Chapter 1

Introduction

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Abstract The future energy system in Europe needs to be decarbonized and thus be based almost exclusively on renewable energy sources. Therefore it is challenged by the intermittent nature of renewables and requires several flexibility options. The interaction between different options and the impact on environment and society are in the focus of this contribution. It is the core objective of this book to analyze and evaluate the development toward a low-carbon energy system with focus on flexibility options in the EU to support the implementation of the Strategy Energy Technology Plan. The analyses are based on a bottom-up modeling environment that considers current and future energy technologies, policy measures and their impact on environment and society while considering technological learning of low-carbon and flexibility technologies.

The reduction of greenhouse gas emissions is one of the main challenges that the European Union is facing in the coming years and decades. Achieving the targeted emission reductions requires a fundamental transformation of the energy sector. Responding to the Paris Agreement the European Green Deal sets the overarching aim of making Europe the first climate neutral continent by 2050 and includes a set of policy initiatives by the European Commission.¹ Until 2030, EU's greenhouse gas emissions should be reduced to at least 55% compared with 1990 levels.

The EU's energy legislation as well as the EU's energy technology and innovation strategy (Strategy Energy Technology Plan—SET), aim at creating an framework

¹The European Green Deal is a concept presented by the European Commission in December 2019. First legislative initiatives e.g. for higher fossil fuel prices and stricter CO₂ regulations are available by mid of 2020.

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conditions that facilitate the evolution of existing as well as developing new low-carbon technologies that can cope with the specific needs for a stable, cost-efficient and sustainable prospective energy supply. Moreover, these legislative initiative and strategy promote in particular the deployment of renewable energy sources (RES), the electrification of demand side sectors and improved energy efficiency in the electricity, heat and transport sector. In addition, these measures are framed by additional roadmaps that trigger investments in the development of complementary technologies for energy conversion (electricity and heat provision), transportation and consumption (mobility, buildings, industry, and transport), such as power-to-x technologies, grid infrastructure, and demand side management.

Yet, several technologies, which will play a crucial role in next decades in the EU strategy, challenge the energy system by their intermittent nature. The two most abundant forms of power on earth are solar and wind. Both have been and will be becoming more cost-competitive compared to other energy carriers for electricity generation and thus are key factors in achieving climate reduction targets. Yet, the integration of intermittent renewable energy sources necessitates flexibility in the energy system. A large bundle of technologies may provide the needed flexibility such as energy storage systems, smart grids, adaptation of conventional power plant technologies, and demand side management. These applications are often cross-sectoral and can be complemented by power-to-x, such as power-to-heat (e.g., heat pumps, district heating), power-to-transport (e.g., electric mobility, fuel cells), power-to-gas (e.g., H_2 , CH_4), power-to-fuels, and power-to-industry (e.g., H_2 for methanol or ammoniac production) for the electrification of other sectors.

It is thus the core objective of this book to analyze and evaluate the development toward a low-carbon energy system with focus on flexibility options including power-to-x options in the EU up to the year 2050 to support a better system integration of renewable energy sources. The analysis and findings in this book are based on the EU-funded project “*REFLEX - Analysis of the European energy system under the aspects of flexibility and technological progress.*” The REFLEX project was embedded in the Horizon 2020 Work Program “Secure, clean and efficient energy” of the EU and addressed the topic LCE-21-2015 “Modelling and analyzing the energy system, its transformation and impacts” during the project duration from May 2016 until April 2019. Thereby nine partners from six European countries contributed with their expertise, especially in energy modeling, to the successful project implementation, in particular: TU Dresden, (Chair of Energy Economics) as coordinator, Energy Systems Analysis Associates—ESA² (Dresden), Fraunhofer Institute for Systems and Innovation Research (Karlsruhe), Karlsruhe Institute of Technology (Karlsruhe), Royal Institute of Technology (Stockholm), TEP Energy GmbH (Zurich), TRT Trasporti e Territorio (Milano), University of Science and Technology—AGH (Krakow) and Utrecht University (Utrecht).

New technologies and innovations are necessary to address the scrutinized challenges having the (future) competitiveness of technologies as well as their social impacts in mind. To assess the competitiveness of technologies and their interrelation, the cost effectiveness of the future energy system in a systemic context requires for a well-founded energy system analysis including an evaluation of technological

Fig. 1.1 Schematic illustration of REFLEX Mod-RES and High-RES scenarios presented in this book in the context of global greenhouse gas reductions. Own illustration adapted and based on Climate Action Tracker (2018)

learning. Within REFLEX this challenge is addressed by the integration of experience curves as well as socio-economic impact analysis in an integrated energy models system. Hence, the analysis is based on a modeling environment that takes into account the full extent to which current and future energy technologies and policies interfere and how they affect the environment, economy and society while considering technological learning of low-carbon technologies and of applications providing flexibility.

An extensive modeling framework combining the expertise of the nine partners is developed using a quantitative scenario approach as basis of the analysis. Thereby, scenarios describe possible futures by formulating a lot of “if-then” conditions. Scenarios reflect different assumptions about how current trends will unfold, what critical impact factors are and what policymakers should take into consideration. It is important to notice that scenarios are current futures (for decision-making today), but not a future present (in the sense of a forecast). Scenarios may be either normative or explorative (cf. Figure 1.1). Normative scenarios describe what has to be done to achieve a given target or “perfect future.” Normative scenarios orient energy policy in terms of what needs to be done today to achieve the targets. Explorative scenarios are from a today’s perspective more plausible and challenge the paths toward what seems to be possible to be achieved.

As depicted in Fig. 1.1, two main scenarios are distinguished in the REFLEX project: a reference scenario based on observed trends and a policy scenario representing more ambitious decarbonization pathways for Europe until 2050. The reference scenario is defined as a moderate renewable scenario (Mod-RES) while the ambitious policy scenario is defined as a high renewable scenario (High-RES). A detailed description of the scenario assumptions can be found in following Chapter 2. While both scenarios cannot be clearly grouped in one of the two scenario categories, the Mod-RES scenario is closer to an explorative (in the sense of continuing trends) and High-RES closer to a normative one (in the sense that it is very ambitious and further strong and additional policy measures are needed). Figure 1.1 depicts these two scenarios with regard to the European Green Deal as well as with regard to estimated ranges of global temperature changes.² Note that Fig. 1.1 is only a schematic illustration that strongly simplifies the paths related to climate change and should not be misinterpreted: especially, the presented scenarios in this book focus only on Europe, while the indicated paths with regard to temperature changes necessitate global action.

To analyze and evaluate the development toward a low-carbon energy system with focus on flexibility options, REFLEX brings together the comprehensive expertise and competences of known European experts. Each partner focuses on one or two of the research fields: techno-economic learning, fundamental energy system modeling or environmental and social life cycle assessment. To link and apply these three research fields in a compatible way, an innovative and comprehensive energy models system (EMS) is developed, which couples the models, tools, findings and data from all involved partners in this book (cf. Chapter 3). It is based on a common database and scenario framework. The results from the energy models system helps to understand the complex links, interactions and interdependencies between different actors, available technologies and impact of the different interventions on all levels from the individual to the whole energy system. In this way, the knowledge base for decision-making concerning feasibility, effectiveness, costs and impacts of different policy measures is strengthened and shall assist policymakers.

This book describes possible pathways and necessary steps toward a more sustainable energy system based on a detailed and fundamental analysis of the energy system. Derived from the abovementioned core objective, following sub-goals are addressed and structure this book:

1. Analyze and model the impacts of technological development and innovation on the energy system by enhancing and combining different sectoral approaches and experience curves (cf. Part I and II).
2. Set up a holistic and consistent (socio-technical) scenario framework based on the Strategy Energy Technology Plan (SET-Plan) up to the year 2050 (cf. Part I, especially Chapter 2).

²The REFLEX Mod-RES and High-RES scenarios were defined long before the more ambitious European Green Deal policy targets were published. However, the High-RES scenario already anticipated the more ambitious targets and comes close to meeting the European Green Deal.

3. Develop an Energy Models System (EMS), which links different models and approaches, including a common database and interface to analyze the complex interactions and interdependencies between the different actors, the available technologies and the impact of the different interventions on all levels from the individual to the whole energy system (cf. Part I, especially Chapter 3).
4. Derive experience curves for energy technologies and incorporate them in the energy models systems to assess the future competitiveness of upcoming technologies and their diffusion into the system as well as their interferences with existing technologies, including grid aspects (cf. Part II).
5. Comparative assessment of prospective flexibility portfolios to integrate RES-based electricity generation, considering demand side management, grid reinforcement, energy storage, flexible generation capacities, and alternative electricity market designs as well as their impacts. While Part III focuses on demand side flexibility and the impact of disruptive technologies, Part IV has a strong focus on the supply side and system perspective as well as on market design issues.
6. Quantification of external costs and socio-environmental impacts of whole energy system transition pathways, considering the entire life cycle of new and existing energy technologies (cf. Part V).
7. Derive policy measures from the entire assessments in the framework of the SET-Plan to assist policymakers in identifying and analyzing effective strategies for a transition to an efficient low-carbon energy system (cf. Part VI).

Reference

Climate Action Tracker (2018) Warming projections global update—December 2018. https://climateactiontracker.org/documents/507/CAT_2018-12-11_Briefing_WarmingProjectionsGlobalUpdate_Dec2018.pdf. Accessed on 21 Jul 2020

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