Project no.:
219123

Project acronym
REALISEGRID

Project title:
REseArch, methodoLogIes and technologieS for the effective development of pan-European key GRID infrastructures to support the achievement of a reliable, competitive and sustainable electricity supply

Instrument: Collaborative project
Thematic priority: ENERGY.2007.7.3.4
Analysis and scenarios of energy infrastructure evolution
Start date of project: 01 September 2008
Duration: 33 months

D3.6.3
Transmission Grid Investments for an Efficient Integration of Renewable Energy Sources

Final

Organisation name of lead contractor for this deliverable:
Energy Economics Group (EEG), Vienna University of Technology

<table>
<thead>
<tr>
<th>Dissemination Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PU</td>
<td>Public</td>
</tr>
<tr>
<td>PP</td>
<td>Restricted to other programme participants (including the Commission Services)</td>
</tr>
<tr>
<td>RE</td>
<td>Restricted to a group specified by the consortium (including the Commission Services)</td>
</tr>
<tr>
<td>CO</td>
<td>Confidential, only for members of the consortium (including the Commission Services)</td>
</tr>
</tbody>
</table>
The major objective of this report is to emphasize the importance of transmission grid investments for an efficient and effective integration of renewable energy sources for electricity generation (RES-E) in Europe. The insights and outcome of the work compiled in this report shall contribute (i) to structure the discussion on and (ii) to better understand the needs of transmission grid investments triggered by the massive integration of RES-E integration. A variety of empirical examples presented in this report addressing currently existing barriers, shortcomings, and inefficiencies of large-scale RES-E integration mainly caused by transmission adequacy problems shall demonstrate that overarching European policy objectives (e.g. EU2020 RES-E targets) obviously also demand for overarching transmission investment models going far beyond national way of thinking. Moreover, it stays on the order of the day that robust approaches and models need to be developed, enabling the estimation of the need/urgency, the cost and benefits (and who are the beneficiaries) of different transmission investment projects in different European regions. Finally, it is important to note that cost remuneration models for any kind of transmission investments must be robust, excluding any kind of investment and regulatory risk in the short-term and long-term.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACRONYMS AND DEFINITIONS</strong></td>
</tr>
<tr>
<td><strong>1 EXECUTIVE SUMMARY</strong></td>
</tr>
<tr>
<td><strong>2 INTRODUCTION</strong></td>
</tr>
<tr>
<td>2.1 Objectives of this Study</td>
</tr>
<tr>
<td>2.2 Expected Outcome</td>
</tr>
<tr>
<td>2.3 Approach</td>
</tr>
<tr>
<td><strong>3 THE ROLE OF UNBUNDLING IN THE CONTEXT OF RES GRID INTEGRATION</strong></td>
</tr>
<tr>
<td>3.1 The Role of Transmission Grids in Competitive Electricity Markets</td>
</tr>
<tr>
<td>3.1.1 Transmission Grid Infrastructure in a Historical Context</td>
</tr>
<tr>
<td>3.1.2 Transmission Grid: Physical Platform in Competitive Electricity Markets</td>
</tr>
<tr>
<td>3.1.3 Status Quo and Uncertainties Ahead for Transmission System Operators</td>
</tr>
<tr>
<td>3.2 Different Boundaries between the Grid Infrastructure and Renewable Generation Capacities</td>
</tr>
<tr>
<td>3.2.1 The Boundary Question of RES-E Integration</td>
</tr>
<tr>
<td>3.2.2 The Locational Signal Question of RES-E Integration</td>
</tr>
<tr>
<td>3.2.2.1 “Deep” Integration Charging: Ideal versus Real World</td>
</tr>
<tr>
<td>3.2.2.2 “Shallow” Integration Charging: Ideal versus Real World</td>
</tr>
<tr>
<td>3.3 “Who follows Whom“: The Electricity Grids the RES Resources or Vice Versa?</td>
</tr>
<tr>
<td>3.3.1 Excursion into the Structural Development in the 20th Century</td>
</tr>
<tr>
<td>3.3.2 Essence for the RES-E Integration Debate</td>
</tr>
<tr>
<td>3.4 Interdependences between Regulatory Policies (Grid Regulation Models, RES-E Support Instruments) and RES-E Grid Integration</td>
</tr>
<tr>
<td>3.4.1 RES-E Developers’ Challenges</td>
</tr>
<tr>
<td>3.4.2 Grid Operators’ Challenges</td>
</tr>
<tr>
<td>3.4.3 Convergence of Different Policies Supporting RES-E Grid Integration</td>
</tr>
<tr>
<td><strong>4 EXISTING SHORTCOMINGS/BARRIERS FOR LARGE-SCALE RES GRID INTEGRATION</strong></td>
</tr>
<tr>
<td>4.1 Problems of a „Sequential Policy Process”: RES Generation Target Policies Decoupled from Grid Infrastructure Development Policies</td>
</tr>
<tr>
<td>4.2 Inefficiencies of Regional/National System Boundaries for RES Grid Integration (Bottom-Up Approach)</td>
</tr>
<tr>
<td>4.2.1 Sub-Optimal/Inefficient Allocation of Resources (in Terms of)</td>
</tr>
<tr>
<td>4.2.1.1 RES Generation Potential Implementation (Diseconomies of Scale)</td>
</tr>
<tr>
<td>4.2.1.2 System Balancing and Reserve Capacity Provision due to Variability/Intermittency of RES Generation</td>
</tr>
<tr>
<td>4.2.2 Missing Business Models (incl. Examples) for Utilization of Low-Cost RES-E Generation Potentials</td>
</tr>
<tr>
<td>4.3 Shortcomings of “Isolated” RES Grid Integration Policies in a more Comprehensive European Energy Policy Context</td>
</tr>
<tr>
<td>4.3.1 Diseconomies versus Economies of Scale of Utilized RES Generation</td>
</tr>
</tbody>
</table>
4.3.2 Inefficient versus Efficient Mitigation of Variability and Intermittency of RES-E Generation
4.3.3 Non-Harmonized versus Harmonized RES-E Integration Charging Approaches
4.3.4 Strategic Behavior versus International Commitment

5 THE FUTURE IMPORTANCE OF TRANSMISSION GRID INVESTMENTS
MEETING “GLOBAL OPTIMA” OF RES-E GRID INTEGRATION ON EUROPEAN LEVEL

5.1 Overcoming Structural Difficulties and Regional/National “Vanities” to meet the “2020 Targets” (and Beyond) with Lowest Total System Cost
5.1.1 Enabling Market Coupling of Different European Sub-Markets
5.1.2 Enabling Access to Efficient and Effective System Balancing and Reserve Capacity Provision Technologies in a European Context
5.1.3 Enabling Connection of Large-Scale RES-E Generation with Load Centers in Dense Areas
5.1.4 Development of European-wide Business and Cost Remuneration Models for Transmission Investments

5.2 Ideas and Visions of Coordinated European-wide (Onshore and Offshore) Transmission Grid Development

6 POLICY RECOMMENDATIONS AND CONCLUSIONS
REFERENCES
ACRONYMS AND DEFINITIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>ACER</td>
<td>Agency for the Cooperation of Energy Regulators</td>
</tr>
<tr>
<td>ATC</td>
<td>Available Transfer Capacity</td>
</tr>
<tr>
<td>APX</td>
<td>Amsterdam Power Exchange</td>
</tr>
<tr>
<td>CCGT</td>
<td>Combined Cycle Gas Turbine</td>
</tr>
<tr>
<td>CSP</td>
<td>Concentrated Solar Thermal Power Generation</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DG</td>
<td>Distributed Generation</td>
</tr>
<tr>
<td>DUoS</td>
<td>Distribution Use of System Charges</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EEX</td>
<td>European Energy Exchange</td>
</tr>
<tr>
<td>Elspot</td>
<td>NordPool Spot Market for Electricity</td>
</tr>
<tr>
<td>ENTSO-E</td>
<td>European Network of Transmission System Operators for Electricity</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EU2020 Targets</td>
<td>Policy targets of the European Union by 2020</td>
</tr>
<tr>
<td>EU27</td>
<td>27 Member States of the European Union</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GT</td>
<td>Gas Turbine</td>
</tr>
<tr>
<td>GUoS</td>
<td>Generation Use of System Charges</td>
</tr>
<tr>
<td>HVAC</td>
<td>High Voltage Alternating Current</td>
</tr>
<tr>
<td>HVDC</td>
<td>High Voltage Direct Current</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technologies</td>
</tr>
<tr>
<td>IPEX/GME</td>
<td>Italian Power Exchange / Gestore del Mercato Elettrico</td>
</tr>
<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
</tr>
<tr>
<td>LRIC</td>
<td>Long Run Incremental Cost</td>
</tr>
<tr>
<td>MENA</td>
<td>Middle East and Northern Africa</td>
</tr>
<tr>
<td>NTC</td>
<td>Net Transfer Capacity</td>
</tr>
<tr>
<td>OMEL</td>
<td>Mercado de Electricidad</td>
</tr>
<tr>
<td>PolPX</td>
<td>Polish Power Exchange</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable Energy Sources</td>
</tr>
<tr>
<td>RES-E</td>
<td>Renewable Energy Sources for Electricity Generation</td>
</tr>
<tr>
<td>RPI</td>
<td>Retail Price Index</td>
</tr>
<tr>
<td>TGC</td>
<td>Tradable Green Certificate</td>
</tr>
<tr>
<td>TSO</td>
<td>Transmission System Operator</td>
</tr>
<tr>
<td>TYNDP2010</td>
<td>Ten-Year Network Development Plan 2010-2020</td>
</tr>
<tr>
<td>UKPX</td>
<td>UK Power Exchange</td>
</tr>
<tr>
<td>Verbund-APG</td>
<td>Verbund Austrian Power Grid AG</td>
</tr>
<tr>
<td>VKW-Übertragungsnetz</td>
<td>Vorarlberger Kraftwerke-Übertragungsnetz AG</td>
</tr>
<tr>
<td>X</td>
<td>Productivity Offset</td>
</tr>
</tbody>
</table>
1 EXECUTIVE SUMMARY

At present, there exists an enormous need for deploying a pan-European policy fostering adequate investments into electricity grids on both transmission and distribution levels, as recently underlined by the EC Communications COM(2010) 639 and, most notably, COM(2010) 677/4. Moreover, after more than ten years of liberalisation of the European electricity market, the inherent transmission adequacy problem is still unsolved. The transmission grid, however, is the physical platform and “backbone” upon which several commercial activities rely on in a competitive electricity market. The transmission adequacy problem has become clear also at policy making level in the meantime. Moreover, at present it is an issue on top of the agenda for the further development of the internal European electricity market. A first attempt by European policy making has been the request for a non-binding “Ten-Year Network Development Plan ([21])” to be compiled by the European Network of Transmission System Operators for Electricity (ENTSO-E). Mainly due to lack of time, the first version of this plan cannot go far beyond a brief justification of the usefulness of the different transmission investment projects listed there; this usefulness is expressed in terms of the contribution to different European policy objectives: (i) improvement of security of supply; (ii) further development of the internal European electricity market; (iii) massive integration of RES-E generation ([47]).

This report here predominately addresses the latter of the three European policy objectives mentioned above. Moreover, the major objective of this report is to emphasize the importance of transmission grid investments for an efficient and effective integration of renewable energy sources for electricity generation (RES-E) in Europe. The insights and outcome of the work compiled in this report shall contribute (i) to structure the discussion on and (ii) to better understand the needs of transmission grid investments triggered by the massive integration of RES-E integration. Since already some important studies and projects have been conducted in recent years dealing with grid infrastructure related aspects of large-scale RES-E grid and market integration (mainly in Europe), throughout this report it is frequently referred to these distinguished references in order to provide some empirical evidence already available from these studies, on the one hand, and/or to underpin some own arguments and recommendations of the authors of this report, on the other hand. Besides that, the mutual relationship to other important Deliverables of the REALISEGRID project addressing also different transmission investment aspects is worked out in detail in this document.

A variety of empirical examples presented in this report addressing currently existing barriers, shortcomings, and inefficiencies of large-scale RES-E integration mainly caused by transmission adequacy problems shall demonstrate that overarching European policy objectives (e.g. EU2020 RES-E targets) obviously also demand for overarching transmission investment models going far beyond national way of thinking. Moreover, it stays on the order of the day that several important European and national experts (European Commission, ENTSO-E, ACER, stakeholders, research institutes, others) shall try to develop robust approaches and models, enabling the estimation of the need/urgency, the cost and benefits (and who are the beneficiaries) of different transmission investment projects in different European regions. A backing on robust methodological frameworks only can guarantee the identification of effective and efficient transmission investments finally supporting the further development of the European electricity market in a sustainable way.

Finally, it is important to note that cost remuneration models for any kind of transmission investments must be robust. Confidence for the investor is a “sine qua non” condition. The risk for any kind of investment to be “sunk” as well as any kind of regulatory risk must be excluded in the short and long-term. Depending on the kind of transmission investment cost remuneration models
can range from cost-based regulation models (e.g. rate-of-return regulation), market-based approaches (e.g. auctioning scarce transmission capacities in case of congestion) and – in case – also others (e.g. financial rights decoupled from physical electricity flows in case of merchant investments).
2 INTRODUCTION

2.1 Objectives of this Study

The major objective of this report is to emphasize the importance of transmission grid investments for an efficient and effective integration of renewable energy sources for electricity generation (RES-E) in Europe. At present, there exists an enormous need for adequate investments into electricity grids on both transmission and distribution levels as recently underlined by the EC Communications COM(2010) 639 and, most notably, COM(2010) 677/4. The major reason for that is that the role, responsibilities and importance of electricity grids in competitive electricity markets simply have not been understood in the early phase of energy policy making after the start of the liberalisation of the European electricity markets in 1999.

Pushed by inherent bottlenecks and congestion problems on almost all important transmission lines all over Europe, in the last couple of years, fortunately, policy makers have understood the need for the implementation of corresponding legal and regulatory frameworks enabling a further development of the European electricity networks. Moreover, after a delay of almost 10 years, now the strategic development of the European transmission networks is one of the most important issues on top of the agenda of European policy makers. Within the “3rd Legislative Package” for the internal European electricity market, the European Network of Transmission System Operators for Electricity (ENTSO-E) has been commissioned to develop a non-binding “Ten-Year Network Development Plan 2010-2020 (TYNDP2010)”. This plan has been published recently and it identifies the most urgent transmission investment projects in the upcoming years across Europe. Moreover, an update of this first version is already under compilation, trying also to develop robust methods to be able to better assess the need for individual transmission investments. In general, the TYNDP2010 provides a detailed classification of the transmission investment needs (new and refurbedished transmission lines/routes) according to the contribution to the different EU policy objectives: (i) improvement of security of supply; (ii) further development of the internal European electricity market; (iii) massive integration of RES-E generation necessary to meet the EU2020 policy targets.

This report focuses on the latter policy objective - transmission grid investment needs (national, cross-border, new (offshore) routes) triggered by the massive integration of RES-E generation. The exact placement of the contents of this report within several transmission investment aspects considered in the REALISEGRID project is conducted in section 2.3 below.

2.2 Expected Outcome

The presentation of the major outcomes of this study is structured as follows:

- In chapter 3 the role of unbundling in the context of RES-E grid integration is addressed. This includes the discussion of the different interpretations of boundaries between grid infrastructures and RES-E generation capacities as well as the critical discussion of the “chicken-egg” problem: who follows whom? - the electricity grids the RES-E resources or vice versa?
- Existing shortcomings and barriers for large-scale RES-E grid integration are discussed in chapter 4, e.g. problems of decoupling RES-E target policies from grid infrastructure policies, inefficiencies of regional/national system boundaries for RES-E integration and also shortcomings of “isolated” RES-E grid integration policies in general.
In chapter 5 the future importance of transmission grid investments for meeting “global optima” of RES-E grid integration on European level is addressed. This incorporates visions to overcome structural difficulties (e.g. currently existing system boundaries far away from physics governing electrical load flows) and also addresses ideas and visions on coordinated European-wide (onshore and offshore) transmission grid development.

Finally, chapter 6 closes with policy recommendations and concluding remarks.

2.3 Approach

This report emphasizing the importance of transmission grid investments for an efficient and effective integration of renewable energy sources for electricity generation (RES-E) in Europe presents the major insights and outcomes of a corresponding task embedded into work package (WP) 3.6 of the REALISEGRID project, dealing with several important aspects on incentives and regulations to support transmission investments. In particular, the major objective of WP3.6 is to analyse the impact of incentive and regulation mechanisms on transmission investments so as to improve transmission adequacy and, subsequently, significantly contribute to the fulfilment of the different EU policy objectives as there are (i) improvement of security of supply, (ii) further development of the internal European electricity market and (iii) massive integration of RES-E generation.

This report tries to contribute (i) to structure the discussion on and (ii) to better understand the needs of transmission grid investments triggered by the massive integration of RES-E integration. Since already some important studies and projects have been conducted in recent years dealing with grid infrastructure related aspects of large-scale RES-E grid and market integration (mainly in Europe), throughout this report it is frequently referred to these distinguished references in order to provide some empirical evidence already available from these studies, on the one hand, and/or to underpin some own arguments and recommendations of the authors of this report, on the other hand. Besides different Deliverables of the REALISEGRID project (see below in detail), the most important European studies and projects - cited in this report - are:

- SUSPLAN (www.susplan.eu), analyzing more efficient integration of RES-E generation into future grid infrastructures both on regional and trans-national level.
- GreenNet-Europe (www.greennet-europe.org), modelling large-scale and least cost grid and market integration of RES-E generation both on country and European level.
- OffshoreGrid (www.offshoregrid.eu), developing a scientifically based view on an offshore grid implementation in Northern Europe along with the development of a corresponding regulatory framework.
- Desertec (www.desertec.org), promoting the suitability of the desert in Northern Africa for large-scale concentrated solar thermal power generation (CSP) and imports to Europe.

Finally, it is important to note, that there also exists a mutual relationship of this report with other Deliverables of the REALISEGRID project (cited correspondingly throughout this document). The most important REALISEGRID documents in this context are as follows:

- Deliverable D3.1.1 ([27]) on a review of existing methods for transmission planning and for grid connection of wind power plants, significantly contributing to the boundary question of RES-E integration in section 3.2.1 of this report.
• Deliverable D3.3.1 ([34]) on recommendation of possible criteria to assess technical-economic and strategic benefits of specific transmission projects, significantly contributing to the discussion on European-wide business and cost remuneration models for transmission investments in section 5.1.4 of this report.

• Deliverable D3.6.2 ([33]) on incentive schemes and a regulatory framework for transmission development in Europe, significantly contributing to the analyses of the interdependences between regulatory policies and RES-E grid integration in section 3.4 of this report.

• Deliverable D3.7.1 (Interim Report, [35]) addressing preliminary results on streamlining planning and approval procedures of electricity transmission infrastructures, significantly contributing to the social acceptance discussion of the implementation of transmission projects in section 3.1.2 of this report.

Last but not least, it is important to note, that the major outcomes of this report (Deliverable D3.6.3) shall also contribute to the final Deliverable D3.6.1 (“Transmission investments and regulation: synthesis and policy regulations”) of WP3.6.
3.1 The Role of Transmission Grids in Competitive Electricity Markets

3.1.1 Transmission Grid Infrastructure in a Historical Context

Historically, the development of a vertically integrated electricity supply system was one of the basic dimensions to enable economic growth in the 20th century (see section 3.3.1 in detail). The sensitive backbone of this system was – and still is also in competitive electricity markets – the transmission grid. In the last century, there have been three major reasons for the construction of large transmission grids (see e.g. [7]):

- The initial core motivation for constructing transmission capacities was to overcome the geographic distance between site-specific power plants and load centres.
- “Economies of scale” in electricity generation: especially from the 1960s to 1980s larger electricity generation units have been considered to be economically more attractive than smaller ones. The basic underlying economic principle in this period of time was to implement the minimal total cost of both generation and grid capacities, see Figure 3.1.
- A certain minimal level of security of supply.

![Figure 3.1: Economic trade-off between electricity generation capacities and transmission grids. Source: [7]](image)

Transmission networks have been built mainly to enable secure, reliable and economically efficient electricity supply within a single country or even within the area of an individual transmission system operator (TSO), see e.g. [31]. Tie-lines between neighbouring transmission systems have been built to improve reliability and efficiency through cooperation in case of faults and through limited electricity exchanges for minimisation of total system cost. Transmission system operators
(TSOs), however, have not designed the interconnectors between their transmission networks primarily to facilitate large-scale commercial power trade. Coordination between the different systems was undertaken on a voluntary basis between the different TSOs. Moreover, limited power trade between them was rather a matter of marginal exchange of surplus to balance nationally independent production systems.

3.1.2 Transmission Grid: Physical Platform in Competitive Electricity Markets

Beginning with the start of electricity market liberalisation in Europe in 1999 (based on the Electricity Directive 96/92/EC, [25]), the requirements for transmission networks have been changing both fundamentally and suddenly. Moreover, the patterns of gradually grown structures over the past hundred years have been confronted with fundamentally different objectives in terms of role, responsibilities and operation of the transmission networks in a competitive electricity market environment. And although the development of the transmission networks have undergone fundamental changes in the last decade since the start of electricity market liberalisation in 1999, the Transmission System Operators (TSOs) have been forced to develop their networks to accommodate European policy objectives without relying on a formal integrated planning of both generation and network assets.

In the last decade, this lack of an adequate policy compensating the dismissal of the integrated planning approach for both generation and transmission assets finally resulted in unrealistic expectations on transmission networks for providing the physical platform for an integrated European electricity market. Moreover, in the early phase of electricity market liberalisation transmission adequacy issues have not been addressed in the new policy making documents adequately.

Even more, in the European policy framework for restructuring the electricity supply industry, one of the most distinctive features of restructured electricity supply industries has been the separation (by ownership or at least functionally) of potential competitive segments (i.e. electricity generation/wholesale market; customer supply/retail market) of the electricity supply chain from segments with natural monopoly characteristics being subject to price and entry regulation (transmission and distribution grids).

This is called “unbundling” the vertically integrated electricity supply chain, see Figure 3.2. The overall objective of this separation is to ensure non-discriminatory access of third parties (i.e. independent generators) to the transmission grid infrastructure, on the one hand, and to avoid cross-subsidization between the different competitive and regulated segments of the supply chain, on the other hand (see e.g. [30]).
Not surprisingly, as a result of the implementation of open third party access to transmission networks – a necessity for competition in electricity markets on both “ends” of the grid – has made a number of bottlenecks in cross-border (inter-TSO) transmission capacities visible. The major reason for that have been (and still are) significantly increasing amount of commercial cross-border (inter-TSO) trades of electricity. Inherent congestion problems in transmission networks, however, have adverse effects on competition in electricity markets:

- In the short-term, congestion in the transmission grids can not be removed. Therefore, in the last decade European TSOs have set up a number of rules and procedures for allocating scarce cross-border (inter-TSO) transmission capacities to market actors in case of transmission congestion. There exist fundamental different approaches to transmission capacity allocation, but the common starting point is usually the determination of available and thus allocable transmission capacities. In order to give market participants and indicative overview of existing transmission capacities, European TSOs have been publishing non-binding values for the so-called “Net Transfer Capacity (NTC)” (and also “Available Transfer Capacities (ATC)” on the cross-border transmission interfaces between their systems. In the future, it is expected that increasingly flow-based allocation methods will be implemented to determine scarce and, thus, congested cross-border transmission capacities. Naturally, flow-based approaches respond even better to the “real” load flows in the meshed transmission networks (for a detailed consideration of this aspect it is referred to the REALISEGRID Report D3.2.1 [11]).

- In the long-term, transmission congestion can be removed only by investments for grid reinforcements/upgrades and implementation of new transmission lines and transmission routes. Most of these longer-term transmission capacity expansion projects are, however, capital-intensive and time-consuming, and have a more or less considerable impact on the environment, and therefore need to be planned carefully. Even more challenging, the main concern still is the lack of social acceptance that severely delays or jeopardises the realisation of almost all transmission projects (see e.g. REALISEGRID Interim Report D3.7.1 [35], comprehensively addressing several aspects of streamlining planning and approval procedures of electricity transmission infrastructures). In the following section 3.1.3, a selection of the major challenges
and uncertainties ahead for future transmission planning and transmission investments is outlined briefly.

3.1.3 Status Quo and Uncertainties Ahead for Transmission System Operators

The good news first: Inherent bottlenecks and congestion problems on many transmission lines across Europe in the last couple of years have taught European policy makers that a harmonised internal European electricity market can’t emerge if the role, responsibilities and importance of transmission grids is not sufficiently understood and pending structural problems - preventing transmission expansion - are not solved correspondingly.

In this context it is important to note, that the point of criticism for “stepmotherly” treatment of transmission grids in the early phase of the electricity market liberalisation process explicitly addresses policy makers and decision makers outside the network industry. The experts in the network industry understood the problems already at the beginning of electricity market liberalisation process quite well. Moreover, they also frequently claimed to solve these problems. However, their inquiries have not been taken seriously for a long time. And without any legal and regulatory backing/frameworks, the hands of network industries experts’ also have been tied to act correspondingly.

After a delay of almost 10 years, now the strategic development of European transmission networks is also one of the most important issues on top of the agenda of European policy makers. Moreover, the “3rd Legislative Package” for the internal European electricity market has been adopted and will come into force in early 2011. The 3rd Package promotes the strong coordination of the operation and development of the national transmission networks, as well as the harmonisation of the European regulatory frameworks. Regulation 714/2009/EC ([23]) has called for the creation of the European Network of Transmission System Operators for Electricity (ENTSO-E) and according to Regulation 714/2009/EC, “ENTSO-E shall adopt a non-binding Community-wide ten-year network development plan (TYNDP) with the objective to ensure greater transparency regarding the entire electricity transmission network in the Community and to support the decision making process at regional and European level.”

In 2010, already the first version of the Ten-Year Network Development Plan 2010-2020 ([21]) has been published by ENTSO-E, called TYNDP2010 in the following. In TYNDP2010, the most urgent and already pending, planned and/or at least envisaged transmission investment projects of European importance are proposed by European Transmission System Operators (TSOs) in the upcoming decade (see Table 2.1). All the reported transmission investment projects are the result of regional, multilateral or bilateral cooperation between European TSOs. The projects cover both tie-lines and national projects, as well as projects contributing to achieving European goals. In total, roughly 42100 km of new or refurbished network routes are envisaged until 2020, of which 18700 km are expected in the medium term until 2015.\(^1\)

---

\(^1\) The still lasting economic crisis (starting in 2008) may delay some projects but is not expected to trigger significant changes of implementation in the upcoming years.
Table 3.1: Length of proposed new and upgraded transmission lines of European significance until 2020 according to TYNDP-2010 ([21]).

<table>
<thead>
<tr>
<th>Project Technology</th>
<th>Total Length [km]</th>
<th>Length of New Connections [km]</th>
<th>Length of Upgraded Connections [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>32500</td>
<td>25700</td>
<td>6900</td>
</tr>
<tr>
<td>of which &gt;300kV</td>
<td>29600</td>
<td>23200</td>
<td>6400</td>
</tr>
<tr>
<td>DC</td>
<td>9600</td>
<td>9600</td>
<td>0</td>
</tr>
<tr>
<td>...mainly subsea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>42100</td>
<td>35300</td>
<td>6900</td>
</tr>
<tr>
<td>of which in mid-term</td>
<td>18700</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In general, TYNDP2010 addresses several important European transmission investment needs in the upcoming years, with special importance to support EU policy objectives like security of supply standards, the development of the European energy market and the massive integration of renewable electricity (RES-E) generation technologies. Moreover, TYNDP2010 provides a detailed classification of the transmission investment needs according to the contribution to the different EU policy objectives mentioned above:

- 26000 km of new and refurbished transmission lines are driven by measures to meet security of supply standards;
- 28500 km of new and refurbished transmission lines are driven by the further development of the internal European electricity market;
- 20000 km of new and refurbished transmission lines are driven by the massive integration of RES-E generation technologies necessary to meet the EU2020 policy targets.

The implementation of the different EU policies cited above (as well as others) is, of course, accompanied with some uncertainties in general, and as far as the requirements and needs of transmission grid developments are concerned, in particular. But even more important than some uncertainties - somebody never can avoid - is the fact, that there exists an absolute and urgent need for transmission investments to overcome the structural deficits on transmission grid level preventing the further integration of the European electricity market.

This report focuses on the most important aspects of transmission grid investment needs triggered by the massive integration of RES-E generation technologies.

### 3.2 Different Boundaries between the Grid Infrastructure and Renewable Generation Capacities

It is important to note, that the main aspects in this section 3.2 cover both transmission and distribution grids. Moreover, the basic principle of the boundary and locational signal question in the context of RES-E integration are true for several voltage levels of electricity networks. The discussion can not be easily separated for a simple reason: different RES-E technologies are connected to different voltage levels of the electricity grid, ranging from low-voltage distribution level to high and extra-high voltage level on the transmission grid. When referring to practical aspects in this section, however, the transmission grid’s point-of-view is favoured.
3.2.1 The Boundary Question of RES-E Integration

When integrating significant amounts of RES-E generation technologies into existing electricity systems, the question, where to define the boundary of (financial) responsibilities between project developers (RES-E generators) and grid operators in terms of grid connection/access aspects is still a controversial and inhomogeneous issue in European practise (see e.g. also REALISEGRID Report D3.1.1 [27] comprehensively dealing with European practise of grid connection of wind power). Moreover, besides the connection of RES-E facilities to the existing grid infrastructure also grid reinforcement and extension measures caused by large-scale RES-E integration “deeper” in the meshed network raise a set of new questions, e.g. whom to allocate which portion of the corresponding extra costs and how to remunerate and/or socialise the different cost items.

Whereas the extra cost for grid connection of RES-E generation technologies can be determined and allocated easier and more precisely, the allocation and quantification of extra measures and cost deeper in the network is much more complex. Even more, in a meshed network infrastructure it might be even ambiguous to allocate extra measures and costs of grid reinforcements/extensions to the marginal net-effects of a new generation facility.

The core problem in this context is that any changes in a meshed grid infrastructure (e.g. also disconnection of a large industrial customer) will alter the load flows in an electricity system. This means that the status quo of load flows in an electricity system represents just a snapshot of the existing randomization of generation and load centres in a predefined geographical area. Moreover, the status quo as well as changes of load flows incorporates a variety of dimensions, as there are e.g. changes in the spatial distribution of generation and load centres in general, intensity and direction of commercial power trading activities, congested transmission lines in peaking periods, etc. In consideration of all of these interactions, the allocation of load flow changes and, subsequently, grid reinforcement and extension measures deeper in the network to the integration of a single new RES-E generation facility appears at least questionable.²

In general, textbooks on economic theory of natural monopolies (e.g. [10], [15], [14], etc.) would expect to allocate both RES-E grid connection costs³ and grid reinforcement/extension costs deeper in the meshed network to the grid infrastructure and to socialize these costs through the

---

² In general, there doesn’t exist a grid integration discussion for conventional power plants having been built up to now and/or are built at present. As an illustrative example the nuclear power plant Olkiluoto – currently being built in Finland – can be cited. This nuclear power plant also causes – besides grid connection costs – significant grid reinforcement/upgrading measures and costs in the Nordic electricity system. Implementation of correct unbundling, however, allocates and remunerates the different cost components correctly; i.e. grid infrastructure cost components are not incorporated into the calculation methodology of the electricity generation costs of the nuclear power plant; they are incorporated into the corresponding grid tariffs directly.

³ However, signals for entry of entrepreneurs (e.g. locational signal cost component allocated to RES-E developer) are foreseen in economic theory. For a more comprehensive discussion in this context it is referred to the following section 3.2.2.
transmission and distribution tariffs (and not to include either of these cost components to the RES-E project costs).\(^4\)

In practice, however, in many European countries major parts of these grid-related cost components are still allocated to the project cost of a RES-E generation facility (see e.g. [46]).

In general, the following grid connection/access boundaries between the RES-E generation facilities and the grid infrastructure are possible (see Figure 3.3; compare also with REALISEGRID Report D3.1.1 ([27]) and, again, [46]):

- **“Deep” Charging**: Based on this approach, costs for grid connection as well as grid reinforcement/extension are allocated to the RES-E developer and added to the overall long-run marginal costs of RES-E generation. So the RES-E developer has to cover also several grid-related costs upfront besides “actual” RES-E project cost.

- **“Shallow” Charging**: In the shallow grid integration approach, the RES-E developer usually bears the grid connection costs, whereas grid reinforcement/extension costs are attributed to the network operator (and, eventually, socialised via grid tariffs).

- **“True Cost” Charging**: Derived from shallow charging, sometimes also the term “true” connection cost charging is used, indicating that the costs paid by the RES-E developer for the new connection are equivalent to the cost of connecting the RES-E developer to the nearest point on the network with sufficient capacity on the network to accommodate RES-E generation without network reinforcements.

- **“Super-Shallow” Charging**: Following this approach, costs resulting from grid connection and reinforcement/extension are allocated to network operators (and socialised via grid tariffs). The term “super-shallow” has been introduced in the GreenNet-Europe projects,\(^6\) referring to future requirements to connect centralised, large-scale RES-E generation technologies like offshore wind, marine technologies, concentrated solar power plants, etc. In these cases, the traditional “shallow” RES-E integration charging approach would be misleading mainly due to the fact that there exist hardly any degrees of freedom for RES-E developers to freely choose/select a particular site. The coordinates of these kinds of – mainly offshore – sites are rather “planned”. But note, this does not mean that the selection of the RES-E developer on a particular site is not based on competitive principles (e.g. like tenders etc.).

\(^4\) In principle, there exist both options: (i) socialisation within the supply area of a grid operator or (ii) socialisation across the whole country/market/region.

\(^5\) In the last couple of years, in general, the same or at least similar “wording” has been used to describe the different connection charging boundaries. Most common are the terms “deep” and “shallow”. Connection charging models in between these two approaches are called “hybrid”, “shallowish” or “mixed”.

\(^6\) See e.g. project website [www.greennet-europe.org](http://www.greennet-europe.org)
At present, in European practice rather hybrid/mixed approaches are implemented, mainly incorporating elements of both “deep” and “shallow” RES-E grid integration charging. This means in particular that usually some parts of grid reinforcement/extension costs are allocated to the newly connected RES-E generation facility and remaining parts of deep costs are socialised in the grid tariffs. In addition, the entire grid connection costs are borne by the RES-E developer and allocated to the long-run marginal generation costs of the RES-E generation facility in the hybrid model. However, in some EU Member States the existing pattern for allocating RES-E grid integration costs might change in the near future, not least due to the currently ongoing benchmarking and grid regulation implementations by national regulatory bodies. Although these regulatory procedures are driven to fulfill the basic unbundling principles of the different EC-Directives and the implementation of cost transparency in grid infrastructure charging rather than by RES-E grid integration policies, finally the existing boundaries between the RES-E power plant and the grid infrastructure may be shifted increasingly towards the RES-E generation facilities, resulting at least in a “shallow” integration policy or even beyond; but still with some kind of locational signal elements – with the exception of connections of centralised, large-scale RES-E generation technologies like offshore wind, marine technologies and/or concentrated solar power plants on transmission grid level where sites are predetermined/planned (“super-shallow” approach) – to maintain economic efficiency of RES-E integration. This expected future development on the generation side increasingly converges with the already existing pattern on the demand side. Moreover, demand customers traditionally have paid “shallow” integration charges. An equal

Interestingly, in the past the demand side always has been treated differently (compared to generation) when defining the grid connection boundary of customers. According to economic theory there is no obvious reason to do so (see e.g. [32]). Demand customers traditionally have paid “shallow” connection charges – for assets specifically required for their connection – whilst distributed generators traditionally have been charged rather on a “deep” basis, i.e. the full costs arising from the connection including the costs of replacing equipment associated with protecting the network or also the provision of ancillary services. However, an increase in RES-E grid integration in the future, especially at connections which may export and import electricity at different times, is expected to blur the established distinction between demand and generation connections thus fundamentally changing grid operators’ cost drivers. These new circumstances also lead to the conclusion that existing charging structures for RES-E grid integration (still mainly “deep” and “hybrid” models) may no longer be appropriate in the future.
treatment of both sides, generation and demand, is important not least to favour the realisation of smart grid concepts in the future where the established distinction between generation and demand connections will be increasingly blurred. For a continuation of the discussion of this aspect it is referred to section 3.4 in this document.

As already briefly introduced above, the “super-shallow” grid integration charging policy option has been developed in the GreenNet-Europe projects in recent years mainly for large-scale offshore wind (but also other future options for large-scale RES-E integration like marine technologies and/or concentrated solar power plants) integration modelling into the exiting transmission grids. E.g., when considering large-scale offshore wind integration into transmission grids, usually the economic situation exists as follows:

If $C_{\text{Transmission},i}$ are the offshore transmission grid connection costs of an individual wind farm $i$ in case of separate grid connection (Figure 3.4 (left)) and $C_{\text{Transmission,common}}$ the common offshore transmission grid connection costs of all wind farms ($c_i$ is the individual inter-array grid component of wind farm $i$; see Figure 3.4 (right)) the following relationship exists:

$$C_{\text{Transmission,common}} + \sum_{i=1}^{n} c_i < \sum_{i=1}^{n} C_{\text{Transmission},i}$$

Equation above demonstrates that cumulated transmission grid connection costs of the individual offshore wind farms (Figure 3.4 (left)) are higher than the common transmission grid connection costs (plus individual inter-array grid components) of a collective of several offshore wind farms (Figure 3.4 (right)).

![Figure 3.4: Left: Separate offshore grid connection of each individual offshore wind farm and indication of different boundaries for different integration policies. Right: Common offshore grid connection of several offshore wind farms and shift of new connection boundaries towards offshore wind farms. Source: [6]](image)

For a comprehensive comparative empirical analysis of strictly individual versus cost efficient joint offshore wind farm connections in UK it is referred to [19], covering “UK Round 2” offshore wind farm implementation examples.
3.2.2 The Locational Signal Question of RES-E Integration

The overall objective of different cost allocation and RES-E integration charging policies is to guide efficient expansion and use of transmission and distribution grids, on the one hand, and efficient management of generation and load assets being connected to the grid infrastructure, on the other hand. Whereas economic theory presents clear approaches and procedures for optimal RES-E grid and market integration into existing electricity systems, circumstances in practise are far more complex and accompanied by a variety of uncertainties, imperfections and problems. A selection of these critical issues of the different RES-E integration charging policies in practise is discussed in the following.

3.2.2.1 “Deep” Integration Charging: Ideal versus Real World

In general, deep RES-E integration charging approaches have the advantage of providing strong locational signals for new entrants. However, this approach – having been traditionally adopted by grid operators in the past – is far from uncritical. In practise there exist at least the following challenges (see also [32], [18], [8], [45], [13]):

- Although deep RES-E integration is characterised by favourable locational signals to new entrants, the computation of proper deep connection costs (and, subsequently, connection charges to RES-E generators) is very difficult because it is impossible to correctly foresee the future number of generators, the demanded connection capacity and choice of locations. Therefore, a best guess has to be made when calculating location-specific deep connection charges, trading-off the benefits of larger increments against the risk of over-sizing connection capacity and hence prescribing excessive charges for the connection of RES-E generators.

- Furthermore, assuming the case that the connection assets of a specific location are shared by more than one RES-E generator, the costs would also be shared, but as the assets would be quasi-public goods, efficient charges would not necessarily be the same for several new entrants at the same location if their willingness to pay is different.

- In almost all cases the situation described above is getting even more complex taking into account dynamics: RES-E connection applications are rather sequential in time than simultaneous. For sequential connection inquiries the first mover problem at a specific location is inherent, i.e. the critical question arises whether or not the first entrant shall be charged the full costs and encourage subsequent entrants to rebate some fraction (either by granting the right to the first entrant to charge successors, or calculating a charge for successors by the grid operator and rebating it to the first entrant).

---

8 In economic theory, the general principle underlying efficient RES-E integration charging is that charges should reflect the different marginal costs and benefits to the electricity system at each node of RES-E connection. In practical discussions this is often called “marginal participation”.

9 Only in theory the grid operator can optimally plan the electricity grid and specify the location of each new entrant by setting corresponding location-specific and entrant-specific deep connection charges. In this ideal world the total collected connection charges from each entrant at each location would exactly add up to the total connection costs of several new RES-E generators.

10 In general, RES-E generators and, therefore, also the first entrant are likely to be less well-informed than the grid operator about the connection capacity needed and corresponding costs. Moreover, the first entrant usually is not in a financial position to raise the capital to pay for more than its own grid connection. Therefore, from the first mover’s point-of-view it is an advantage if grid operators charge for the cost of the connection in proportion to the use made of...
• Last but not least, there exists a strong concern about the deterrent effects on large-scale RES-E deployment in case of deep integration charging policies. Moreover, it also has to be taken care that this approach is not misused for non-eligible “cross-subsidies” flowing from the competitive generation segment to the regulated grid infrastructure part of the electricity supply chain. This would clearly violate the basic unbundling principle and, therefore, also undermine the legal framework of the EC-Directives (e.g. Directive 2003/54/EC [24] as well as former Directive 96/92/EC [25], Others) trying to implement and establish a common internal European electricity market.

3.2.2.2 “Shallow” Integration Charging: Ideal versus Real World

Although deep RES-E integration policies provide strong locational signals, recognition of the disadvantages of this approach has favoured rather hybrid mechanism (incorporating elements of both deep and shallow charging) in the majority of EU Member States in recent years. Moreover, not least driven by the expectations to fulfil the basic unbundling principles of the EC-Directives (e.g. Directive 2003/54/EC [24] as well as former Directive 96/92/EC [25], Others) further amendments towards shallow integration policies are expected in the context of RES-E integration in the near future. Shallow RES-E integration policies aim to limit the connection assets attributed to the RES-E generator (e.g. up to the next voltage level).

However, if it is to signal locational preferences for RES-E integration into the existing grid efficiently, then a shallow integration charge has to incorporate also location specific cost elements. Otherwise a conflict of interests will arise between a RES-E generator wishing to connect a remote power plant – utilising favourable resources – to the closest point of the existing grid infrastructure, on the one hand, and the respective grid operator favouring a connection point at which total network costs are minimised, on the other hand. This could lead the grid operator to delaying or obstructing connection in certain grid areas, which are regarded not to be cost-minimising. The rejection of a RES-E connection/access inquiry can therefore be regarded as an extreme variant of setting locational signals in the shallow integration approach.

Compared to the deep integration charging approach, shallow integration charging has at least the following further advantages (see also [32], [18], [8], [45], [13], [46]):

• Shallow RES-E integration costs and corresponding charges are presumably easier to define than those for the deep integration approach.

• The first mover problem disappears since the first entrant is expected to be charged only costs of the connection in proportion to the use made of it. Moreover, from the grid operator’s point-of-view the risk of non-recoverable costs, which cannot be recovered from generators, in case of over-sizing connection capacity (e.g. for providing the basis for synergies for later RES-E connections at the same location) disappears since grid reinforcement and upgrading costs are socialised in the grid tariffs and, therefore, are directly borne by the network users.

• Previous arguments lead to the conclusion that barriers for entry are low in case of shallow integration policies, providing favourable framework conditions for large-scale RES-E the different entrants. However, in this ideal case the grid operator faces the following risks: (i) subsequent entrants must arrive as predicted, (ii) the correct connection capacities must be chosen and (iii) the willingness to pay for connection of subsequent entrants must be similar.
deployment. Moreover, shallow RES-E integration is supposed to be more transparent for stakeholders concerned.

- Costs of capital are likely to be higher for RES-E developers than for regulated grid operators.\(^{11}\) Subsequently, shallow integration policies can lead to lower overall integration costs: cost components for grid reinforcements and upgrades – being allocated to the grid operator and socialised in the grid tariffs of the network users in case of shallow integration – are not included in the financing costs of the RES-E power plant to be connected. This provides a strong argument against deep RES-E integration charging.

- Finally, the shallow RES-E integration charging approach goes more in line with the unbundling principles of the EC-Directives than the deep approach. Moreover, due to clear separation of the assets of RES-E generation facilities, on the one hand, and the grid infrastructure, on the other hand, extra grid infrastructure costs (grid reinforcements, upgrades and extensions) caused by large-scale RES-E integration can be better incorporated into “forward-looking” grid regulation models where an extra term can be foreseen to socialise these extra costs (see section 3.4.3 in detail).

### 3.3 „Who follows Whom“: The Electricity Grids the RES Resources or Vice Versa?

Previous section 3.2 has shown that both boundary and locational signal question provide important insights to better understand the complexity of RES-E grid and market integration. However, the pros and cons of the different philosophies to provide signals to different actors in the electricity market on how to best manage the further development of spatial dispersion of RES-E generation, on the one hand, and connection to the existing transmission and distribution grids, on the other hand, do not give a final, ultimate answer. They rather highlight contradictory objectives of different approaches, ranging from market-based signals resulting in free choice of future RES-E generation sites to pure planning of the coordinates of future RES-E generation sites (incl. the transmission grid connection to the best fitting connection point of the existing transmission grid infrastructure).

In practical discussions in recent years, the different proponents of the different philosophies (market versus planning) frequently urged their favourable arguments to reject the opposite approach. Some examples are as follows:

- We can’t implement RES-E generation technologies at sites with excellent resource conditions because it is far away from the existing network infrastructure. So take those nearby the existing network infrastructure and skip others far away.

- There is no need to implement RES-E generation technologies at sites with excellent resource conditions because the loads in the “political entity” (e.g. municipality, province, region, country) are too small and/or already balanced.

---

11 Mainly due to higher risk premiums and shorter depreciation periods the financing costs are likely to be higher for RES-E developers than for regulated grid operators. For example, RES-E generation facilities are depreciated in time horizons of 15-20 years whereas regulated grid operators depreciate their grid infrastructure assets in 30-40 years.
• Others argue: If there is a mandatory exogenously defined goal of RES-E deployment (have been set beyond any market-based principles), the major objective of this planning shall be to meet the goal with minimal total cost; i.e. sum of yields of RES-E generation and integration into the existing grid infrastructure.

• Or: There is no chicken-egg problem (resource availability versus grid availability) at all. Both have to be developed if efficient and effective.

Although these arguments do not really contribute to overcome the deadlock situation of arguments, they show the bandwidth of possible interpretations of RES-E integration problems. In order to get further insight into the patterns of effective and efficient generation and transmission developments, below an excursion into the 20th century is conducted to study how the existing electricity system gradually developed. In particular, the development and instruments to implement the – partly site-specific – generation centres and transmission grid infrastructure is studied. This may contribute to clarify the actual RES-E grid integration dilemma. Moreover, this excursion into the 20th century (see also Figure 3.1 in section 3.1) may give further valuable inputs to understand how cost-minimising solutions have been found to

• reach first best resource availabilities for conventional electricity generation (like coal mines, large rivers, topographies for natural storages, lakes providing cooling water, etc.), on the one hand, and

• implement corresponding transmission routes to transport centralised electricity generation to the load centres based on the total cost minimizing principles of the entire electricity supply chain, on the other hand.

3.3.1 Excursion into the Structural Development in the 20th Century

Already by the end of the 19th century, the first electricity systems were organised along decentralised lines. The large power losses of direct current (DC) transmission necessitated small, locally implemented power plants. However, the electricity industry gradually moved towards a larger integrated system. The first important invention to move electricity beyond the local level was the transformer. This made it possible to link urban load centres to power stations situated far away, thermal to hydropower stations, and rural to urban areas (see e.g. [37]). The transformer stimulated further technological developments. Alternating current (AC) became the dominant technology and the steam-turbine replaced the steam engine. Over time, steam-turbine sized increased significantly, as did the voltage in transmission systems. These various economies of scale pushed down the real price for electricity over the course of the century, providing a basis for mass production and the emerging national utilities. Moreover, a gradual development of the electric infrastructure increasingly has been interpreted to be a public assignment. Even beyond, it was one cornerstone of the process of nation building. In this period, large investments were therefore made in electricity systems, and subsidies were often made available to expand electrification to remote rural areas.

The post-World War II reconstruction put the electricity sector in focus as a major factor for modernisation, and again pushed the electricity supply industry on the political agenda of several European countries, strengthening the public ownership position (again, see [37]). The development of nuclear power plants and other large-scale electricity generation technologies like coal-fired and hydro-power plants characterise this period in the 1950ies and onwards. The perception of electricity as a public infrastructure with natural monopoly characteristics, and the organisation of
the sector into publicly owned or franchised institutional monopolies’ led to a build-up of powerful sectoral configurations, dominantly operating as closed national systems. Coordination between these electricity systems was undertaken on a voluntary basis, organised by neighbouring Transmission System Operators (TSO). These patterns finally remained until the end of the 20th century. In 1999, when the European electricity market was liberalised, the legal basis and the structures of the electricity supply industry changed fundamentally (see section 3.1.2).

Trying now to build a bridge between the gradual development in the 20th century and the currently ongoing RES-E integration discussion in 2010, the following similarities can be observed:

- One of the overarching objectives in the past was to set-up an electricity supply industry with the resources and its spatial dispersion available in those days. In particular this means, that coal-fired power plants have been built near coal mines, run-of-river hydro power plants on big rivers, pumped-hydro storage power plants in the Alps/Scandinavia, nuclear power near lakes/rivers providing access to cooling water, etc. Majority of these generation units have been inherently site-specific, regardless where and how far the load centres and also already existing network infrastructures have been away in those days.

- Transmission grid was only built to connect generation and load centres based on total cost-minimizing principles (see e.g. Figure 3.1 in section 3.1) and the corresponding costs were socialised in the grid tariffs. The question whether or not the resources were first and generation units triggered transmission expansion or vice versa simple was not raised. Both has been planned and implemented simultaneously.

- One of the overarching objectives today is to significantly increase RES-E electricity generation and to meet – exogenously – defined and legally binding targets by a target date; independently of the economics of the different RES-E generation technologies in relation to the wholesale electricity market price development and the status quo of the existing network infrastructure. Also almost all of renewable resources qualified best for RES-E generation are inherently site-specific; regardless where and how far load centres and existing network infrastructures are away.

- Today the transmission (and distribution) grid development question bringing together RES-E generation and load centres is supposed to be much more complex than in the past. Is it really? Obviously it is, albeit experience from historical developments can significantly contribute to meet the challenges we are facing today in the context of RES-E integration. In order to underpin today’s complexity of transmission (and distribution) grid development issues, exemplarily the following two examples are quoted: (i) decoupling of generation planning from transmission and distribution grid planning has put grid operators in serious troubles since new generation facilities are often settled in non-efficient locations only depending on private (and/or local communities’) decisions, disregarding any consideration to the grid, and (ii) variability and non-controllability of most RES-E generation technologies add problems both for grid planning (e.g. crucial question of reference load flow in case of highly variable RES-E generation in the system) and for system operation.

---

12 As already comprehensively described in section 3.1, trade between the different electricity systems was rather a matter of marginal exchange of surplus to balance nationally independent production, and the exchange prices were usually based on short-term marginal costs.
3.3.2 Essence for the RES-E Integration Debate

Wrapping up the essence from the previous section 3.3.1, there are many similarities between the RES-E grid integration debate today and the set-up of the electricity supply industry in the 20th century. Moreover, surprisingly there are even more similarities than differences. As already indicated above, one of the most obvious differences is the vertical disintegration of the electricity supply chain today. However, this is not necessarily a significant barrier for RES-E grid integration.

When considering in addition also experience from the grid connection/access boundary and locational signal discussion in section 3.2 the following can be concluded:

- The early phase of RES-E generation technology deployment and grid integration can be clearly characterised as a decentralised bottom-up approach. The actors have been mainly independent third parties, integrating their RES-E generation facilities mainly on distribution grid level (with the exception of parts of onshore wind). To some extent it has been also the conception of the RES-E developers themselves that the basis for their business relies on the free democratic choice of the individuals to decide on the sites for the implementation of the RES-E generation facility. Therefore, in the past it has been (and still is for small decentralised RES-E generation facilities on low voltage levels) necessary to provide locational and market price signals from an overarching perspective to RES-E developers in order to meet minimal standards on effective and efficient RES-E grid integration on decentralised level. In a situation like that, a “shallow” integration policy with some kind of locational signal elements is supposed to be the best solution.

- When considering RES-E integration on large-scale with the clear focus to increasingly replace centralised conventional electricity generation, then relying exclusively on decentralised RES-E integration approaches clearly fails. Moreover, also pure market mechanisms and locational as well as market price signals are supposed to be insufficient to manage an efficient and effective RES-E grid and market integration on transmission grid level with minimal total system cost. Desirable developments like that, incorporating also economies of scale of large-scale RES-E generation (i.e. choice of first best generation sites) and integration to the existing transmission network infrastructure with minimal total system cost simple must be “planned.” The more “centralised” and the more “coordinated” RES-E generation and transmission planning, the more cost effective and efficient it would be from a total system cost perspective. A situation like that would be finally similar to the way the conventional electricity supply industry has been planned in the 20th century.

This conclusion might be old-fashioned and also to some extent strange, because not really market driven (except the selection process of the RES-E developer for a particular, planned site). But it is supposed to be effective and efficient. And all recent developments (e.g. the “order” of the

---

13 In practice, however, claims like that most probably would embarrass the fulfillment of some key energy policy objectives of the European Commission as there are e.g. free market opening to generation, fulfillment of predefined RES-E shares in each of the EU Member States in year 2020, disregarding the consideration of the economics of available RES-E potentials and the grid situation, and others.

14 It is straightforward, however, that compared to conventional electricity generation units still some technological improvements of RES-E generation technologies are expected (e.g. improvement of performance parameters of grid code for wind turbines, etc.) to be entirely comparable.
European Commission in EC Regulation 714/2009/EC to develop the TYNDP2010 (see section 3.1.3 in detail) and similar documents to follow in the next years), clearly indicate that also in the context of large-scale RES-E integration the chicken and egg problem (renewable resource versus grid infrastructure availability) does not exist any more.

3.4 Interdependences between Regulatory Policies (Grid Regulation Models, RES-E Support Instruments) and RES-E Grid Integration

3.4.1 RES-E Developers’ Challenges

Previous sections have shown that in the past grid connection has often been a significant economic barrier for small RES-E developers in dispersed locations especially in case of a “deep” integration charging policy. If the new RES-E developer had to pay all the costs of grid connection up-front (i.e. also including those grid integration costs deeper in the meshed network), then a compromise between the best generation sites and acceptable grid access/integration conditions had to be made. In the past, this often has been the case for onshore wind and also small-hydro power projects (see e.g. [40]). On the contrary, grid connection for other RES-E generation technologies like biomass, biogas and/or photovoltaic – usually – has been a less crucial barrier as the particular location of these plant types has been even more independent from resource conditions.

In general, a RES-E developer includes several relevant cost components - i.e. also those related to grid connection/integration - to the total RES-E project costs. Subsequently, these kinds of cost elements are also somehow reflected in the electricity generation costs of the RES-E power plant. However, if parts of the grid connection/integration costs are covered by the grid operator and the corresponding costs are socialized in the grid tariffs, then this part of the initial burden does not fall on the RES-E developer and the end-user has to pay it in the grid tariff.

Besides new grid connection lines (regardless of the distance and/or voltage level of connection) also grid reinforcement, upgrading and extension measures may be necessary elsewhere in the existing network due to large-scale RES-E integration. As already comprehensively analysed in the previous sections (section 3.2.1 in particular), fundamentally different philosophies exist in this context, reaching from “deep”, “shallow”, “true” to “super-shallow” integration charging policies. Whereas the “deep” integration charging approach puts the highest economic burden to RES-E developers to pay for grid-related measures deeper in the meshed network infrastructure, the “super-shallow” integration approach marks the opposite cornerstone in this respect.

3.4.2 Grid Operators’ Challenges

So far, in this document RES-E integration into electricity systems has not been analysed from the grid operators’ point-of-view. Moreover, the challenges faced by grid operators in bearing their additional RES-E integration costs have to be addressed equally not least due to the following two currently ongoing developments (being not linked together at present):

- rapidly increasing shares of RES-E integration in the European transmission and distribution networks expected in the near future (e.g. 20% RES (34% RES-E) policy target on European level to be met in year 2020), and
• implementation of new grid regulation and grid tariff determination models by national regulators accompanied by cost benchmarking procedures determining efficient and effective grid infrastructure planning and grid operation.

Moreover, when considering large-scale RES-E grid and market integration also transmission and distribution grid operators are confronted with much more financial risk than recognized in the last 10 years after liberalization of the European electricity markets ([4]):

• On the one hand, currently implemented grid regulation models (incentive regulation based on price-caps, revenue-caps, yardsticks) apply some pressure to grid operators to optimize their cost which, subsequently, will also affect grid tariffs. A regulatory environment like that adversely affects investment initiatives into the network infrastructure in general, and those foreseen to provide a level playing field for large-scale RES-E grid and market integration and other innovations like so-called “smart grid” concepts in particular. For a detailed discussion in this context it is referred to Deliverable D3.6.2 ([33]) of the REALISEGRID project on incentive schemes and regulatory frameworks for transmission development in Europe.

• On the other hand, electricity grids are capital intensive infrastructures characterized as natural monopolies over a defined geographic and/or voltage region. The grid assets’ life-times can be up to 40 years and once investments are made they are actually sunk. Therefore, grid assets are vulnerable to changes in regulatory conditions which could prevent or hinder cost recovery. In particular, financial RES-E support policies not directly taking into account effects on grid operations can impose costs on transmission and distribution grids and give rise to the question of cost recovery. At present, from the grid operators’ point-of-view these uncertainties are significant economic disincentives to absorb large-scale RES-E generation technologies into their grids.

Figure 3.5 presents the two categories of cost pressure forces regulated grid operators have to cope with in an incentive regulation scheme: (i) cost cutting incentives according to the currently implemented incentive regulation models (left); (ii) a variety of currently unconsidered extra cost drivers in case of large-scale RES-E (and also DG) grid integration on both levels transmission and distribution (right).

Figure 3.5: Problem of asset stranding in existing grid regulation models due to cost drivers caused by large-scale RES-E (and DG) integration. Source: [4].

Below selected examples of extra cost drivers caused by large-scale RES-E (and DG) integration are listed:

• Significant reinforcements, upgrades and extensions of existing network infrastructure elements (overhead lines, cables, transformers, switching devices, etc.) are necessary.
• Completely new design criteria and operational concepts are necessary on distribution grid level due to bidirectional load flows in case of significant amounts of RES-E generation on distribution grid level.

• Higher technical standards and new concepts for ancillary service provision like voltage and frequency regulation, accounting and billing devices and procedures are necessary.

• The installation of new information and communication technologies (ICT) is necessary to be able to manage active and intelligent distribution grids.

• Higher transaction costs have to be taken into account to operate actively managed distribution grids due to the increasing number of market actors.

Due to the fact that above mentioned extra cost for transmission and distribution grid operators are not explicitly taken into consideration in the existing grid regulation models – but cost recovery is essential for capital intensive infrastructure investments being effectively sunk once the investment is made – the risk of asset stranding for grid operators is too high. Therefore, based on the existing regulatory environment grid operators might not be willing to integrate RES-E projects on large-scale, regardless which voltage level is envisaged.

Analytically, from the grid operator’s point-of-view, the disincentives for any kind of investment into the existing grid infrastructure can be immediately derived from the grid regulation formula. The basic incentive regulation formula is as follows (for details see e.g. [4]):

\[ P_t = P_{t-1} \times (1 + RPI - X) \]

where

- \( P_t \) ........authorized price-cap in year \( t \)
- \( P_{t-1} \) ........authorized price-cap in year \( (t-1) \)
- RPI ........annual inflation index (Retail Price Index)
- X ........productivity offset

This formula determines the authorized price (tariff) a grid operation can set within a regulatory period, incorporating also efficiency improvements (based on cost benchmarking results) over the years.

Regardless of investments into the grid infrastructure in the context of large-scale RES-E and/or DG integration on different voltage levels, any investment decision of a grid operator is based on the basic economic criterion that maximises revenues minus cost over a predefined period.\(^{15}\) In detail, the analytical framework describing an economic decision for the most common incentive regulation models (price-caps and revenue caps) looks as follows:

\(^{15}\) In this context it is important to note, that a grid operator (at least theoretically) shall not primarily act for its revenue but for the system sake (i.e. benefits for the system). Since grid operators are regulated firms, the system benefit aspects usually are incorporated already in the regulatory framework (see e.g. also the cost-benefit analysis treatise in Deliverable D3.3.1 ([34]) of the REALISEGRID project). The basic economic principles indicated here, however, are true for both regulated firms like grid operators (being restricted in the degrees of freedom to make solely individual business decision) and non-regulated firms.
Price-Caps: \[
\text{Profit } \pi = \max_{x,c} px - c \quad \text{whereas } \quad p = \text{fixed} \quad x,c = \text{variable}
\]

Revenue-Caps: \[
\text{Profit } \pi = \max_{p,x,c} px - c \quad \text{whereas } \quad p, x, c = \text{variable}
\]

The most obvious difference between the price-cap and revenue-cap regulation model shown above is the degree of freedom for setting several different parameters independently which determine revenues and cost. Whereas in case of revenue-caps several parameters (price, quantity, cost) are variable, this is the case only for quantity and cost for price-cap regulation models. However, when addressing changes of the cost basis of grid operators – ceteris paribus – there is no difference for the two most prominent grid regulation models presented above.

In the following, a thought experiment shall demonstrate the reluctance of grid operators (being subject to “ex-post” oriented price-cap or revenue-cap regulation) to invest into the grid infrastructure, in general, and to accept extra cost for the provision of technical infrastructure and equipment enabling large-scale RES-E and/or DG grid integration in particular:

- If \( c_{DG/RES} \) is assumed to be the extra cost for grid operators driven by the integration of large-scale RES-E and/or DG generation facilities, the initial cost basis \( c \) of a grid operator is increased to \( c_{\text{new}} = c + c_{DG/RES} \).
- If it is assumed further that these extra cost are not validated to be eligible in the grid regulation process (i.e., the extra cost can’t be socialised in the grid tariffs directly) there is no incentive for grid operators to favour any RES-E and/or DG connection, simply because increasing RES-E and/or DG integration cost decrease profits (i.e., revenue minus cost):

\[
\frac{\partial \pi}{\partial c_{\text{new}}} \bigg|_{c,x,p=\text{const}} < 0
\]

This analytical relationship impressively demonstrates why currently implemented grid regulation models result in reluctant investment behaviour of grid operators in general and as far as RES-E and/or DG grid integration is addressed in particular.\(^{16}\)

### 3.4.3 Convergence of Different Policies Supporting RES-E Grid Integration

The previous sections have illustrated the dilemma of policy making when referring to the core objectives of RES-E and grid regulation policies simultaneously:

- If the **RES-E policy** aim is to maximise the share of RES-E generation technologies in the electricity system by a target date (e.g., “EU2020” target), then taking into account also the extra

---

\(^{16}\) Underinvestment into the grid infrastructure is one of the most critical medium- to long-term problems of incentive regulation models. This is true for both transmission and distribution grids. In practice, however, the implementation of pure incentive regulation models is much more established on distribution grid level. Although on transmission grid level there is also a strong focus on cost efficiency in general, transmission grid regulation models are still some kind of rate-of-return regulation models. For a comprehensive overview and discussion in this context it is referred, again, to Deliverable D3.6.2 [33] of the REALISEGRID project on incentive schemes and regulatory frameworks for transmission development in Europe.
costs imposed deeper in the electricity network by making the RES-E developers pay for them may, hence, not favour the first best RES-E resource availabilities (“deep” integration charging approach). However, the deep RES-E integration charging approach avoids the grid operator’s problem of asset stranding in case of tight grid regulation.

- If the grid regulation policy aim is to overcome the grid operators’ economic disincentives of asset stranding caused by large-scale RES-E grid integration and, subsequently, to maximise the amount of RES-E generation technologies in the system by a target date (e.g. “EU2020” target), then the extra RES-E related network integration costs have to be clearly accepted in the grid regulation procedure and, subsequently, socialised in the corresponding grid tariffs (“shallow” integration charging approach). Although this approach most probably favours the first best RES-E resource conditions, an overall increase of grid tariffs in a weak grid regulation model is expected.

In order to get a better understanding of a convergence of RES-E and grid regulation policies, it is recommended to study the recent innovations of the grid regulation model in UK. Moreover, this model demonstrates the way forward for amending the traditional incentive regulation approach. The overarching amendment of the traditional incentive regulation model has to be an extension of the traditional grid regulation formula towards forward-looking elements for remuneration/socialisation of RES-E and DG integration cost. Therefore, besides the well-known (1+RPI-X) factor an additional term has to be implemented into the existing incentive regulation model fulfilling at least the following features:

- Consideration of a mechanism to directly socialise – at least parts of – grid connection, grid reinforcement and grid extension cost in the grid tariffs (e.g. direct cost pass through as well as other fixed connection (e.g. €/kW<sub>DG/RES</sub>, €/kW<sub>DG/RES/yr</sub>) and volume based (€/kWh) use of system charges having to be paid by RES-E and/or generators directly to grid operators)\(^{17}\) similar to UK’s recently modified incentive regulation model.

- Provision of some kind of cost-reflective locational signals for RES-E and/or DG generators, e.g. on the basis of forward-looking long run incremental cost (LRIC) rather than solely in relation to the direct cost incurred of a specific connection of a single RES-E and/or DG generation facility.\(^{18}\) This approach is supposed to minimise the problems associated with first movers and free-riding in case of more than one RES-E and/or DG generator on the same connection point of the grid.

- Consideration of a mechanism to directly cover and/or remuneration operational cost allocated to innovative RES-E and/or DG integration projects (i.e. personnel cost for research, feasibility studies and preparatory work) in the incentive regulation model.

\(^{17}\) The volume based part of the use of system charge allocated to generators usually is called ‘Generation Use of System Charges (GUoS)’.

\(^{18}\) In general, the decision on the boundary between fixed connection charges and volume based ‘Generation Use of System Charges (GUoS)’ – both having to be paid by RES-E and/or DG generators to grid operators – needs to take account of the desirability of reflecting cost to RES-E and/or DG generators on a forward-looking long-run incremental cost (LRIC) basis. These charges, furthermore, should be cost reflective and also incorporate a sensible apportionment of forward-looking LRIC providing both correct signals and cost-recovering mark-ups. However, the mark-up should minimise distortions. This also implies that usually ‘Generation Use of System Charges (GUoS)’ and ‘Distribution Use of System Charges (DUoS)’ are set differently, due to the differences in price elasticities of generation and demand customers.
• Avoidance of unmanageable complexity of additional terms in an extended incentive regulation formula.

Exemplarily, an extension of the traditional incentive regulation formula (e.g. price-cap and/or revenue-cap regulation model) can be indicated as follows (see e.g. [4]):

\[ P_t = P_{t-1} \times (1 + RPI - X) + \Delta C_{DG/RES, j} \times kW_{DG/RES, i} \times (1 + RPI - LR_{DG/RES, j}) \]

whereas

\[ \Delta C_{DG/RES, j} \] ... specific cost for a grid operator caused by the integration of a RES-E and/or DG generation technology i into an existing grid topology and/or smart grid concept j

\[ kW_{DG/RES, i} \] ... installed capacity of RES-E and/or DG generation technology i integrated into an existing grid topology and/or smart grid concept j

\[ LR_{DG/RES, j} \] ... expected dynamic learning rate and/or economies of scale of specific grid integration cost caused by the integration of a RES-E and/or DG generation technology i into an existing grid topology and/or smart grid concept j

It is important to note, that the analytical approach presented above only suggests the cornerstones of a possible way forward to extend the traditional incentive regulation model. Although it is still incomplete and subject to further disaggregation and empirical scaling, innovations – compared to the traditional model presented in the previous section 3.4.2 – are obvious at least in two dimensions:

• implementation of a forward-looking element enabling ex-ante socialisation of grid related cost caused by the integration of RES-E and/or DG generation,

• consideration of a dynamic element putting downward pressure on specific grid integration cost (e.g. due to technological learning and economies of scale) with increasing shares of RES-E and/or DG generation.

An amendment of the traditional incentive regulation model according to the basic principles shown above finally also shifts the connection boundary between the RES-E and/or DG generation facilities and the transmission and distribution grid infrastructure increasingly towards the generation units. Moreover, if grid infrastructure related cost of RES-E and/or DG integration are allocation to grid operators rather than to RES-E and/or DG generators, there also exist direct interdependences with the design of financial RES-E/DG support instruments (e.g. like feed-in tariffs). More precisely, in case of RES-E generation technologies a re-design of the financial RES-E support instruments is necessary, if parts of the initial cost (previously allocated to the RES-E power plant) are assigned to the grid infrastructure (e.g. grid connection cost) and socialised in the grid tariffs.

In case of tradable green certificate (TGC) support schemes of RES-E generation technologies an allocation and socialization of several grid related integration cost (i.e. grid connection, grid reinforcement/upgrading) to the grid tariffs finally shall also result in lower certificate prices indicated on the TGC market (due to lower long-run marginal RES-E generation cost).
4 EXISTING SHORTCOMINGS/BARRIERS FOR LARGE-SCALE RES GRID INTEGRATION

4.1 Problems of a „Sequential Policy Process“: RES Generation Target Policies Decoupled from Grid Infrastructure Development Policies

In the last decade, one of the biggest problems for transmission grid investments favouring the implementation of large-scale RES-E integration was the “sequential policy process”. This means that RES and RES-E policies and targets have mainly been discussed and implemented after the start of the electricity market liberalisation in Europe in 1999. However, the grid infrastructure and market integration aspects were completely neglected in the first years after the liberalisation of the European electricity markets. Although in the course of time this lack increasingly became obvious, policy making on both levels national and EU treated it still as “grid issues” and did not understand the need to implement policy frameworks dealing with transmission (and distribution) grid adequacy in general and RES-E integration in this context in particular. Outside the expert level, in the early phase RES-E power plant integration mainly was understood as a “plug-in” exercise. Moreover, on grid-level the implementation of different incentive regulation models (see section 3.4 in detail) has been another significant disincentive for any kind of investments into the grid infrastructure.

Besides lost time for providing grid-related legislation and policies in due course, there is another significant difference between the implementation of a RES-E power plant and an upgrade, extension and/or new route of a grid infrastructure: the lead-time due to environmental verification and public consultation processes. This lead time is significantly higher for grid-infrastructure projects (sometimes lasting more than 10 years or so) than for RES-E power plants.

As a result of these structural shortcomings and barriers, in the last couple of years the transmission investment problem has become significantly severe. Some European countries have started to conduct comprehensive “grid-studies” to better understand the effects of and needs for RES-E grid and market integration, e.g. “Dena Grid Studies I&II” in Germany in 2005&2010 ([48], [49], www.dena.de), “All Island Grid Study” in Ireland 2005 ([50], www.dcenr.gov.ie), “Ofgem’s Electricity Network Scenarios for Great Britain in 2050” in UK in 2007 ([51], www.ofgem.gov.uk), etc. These kinds of studies finally have led to corresponding legal foundations and regulations on national level to provide the basis to further develop the transmission grid for enabling also large-scale RES-E grid and market integration. As a representative example the German “Infrastrukturbeschleunigungsgesetz 2006” can be cited here; an immediate outcome of the results of “Dena Grid Study I” in 2005 ([48]).

Finally, after a delay of almost 10 years, at European level now the strategic development of the European transmission networks is also one of the most important issues on top of the agenda of European policy makers. As already comprehensively discussed in section 3.1.3, the “3rd Legislative Package” for the internal European electricity market has been adopted and will come into force in early 2011. In this context, Regulation 714/2009/EC has been implemented, calling (besides others) for a non-binding European-wide Ten-Year Network Development Plan (TYNDP) [21]. The first version of this TYNDP has been published in 2010; a more comprehensive next version is expected for 2012.
4.2 Inefficiencies of Regional/National System Boundaries for RES Grid Integration (Bottom-Up Approach)

The “product” electricity has a lot of complex properties. Besides others, one of the biggest challenges for handling the “product” electricity is its non-storability, on the one hand, and its complex load flows in meshed electricity grids, on the other hand. Moreover, the physical laws that govern electricity flows neglect any kind of institutional, organisational, legal and/or political system boundaries. Therefore, an inherent problem can be expected when trying to “squeeze” an electricity system into system boundaries defined others than followed by physical laws. To be more precise, there are supposed to be no problems in operating the electricity systems in practise. However, a sub-optimal and/or inefficient allocation of resources and operational procedures is supposed to be straightforward in a European-wide context, if the European-wide, meshed electricity system is “squeezed” into national parameter definitions and scaling. In the following, selected examples of sub-optimal and inefficient resources allocations in the context of RES-E grid and market integration in Europe are discussed when exclusively relying on bottom-up approaches set by national boundaries rather than top-down approaches in a European-wide context.

4.2.1 Sub-Optimal/Inefficient Allocation of Resources (in Terms of)

4.2.1.1 RES Generation Potential Implementation (Diseconomies of Scale)

In December 2008, the European Parliament and the Council of the European Union finally agreed on a new EU Directive on the promotion of the use of renewable energy sources (RES), which was formally adopted in April 2009 (Directive 2009/28/EC, [47]). It sets binding targets for all EU Member States to reach the European target of 20% RES share in EU gross final energy consumption by 2020. However, the allocation of the different national targets is based on a flat rate approach (same additional share for each country) adjusted to the member state’s gross domestic product (GDP), see Table 4.1. The problem in this context is that this target allocation approach does not necessarily correlate with the Member States’ 2020 RES potentials (see Figure 4.1) and 2020 RES-E potentials (see Figure 4.2) respectively. Moreover, the physical availability and corresponding utilization cost of biomass, wind, hydro, tidal, wave and solar resource base varies significantly across the different European countries.

Table 4.1: National Binding 2020 RES Target in the different EU Member States. Source: [39]

<table>
<thead>
<tr>
<th>EU Member State</th>
<th>RES in 2005</th>
<th>2020 RES Target</th>
<th>% Increase Required</th>
<th>EU Member State</th>
<th>RES in 2005</th>
<th>2020 RES Target</th>
<th>% Increase Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>23.3%</td>
<td>34%</td>
<td>10.7%</td>
<td>Latvia</td>
<td>32.6%</td>
<td>40%</td>
<td>7.4%</td>
</tr>
<tr>
<td>Belgium</td>
<td>2.2%</td>
<td>13%</td>
<td>10.6%</td>
<td>Lithuania</td>
<td>15.0%</td>
<td>23%</td>
<td>8.0%</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>9.4%</td>
<td>16%</td>
<td>6.6%</td>
<td>Luxembourg</td>
<td>0.9%</td>
<td>11%</td>
<td>10.1%</td>
</tr>
<tr>
<td>Cyprus</td>
<td>2.9%</td>
<td>13%</td>
<td>10.1%</td>
<td>Malta</td>
<td>0.0%</td>
<td>10%</td>
<td>10.0%</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>6.1%</td>
<td>13%</td>
<td>6.9%</td>
<td>Netherlands</td>
<td>2.4%</td>
<td>14%</td>
<td>11.6%</td>
</tr>
<tr>
<td>Denmark</td>
<td>17.0%</td>
<td>30%</td>
<td>13.0%</td>
<td>Poland</td>
<td>7.2%</td>
<td>15%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Estonia</td>
<td>18.0%</td>
<td>25%</td>
<td>7.0%</td>
<td>Portugal</td>
<td>20.5%</td>
<td>31%</td>
<td>10.5%</td>
</tr>
<tr>
<td>Finland</td>
<td>28.5%</td>
<td>38%</td>
<td>9.5%</td>
<td>Romania</td>
<td>17.8%</td>
<td>24%</td>
<td>6.2%</td>
</tr>
<tr>
<td>France</td>
<td>10.3%</td>
<td>23%</td>
<td>12.7%</td>
<td>Slovak Republic</td>
<td>6.7%</td>
<td>14%</td>
<td>7.3%</td>
</tr>
<tr>
<td>Germany</td>
<td>5.8%</td>
<td>18%</td>
<td>12.2%</td>
<td>Slovenia</td>
<td>16.0%</td>
<td>25%</td>
<td>9.0%</td>
</tr>
<tr>
<td>Greece</td>
<td>6.0%</td>
<td>18%</td>
<td>11.1%</td>
<td>Spain</td>
<td>8.7%</td>
<td>20%</td>
<td>11.3%</td>
</tr>
<tr>
<td>Hungary</td>
<td>4.3%</td>
<td>13%</td>
<td>6.7%</td>
<td>Sweden</td>
<td>39.8%</td>
<td>49%</td>
<td>9.2%</td>
</tr>
<tr>
<td>Ireland</td>
<td>3.1%</td>
<td>16%</td>
<td>12.9%</td>
<td>United Kingdom</td>
<td>1.3%</td>
<td>15%</td>
<td>13.7%</td>
</tr>
<tr>
<td>Italy</td>
<td>5.2%</td>
<td>17%</td>
<td>11.8%</td>
<td>EU27</td>
<td>8.5%</td>
<td>20%</td>
<td>11.5%</td>
</tr>
</tbody>
</table>
Figure 4.1: RES potentials (achieved in 2005; additional 2020 potentials) in terms of final energy in the EU27 Member States. Source: [5]

Figure 4.2: Achieved and additional mid-term potentials for RES-E generation technologies in EU27 incl. CH and NO. Source: [5]

Derived from Table 4.1 and a disaggregation of 2020 RES-E potentials (from Figure 4.2) on technology-level, in the following Figure 4.3a-d a detailed discussion on the needs for reaching the 2020 RES targets in the different sectors is presented for four different countries: UK, Germany, Denmark, and Sweden (Source: [39]).
Figure 4.3 a-d: 2020 RES and RES-E Targets and Potentials as well as 2007 Production in 4 different EU Member States. Source: [39]
The RES and RES-E situation in the 4 different EU Member States presented in Figure 4.3a-d is completely different in terms of both status quo and 2020 target strategies. A comparison of these different countries in terms of the RES-E deployment strategy in the next decade up to 2020 shows that the definition of the national binding 2020 targets (neglecting the RES and RES-E resource availability) results in sub-optimal resource allocations:

- **UK**: Starting from a very low level of RES and RES-E shares in 2007, the UK is in the fortunate situation to have high wind potentials; offshore wind in particular (see Figure 4.3a). Therefore, the implementation of a significant number of offshore wind farms is a precondition in the UK to reach the 2020 RES and RES-E target. There is supposed to be no degree of freedom for a kind of strategic behaviour in a European context.

- **Germany**: Starting from a higher level of RES and RES-E shares in 2007, Germany is also in the lucky situation to have both still high additional unexploited both onshore and offshore wind potentials (see Figure 4.3b). In Germany, however, the 2020 RES and RES-E targets are not the only drivers to further significantly increase RES-E in their electricity generation portfolio. The nuclear phase out policy – recently amended by an extension of nuclear operation time of 12 years on average – is an equally important driver for the ambition to strongly promote RES and RES-E integration. Therefore, Germany has strong incentives to implement the most attractive RES-E potentials in the next decade(s).

- **Denmark**: According to the RES and RES-E situation presented in Figure 4.3c, Denmark can – more or less – voluntarily decide whether or not they further push offshore wind integration in the next decade up to 2020. The 2020 target settings do not put significant pressure to further increase the shares of RES-E integration in Denmark. In case of a reluctant RES-E integration policy in the next years this would be a pity due to the fact that Denmark’s offshore wind potentials are among the most attractive once all over Europe. In practice, however, it is expected that Denmark will be on the leading edge of offshore wind development to maintain the country’s position and reputation in the European (and global) wind industry in general.

- **Sweden**: Finally, the Swedish situation presented in Figure 4.3d demonstrates that the rules to meet the binding national 2020 targets enable also some kind of strategic behaviour and/or free riding. To be more precise, Sweden already has reached the 2020 targets with the RES-E projects implemented in the last couple of years since 2007. So they do not have any obligation to further increase RES-E shares in the next decade. This might explain the drop-out from the joint “Kriegers Flak” offshore wind project together with Germany and Denmark recently (see discussion in section 4.3 in detail). Moreover, the revision of the nuclear phase-out policy also clearly indicates the lower priorities of RES-E integration ambitions in the next decade until 2020; this policy is supposed to be independent whether or not there exist attractive RES-E potentials in Sweden with low utilization cost.

The RES Directive 2009/28/EC ([47]) has foreseen “flexibility” or “cooperation” mechanisms, allowing those countries with low or expensive RES/RES-E potentials to partially fulfil their RES targets in other countries with higher RES potentials or lower production costs in order to take into account differences in terms of RES and RES-E potentials and utilization cost in the different EU Member States. The three intra-European cooperation mechanisms are: (i) statistical transfer, (ii) joint projects, and (iii) joint support schemes. Additionally, there is the option to physically import RES electricity from third countries outside the EU (“joint projects between EU Member States and third countries”).
However, these options are rather theoretical reflections than practical solutions. The RES Directive 2009/28/EC ([47]) does not provide a detailed definition of joint projects between EU Member States. The basic accounting rules for joint projects are defined; however, the host country (i.e. territory where the RES-E power plant is built) shall notify the European Commission regarding the proportion or amount of RES-E generation that shall be attributable to the national target of another EU Member State (receiving EU Member State). It shall also specify the period of this transfer (RES-E installations that become operational after the date of entry into force of the directive in 2009 are eligible only). Figure 4.4 depicts the institutional framework for joint projects. For further details in this context it is referred to the Project RE-SHAPING (www.reshaping-res-policy.eu, [39]).

![Figure 4.4: Institutional framework for joint projects allowing countries to partially fulfil their RES targets in other countries. Source: [39]](image)

4.2.1.2 System Balancing and Reserve Capacity Provision due to Variability/Intermittency of RES Generation

When defining large-scale RES-E grid and market integration purely on national/political boundaries rather than on the physical laws governing the operation of electricity systems, there is another important aspect to be discussed besides sub-optimal/inefficient allocation of resources in terms of RES-E potentials: online system balancing and reserve capacity provision. There is supposed to be a significant difference whether each single European country is exclusively responsible to be flexible enough to manage their electricity systems or if countries can also “rely” on the power plant portfolios of their neighbours.

1. The Role/Importance of Flexible Pumped-Hydro Storage for Continental Europe

At present, the most prominent power plant technologies qualified to bring flexibility into a power plant portfolio are pumped-hydro storage power plants, on the one hand, and combined cycle gas turbines (CCGT) / gas turbines (GT), on the other hand. In terms of European pumped-hydro storage capacities it is well known that the most prominent areas are in Scandinavia, in the Western and Eastern Alps in Central Europe and also to a minor extent in the Pyrenees. It is straightforward, that within these areas the balancing and reserve capacity provision problem of the
electricity system is supposed to be minor also in the medium to long term with high shares of variable and intermittent RES-E generation. However, in this context also the question arises, if also other European countries can participate on the flexibility of their neighbours or if they are obliged to implement their own flexible technologies. As an example the Central and Eastern European countries are selected here, being “squeezed” between pumped-hydro capacities in Scandinavian and the Eastern and Western Alps in Central Europe.

Many of the Central and Eastern European countries are characterised by a rather inflexible power plant mix (e.g. Poland with its more than 90% coal-fired power plants; but also many other countries like Germany and Czech Republic with significant shares of nuclear and other base load power generation technology types). However, many of them also have significant RES-E potentials, onshore and offshore wind in particular. Table 4.2 below presents the expected wind penetrations in the majority of Central and Eastern European countries up to 2030 for two different wholesale electricity market price levels (being some kind of benchmark/reference for the economics of wind generation in general).

Table 4.2: Expected Wind Penetration in different Central and Eastern European countries up to 2030. Source: [5]

<table>
<thead>
<tr>
<th>Country</th>
<th>Expected Wind Generation [GWh/yr] at Wholesale Electricity Market Price and/or Financial Wind Support Level of 80 and 100 €/MWh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>80 €/MWh</td>
</tr>
<tr>
<td>Germany</td>
<td>90,000</td>
</tr>
<tr>
<td>Switzerland</td>
<td>100</td>
</tr>
<tr>
<td>France</td>
<td>51,500</td>
</tr>
<tr>
<td>Italy</td>
<td>17,500</td>
</tr>
<tr>
<td>Slovenia</td>
<td>220</td>
</tr>
<tr>
<td>Hungary</td>
<td>800</td>
</tr>
<tr>
<td>Slovakia</td>
<td>380</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>4,000</td>
</tr>
<tr>
<td>Poland</td>
<td>8,750</td>
</tr>
</tbody>
</table>

Increasing shares of variable and intermittent wind generation, however, also results in increasing needs for flexibility of the electricity systems; but not necessarily inside the footprint of each country. Below it is demonstrated that there can/could be used synergies of neighbours to mitigate variable and intermittent effects of wind generation in the Central and Eastern European countries if transmission grid expansion enables access to flexible pumped-storage hydro power both towards Scandinavia and the Alps:

- **Alps (represented by Austria):** Besides maintaining security of supply aspects and contributions to further integrate the European electricity market, an equally important driver for further transmission investments in Austria is the implementation of the still unexploited RES-E generation potentials; most notably pumped-hydro storage power in the Easter Alps. Moreover, pumped-hydro power plants have been playing an important role already in the last decades due to the fact that they guarantee a high degree of flexibility of the electricity systems not only in Austria but also in the neighboring countries (e.g. economically attractive “peak-base” exchange contracts with Germany). In the future, the provision of flexible reserve capacities and balancing power demanded by large-scale onshore and offshore wind integration into the Central and Eastern European electricity systems is expected to enable further attractive business opportunities for additional pumped-hydro power generation capacities (e.g. at present
the following pumped-hydro capacity expansions take place: Kops II in the control zone of VKW-Übertragungsnetz AG; Kaprun-Limberg II&III in the control zone of Verbund- Austrian Power Grid AG). Figures 4.5 and 4.6 below present the expansion plans of pumped-hydro (and also wind) capacities in Austria up to 2020, on the one hand, and also the corresponding transmission expansion needs to fulfill the international and national duties, on the other hand.

Figure 4.5: Expansion plans of power plants capacities in Austria up to 2020. Source: [44]

Figure 4.6: Expected transmission routes (incl. indication HVDC line of “Brenner-Basis-Tunnel”) in Austria in year 2020. Source: [44]

20 Besides the “cross-border” transmission investment driver in Austria there also exist another one on national level: national wind power sites. The most attractive Austrian wind power plants already in operation (and also still not exploited wind potentials) are largely located in the eastern part of the country (“Pardorfer Platte”), flexible pumped-hydro power potentials in the western part (“Alps”). There is a lack of sufficient transmission capacities between these two areas. Therefore, incentives for transmission investments to further increase “east-west” transmission capacities in Austria are supposed to be evident.
- **Scandinavia (represented by Norway):** In the north, the Central and Eastern European countries have – at present limited – access to the Scandinavian electricity system. Due to the high share of flexible hydro power (in Norway in particular) this is another resource in a wider context to balance future electricity systems with high shares of variable and intermittent RES-E generation. In order to do so (and to release to some extent those countries with rather inflexible power plant portfolios) further transmission grid upgrades, expansions and also new transmission routes are necessary. Figure 4.7 below presents the expected transmission grid measures in this context; derived from the Norwegian scenario study results of the project SUSPLAN (see www.susplan.eu in detail). The patterns of transmission grid development presented in Figure 4.7 go also in line with the short-, medium- and long-term plans of the Norwegian transmission system operator Statnett (see e.g. [42], [43]).

![Expected Grid Development up to 2030](image)

**Figure 4.7:** Expected transmission grid expansion in Scandinavia up to 2030. Source: [29]

2. The Role/Importance of Flexible CCGT Power Plants on European Border Countries

The second set of flexible electricity generation technologies qualified to balance electricity systems and to provide reserve capacities in systems with high shares of variable and intermittent RES-E generation comprises combined cycle gas turbines (CCGT) and gas turbines (GT). In this context it is important to note, however, that rotating thermal reserve generation creates additional CO₂ stabilizing, at least partly, the environmental advantages of increasing RES-E generation. Despite this reduced environmental net effect of increasing RES-E generation, these gas-fired generation technology types are need and, thus, key candidates for maintaining smooth system operation especially in areas on “borders” of electricity systems, i.e. in a European context on the Iberian Peninsular, Italy, UK (necessity depending also on the future interconnection with Scandinavia) and also others (e.g. Balkan countries in the future passed through by gas pipelines like Nabucco and/or

---

21 The SUSPLAN project (www.susplan.eu) has already been introduced in section 2.3.
South Stream). These countries, furthermore, also have access to natural gas (either own resources and/or transit countries of natural gas corridors/hubs) as a primary energy carrier.

In Figures 4.8 and 4.9 demonstrate the need of a “gas-strategy” in countries like Spain\textsuperscript{22} in case of a further significant increase of variable and intermittent onshore and offshore wind in the future (pumped-hydro capacities in the Pyrenees are supposed to be not sufficient to cover the straggly Iberian Peninsular (incl. South of France) in the medium- to long-term.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure48.png}
\caption{Installed RES-E capacities in Spain in 2050 in the four different storylines of the SUSPLAN project.\textsuperscript{23} Source: [26]}
\end{figure}

\textsuperscript{22} This is also true for the other countries cited above, like Italy (in the future, LNG terminals increasingly will provide access to further natural gas resources), UK (necessity depending also on future interconnection with Scandinavia), and also others.

\textsuperscript{23} In the SUSPLAN project four different storylines have been analyzed. In a two-dimensional space (resulting in four quadrants describing one storyline each) the two dimensions (each of them positive and negative) are: (i) technological development and (ii) public attitude. The “Blue” storyline describes the quadrant characterized by positive (i.e. fast) technological development of new energy technologies and negative public attitude (i.e. public is not interested in decentralized structures and also not willing to be an active player in shaping sustainable energy systems). In terms of future RES-E generation this means that in the “Blue” storyline economies of scale of large-scale centralized RES-E generation are utilized incorporating – besides several onshore RES-E generation options – also several kinds of offshore RES-E generation technologies (i.e. offshore wind, wave and tidal energy, further new marine energy technologies available for commercial use up to 2050). Since the ocean is blue, this storyline is called “Blue”. In the following sections some country-specific SUSPLAN results – referring to the “Blue” storyline each – are presented to illustrate different problems having to be overcome in the context of large-scale RES-E grid and market integration in Europe.
4.2.2 Missing Business Models (incl. Examples) for Utilization of Low-Cost RES-E Generation Potentials

Besides sub-optimal and inefficient allocation of resources in terms of both RES-E generation potentials and system balancing and reserve capacity provision due to variability/intermittency of RES-E generation, another important inefficiency of artificial system boundaries (e.g. based on institutional, organisational and/or political borders) for RES-E grid and market integration is the fact that in many cases there simply do not exist corresponding business models. To be more precise, there frequently occurs the situation that the different market participants in a region with – in principle – attractive RES-E generation potentials have diverging interests; or no interest at all to implement any of these RES-E generation potentials if not needed in the “home-market”.

As an example Norway can be cited in this context: Norway is characterised by huge offshore wind potentials along the coast line of the country. Depending on the distance to shore (Fjords), offshore wind potentials are quantified in the range of hundreds of TWhs. But the problem is that Norway, in general, has no interest to expand off-shore wind deployment at all; at least not as long as Norwegian end-users have to pay offshore-grid expansion in their grid tariffs.

At present, Norwegian electricity generation is based on almost 100% hydro-power generation. Norway, however, still has plenty of currently not implemented, cheap hydro-power potentials. So hydro-power is supposed to be preferred for two reasons: (i) its cheap, and (ii) brings flexibility to the own system and for exports. Figure 4.10 provides empirical evidence of the Norwegian offshore wind potentials (expected implementation as well as additional, attractive potential alongside the coastline up to 2050; both identified in the Blue Storyline of the SUSPLAN project).
Figure 4.10: Offshore wind deployment in the different European countries up to 2050 in the Blue SUSPLAN storyline. Source: [53]

Figure 4.10 impressively shows that small parts of offshore wind are expected to be implemented in Norway according to the reasons mentioned above (and also according to the Norwegian experts involved into the SUSPLAN project). The corresponding offshore wind grid necessary to implement Norwegian offshore wind generation is shown in Figure 4.11. But who is willing to pay for it? At present it is not clear. And as long it is not clear and there do not exist business models, Norwegian offshore wind will be rather fiction than reality.

Figure 4.11: Expected transmission network expansion in Norway until 2050 in the Blue SUSPLAN storyline. Source: [29]
4.3 Shortcomings of “Isolated” RES Grid Integration Policies in a more Comprehensive European Energy Policy Context

In section 4.2 many inefficiencies of currently existing grid and market integration policies of RES-E generation technologies – relying purely on national system borders – are pointed out. This section 4.3 tries to briefly wrap-up and to discuss the most obvious shortcomings in detail (there exist, however, many others not discussed in detail in this document):

- Diseconomies versus Economies of Scale of utilized RES generation
- Inefficient versus efficient mitigation of variability and intermittency of RES-E generation
- Non-Harmonized versus harmonized RES-E integration charging approaches
- Strategic behavior versus international commitment

4.3.1 Diseconomies versus Economies of Scale of Utilized RES Generation

In section 4.2.1 the problems of sub-optimal/inefficient allocation of resources in terms of RES-E generation potentials already have been described comprehensively. Moreover, the aspect of diseconomies of scale in case of RES-E target definitions on country level – neglecting relative differences of available amounts and utilization cost of resources between the different countries – has been worked out. To be more precise, this means that the outcomes of the sum of the merit order curves of RES-E potentials and cost of each of the countries is different from the merit order curve of the sum of all countries. Exemplarily the difference between the two alternatives is shown in Figures 4.12a and 4.12b. In the context of European 2020 RES-E target definitions this means that Figure 4.12a represents the status quo: each of the EU Member States is obliged to increase the amounts of RES-E generation by a certain share in percentage – independently of the convexity of the country’s potential/cost merit order curve of still not implemented RES-E resources.

![Figure 4.12a: Merit order, definition of targets and implementation of the most attractive additional RES-E potentials in each country (bottom-up approach).](image-url)
In a European context to reach EU 2020 RES-E targets with minimal total system cost, this approach is supposed to be sub-optimal. However, due to the lack of transmission adequacy (i.e. mainly caused by currently existing disincentives for transmission investments) on both levels national and cross-border this is seen as the – one and only – reasonable solution in practice.

When referring to Figure 4.12b – and having in mind the EU 2020 RES-E target definitions – this represents a European-wide optimum for reaching a certain target of additional RES-E generation with minimal total system cost. This approach expects that access to the most attractive European RES-E potentials is available and, subsequently, economies of scale of large-scale RES-E generation can be exploited. An approach like that, however, expects top-down approaches and definitions of system borders on European level, say 27 or more European countries (i.e. merit order curve on aggregated European level). And even more important, functioning electricity market structures and transmission adequacy (facilitated by transmission investments) are necessities and preconditions for “global” European optima of RES-E resource exploitation (see section 5 in detail).

Figure 4.12b: Merit order, definition of targets and implementation of the most attractive additional RES-E potentials in a cluster of countries (top-down approach).

4.3.2 Inefficient versus Efficient Mitigation of Variability and Intermittency of RES-E Generation

Section 4.2.1.2 has clearly pointed out the inefficient allocation of resources in terms of mitigation strategies of variability and intermittency of RES-E generation if system boundaries are set by institutional, organisational and/or structural criteria rather than physical laws of load flows of electricity in meshed electricity networks. Furthermore, some examples have been presented in different European regions, which kind of – already existing – flexible electricity generation technologies (like pumped-storage hydro power, combined-cycle gas turbines, gas turbines) are qualified to balance the electricity system in general, and what’s the possible “sphere of action” in geographic terms, in particular. In the future, also the potentials and fields of application of new
technologies (e.g. storage technologies like battery systems of electric vehicles) has to be taken into consideration for system balancing and reserve capacity provision purposes. Concluding, according to the law of physics – finally governing the functioning of the complex electricity system – a European-wide top-down approach is preferable where the spatial dispersion of flexible generation technologies and fluctuating RES-E generation is optimised aside from “artificial” system borders. Transmission investments to connect and integrate the different technologies are an important cornerstone to overcome the lacks of “isolated” strategies.

4.3.3 Non-Harmonized versus Harmonized RES-E Integration Charging Approaches

The bandwidth and the pros/cons of each of the RES-E integration charging approaches have been comprehensively discussed in chapter 3 of this document (section 3.2 in particular). Moreover, in the project REALISEGRID Deliverable D3.1.1 [27] comprehensively deals with the existing methods for grid connection charging of wind power plants in Europe. In [27], furthermore, also an empirical overview of currently implemented grid connection charging methods in several of the EU27 Member States is presented (Section 4.3, Table 4.3 in [27]). The major essence of this integration charging overview for wind (as well as for several remaining other RES-E generation technologies) in Europe is that there exist extremely heterogeneous patterns in the different EU Member States. Concluding, someone can imagine that harmonized and homogenous RES-E grid integration charging methods are preferable and, subsequently, favor the removal of non-technical barriers of RES-E grid and market integration; especially in case of projects on “international borders”, see “Kriegers Flak” discussion below.

4.3.4 Strategic Behavior versus International Commitment

The possibility of strategic behaviour and/or free riding in case of “international projects” is discussed based on the offshore wind project “Kriegers Flak” in the Baltic Sea (see Figure 4.13).

As already mentioned in section 4.2.1, Sweden (to be more precise: the TSO Svenska Kraftnät) informed the public early 2010 that it abstains from engaging in a combined development of the “Kriegers Flak” offshore wind project due to the fact that offshore wind farms are not expected to be constructed at the Swedish part of “Kriegers Flak” in the foreseeable future. This decision might
perhaps be thought as an immediate consequence of the mechanism to allocate the EU 2020 RES-E targets to the different EU Member States on national level. Based on this mechanism (see section 4.2.1.1 in detail), Sweden already has fulfilled the national binding 2020 RES-E target in the electricity sector in the period 2007-2010 (2007 is the reference year for target setting) and might have less interest to push in the ambition of new RES-E installations in the next decade until 2020, regardless whether or not there exist attractive RES-E potentials with low utilization cost\textsuperscript{24}.

Originally, a few years ago the three Transmission System Operators (TSOs) Energinet.dk (Denmark), Svenska Kraftnät (Sweden) and Vattenfall Europe Transmission\textsuperscript{25} (Germany) initiated the visionary idea of connecting the offshore wind power plants at “Kriegers Flak” through a combined, international offshore grid connecting Germany, Sweden and Denmark. Such a combination has never been built before, but it would have been the first project providing empirical evidence which serves the three most important needs in the European electricity market (also claimed in different EC directives and regulations as well as addressed in the “Ten-Year Network Development Plan 2010”; see [21] and section 3.1.2 in this document for details):

- bring RES-E generation to the European consumers,
- strengthen the further integration of the European electricity markets,
- increase security of supply by providing interconnected transmission capacities.

These synergies would be exactly the result of optimizing grid connection of offshore wind power plants not just nationally (i.e. separate radial connection to each country) but also in a wider European context. Because of the position of “Kriegers Flak” in the Baltic Sea and the distances to the different onshore grids, it might be advantageous to connect the offshore wind power plants through a combined solution which would also serve as an interconnector between Germany, Sweden and Denmark. Figure 4.14 presents the possible technical solutions for grid connection of Kriegers Flak’s offshore wind power plants according to the three involved TSOs’ points-of-view.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{possible_solutions.png}
\caption{Possible technical solutions for grid connection of Kriegers Flak’s offshore wind power plants. Source: [20]}
\end{figure}

\textsuperscript{24} Also the revision of the nuclear phase-out strategy clearly indicates a “realignment” of the Swedish energy policy.
\textsuperscript{25} Vattenfall Europe Transmission recently has been renamed to „50Hz Transmission“.
The different possible technical solutions for grid connection of Kriegers Flak’s offshore wind power plants presented in Figure 4.14 are not discussed in detail here; rather it is referred to [20].

From the technical point-of-view, however, it is important to note that the Swedish TSO Svenska Kraftnät is willing to technically support the further development of the Danish and German parts of the combined structure. Moreover, Energinet.dk (Denmark) and Vattenfall Europe Transmission (Germany) continue the EU supported project to combine the connection of the offshore wind plants at Kriegers Flak with interconnections between Denmark and Germany. The technical solution will allow future participation of Svenska Kraftnät and increased trading capacity should offshore wind power projects on the Swedish part of Kriegers Flak be constructed in the future.
5 THE FUTURE IMPORTANCE OF TRANSMISSION GRID INVESTMENTS MEETING “GLOBAL OPTIMA” OF RES-E GRID INTEGRATION ON EUROPEAN LEVEL

5.1 Overcoming Structural Difficulties and Regional/National “Vanities” to meet the “2020 Targets” (and Beyond) with Lowest Total System Cost

In this section the benefits of transmission grid investments are demonstrated to solve not only the sub-optimal RES-E grid integration problems, but also other barriers and shortcomings in the international European electricity market. The following aspects are addressed in detail:

- market coupling of different European sub-markets;
- access to efficient and effective system balancing and reserve capacity provision technologies;
- connection of large-scale RES-E generation with load centres in dense areas;
- development of European-wide business and cost remuneration models.

5.1.1 Enabling Market Coupling of Different European Sub-Markets

In 1999, the major intention of the European Commission was (and still is) the creation of a common, homogeneous European electricity market. However, currently Europe rather consists of at least seven (or even more) distinct sub-markets, each of them separated by inadequate cross-border transmission capacities and different barriers for access to the grid. The most impressive indicator identifying market separation is the wholesale electricity market price development in the different regional electricity markets in Europe. Figure 5.1 presents the empirical development of the annual average wholesale electricity market price on the most important market places for wholesale electricity trade in Europe from 1999 until 2009.

![Wholesale electricity market price development in different European “sub-markets” from 1999-2009. Source: [2]](image_url)

Figure 5.1: Wholesale electricity market price development in different European “sub-markets” from 1999-2009. Source: [2]

---

26 OMEL - Iberian Peninsular; Elspot - Scandinavia; EEX - Central Europe; PolPX - Eastern Europe; IPEX/GME - Italy; APX - Benelux; UKPX - UK
It is supposed to be obvious that investments into physical cross-border transmission capacities significantly can contribute to mitigate this problem. However, at this point it is important to note, that this document does not deal with details of “market coupling” aspects; this is rather done e.g. in the REALISEGRID Deliverable D3.2.1 (“Coordination Mechanisms, Tools and Load-Flow Issues of Cross-Border Transactions” [11]) and other references (e.g. [22]). Actually, the topic “market coupling” would deserve a special in-depth analysis that lies outside the aim of the present report. In the following footnote just a brief introduction into the topic is presented to get a basic understanding of the topic.27

Coming back to large-scale RES-E integration debate, at present one of the most relevant topics is to develop strategies and network infrastructures for offshore wind integration. The most prominent sites are located in the North and Baltic sea (see also “Kriegers Flak” discussion in section 4.3.4). In the following, some examples (four in total) are shown how different design options of offshore grids in the North Sea also can contribute to policy objectives of the European Commission other than pure offshore wind connection. The four different examples of design options shown in Figures 5.2a-d have been developed in the “OffshoreGrid” project28 and are described in [16], available on the project website www.offshoregrid.eu.

Based on different possible drivers, the four offshore grid design examples are as follows (see [16] in detail):

- **Trade-driven design (Figure 5.2a):** In this approach the development of an offshore transmission grid is driven by requirements to increase both trade and security of supply. This approach corresponds with the way offshore grid developments have been done until now.

- **Wind-driven design (Figure 5.2b):** Following this approach, the offshore grid will be based on a large number of wind power clusters, being interconnected to several different shores and to other wind power clusters, resulting in a meshed grid with a large number of nodes.

- **Wind-driven - special design (Figure 5.2c):** In a special case of a wind-driven design one single wind farm cluster is connected to several different shores.

- **Mixed design (Figure 5.20d):** There is also a mixed approach between a trade-driven and wind-driven approach possible. According to the explanations in [16] the development of an offshore grid is initially driven by trade and later, when the installed wind farms will be larger and further from the shore, by offshore power generation.

---

27 There exist two alternative market coupling approaches: (i) price-based market coupling (“price-coupling”) and (ii) volume-based market coupling (“volume-coupling”). In price-coupling, both flows and prices are determined by the coupler. On the other hand, in volume-coupling only the flows between the two markets are determined in a first stage, and prices are determined subsequently by the local power exchange. The quality of the volume-coupling can be adjusted, from “loose” to “tight”, depending on how well the flow calculation has replicated the bids and local market rules of individual price determinations. Market coupling to date has been applied to the borders within a market region (a group of markets). So far, market regions have adopted price-coupling. Price-coupling can be organised in two ways (is an organisational issue): (i) “actual” market coupling (two or more power exchanges are involved) or (ii) market splitting (involving only one power exchange, operating in two or more bidding areas). For further details on that topic it is referred e.g. to the references cited in the text above.

28 The “OffshoreGrid” project (www.offshoregrid.eu) has already been introduced in section 2.3.
D3.6.3 Transmission Grid Investments for an Efficient Integration of Renewable Energy Sources

Figure 5.2a: Example of a trade-driven offshore grid design in the North Sea. Source: [16], available for download at www.offshoregrid.eu

Figure 5.2b: Example of a wind-driven offshore grid design in the North Sea. Source: [16], available for download at www.offshoregrid.eu

Figure 5.2c: Example of a special case of a wind-driven offshore grid design in the North Sea. Source: [16], available for download at www.offshoregrid.eu
Finally, it is important to note that the examples shown above are first ideas how offshore grid design and implementation could work in the future. What is clear at the moment is that different drivers affect offshore grid development in a different manner. Which approach ultimately will be favoured in the upcoming years is still unclear. Desirable is a model going beyond pure grid connection of different offshore wind farm clusters.

5.1.2 Enabling Access to Efficient and Effective System Balancing and Reserve Capacity Provision Technologies in a European Context

The “system boundary” question addressing the future challenges caused by the massive integration of variable and intermittent RES-Electricity generation has already been discussed comprehensively in section 4.2.1 and 4.3.2 of this document. In these sections also the importance of flexible pumped-hydro storage technologies, gas-fired power plants (CCGTs, GTs) and – most probable – in the future also to some extent battery systems due to the increasing market penetration of electric vehicles has been underpinned.

In these previous sections it has already been concluded that transmission grid investments are the “key” element to enable access to the different sites and flexible technologies throughout Europe. It is also evident that in the future a purely country-specific consideration of the flexibility aspect of conventional electricity generation in case of massive variable and intermittent RES-E integration falls too short.

As already introduced in the corresponding sections in chapter 4, many of the Central and Eastern European countries are characterised by a rather inflexible power plant mix, on the one hand, but they also have significant RES-E potentials (both onshore and offshore wind), on the other hand. In a wider European context these countries are somehow “squeezed” between the hydro-dominated countries in Scandinavia and in the Western and Eastern Alps.

In the following, as an illustrative example the Polish situation is studied more in detail. Below it is mainly referred to the outcomes of the regional case study analyses in the Pomeranian region, having been subject to a detailed analysis in the FP7 project SUSPLAN (www.susplan.eu).
Within this field study analyses in the SUSPLAN project in the different public events in the region (kick-off workshop, feedback-workshop, final dissemination workshop) it has frequently been argued that the amount of onshore- and offshore wind penetration is supposed to be limited in the medium- to long-term mainly due to the “inflexibility/inertia” of the conventional power plant mix (at present, Poland has more than 90% coal-fired power plants). Although fuel-switching in the thermal electricity generation portfolio towards more flexible gas-fired power plants would be possible (e.g. Yamal-Europe gas pipeline passes Poland), in a wider regional context it can be argued that cross-border transmission investments towards North (Scandinavia) and South (Alps) enable direct access to plenty of pumped-hydro power technologies to balance the electricity system and to provide reserve capacities in the region.29

Figure 5.3 below presents the areas of wind farm locations in Poland by 2015 on the map of the transmission grid valid as of 2009 (left) and the map of planned and existing cross-border transmission interconnectors in Poland (right). In our case, adequate transmission links to Scandinavia – e.g. underground cable as a part of a wider offshore grid in the Baltic sea (see also discussion in the previous section 5.2) – and the Alps (via Czech Republic and Slovakia) are meant in particular. An implementation of them, however, is possible only if the issue is treated in a wider context in the Baltic sea region (comparable with the ideas on offshore grid design in the North sea presented in the previous section 5.1.1) and the North-South transmission corridor discussion in the Alps. The successor documents of TYNDP2010 ([21]) shall deal with issues like that in detail.

![Figure 5.3: Areas of wind farm locations in Poland by 2015 on the map of the transmission grid valid as of 2009 (left); Map of planned and existing cross-border transmission interconnectors in Poland (right). Source: [38]](image)

29 In 2010, the following capacities of pumped-hydro storage plants are installed in Central and Eastern European countries: Austria 2.9 GW, Germany 3.8 GW, Switzerland 1.6 GW, France 4.3 GW, Italy 4.2 GW, Slovakia 0.9 GW, Czech Republic 1.1 GW, Poland 1.7 GW (Source: [5]). It is important to note, that at present in many of these countries pumped-hydro storage capacities are expanded and/or hydro-storage/reservoir power plants are upgraded with a pumping mode to increase flexibility. Besides the countries mentioned above, in the entire Balkan region many hydro power plants (incl. pumped-hydro storage) will be implemented in the future.
In section 4.2.1.2 the role and importance of the second set of flexible electricity generation technologies – as there are gas-fired technologies like CCGTs and GTs – already has been discussed sufficiently; therefore, this isn’t done here again. Based on own domestic resources and/or access to natural gas via corridors these technologies are important in areas on “borders” of electricity systems. Although this type of balancing and reserve capacity provision strategy may expect less cross-border transmission grid investments, it is important to note, that from the environmental point-of-view (emissions) part loaded operation of fossil-fuelled power plants are supposed to be sub-optimal.

5.1.3 Enabling Connection of Large-Scale RES-E Generation with Load Centers in Dense Areas

In order to meet the ambitious future RES-E generation targets with minimal total system cost (i.e. cost of renewable electricity generation and grid infrastructure), it is important to utilize RES-E generation on those sites where energy yields are highest; then only economies of scale of RES-E generation can be exploited. In the different sections throughout this document – in particular those where empirical examples have been shown – it already has been obvious that in almost all cases attractive and high RES-E potentials are far away from load centres in terms of geographical distances. Even more, in many cases the nearest connection point to the existing electricity grid infrastructure is not necessarily the nearest fitting connection point qualified to absorb large amounts of RES-E generation. The reason can simply be that network capacities are not sufficient because load density in the area/region is also low. Therefore, in many cases new transmission routes and longer distances are necessary to bring large-scale RES-E generation and dense load centres together.

Although it might look “old-fashioned”, at this point it is referred to sections 3.3.1 and 3.1.1 of this document again where an excursion into the structural development in the 20th century is conducted and the role of the transmission grid infrastructure in this context is discussed. Moreover, when having in mind the three cornerstones (i.e. overcoming geographic distances between sites of large-scale generation and load centres, exploitation of economies of scale of large-scale generation, and security of supply) justifying the construction of large transmission grids in the 20th century in section 3.1.1, the question arises what’s the difference right now in the renewable debate in the 21st century compared to the past? An immediate answer could be: the market! However, is this really the small difference that matters? Most probably: yes!

Compared to the past, an attempt of an explanation at least in two dimensions for much more problems for transmission investments and the implementation of new transmission routes could look as follows:

- Opposition of the public: If the public is confronted with new transmission lines/routes, but has no immediate benefit, they most probably oppose in general. This is supposed to be even worse in case of privately-owned transmission system operators, since the public could argue the only beneficiaries of “interventions into landscape” are the shareholders of the company (regardless

30 A discussion on the possible future role of battery systems in this context triggered by an increasing market penetration of electric vehicles is omitted here.
what’s their opinion about the need of a transmission project from a technical point-of-view). In the past, in a rather public-owned organisation of a vertically integrated electricity supply industry the beneficiaries – at least indirectly – have been all tax-payers.

- The second argument refers to the risk and uncertainties of cost remuneration from the transmission grid operator’s point-of-view in case of deviations (e.g. incentive regulation; see section 3.4) from “old-fashioned” cost-based regulation models (e.g. rate-of-return).

Apart from the differences mentioned above, the exercise to bring together large-scale RES-E generation and load centres is very similar to the exercise having been conducted in the 20th century successfully. Below two illustrative empirical examples are presented, referring again to the outcomes in two regional scenario studies in the SUSPLAN project:

- Figure 5.4 presents the long-term development of electricity generation and gross electricity demand in the Pomeranian region (northern part of Poland) up to 2050 (Blue Storyline). This figure impressively shows that the region will become an exorbitant net-exporter to the interior of Poland in the south and - maybe - also to other neighbouring countries. Adequate transmission investments and routes towards dense load centres are supposed to be straightforward. However, the public being confronted with new transmission lines and routes, but having no immediate benefit of it, must be convinced (and maybe compensated somehow).

![Figure 5.4: Development of electricity generation and gross electricity demand in the Pomeranian region (northern part of Poland) in the Blue-Storyline up to 2050. Source: [52]](image)

- Figures 5.5 and 5.6, finally, present a similar situation referring to a region in Northern Scotland, the Western Isles in particular. Figure 5.5 shows the wave potential in Northern Scotland coming from the Atlantic Ocean, Figure 5.6 the long-term development of installed RES-E capacities and gross electricity demand in the Western Isles up to 2050 (reference to the “Blue Storyline” SUSPLAN scenario). Massive amounts of marine energy (wind offshore,
wave energy) are supposed to be exploited in these long-term scenarios. Again, similar patterns and challenges as in the Pomeranian region can be observed: dense load centres are far away, either in the southern part of England (London region) or in Continental Europe. Therefore, massive transmission investments, onshore and offshore, are needed to integrate these huge amounts of offshore RES-E potentials.

![Figure 5.5: Wave power potential in Northern Scotland. Source: [28]](image)

![Figure 5.6: Development of installed RES-E capacities and gross electricity demand in the Western Isles in the Blue-Storyline up to 2050. Source: [28]](image)
5.1.4 Development of European-wide Business and Cost Remuneration Models for Transmission Investments

In section 4.2.2, it has already been indicated that, at present, there do not exist fitting business models for implementing grid infrastructures to enable both utilization of low-cost RES-E generation and fulfilment of other energy policy objectives like the further integration of the European electricity market and/or improvement of security of supply. From the technical and economical point-of-view many analyses, modelling results, technical solutions and also economic (cost) estimates exist for the implementation of the most attractive RES-E potentials in the different regions throughout Europe. E.g., in theory it is supposed to be rather easy to identify the cost minimizing total system cost solution to meet the “EU 2020 RES-E” target [47].

In practice, however, things are much more complex. The Norwegian example in section 4.2.2 has demonstrated that in almost all cases pareto-optima are violated for at least one of the parties involved. To be more precise, the Norwegian end-users are supposed to be not interested on increases of grid tariffs in case the Norwegian TSO Statnett implements offshore grids to enable utilization of low-cost offshore wind generation on the Norwegian coastline, one the one hand, and Norwegian end-users and policy makers might not be interested to push large-scale wind integration due to almost 100% hydro power generation and still not exploited, attractive hydro power potentials, on the other hand. All over Europe, in many regions similar situations can be cited negating “go”-decisions for investments into existing and/or new grid infrastructure projects (see e.g. the Western Isles example shown in the previous section 5.1.3).

So it seem to be obvious, that overarching goals demand overarching (business-)models being not restricted to national thinking to reach first best solutions. Speaking in a European context, the currently implemented regulatory and RES-E support schemes are second best solutions at most.

Being confronted with a situation like that, one might think of third-party investors, e.g. merchant transmission investors. Although this concept is sound in theory, in practice only few successful examples provide empirical evidence so far. Merchant transmission investments are based on an entrepreneurial basis in response to transmission grid congestion between points on the same network or different networks that the merchant project connects; moreover, merchant investments can also be argued in the context of large-scale RES-E integration (with or without fulfilment of further European policy objectives like market coupling). Initially, the main reason for opening transmission investments to profit-motivated third party investors was that this may address the problem of under-investments into transmission grid infrastructures since the beginning of electricity market restructuring almost everywhere. However, merchant transmission investments are ambiguous for third party investors: whereas these kinds of investments have been generally seen as an instrument to stimulate electricity market integration across separated geographic regions, the third parties involved have a considerable interest in case of an investment to keep the electricity markets – at least to some extent – disintegrated (i.e. also to under-invest) in order to maintain continuous revenue streams. In detail, this means that the investment for the merchant is appealing only if the investor gets (at least parts of) the congestion rent also in the long-run. An alternative financing incentive for a third party merchant investor could be to give the investor a capacity reservation on (parts of) the new interconnector. However, this is against the alleged pillar of the European Commission of creating a common non-distorted pan-European electricity market. Concluding, several investment incentives (see above) and cost remuneration models (e.g. also
approaches like firm transmission rights, etc.) trying to mitigate the risk of free riding of other parties in the context of merchant transmission investments are rather theoretical reflections lacking of evidence of practical capability so far.

In general, it can be stated that any kind of “economic-analyses” of transmission investments is rather simple in theory. However, simple economic analyses of (congested) two or three node models of transmission networks typically used to identify investment needs have little to do with the way transmission investments are actually planned in practice, and also associated transmission services are priced. Moreover, economic models and analyses need to be expanded to better capture several complex factors affecting transmission investments. This means that sophisticated cost/benefit analyses methods need to be developed taking into account several important dimensions affected by transmission grid investments. Deliverable D3.3.1 [34] of the REALISEGRID project (“Possible criteria to assess technical-economic and strategic benefits of specific transmission projects”) gives comprehensive insights into this issue and provides valuable contributions to further develop cost/benefit analyses towards practical application.

Forward-looking business models and cost remuneration approaches shall go in the direction that, in a first step, it is somehow possible to clearly identify several parties affected by and/or are the beneficiaries of particular transmission investments. Then, it is necessary to identify the impacts of each of the parties for the “marginal participation” on the commercial businesses within the “system boundaries” of a transmission investment. Finally, cost recovery for the investing party/parties into the transmission line must be guaranteed. In general, cost recovery mechanisms can be composed by different elements, incorporating regulatory components (e.g. rate-of-return regulation), market driven components (e.g. auctioning revenues) and also others (e.g. financial rights decoupled from physical electricity flows). Finally, this depends on the “kind” of transmission investment and on the “dominance” which kind of energy policy goal is predominantly pursued (i.e. further market integration or RES-E integration or security of supply).

At this point it is important to note, that the discussion on business models and cost remuneration methods in the context of transmission investments is an ongoing process. At present is rather important to “structure” the discussion than to provide definite solutions. Also this section here is not capable to go beyond a contribution to structure the issue.
5.2 Ideas and Visions of Coordinated European-wide (Onshore and Offshore) Transmission Grid Development

Experience and different empirical examples on large-scale RES-E integration throughout this document have emphasised the importance of transmission investments enabling massive RES-E integration in Europe. Moreover, investments into an upgrade/extension of existing transmission lines as well as new transmission routes are supposed to be the “key” element to connect the most attractive European RES-E generation sites with load centres in dense areas. Different existing inefficiencies, shortcomings and barriers have been highlighted showing how they prevent the access to RES-E generation sites in Europe with huge potentials, as there are:

- Large-scale offshore wind and marine energy generation potentials in the Atlantic Ocean, North and Baltic Sea;
- Further potentials to increase capacities of pumped-storage hydro power in Scandinavia, Western and Eastern Alps as well as in the Pyrenees for balancing and reserve capacity purposes to mitigate variability and intermittency of onshore and offshore wind generation.

If someone further develops this thought experiment, the ultimate end describes the vision of a “Supergrid”, overlaying the existing European HVAC grid by a HVDC grid not only on the European continent, but also interconnected with neighbouring regions like Northern Africa and the Middle East (MENA Countries)\(^{31}\). Recently, this vision has been given a first “name” by the DESERTEC project (see www.desertec.org, [17])\(^{32}\). DESERTEC aims at the creation of a solar thermal path of electricity generation in Northern Africa (MENA countries in general) and to import it to dense load centres in Europe, see Figure 5.7. Advocates of DESERTEC estimate up to 15% of European electricity demand to be imported from this project in the long-term.

\[\text{Figure 5.7: Vision of a “Supergrid” in Europe, Northern Africa and Middle East. Source: [17]}\]

\(^{31}\) MENA: Middle East and Northern Africa
\(^{32}\) The “DESERTEC” project (www.desertec.org) has already been introduced in section 2.3.
The advocates of this “Supergrid” concept see it as one of its important advantages that a technically efficient and, because of the economies of scale of RES-E generation to be expected, cheaper solution can be found than by means of a decentralised expansion of RES-E generation. In a concept (or similar) shown in Figure 5.7, in terms of system integration of different types of RES-E generation technologies the geographic spread in a combined system would justifiably ease the compensation of variable and intermittent generation of onshore- and offshore wind especially when concentrated solar thermal power generation technologies (CSP) are part of a combined solution besides pumped-hydro storage technologies and also flexible gas-fired power plants (like CCGTs and GTs). The contribution of CSP generation technologies to system integration is above all seen in their ability to feed in electricity continuously and reliably (e.g. by using special storage systems at night). Moreover, it is expected that concentrated solar thermal power plants (CSP) are capable of providing safe and stable capacities of base-load as well as balancing and reserve capacity power.

At this point, however, it is important to note that it is not the intention here in this document to comprehensively discuss more details of the vision of a “Supergrid” and projects like DESERTEC. It has been rather introduced just for completeness when talking about transmission investments in the context of large-scale RES-E grid and market integration in European. At present, the “Supergrid” vision seems to be still “futuristic” and it is supposed to be even more important in the short- to medium term to understand the transmission investment problems and needs on the European continent; using the existing European HVAC transmission grid as a “backbone” for further upgrades and extensions to enable the absorption of large-scale RES-E generation with the lowest total system cost as possible.

33 In a critical discussion of concepts like that also possible conflicts like blame of colonialisation, import dependence, risk of restoration and many others have to be addressed.
6 POLICY RECOMMENDATIONS AND CONCLUSIONS

After more than ten years of liberalisation of the European electricity market the inherent transmission adequacy problem is still unsolved. The transmission grid, however, is the physical platform and “backbone” upon which several commercial activities rely on in a competitive electricity market. This has become sufficiently clear in recent years also at policy making level on both European and national sides. Moreover, in the meantime it seems to be an issue on top of the agenda for the further development of the internal European electricity market.

A first attempt by European policy making has been the request for a non-binding “Ten-Year Network Development Plan [21]” to be compiled by the European Network of Transmission System Operators for Electricity (ENTSO-E). This plan has been published recently and it identifies the most urgent transmission investment projects in the upcoming years across Europe. Mainly due to lack of time, this plan cannot go far beyond a brief justification of the usefulness of the different transmission investment projects listed there; usefulness is expressed in terms of the contribution to different European policy objectives: (i) improvement of security of supply; (ii) further development of the internal European electricity market; (iii) massive integration of RES-E generation necessary to meet the EU2020 policy target ([47]).

This document here predominately addresses the latter of the three European policy objectives mentioned above. The different empirical examples presented throughout this document, however, have impressively demonstrated that the strategic importance of investments into transmission capacity expansion and/or new transmission routes cannot be broken down any more exactly towards the contribution to the different policy objectives; there is also no need to do so. In almost all cases transmission investments significantly contribute to several of them.

A variety of empirical examples throughout this document addressing currently existing barriers, shortcomings, and inefficiencies of large-scale RES-E integration mainly caused by transmission adequacy problems shall demonstrate that overarching European policy objectives (e.g. EU2020 RES-E targets) obviously also demand for overarching transmission investment models going far beyond national way of thinking. Moreover, it stays on the order of the day that several important European and national experts (European Commission, ENTSO-E, ACER, stakeholders, research institutes, others) shall try to develop robust approaches and models, enabling the estimation of the need/urgency, the cost and benefits (and who are the beneficiaries) of different transmission investment projects in different European regions. A backing on robust methodological frameworks only can guarantee the identification of effective and efficient transmission investments finally supporting the further development of the European electricity market in a sustainable way. E.g., the cost/benefit analyses developed in D3.3.1 ([34]) of the REALISEGRID project is a valuable contribution in this context.

Finally, it is important to note that cost remuneration models for any kind of transmission investments must be robust. Confidence for the investor is a “sine qua non” condition. The risk for any kind of investment to be “sunk” as well as any kind of regulatory risk must be excluded in the short and long-term. Depending on the kind of transmission investment (e.g. transmission capacity expansion on existing lines versus new routes; transmission investment “embedded” into the existing ENTSO-E network versus new offshore transmission network) cost remuneration models can range from cost-based regulation models (e.g. rate-of-return regulation), market-based approaches (e.g. auctioning scarce transmission capacities in case of congestion) and – in case –
also others (e.g. financial rights decoupled from physical electricity flows in case of merchant investments). However, further research and also empirical verifications on the practicability of the different cost remuneration models is needed for different kinds of transmission investments in the future.

Last but not least, the authors of this document would like to conclude with reference to the set up of the electricity supply industry in the previous century, and to the role of and rational for building transmission grids in those days in particular. Although a few boundary conditions are fundamentally different in competitive electricity markets in the 21st century (e.g. vertical disintegration of the electricity supply chain, availability of new technologies34, others), there are much more similarities than someone initially could imagine. Similarities should be identified and, if applicable, translated to positively contribute to solve the inherent transmission investment problem we are facing at the moment. Therefore, also in some sections in this document the attempt is undertaken to bridge these different “energy worlds”.

34 Besides structural and organisational differences in competitive electricity markets another important element is different compared to the past: availability of new technologies. In some cases, new technologies can help to circumvent regulatory, consensus and other problems. E.g., in the 20th century DC initially lost the “battle” against AC (see section 3.3.1 in this report), but now advanced DC networks are becoming fashionable again e.g. for connecting offshore wind farms and also as a future option for long-distance connections of European and neighbouring generation and load centres in general. Compared to AC solutions, the key advantage of DC connections is that they avoid excessive losses and reactive power creation. For comprehensive details in this context it is referred to Deliverable D1.3.3 ([41]) of the REALISEGRID project (“Comparison of AC and DC technologies for long-distance interconnections”).
REFERENCES


[50] DCENR (Department of Communications, Energy and Natural Resources), DETINI (Department of Enterprise, Trade and Investmntent): ”All Island Grid Study – Study Overview”, Dublin, January 2008.
