integration, within the scope of RES integration challenges in the power sector. Even within this scope, there are, however, a large number of additional topics that we have not, or only very briefly, touched upon, that are nevertheless of crucial importance for the success of the energy transition. Some of them include: the role of information technology and cyber security in the energy system, gas and heating systems and their interaction with the electrical power system, macro-economic and geopolitical issues, financial ownership structures, and social and behavioral aspects. When considering the wider scope of the energy transition in general, the number of important aspects is even longer and more diverse, including fundamental research in materials science and bio- and nano-technology, new pathways to products and fuels, sustainability of the chemical, transport and agricultural sectors, energy efficiency, the built environment, electrification of developing countries, and many others.

Lessons for the energy transition  The energy sector, while still in the process of transformation due to liberalization, must face the challenge to transform itself once again. This time the change should be towards a RES based energy system. Despite recent technological progress and cost reductions, major breakthroughs are needed, in technology, markets and regulation. In addition to clear policy choices supporting the further deployment of RES, it will require significant additional investment in research and development. Within the scope and limitations of our paper, we have argued for a systems integration approach to the current and future RES integration challenges that we face. This approach, that we defined as the process of jointly shaping the technical and institutional sub-systems in a way that supports the transition to a renewable, affordable and reliable energy system, is needed because of the many interrelations and strong dependencies between the technical and institutional sub-systems, some of which we have treated in this paper. Furthermore, it is not only a necessary condition for shaping the energy system of the future, it is a challenge in itself to develop this approach. Hence, to effectively guide the transition process, new modeling and decision making tools need to be developed that can capture the complexity of a largely decentralized and interlinked RES based energy system.

Towards a green economy  By investing in a RES based power system, we accelerate change and we expose our energy sector to economic risk in the short run. We should, however, realize that the risks of doing nothing may be orders of magnitudes larger on the longer term. Moreover, the economic potential related to the innovations needed to make the transition a success is enormous. The business opportunities for improved RES generation technologies, energy storage, demand response and network technologies cannot be emphasized enough. Furthermore, it seems almost certain that in the energy systems of the future, a central role will be played by information technology. The influence is expected on many levels and on almost every aspect of the energy system: metering, control, forecasting, optimization, planning, etc. The development of the next generation energy infrastructure, both the enabling information technologies
and the new generation and network technologies itself, could prove to be a crucial sector empowering the green economy of the 21st century.

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