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Efficient strategies for the integration of renewable energy into future energy infrastructures in Europe – An analysis based on transnational modeling and case studies for nine European regions

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HIGHLIGHTS

- We present the main outcomes of the SUSPLAN EU project.
- It assesses long-term energy infrastructure needs to integrate RES in Europe.
- Regional and transnational analyses are performed for 4 RES scenarios until 2050.
- Major barriers to the integration of RES into energy infrastructure are identified.
- Efficient strategies to mitigate these barriers are proposed.

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ABSTRACT

As a result of the current international climate change strategy, the European Commission has agreed on ambitious targets to reduce CO_2 emissions by more than 80% until 2050 as compared to 1990 levels and to increase the share of renewable energy and improve energy efficiency by 20% until 2020. Under this framework, renewable energy generation has increased considerably in the EU and it is expected to keep growing in the future years. This paper presents long-term strategies for transmission infrastructure development to integrate increasing amounts of renewable generation in the time horizon of 2030–2050. These are part of the outcomes of the SUSPLAN project,[1] which focuses on four possible future renewable deployment scenarios in different European regions taking into account the corresponding infrastructure needs, especially electricity and gas grids, both on regional and transnational level. The main objective of the project is the development of guidelines for the integration of renewable energy into future energy infrastructures while taking account of national and regional characteristics. Therefore, the analysis is based on a two-track approach: A transnational modeling exercise ("top-down") and in-depth case studies for nine representative European regions ("bottom-up").

1. Introduction

The current international climate change strategy implies ambitious targets in the EU to reduce CO_2 emissions, increase the share of renewable energy and improve energy efficiency by 20% in 2020 (European Commission, 2008). Furthermore, the EU is committed to reducing greenhouse gas emissions by 80–95% below 1990 levels by 2050 (European Commission, 2011a). The electricity sector will play a key role in achieving these targets. The EU expects an increase in the share of low carbon technologies in the electricity mix from approximately 45% today to 60% in 2020, 75–80% in 2030, and nearly 100% in 2050. Out of the 100% target in 2050, 50–55% would come from renewable energy sources (RES) (European Commission, 2011d). To integrate these high amounts of RES generation, significant infrastructure extensions will be necessary not only at national level but also at transnational level, especially if large-scale onshore and offshore wind parks in Northern Europe and large solar power facilities in Southern Europe and Northern Africa are to be developed. The development of an integrated energy network has been pointed out as essential for the achievement of the EU's energy policy goals

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[1] SUSPLAN (PLANning for SUStainability) is a project initiated in 2008, and finished in 2011, under the European Union's 7th Framework Program and sponsored by the Directorate General Transport and Energy (DG-TREN). The sole responsibility for the content of this paper lies with the authors. It does not represent the opinion of the European Commission. The EC is not responsible for any use that may be made of the information contained therein.

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of competitiveness, sustainability and security of supply (European Commission, 2010). In this context, the European Commission (EC) published a proposal for a regulation on guidelines for trans-European energy infrastructure, identifying energy infrastructure priorities for 2020 and beyond, and three main groups of strategies to facilitate the development of this infrastructure. These include the streamlining of authorization procedures to reduce their duration and raise public acceptance, allocation of costs according to the benefits achieved by the agents, and provision of market-based and direct EU financial support (European Commission, 2011b).

Under this framework, several relevant long-term roadmaps and large European projects were launched to address the future development of energy infrastructure required to integrate large amounts of RES generation. For instance, the roadmap presented by (European Climate Foundation, 2010) provides a technical and economic assessment of three main de-carbonization pathways with 40%, 60% and 80% RES generation, and the respective electricity transmission grid expansions in the EU. According to this study, the required additional transmission capacity ranges between 50 GW and 165 GW, in the 40% RES and 80% RES pathways, respectively. Also, some European projects under the 7th Framework Programme such as REALISEGRID (realisegrid.rse-web.it), IRENE-40 (www.irene-40.eu) and TWENTIES (www.twenties-project.eu) stand out. The main outcome of the REALISEGRID project is the development of a cost-benefit methodology to assess pan-European infrastructure investments (Miglavacca et al., 2011). The IRENE-40 project identifies network bottlenecks within the electrical transmission system and aims at elaborating a technology roadmap including actions and milestones towards the future electricity network infrastructure up to 2050. In the TWENTIES project, six local demonstration projects are being developed to show that wind farms and flexible load can provide system services, the operation of offshore high voltage direct current (HVDC) networks, and the increase in transmission grid flexibility and capacity due to the application of innovative Flexible AC Transmission Systems (FACTS) and Dynamic Line Rating (DLR).

The objective of the paper on hand is to provide an overview over some of the main outcomes of the SUSPLAN project, namely barriers and strategies for RES integration in the European context. As well as the previously indicated projects, SUSPLAN attempts to bring solutions to the energy challenges facing the EU, with focus on energy infrastructure development. While the above named projects focus on evaluating costs and benefits of new infrastructure (including new technologies), the SUSPLAN project computes the economically optimized energy infrastructure under different framework conditions (scenarios), represented by varying portfolios of RES generation. The novel aspect regarding this project is that it deals with different types of energy infrastructure – electricity and gas – and covers a long-term time horizon (up to 2050). Furthermore, the analyses within the project are performed not only for the pan-European system but also for selected regional/national systems with diverging RES penetration levels and different issues related to RES integration. Consequently, strategies and policy recommendations for an optimal integration of renewable technologies into future electricity and gas infrastructures were derived at regional/country-based and transnational levels.

This paper's main aim is to present the major barriers and strategies for high RES deployment in an international, European context (it does, however, not include a detailed economic assessment of the different scenarios). The paper is divided into five sections apart from this introduction. Section 2 defines the four storylines considered in SUSPLAN and the methodology adopted to perform the analyses. Section 3 shows the results regarding the deployment of RES potentials across the different storylines and the corresponding energy infrastructure needs. Section 4 describes the main barriers to energy infrastructure development. Section 5 discusses strategies for the removal of infrastructure development barriers. Finally, Section 6 presents the conclusions.

2. The SUSPLAN project approach

2.1. Methodology

In the SUSPLAN project, nine different regions/countries have been selected throughout Europe for comprehensive in-depth analyses of future grid integration of renewable generation technologies. These regions were chosen according to their characteristics (higher or lower potential for RES, incentives for RES technologies, weak or strong infrastructures, etc.) in such a way that other similar European regions could be represented in the analysis. These regions are described in (Graabak and Bakken, 2011) and include the Island of Lewis in North West Scotland (Islands), Norway (Northern Europe), Rhine-Neckar Region in Germany (Central/Western Europe), Pomeranian Region in Northern Poland (North-Eastern Europe), Romania (South-Eastern Europe), Spain (South-Western Europe), Italy (Southern Europe), Serbia (Western Balkan) and Austria (Alpine region). The modeling approach to perform the regional studies comprises three main steps (Auer et al., 2009): (i) identification of the long-term 2050 technical potentials for different RES technologies; (ii) incorporation of barriers and constraints against the deployment of RES potentials and the development of grid infrastructures; and (iii) computation of grid infrastructure costs for different RES penetration levels. Each regional analysis was performed by experts of the respective region/country and involved an in-depth regional stakeholder consultation. The complete results of these analyses are available at the SUSPLAN project webpage (www.susplan.eu).

Taking into account relevant results from the regional case studies,[2] a comprehensive transnational analysis determined electricity and gas infrastructure routes and capacities required to integrate future RES generation. For this purpose, a cost-benefit analysis was performed to determine whether the benefits of the new infrastructure (CO_2 emissions savings and security of supply in a European context) outweigh its costs (Auer et al., 2009).

The regional and transnational analyses together with close consultation with regional experts in the course of several workshops, as well as surveys using questionnaires, provided the basis for the elaboration of strategies and policy recommendations for the implementation of RES technologies and the development of the required grid infrastructures in the pan-European system.

2.2. Future energy contexts: SUSPLAN storylines characterization

Regional and transnational studies in the SUSPLAN project were developed against the background of a consistent framework comprising four storylines – green, yellow, red and blue – with a time horizon up to 2050. The storylines are characterized by two driving forces: Technical development rate (slow or fast) and public attitude towards the adoption of environment-friendly options (positive or indifferent). Within this coordinate system, a consistent set of assumptions has been derived for the

[2] Please note that due to the high complexity of the transnational modeling exercise the scope of the optimization had to be reduced as far as possible, implying that certain regional features had to be simplified. This applies, for example, to the exclusion of some technologies which only play a role in individual countries (such as CSP) or to the simplified representation of power flows beyond the borders of the EU. Also, distribution grids are only analyzed on regional level whereas the transnational analysis focuses on the transmission system.

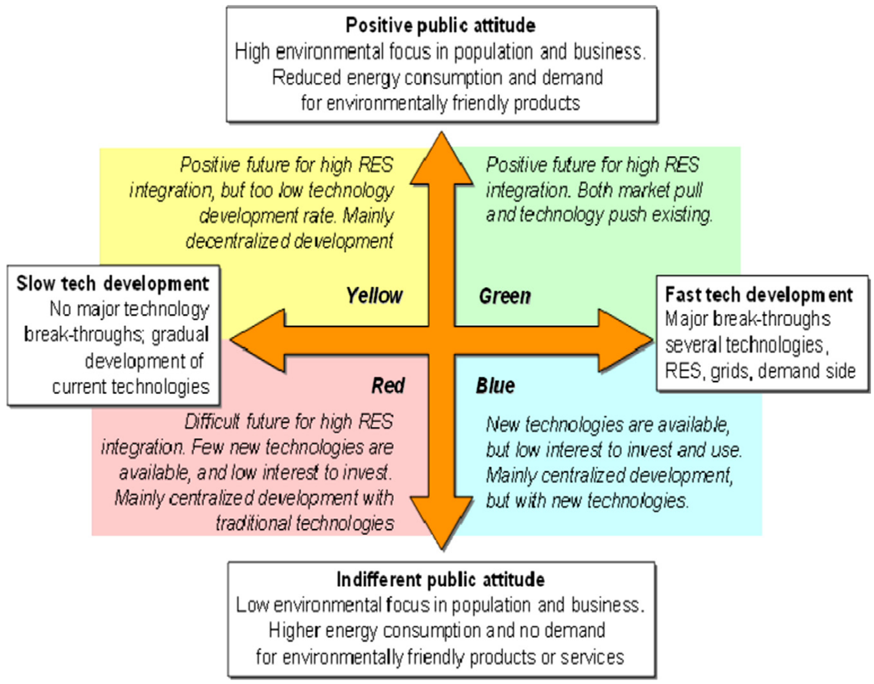

Fig. 1. SUSPLAN storylines overview (for a color version of this figure, the reader is referred to the web version of this article).

development of electricity and gas demand and RES deployment. The four storylines are shown in Fig. 1 and detailed described in (Auer et al., 2009).

Technological development determines whether RES and energy efficient technologies as well as innovative storage, transmission and smart grid appliances are available on the market. Public opinion is of particular importance for the deployment of RES and energy efficient technologies, and the diffusion of distributed RES generation as well as smart grid applications in households and grid development.

Positive public attitude favors RES penetration in the green and yellow storylines. Also, high consumer awareness in these storylines implies lower demand levels (for electricity and gas) due to high potential for demand response and overall energy savings. On the other hand, lack of environmental concern and public acceptance in the red and blue storyline hinders the use of energy efficient technologies, the deployment of RES and grid development. Consequently, the deployment of RES technologies, as far as these are technologically available in these storylines, takes place only on a government-driven, "top-down" level. Fast technology development favors the deployment of RES technologies in the green and blue storylines.

The red storyline is the least sustainable one, where RES deployment is inhibited by slow technology development and lack of consumer awareness. In the yellow and blue storylines, RES deployment is hindered by slow technology development in the former, and lack of public awareness in the latter. Finally, the combination of positive public attitude with fast technology development makes the green storyline the most sustainable future context of SUSPLAN, where high shares of renewable energy generation are achieved.

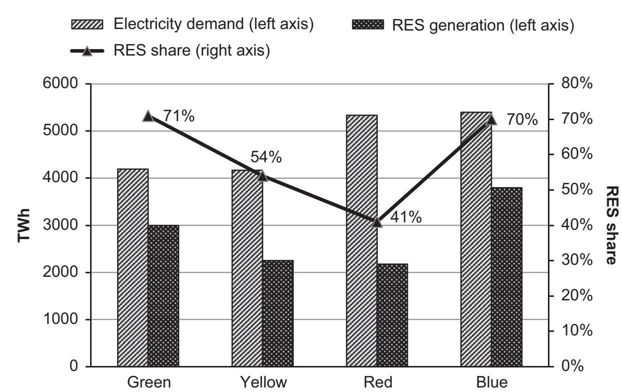

Fig. 2. RES share in electricity generation in the EU in 2050.
Source: Based on Joode et al. (2011).

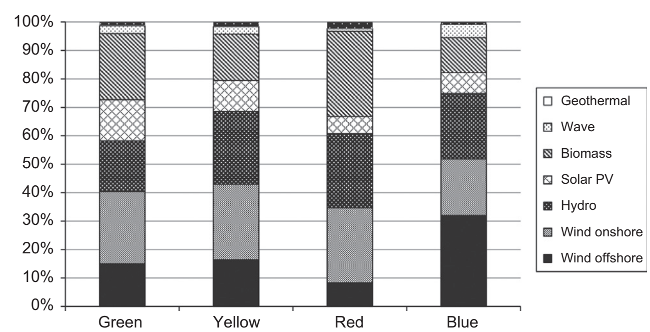

Fig. 3. Share of different RES technologies on total RES generation portfolio in 2050.
Source: Based on Joode et al. (2011).

3. Infrastructure needs to integrate renewable energy

3.1. Deployment of RES potentials in the different storylines

The main drivers for energy infrastructure development in the EU are directly related to the policy goals of internal market integration, security of supply and RES integration. According to the studies performed for the Ten-Year Network Development Plan (TYNDP) elaborated by the European Network of Transmission System Operators for Electricity (ENTSO-E), the integration of RES is the main driver behind larger and more volatile power flows over long distances across Europe (ENTSO-E, 2012). According to the plan, 80% of the 100 identified transmission bottlenecks until 2020 are related to RES integration. The impact of RES on infrastructure needs will become even higher if full long-term potentials are deployed. Therefore, a clear picture of future renewable potential deployment is essential for infrastructure development planning. In the SUSPLAN project, according to the storylines definition, four different empirical sets for RES generation share on total electricity production were determined on aggregated level for the EU. These were based on Green-X (www.greennet-europe.org) modeling results up to 2030 and extrapolated from 2030 up to 2050 based on RES potentials and efficiency targets. Total electricity demand in each storyline was computed based on an extrapolation up to 2050 of the Primes model results for 2030 (European Commission, 2007). Fig. 2 shows the RES shares as compared to the total electricity demand by 2050 in the different storylines of SUSPLAN. As it can be observed in the figure these shares vary between 41% (red) and 71% (green).

Joode et al. (2011) present the share of each renewable technology within RES generation portfolios in each storyline by 2050 (see Fig. 3). In all storylines, wind energy represents the largest share within RES generation portfolios in 2050, varying from 35% in the red storyline to 52% in the blue one due to higher deployment of offshore wind in this storyline. Onshore wind is a proven technology and implies the least uncertainties regarding its future deployment. Higher or lower potentials for onshore wind can be found in all regions analyzed within SUSPLAN (Frías et al., 2011a). High potentials for offshore wind are located in the North Sea. According to the results from the transnational analysis, more than 500 TWh would be generated in 2050 in the blue storyline by the UK and Ireland alone (Joode et al., 2011). Also Norway has significant potential for offshore wind.

With respect to solar power, results from the transnational analysis pointed out, that shares of generation by solar photovoltaics (PV) in 2050 could be varying from 7% in the red storyline to 15% in the green storyline. These lower shares (compared to wind generation) can be explained by higher uncertainties regarding the development of this technology. Nevertheless, recently there have been impressive improvements in technology and costs of PV systems and it is expected that investments needed to develop these systems will continue to decrease in the future (IEA, 2010). The main potential for solar generation in Europe is located in Southern European countries, such as Spain and Italy. Results of SUSPLAN indicated that Spain could generate more than 200 TWh from PV systems in the green storyline (Joode et al., 2011).

Regarding concentrated solar power (CSP), this technology could play a role in the European context, but limited mainly to the Southern European countries[3] (see (Frías et al., 2010) and (Lanati and Gelmini, 2010)). Also, great potentials in the Middle-East and North Africa deserts could be exploited and electricity could be transported to Europe (see e.g. DESERTEC Project (Dii-Eumena, 2011) or Mediterranean Solar Plan (UfM, 2011)). However, the transnational analysis within the frame of the SUSPLAN project focused on the European region and did not explicitly include an optimization of external RES generation potentials. Referring to the DESERTEC vision, a transport of around 700 TWh/year of solar electricity from the Middle-East and North Africa to the main centres of demand in Europe is conceivable by 2050. To transport this energy, 20–40 HVDC transmission lines with 2.5–5 GW of capacity would have to be built by 2050 (Trieb and Müller-Steinhagen, 2009). An assessment referring to the potential impacts of power imports from North Africa is provided in the SUSPLAN case study for Spain (Frías et al., 2010).

[3] Please note that the transnational modeling exercise did not include an optimization of CSP capacities.

The future deployment of biomass is subject to uncertainties. According to the SUSPLAN analyses, barriers such as a lack of biomass markets, transportation infrastructure and supply chains as well as requirements in terms of efficiency improvement and application of new combustion technologies will limit a strong deployment of this technology. Within the SUSPLAN project, shares of biomass generation on RES generation portfolio range from 12% in the blue to 30% in the red storyline in 2050. The main potential is located in Northern and Eastern European countries.

Hydro power will be no longer the main source of renewable generation in Europe by 2050 but will continue to provide an important share of RES generation, which varies from 18% in the green storyline to 26% in the red and yellow storylines (the latter due to the lower penetration of new RES technologies in those storylines). The highest potentials for hydro power generation in Europe are located in Northern Europe, mainly Norway and Sweden.

Finally, other new technologies like geothermal or wave and tidal energies are expected to play a limited role in 2050. Together, their share could reach 5% in the blue storyline by 2050.

The location and the deployment of RES potentials are the main drivers for electricity grid expansions. The highest RES shares in individual countries within the EU are likely to be achieved in the UK and Ireland due to wind power potential, Iberian Peninsula due to solar and wind power potentials, Norway and Sweden due to hydro power, and Denmark due to wind power. The Balkan Peninsula and Greece also have significant RES potentials in the long-term.

3.2. *Resulting energy infrastructure needs*

3.2.1. *Electricity transmission infrastructure*

Based on the assumed increase in RES generation and the development of electricity demand a substantial extension of transmission capacity is expected in all storylines. According to the deployment of RES generation potentials, important electricity corridors that should be developed or expanded include the connection of the Iberia Peninsula to Central Europe through France, the expansion of links between South Europe and Eastern Europe, and the development of a North Sea offshore grid (Joode et al., 2011). In general, major net electricity flows will occur from the high potential areas in the southwest and north to load centers in the central and eastern part of Europe. The extension of cross border capacity within the SUSPLAN project is analyzed with a grid model which optimizes grid extension costs and costs for power plant dispatch (Joode et al., 2011). Table 1 summarizes the resulting AC and DC cross border capacity additions across Europe up to 2050. The results indicate that a doubling of cross border capacity until 2030 and another doubling until 2050 would be required in the scenarios with a high European wide RES share. Particularly large extensions can be expected between Spain and France and further on to Germany especially in the green storyline with the highest RES share. Further major corridors are between the Scandinavian countries and UK to central Europe as well as between eastern and central Europe (see Fig. 4). Generally, network expansion needs and related costs rise with the amount of intermittent RES-generation (with particularly high shares in blue and green scenarios) and are negatively correlated with the need for gas infrastructure extensions (see Section 3.2.3.). Therefore, in an overall assessment of the transmission system extensions, the green and yellow storylines display the lowest costs (for a detailed cost assessment please refer to (Joode et al., 2011)). However, one has to note that through the further development of storage technologies, demand side management and integration of distributed generation the extension needs in both sectors could still be reduced. Therefore, the results might be seen as an upper boundary for the required extensions.

3.2.2. Electricity distribution infrastructure

The expected future growth of RES generation will certainly increase the amount of distributed generation (DG) that is connected to distribution networks, which will affect distribution network investment requirements. Typically, distribution investments decrease for moderate DG penetration levels whereas they increase for large penetration levels. Nevertheless, the actual impact of DG on distribution network costs will largely depend on how the connection of this capacity is carried out – under a passive "fit-and-forget" approach or under an advanced integration of DG facilitated by the development of the Smart Grids (Cossent et al., 2011). Furthermore, the search for cleaner and more efficient sources of energy is pushing the electrification of the transportation sector. Electric vehicles (EVs) will presumably be connected mostly to distribution networks, and, similarly to the case of DG, the widespread adoption of EVs will impact distribution networks costs. This impact will depend on the management of battery charging and on the implementation of vehicle-to-grid (V2G) capability (Pieltain et al., 2011).

The distribution grid costs to supply the demand and to accommodate the expected DG and EV penetration by 2050 were estimated in the Spanish case study of the SUSPLAN project, based on three main components: The baseline cost, which represents the costs incurred by distribution companies to supply the demand, i.e., without considering DG and EVs, the incremental cost due to the connection of DG, and the incremental cost due to the connection of EVs. These costs were computed by a large-scale distribution planning

Table 1
Cross-border capacity extensions in the EU27+Norway, Switzerland and Balkan countries under the four SUSPLAN storylines.
Source: Based on Joode et al. (2011).

Storyline	Status quo	Extension of cross border capacity	
	2010 AC/DC (GW)	2010–2030 AC/DC (GW)	2030–2050 AC/DC (GW)
Blue	47/8	52/21	93/20
Green	47/8	52/21	117/20
Red	47/8	52/21	44/12
Yellow	47/8	52/21	45/17

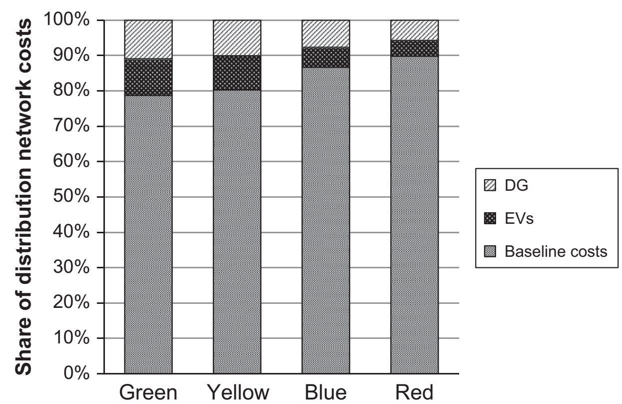

Fig. 5. Share of different cost components in the total distribution grid investments in the Spanish case study in 2050.
Source: Frías et al. (2010).

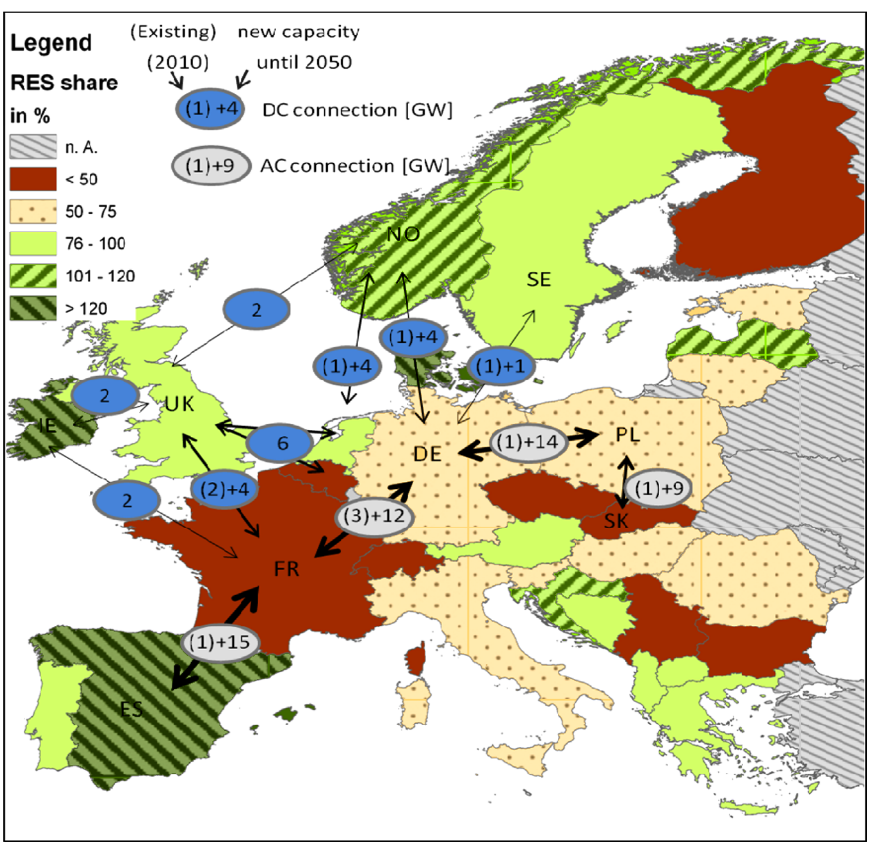

Fig. 4. RES share in EU countries and extension of cross- border transmission capacities until 2050 in the green storyline.
Source: Based on Joode et al. (2011).

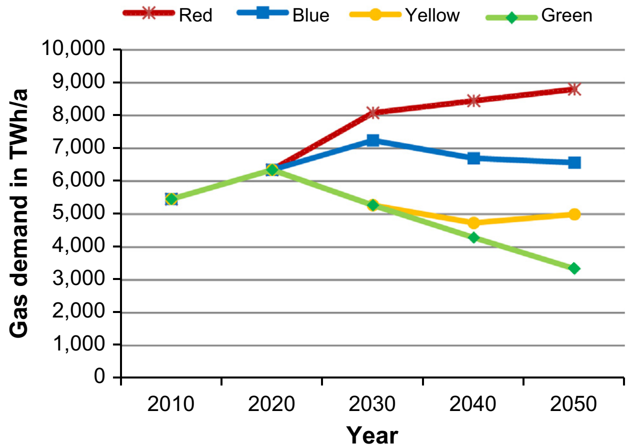

Fig. 6. Results on possible developments of the European gas demand until 2050, according to the SUSPLAN storylines.
Source: Auer et al. (2009).

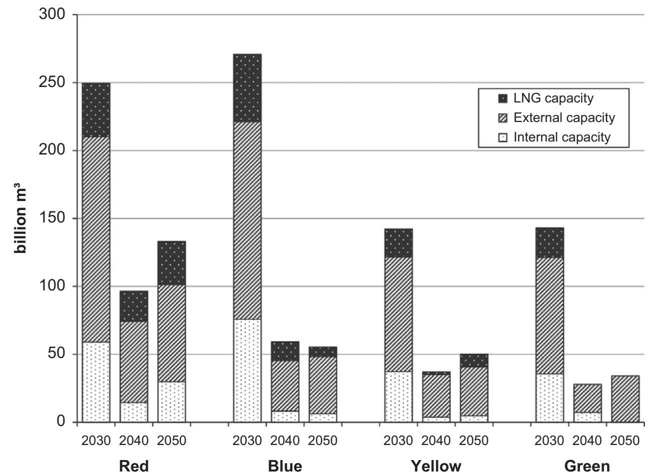

Fig. 7. Extension of gas pipeline capacity between 2020 and 2050 in the four SUSPLAN storylines.
Source: Based on Joode et al. (2011).

model (reference network model), described in (Mateo et al., 2010). The detailed methodology applied to compute incremental distribution costs caused by DG and EVs are described in (Cossent et al., 2011) and (Pieltain et al., 2011), respectively. In the Spanish case study different factors conditioning the impact of DG and EVs on distribution costs were considered depending on the storylines characterization. In the case of EVs this refers mainly to batteries charging management (dumb or smart charging). Regarding DG, the main influence factors are active or passive network operation and type of distribution area. The detailed methodology and assumptions adopted in this analysis can be found in (Frías et al., 2010).

Fig. 5 shows the share of baseline costs, costs driven by EVs and costs driven by DG in the estimated total distribution costs in Spain in 2050. According to the results, in the green storyline more than 20% of 2050 total distribution costs will correspond to the connection of EVs and DG. It is important to mention, though, that results have certain limitations. Firstly, due to model restrictions, the interactions between battery charging and local DG production could not be considered although synergetic effects could reduce total distribution costs. Secondly, the costs of Smart Grid infrastructure are not included in the analysis due to a lack of predictability.

3.2.3. Gas infrastructure

The extension of RES electricity generation will not only have an impact on the development of the electricity grid but also on the gas infrastructure. Particularly in the medium term, an extension of gas import infrastructure is expected as EU gas resources will be depleted and additional gas imports will be necessary. Therefore, substantial investments in external gas infrastructure and LNG terminals are expected already until 2030. In addition, high gas imports will also require an upgrade of EU-internal transfer capacities. However, other factors influencing the future gas infrastructure developments are less predictable or evolve in different directions. On the one hand, gas might play an important role in the power sector as the fossil fuel with the lowest specific CO_2 emissions. On the other hand, gas consumption in Europe might decrease due to efficiency gains and increased RES usage in the electricity- and heating sector (as assumed for the green and yellow storylines which are characterized by a very positive public attitude towards RES). The resulting overall gas demand across Europe is displayed in Fig. 6.[4] Consequently, the needed investments beyond 2030 differ significantly depending on the expected RES electricity generation and assumed energy efficiency improvements (see Fig. 7, for detailed results refer to (Joode et al., 2011)).

4. Barriers to energy infrastructure development

The development of energy infrastructure faces strong barriers both at regional/national and pan-European level. The types of barriers that hinder the development of energy infrastructures can be categorized in various ways, for example into technical and non-technical barriers, societal, administrative or financial barriers. The investigations within the SUSPLAN project pointed out three main fields of particular relevance, namely issues related to infrastructure development procedures (planning and authorization), infrastructure-related financing schemes and aspects of network management (Klobasa and Boie, 2011).

4.1. Barriers related to infrastructure development procedures

Planning of new energy infrastructures in general is a complex process which needs to take into account a multitude of factors, like the development of electricity and gas demand, evolution of future generation capacities and technology portfolios as well as potential changes in the political framework conditions. Some of the most relevant barriers related to the planning and authorization phases of infrastructure development include:

(i) Strong interrelation between goals related to energy planning and spatial planning (e.g. transportation, agricultural, tourism or military purposes) or environmental planning (e.g. nature conservation goals or protection of endangered species). These interdependencies as well as the limited predictability of the above named factors create a high level of uncertainty for the planning process in general.
(ii) High number of actors involved in the development of new energy infrastructures. Although, transmission and distribution system operators hold the general responsibility for the elaboration of network expansion plans, several other authorities

[4] Please note that there is a differentiation between the gas demand in the residential and industrial sector which are both determined exogenously (input according to the storyline setting) and the demand in the power sector, which is a result of the power system optimization.

Table 2
Characteristics and duration of electricity infrastructure planning processes in the SUSPLAN case study regions.
Source: Based on Frías et al. (2011b).

Region	Planning horizon	Aspects that delay the infrastructure development processes
Outer Hebrides (north-western Scotland)	7 years	Multitude of involved local authorities causes planning delays
Norway	5–15 years	Large possibilities for NGOs and interest groups to oppose to construction plans; besides TSO's and regulatory authority also Ministry of Environment, Climate and Pollution Agency and Plan and Building offices are involved
Rhine Neckar Region (south-western Germany)	10 years	Besides TSO's and regulatory authority also the Federal Ministry of Economics and Technology, the Federal Ministry of the Environment and local authorities are involved
Pomerania region (northern Poland)	15 years (and 7 years implementation plan)	Particularly complex planning procedures and lack of consistency between spatial and energy planning; besides TSO's and regulatory authority a multitude of stakeholders, also on municipal level, is involved and many consultations and approvals are required; unclear situation for offshore infrastructure (also Ministry of Infrastructure involved)
Romania	10 years	Need for several approvals; lack of transparency of the process
Spain	10–20 years	Long administrative procedures; lack of coordination between the different levels of government (no clear definition of responsibilities); besides TSO's and regulatory authority involvement of Ministry of Industry, Tourism and Trade
Italy	10 years	Timeframe for the conclusion of the authorization process and the construction of new lines 7–10 years; besides TSO's and regulatory authority involvement of Ministry of Economic Development and Ministry of the Environment
Serbia	5 years (also considers perspectives of longer-term studies)	Besides TSO's and regulatory authority involvement of Ministry of Mining and Energy, Ministry of Environment and Space Planning and several local authorities; a negative image of grids is constantly propagated by the media
Austria	10 years	Besides TSO's and regulatory authority involvement of Federal Ministry of Economic Affairs; several NGO's; local authorities and citizen forums; possibility for many parties (NGO's, local authorities, etc.) to present new entries during the process; Environmental Verification Process (EVP) is often delaying the procedure

are involved in the process: Environmental authorities are responsible for the environmental impact assessment, different national and regional authorities and administrative bodies are consulted and also several non-governmental organizations (NGOs) and regional citizens' organizations interfere with, and can thus significantly delay, the planning process.

Typically, the implementation process for new electricity infrastructure can be divided into three stages: (a) preliminary stage during which network extension demands are identified and technical studies with respect to potential reinforcements are conducted; (b) an authorization stage which implies public consultation, environmental impact assessment and consultation of the permitting authorities; and, (c) the construction stage which involves the eventual construction of the new lines and the compensation of potentially aggrieved parties (ENTSO-E, 2010). However, planning procedures can significantly differ among the European member states (and even between the regions investigated in the SUSPLAN project (Frías et al., 2011b)) in terms of the number of actors involved, the level of coordination and cooperation among them (and the different policy goals) and the regarded planning horizon, which can vary between 5 and 20 years (see Table 2).

This lack of harmonization of planning procedures for energy infrastructures among the European member states will gain particular gravity in the context of a future pan-European energy system reaching high RES shares, for example by exploiting the vast offshore wind potentials of the Nordic states or the huge solar potentials of the southern European or North African countries (as assumed in the blue storyline of the SUSPLAN project, with offshore wind contributing with more than 30% of the total RES share (Joode et al., 2011) or as envisioned for realization of the Mediterranean Solar Plan (UfM, 2011) or the DESERTEC project (Dii-Eumena, 2011)). Such scenarios will require a maximum of coordination and cooperation on a European level as well as efficiently functioning and well integrated national and regional planning structures as the basis for this transnational cooperation.

(iii) Lack of integration between planning for different RES and for electricity and gas infrastructures. As there are significant interdependencies between the development of the future electricity and gas demand (Joode et al., 2011), this lack of coordination creates an additional uncertainty for investments in the respective infrastructures.

(iv) Public opposition to grid extensions. Public resistance is a common reason for significant delays or sometimes even a complete obviation of projects. This is all the more important with a view to a future energy system with a high RES penetration, large shares of distributed generation and extensive application of energy-efficiency and Smart Grid technologies since these developments require substantial behavioral changes at consumer or household level, respectively. The lack of public acceptance for RES and infrastructure projects, however, is often oversimplified and merely attributed to the NIMBY (Not in My Back Yard) syndrome. In the course of the analysis in SUSPLAN project, different dimensions of public resistance could be distinguished which also vary in their relevance for the investigated case study regions (Klobasa and Boie, 2011). In this respect, three major aspects can be emphasized:

- Fear of negative health-impacts and of a general reduction of well-being and quality of life. This can be attributed to electromagnetic radiation caused by by-passing high voltage transmission lines but can also be a result of the potentially drastic changes in the landscape which disturb the scenery which the affected population is emotionally attached to and rooted in.
- Concerns in terms of economic disadvantages. This might imply a loss of property value, loss of income due to land use conflicts (e.g. with agriculture, fishery, hunting or tourism) or rising household electricity prices as a result of cost allocation for RES- or transmission projects to the consumers.
- Environmental concerns/fear of negative impacts on endangered species. Noteworthy in this context are particularly wild birds which might be affected by overhead transmission lines or wind parks and marine life (dolphins or whales) that might impaired by offshore wind parks or wave/tidal power stations.

Additional to these different dimensions of public resistance, which each need to be specifically addressed depending on their relevance in the region concerned, there is a general need for creation of confidence, trust and knowledge among the population. The public often generally questions the need for infrastructure expansions or holds a general mistrust towards planning and siting decisions of RES and transmission projects, particularly if decisions are taken on a high (e.g. on national or European) level (Schweizer-Ries et al., 2010; Deutsche Umwelthilfe, 2010).

4.2. Barriers related to infrastructure investment and financing

Construction of new energy infrastructures is highly capital intensive and since the facilities have a long operating lifetime (depending on the technology 40 up to 80 years) the respective investments require particular security and stability of the regulatory framework and capital markets. This is even more relevant if cross-border projects or multinational offshore grid developments are concerned, since they are subject to particular risks and planning insecurities and require notably high investment volumes (for detailed cost estimations refer to (European Commission, 2011b)). Based on a Europe-wide survey among financial institutions, national regulatory authorities and Transmission System Operators (TSOs), (Roland Berger Strategy Consultants, 2011) point out that past investment volumes in electricity and gas infrastructure have been substantially lower than the volumes that will be needed to meet the 2020 targets as indicated by the European commission in (European Commission, 2010). In the period 2005–2009 a total of 9.1 billion Euro per year has been raised by European TSO's, of which 5.8 billion Euro were allocated to electricity and 3.3 billion Euro to gas infrastructure investments, respectively. Particularly in the electricity sector, yearly investment volumes are expected to increase by 70% in the period up to 2020 (Roland Berger Strategy Consultants, 2011). It is questionable whether this increase in investment volumes can be achieved without strong efforts to enhance the conditions for private finance. In this context, the main investment and financing barriers to the development of energy infrastructures comprise:

(i) Difficulty to attribute costs and benefits of infrastructure expansions by country (European Commission, 2011b). Existing regulatory frameworks and investment incentive schemes in the European Member States are mainly aimed at cost-optimal solutions on national level. Under these conditions, national regulatory authorities focus on minimizing tariffs rather than realizing solutions which would be beneficial (e.g. in terms of cost savings, security of supply or climate protection) on a regional or pan-European level (European Commission, 2011b; Klobasa and Boie, 2011; Van der Welle et al., 2011). Respective targets and mechanisms for identifying and sharing positive as well as negative externalities of energy infrastructure developments and the creation of respective investment incentives for TSOs are still widely lacking. Consequently, one of the major challenges with respect to RES integration in the European context is the creation of efficient mechanisms for transnational cost allocation for investments in cross-border transmission capacities and offshore grid infrastructures of multinational interest.
Within the SUSPLAN analysis, cross-border transmission capacity extensions of more than 100 GW are assumed for the green and blue storylines (see Section 3.2), which implies substantial cross-border infrastructure investments. This requires the elaboration of innovative cost sharing strategies in order to avoid that regions with high RES potentials or electricity transit suffer from rising electricity tariffs although they do not directly benefit from the utilization of these potentials. This would possibly evoke strong public opposition to such developments.

(ii) Lack of financing mechanisms for the upgrade and extension of national transmission capacities. To allow for the required investments, effective financial incentives and sufficient availability of debt capital for TSO's must be secured on national level. To this effect, the economic capabilities and existing incentive schemes in the individual EU Member States vary greatly in terms of capital availability, level of return on investment and effectiveness of hedging country specific risks. Such discrepancies between national financial regulations and shortcomings in the financial markets will set boundaries to RES integration into the European energy system in the future.

4.3. Barriers related to infrastructure management

Some aspects regarding the management of energy infrastructures hinder a massive penetration of RES generation since they may limit the amount of renewable generation integrated into the network and they may also lead to a sub-optimal utilization of the network capacity. These aspects include:

(i) Inefficiencies of capacity allocation and congestion management mechanisms leading to high congestion management costs and sub-optimal utilization of network and generation resources (Neuhoff et al., 2011; Van der Welle et al., 2011). One source of inefficiency results from the fact that in many European countries internal transmission congestions are solved by countertrading or redispatching. This type of mechanism may result in high congestion management costs since generators in the export constrained zone have an incentive to sell electricity (causing congestion) in the day-ahead market expecting payments from the system operator to not produce it, and generators in the import constrained zones have an incentive not to sell in day-ahead markets and wait until the system operator requests their production, which would also imply an extra revenue for these generators. Another source of inefficiency is related to the allocation of cross-border transmission capacity. To allocate cross-border transmission capacity, first the Net Transfer Capacity (NTC) is defined and then this capacity is auctioned. NTC values are generally defined for several interconnections on a bilateral basis, without taking into account interdependencies among the different interconnections in meshed grids. TSO's have an incentive to set conservative limits for the available transmission capacity in order to maintain feasibility under different scenarios of generation and demand and to avoid congestions within their countries. Differences between national and cross-border congestion management schemes in many European countries distort the level playing field for market participants. National congestions are handled by redispatching or countertrading, keeping energy prices equal on both ends of the congestion. In contrast, cross border congestion management results in two zones with different prices. Costs for redispatching or countertrading are in general included in grid tariffs paid by the consumers while the costs for auctions on cross border capacity are paid by suppliers. Therefore, internal transactions and resulting loop flows are preferred to inter-zonal transactions. Furthermore, zonal pricing requires problematic zone delineation. With increasing amounts of renewable generators, congestion patterns may change very frequently making an adaptation of price zones necessary. Since zone delineation changes the allocation of costs between stakeholders, its definition is a complex process.

(ii) Lack of balancing services market harmonization across Europe. Growing levels of wind energy and other intermittent generation increase the uncertainty about power production in day-ahead and longer-term forecasts. More accurate

Table 3
Most relevant barriers for grid development and RES integration in the nine SUSPLAN case study regions.
Source: Based on Klobasa and Boie (2011) and Van der Welle et al. (2011).

Case study	Key issues
Norway (N Europe)	Lack of international cost-allocation strategies, lack of public acceptance due to the already high national RES share, lengthy planning procedures
Outer Hebrides (N-W-Scotland)	Lack of international cost-allocation strategies, lack of public acceptance due to high environmental vulnerability of the region, conflicting goals concerning RES development and environmental (in particular marine) protection
Austria (Alpine Region)	Lack of international cost-allocation strategies, lack of public acceptance due to the already high national RES share, lengthy planning procedures
Rhine-Neckar Region (C-W Europe)	Lack of balancing options in distribution networks with high RES shares and lack of respective financing schemes for investments, public resistance due to high population density, lengthy planning procedures
Pomerania (N-E Europe)	Partly obsolete grid infrastructure requires extensive modernization to allow for RES integration, lack of respective national financing opportunities, complex planning and permitting procedures and lack of coordination between spatial- and energy planning
Romania (S-E Europe)	Partly obsolete grid infrastructure requires extensive modernization to allow for RES integration, lack of respective national financing opportunities, insufficient national transport infrastructure
Serbia (E Europe)	Partly obsolete grid infrastructure requires extensive modernization to allow for RES integration, lack of respective national financing opportunities, social issues related to potentially rising electricity prices
Italy (S Europe)	Strong need for investments in cross-border transmission capacity and balancing options (demand side management) and lack of respective cost allocation schemes, lengthy planning procedures
Spain (S-W Europe)	Strong need for investments in regional and cross-border transmission capacity and balancing options (demand side management) and lack of respective cost allocation schemes

forecasts closer to real time production would reduce this uncertainty and allow for a higher integration of RES. However, different gate-closure times and transaction costs that characterize the different national balancing markets limit the adjustment of energy and balancing services among different countries creating inefficient transmission capacity allocation and reducing the responsiveness of international flows to national bids (Neuhoff et al., 2011; Borggrefe and Neuhoff, 2011).

(iii) Lack of harmonization among grid codes, imposing difficulties to the connection of renewable generators to the grid. As a consequence of the challenges imposed by high penetration of intermittent generation to power systems operation, "new" technical requirements for the connection of wind farms were added to regional/national grid codes. In general, these requirements establish the behavior of wind farms under fault condition and the participation of wind generators in power system control (frequency and voltage control). However, there is a lack of harmonization among grid codes of different EU countries mainly due to different technical requirements, absence of homogeneity and inaccessibility due to differences in language and structure, and the dimension of requirements regarding the capabilities and behavior of wind power plants. This lack of harmonization among grid codes creates significant inefficiencies for manufactures and wind power developers imposing extra costs and requiring additional efforts from the wind power industry (EWEA, 2008).

(iv) Insufficient grid flexibility, limiting the amount of intermittent renewable generation integrated into the system. According to (Denholm and Hand, 2011), grid flexibility is related to the ability of the aggregated set of generators to respond to net load uncertainty and variation. In this sense, grid flexibility (and, consequently, RES penetration) is constrained in most European countries by the limited flexibility of thermal generators to change their output and the limited capacity to exchange power with neighboring grids.

4.4. Relevance of infrastructure development barriers in the transnational and regional/national context

A number of the identified barriers are equally relevant for all regions or particularly important on a transnational level, respectively. Other barriers, however, are of varying importance depending on the specific national or even regional framework conditions. Such regional differences and varying applicability of issues should be taken into account in the design of strategies and policies addressing RES and infrastructure development in a European context. Table 3 presents the most relevant barriers for grid development and RES integration in the SUSPLAN case study regions.

An aspect which is of particular relevance in the transnational context is the lack of consistent goals and a coordinated approach in infrastructure planning among European countries. Also, the absence of strategic financing schemes for transnational interconnections as well as for required grid enforcements in electricity transit countries impedes an efficient use of RES on a European scale. Furthermore, the lack of incentives and international financing schemes for the development of balancing capacities constitutes a major barrier on the transnational level. And finally, public resistance to energy infrastructure projects is, to a certain degree, relevant in all regions, although the magnitude of the resistance and the underlying reasons may vary from region to region (Frías et al., 2011b; Klobasa and Boie, 2011; Van der Welle et al., 2011).

A lack of international cost allocation strategies for infrastructure investments is relevant for all regions but is of particular importance for electricity transit countries (e.g. the Southern European regions in the case of major imports of solar electricity from North Africa (Frías et al., 2010; Lanati and Gelmini, 2010)) and regions with high RES potentials but low additional RES demand (e.g. the Northern European regions with vast offshore wind- or wave energy potentials but already high national RES shares (Gair et al., 2010; Graabak et al., 2010)).

National financing issues have been found to be of particular relevance in the Eastern European countries (Linnerud et al., 2010; Graabak et al., 2010; Tantareanu et al., 2010). Here, the partly obsolete grid infrastructures currently do not allow for a large-scale integration of RES but insufficient economic possibilities prevent the required extensive infrastructure reinforcements on national level. In these regions, also complicated planning procedures and conflicts of interests between spatial and energy planning constitute major barriers because there is a particular lack of integration between the respective planning systems (definition of processes, responsibilities and time horizons) on national and regional level (Klobasa and Boie, 2011).

Densely populated areas as well as areas of particular environmental vulnerability or natural beauty record strongest problems in terms of public resistance against RES and the related infrastructure developments. This is valid, for example, for the populous regions of Northern Europe (e.g. Rhine-Neckar region) or for the particularly sensitive landscapes in the Austrian Alps or on the islands of Scotland (Outer Hebrides) (Gair et al., 2010; Luxembourg et al., 2010; Weiss et al., 2010). Another issue causing strong public resistance, again particularly in economically less developed regions (e.g. in the eastern European countries), is the fear of potentially rising consumer prices for electricity in the wake of strong RES development and subsequently required grid reinforcements (Linnerud et al., 2010; Michalowska-Knap et al., 2010; Tantareanu et al., 2010). Since allocation of resulting costs to the disadvantage of the economically weak consumer groups might cause severe social problems, the deployment of large amounts of RES into the energy system is a very sensitive subject in such regions.

5. Integrated strategies to accelerate energy infrastructure development

The identified barriers in the fields of grid development procedures, infrastructure financing and management require the development of strategic measures addressing a multitude of issues within the various areas at the same time. Thereby, an integrated strategy focusing at all these areas must consider conflicts and adverse effects which might occur between different measures and should, at the same time, be able to exploit potential synergies between actions. The following sub-sections present the measures in the three fields of barriers identified within the SUSPLAN project. The policy recommendations derived from the analyses carried out in this project are detailed described in (Klobasa and Boie, 2011).

5.1. Strategies to enhance infrastructure development procedures

As described in Section 4, the major precondition for the realization of fast and effective authorization procedures for energy infrastructure projects is the creation of a broad public acceptance. Consequently, the affected population should be involved in the planning process as early as possible and the procedures should allow for a maximum level of transparency and integration of bottom-up inputs. On the other hand, infrastructure development processes must be simplified, accelerated and harmonized on EU-level to allow for a fast and efficient adaptation of the European national grids to the requirements of a high level of RES integration. Potential conflicts emerging from this two-sided approach must be taken into account when developing strategies for enhanced planning procedures.

Measures to raise the public acceptance of RES and energy infrastructure projects should include the following main aspects:

(i) Public information. The public should be integrated as early as possible into planning processes and should be informed about different technological options. Information should be made available concerning related costs and effects on health and environment, for example concerning overhead transmission lines in contrast to underground cable solutions (Schweizer-Ries et al., 2010; Deutsche Umwelthilfe, 2010). The use of advanced communication tools, like photomontage or three dimensional landscape models depicting the visual impacts of different technology solutions for a concrete landscape could help to create a more realistic image in the heads of the affected population and to reduce vague fears and undefined concerns (Klobasa and Boie, 2011). For the planning process the use of standardized tools, like the toolbox for implementation of energy projects as developed in the ESTEEM project (www.esteem-tool.eu) (ESTEEM, 2008), could help to create more transparency and to clearly define phases during which different stakeholder groups can express concerns and raise objections. The application of enhanced communication strategies and the formulation of clear political statements concerning RES-deployment and grid infrastructure development are required to foster the public understanding of the need for grid expansions. If infrastructure projects can be linked more closely to the target of developing RES and combating climate change, the public will more likely accept the developments (Schweizer-Ries et al., 2010; Deutsche Umwelthilfe, 2010).

(ii) Stronger integration of bottom-up inputs in the planning process. To allow for active involvement and participation of the affected population respective mechanisms should be created. However, at the same time, it is inevitable that the process duration is limited to prevent continuous interferences which obviate the overall project implementation (Gross, 2007; Van der Welle et al., 2011).

(iii) Implementation of satisfactory compensation mechanisms for affected communities and effective schemes for trans-regional burden and profit sharing. Particularly electricity transit regions suffering from landscape consumption but not directly benefitting from the RES deployment need to be compensated and incentivized. Transit fees for electricity, splitting of business taxes, commissioning fees or compensation payments for landscape consumption are possibilities which are currently under debate (Niedersächsische Staatskanzlei, 2011).

(iv) Creation of stronger regulations and incentives to minimize the visual impacts of transmission projects, for example stronger boundaries on the minimum distance to residential areas, financial incentives for TSOs to apply underground cable solutions and the long-term definition of designated infrastructure corridors.

Moreover, it is crucial to accelerate planning and authorization procedures. Noteworthy developments in this respect are, for example, the enforcement of the Energy Line Extension Act (EnLAG, 2009) and the Grid Expansion Acceleration Act (NABEG, 2011) in Germany. The EnLAG facilitates the realization of underground cable solutions for extensions of the extra high voltage network by providing a better legal basis for TSOs to allocate the resulting higher costs to the electricity consumers and by simplifying and accelerating the respective authorization procedures. It also defines binding guidelines concerning the choice of underground cable solutions in proximity to built-up areas and nature preservation areas. Complementing the EnLAG, the NABEG has a particular focus on the accelerated implementation of transmission projects of trans-regional or European interest. The law provides standardized guidelines for approval procedures for new transmission lines and reduces bureaucratic efforts by transferring the responsibility from the individual States' governments to the Federal Network Agency. The NABEG further fosters the promotion of transparency and the provision of financial compensation for municipalities which are affected by the construction of new power lines and it sets mandatory regulations for the connection of offshore wind parks through TSO's.

Similar legislations for the acceleration of grid planning procedures have been introduced by other European Member States such as the UK, Ireland or the Netherlands (European Commission, 2011b). However, harmonized or at least comparable legislation in all European member states as well as a stronger super-ordinate regulatory framework would be required to allow for the future facilitation of infrastructure expansions on the European level.

Finally, it is crucial to improve and better coordinate planning procedures among the responsible institutions for electricity and gas network planning and between interrelated policy fields (e.g. environmental-, transport infrastructure- and energy policy). A first step in this respect was the establishment of the Agency for the Cooperation of Energy Regulators (ACER) and the creation of ENTSO-E and the European Network of Transmission System Operators for Gas (ENTSO-G), respectively. Also with the creation of the Council of European Energy Regulators (CEER) and the organization of the Florence and Madrid forums have been established where relevant stakeholders can discuss further progress. However, future measures should build on a stronger institutional framework for planning, cooperation and coordination between actors responsible for gas and electricity network development as well as a streamlining of European policy goals concerning environmental conservation and renewable energy/climate change.

5.2. Strategies to facilitate infrastructure investment and financing

As discussed in Section 4.2, important milestones for the realization of investments for large-scale, cross border infrastructure projects and offshore grids include: (a) The design of an efficient transnational cost allocation mechanism, which allows for clearly identifying and sharing positive and negative externalities of cross-border infrastructure investments and large scale offshore developments, and (b) the creation of the corresponding regulatory framework and financial incentives on national level to facilitate the selection and realization of priority projects in the European context. This includes, besides enhancement of national transmission capacities, the targeted promotion of research and development and application of innovative technologies, like e.g. RES generation forecasting, storage, Smart Grid and innovative transmission technologies.

Enhancing the framework for investments in energy infrastructure on national and international level implies, besides others, the following measures:

(i) Creation of a long term, reliable and stable regulatory and financing framework on pan-European- and Member State level, reducing planning uncertainties and the risk of stranded investments in infrastructure projects. This involves, in particular, an enhancement of coordination among European regulators in the electricity and gas sectors. In this respect, an integrated planning approach taking into account the interdependencies between the development of electricity and gas demand will be a key point to ameliorate the predictability of infrastructure needs in both sectors (Joode et al., 2011; Klobasa and Boie, 2011; Van der Welle et al., 2011). An important step in this direction has already been taken by the formation of the ACER. A possibility to further push the coordinated development of European regulatory regimes and to advance in terms of harmonized gas and electricity planning approaches would be to grant more decisive power to ACER (which currently has a mainly coordinating and supervisory role) and to create a formal setting for a stronger dovetailing of electricity and gas network development. ACER in its role as mediator between ENTSO-E and ENTSO-G could be a key player for identifying projects of European interest and providing unified criteria for their acknowledgment as well as for developing harmonized guidelines for their accelerated implementation.

(ii) Provision of pan-European guidelines on accelerated and harmonized permit granting schemes. This is a key area to reduce the risks for investors, shorten pay-back periods and thus enhance the attractiveness of relevant investments in cross-border infrastructure. In the frame of several EU projects such as “RES-LEGAL” (http://www.res-legal.eu), “PV GRID” (http://www.pvgrid.eu) or “Wind Barriers” (http://www.windbarriers.eu) databases and country reports on the administrative framework and major barriers for the realization of different types of RES and RES grid access were prepared for EU countries. Continuing this work, also best practices for infrastructure development should be derived and disseminated across Europe in order to facilitate a stepwise harmonization of procedures.

(iii) Creation of specific investment incentives, ensuring sufficient rates of return for the investors. In this respect, national regulatory regimes need to be adjusted and coordinated on European level to allow for sustainable project development. According investment incentives have so far only been put in place by individual European Member States and have rarely been specifically focused on RES integration. For example, France, the UK and Italy have introduced specific incentives, e.g. in form of revenue premiums for investments in infrastructure projects of particular importance (European Commission, 2011b).
Also with respect to this issue, ACER could play an important role in helping to push for a coordinated regulatory approach among the European Member States and to develop efficient incentive schemes (e.g. investment premiums) which are tailored to the needs of the TSOs (e.g. through a stakeholder consultation process).

(iv) Inclusion of non-European countries in the Inter-TSO Compensation (ITC) mechanism. Currently, the ITC mechanism does not cover congestion losses caused by power flows originating from non-European countries. This would, however, be of particular importance if large-scale exploitation of regional potentials is to be achieved, for example the realization of extensive solar power imports from Northern African countries (Mediterranean Solar Plan or DESERTEC vision). In this context solutions to incentivize investments in cross-border connections (also with non-EU countries) are of particular importance. Regarding strategic interconnections with non-EU countries for which the ITC-mechanism currently does not apply, it is conceivable that the EU or ACER, respectively, offers guidelines or standardized template agreements to facilitate the negotiations.
Although a step in the right direction and currently the only pan-European cost allocation mechanism in place, it offers only limited possibilities to stimulate the required infrastructure developments. This is due, besides others, to the following reasons: The volume of the fund is limited to 100 million Euros which might not be sufficient to fully cover future costs; allocation of compensation payments might become increasingly complicated assuming advancing European market integration causing more complex constellations with respect to power flows and the mechanism offers only ex-post compensation and does not directly (ex-ante) incentivize cross-border investments.
For gas, however, no comparable mechanism exists so far. It could thus be recommended to develop an according compensation system for cross-border gas flows as well.

(v) European financial support instruments, like the Trans-European Energy Networks (TEN-E) fund, the European Neighborhood Partnership Instrument/Neighborhood Investment Facility (ENPI/NIF), the European Energy Programme for Recovery (EERP) or the 7th Framework Programme for research, technological development and demonstration activities (RTD), and the Connecting Europe Facility (CEF) provide financial support for different areas of infrastructure (energy, information, transport) through the European Infrastructure Package (EIP) (for detailed information about the programs please refer to (European Commission, 2006; ENPI/NIF, 2012; EERP, 2012; FP7-RTD, 2012; CEF, 2011)). Notably the EERP provided targeted funds of 565 million Euros for the development of offshore wind power projects with pan-European significance in terms of meshed offshore grids connecting several countries thus enhancing the possibilities for cross-border electricity trading (European Commission, 2011b). However, according to consultation of European TSOs by (Roland Berger Strategy Consultants, 2011), grants provided by the European Union so far played a minor role in infrastructure financing. It can thus be recommended to review the current allocation of European infrastructure funds in the context of cross-border infrastructure developments and RES integration and to allocate further funds specifically to the realization of respective projects of pan-European interest.

(vi) Development of electricity infrastructure in form of “citizens' grids” (“Bürgernetze”), has been discussed in Schleswig Holstein, Northern Germany (Arge Netz, 2012) and was recently suggested by the German minister for the environment Altmeier in order to support the realization of the German “Energiewende”. The suggestion involves that, primarily for the population affected directly by new transmission lines, a share of 15% of the total investment shall be reserved as “citizens' dividend”, allowing them to benefit from a fixed interest rate of 5% (BMU 2012). Analog to communal ownership of RES generation facilities (e.g. wind parks), this innovative approach could contribute, on the one hand, to developing additional sources of project finance and, on the other hand, it would be a possibility for the local population to benefit from energy infrastructure projects, which may enhance public acceptance of infrastructure developments. Consequently, a conducive regulatory framework should be created for developments of this kind including provision of information and administrative support for communities willing to involve in network investment.

5.3. Strategies to improve infrastructure management

In order to optimize the use of infrastructure capacity and to integrate more RES generation within electricity networks in Europe, harmonized and efficient rules and mechanisms for network management must be established. Some of the measures required for a more efficient network management include:

(i) Establishment of efficient capacity allocation and congestion management (CACM) mechanisms, which implies:
   - Improved computation of transfer capacities between different zones using a flow-based method instead of arbitrary assignment of capacity at the borders. This method considers locational information for system security assessment, taking into account parallel flows and allowing a more efficient utilization of the grid.
   - Coordinated capacity allocation considering not only international transmission constraints but also internal constraints, eliminating the incentive TSOs have to declare lower transmission capacity for international transfers so as to avoid congestion within their country.
   - Integration of transmission capacity allocation with intraday markets so market participants can benefit from improved wind and demand forecast, and avoid other uncertain parameters such as outages.

   These issues could be addressed by the implementation of locational marginal pricing (nodal pricing), which would optimize the dispatch of a European power market including all physical network constraints. Furthermore, under this scheme, capacity allocation could be integrated with intraday markets (Neuhoff et al., 2011; ACER, 2011).

   With respect to CACM mechanisms in the EU, the ENTSO-E is responsible for developing a network code on CACM for electricity by September of 2012 based on the guidelines published by ACER, which establishes that capacity allocation should be based either on a flow-based method or on a coordinate Available Transfer Capacity (ATC) method, with day-ahead and intraday implicit auctions (ACER, 2011).

(ii) Harmonization and integration of balancing services markets. Harmonized and integrated balancing markets facilitate cross-border balancing services exchange and more efficient balancing capacity provision, contributing to a lager penetration of intermittent generation (ETSO, 2007). According to (Vandezande et al., 2008), based on the Nordic electricity market experience, the steps for balancing services harmonization should include the technical characteristics of balancing services, including activation time and full activation time, imbalance settlement, gate closure times and the time interval for the submission of real-time energy bids in the real-time market. In this sense, ERGEG is responsible for developing guidelines on balancing markets (ERGEG, 2006) and, after that, ENTSO-E must publish a Balancing Network Code.

(iii) Harmonization of European grid codes. A European grid code will benefit the integration of RES generation, improving system security and reducing inefficiencies and additional costs for manufactures, wind farm developers and consumers. According to the EWEA (EWEA, 2008), harmonization strategies should be developed based on two aspects: Structural and technical requirements of grid codes. Regarding the first aspect, requirements must be comprehensive and transparent in order to avoid misinterpretation and include common definition of terms. Technical requirements are related to power plant behavior in normal network conditions, behavior during and after network disturbances, frequency and voltage control. In this respect, it is recommended that requirements should balance cost and benefits of technical performance.

   A main groundwork for the definition of new grid-codes or standards takes place within the technical working groups (such as CIGRE, IEEE, etc.) or other industrial associations (such as those of manufactures, EWEA, ENTSO-E, ENTSO-G, etc.). The EU Commission has already set up a mandate to develop a harmonized European network code, which has to be prepared by ENTSO-E and ENTSO-G in close cooperation with ACER and ERGEG. It should address security of supply and reliability rules. In this context, some demonstration activities have been started to show the capability of RES generators to support system operation. For instance, under the TWENTIES EU project a demonstration involving the Spanish TSO (REE), a generation company (Iberdrola), and a wind turbine manufacturer (GAMESA) is being performed in Spain to show that aggregated wind farms can provide frequency and voltage control. Another initiative to be mentioned is the association of European Distribution System Operators (EDSO) which is engaged in promoting a broad diffusion of Smart Grid technologies.

(iv) Increasing grid flexibility. Increased grid flexibility can compensate for the unpredictability of intermittent sources and power flows. Therefore, incentives should be established for the adoption of Smart Grids, which will enable the network to integrate consumers, storage technologies, electric vehicles, and other technologies with variable RES generation. Besides, the improvement of prediction tools and meteorological input for intermittent generation allows the incorporation of resource uncertainties into existing production and planning tools. In this sense, the creation of control centres for RES generation improves the supervision and control (active and reactive power, voltage, temperature, wind speed, etc.) over these sources. Furthermore, the installation of flexible devices such as Flexible AC Transmission Systems (FACTS) and Dynamic Line Rating (DLR) can also contribute to a higher and more efficient integration of intermittent generation. FACTS devices allow for a faster control of active and reactive power up to a certain level, increasing the capacity of transmission lines. The use of dynamic line ratios instead of static seasonal ratios intends to optimize the use of transmission lines using real-time monitoring.

Currently, many large EU funded projects are developing demonstrations to address these issues. Some examples are the GRID4EU project (http://grid4eu.eu/), which will implement six large-scale demonstration pilots of Smart Grids solutions, the EcoGrid project (http://www.eu-ecogrid.net/), which will also demonstrate Smart Grids solutions in a Danish island with more than 50% electricity consumption from renewable energy production, and the TWENTIES project, which will implement two demonstrations to show that the transmission network can evacuate more wind energy by extending operational capacity limits through the installation of FACTS and DLR devices.

Table 4 summarizes the suggested measures within the three fields of barriers identified in the SUSPLAN project as well as the main responsible actors. Furthermore, it indicates in which fields there are already ongoing activities and in which areas further initiatives are required.

Abbreviations and symbols used in **Table 4**
Actors:
EC = European Commission (including ACER)
NG = National governments
NR = National regulators
SO = TSO's/DSO's (including ENTSO-E/G)
Status:
☑ = Activities ongoing or planned (additional measures to be considered)
☒ = Currently no activities ongoing (measures/ activities urgently required)
Responsibility:
● = Primary responsibility
○ = Secondary responsibility

6. Conclusions

In order to reach high shares of RES in the European electricity system as demonstrated by four possible scenarios for RES integration across Europe, measures have to efficiently address a multitude of issues from various areas. Within the SUSPLAN project the combination of pan-European energy modeling (integrating electricity and gas infrastructure) with in-depth stakeholder consultation on regional level, adds value to the current literature base and allows for a more specific assessment of the adequacy of the current RES policy framework on EU level. Nine in-depth regional case studies of characteristic European regions point out that the relevance of certain inhibitory factors varies between individual Member States. Further, there are indications for regional patterns regarding inhibiting factors for RES deployment which could potentially be transferred to other regions.[5] Finally, four main thematic fields could be identified which should, in any case, be taken particular account of in the future policy making process on national as well as on European level. These major areas are grid development (planning and authorization processes), financing issues and the management of the grid infrastructure. An integrated strategy that tackles these areas must consider conflicts and adverse effects which might occur between different measures and should be able to exploit potential synergies between actions.

A fundamental precondition for the realization of high RES shares and infrastructure extensions is the creation of a broad public acceptance for these developments, since public resistance is a common reason for delays in the authorization process. Furthermore, it is crucial to improve and better coordinate planning procedures, not only on transnational level but also with respect to inner-regional planning processes. A special focus should be laid on the coordination between electricity and gas infrastructure development since developments in both infrastructure systems interact with each other and mutually aggravate the uncertainties related to the respective investments.

Another major aspect in a European energy system with high RES shares will be the implementation of mechanisms for financing cross border infrastructure extensions and the improvement of national grid financing mechanisms. It is very important to develop a long term vision and to establish a long term planning horizon to avoid over- or false investments. The establishment of 'citizens' grids' could be an option to facilitate financing of new grid infrastructures and, at the same time, enhance public acceptance. Another important issue is the implementation of compensation mechanisms for the population affected by infrastructure projects which will be crucial to achieve a balanced ratio between costs and benefits, especially for such regions which do not directly profit from further RES deployment and grid infrastructure projects.

Finally, the network development must be effectively coordinated among the member states to allow for a large scale exploitation of the European RES potentials. This includes not only the harmonization of technical network standards and the introduction of improved methods for congestion management but also a targeted promotion of active network management, participation of the demand side and distributed generators. In the case of large congestions on cross border capacity but also within countries, nodal pricing could be an option to optimize power plant dispatch as well as utilization of congested capacities.

In the identified key areas the relevant stakeholders are already active in improving the conditions for RES integration. The policies and measures that are suggested within the analysis of the SUSPLAN project are generally in line with current approaches on EU and national level. However, the question remains open whether the currently proposed or partly implemented measures will be sufficient to improve the conditions for RES integration substantially. In particular, it will be necessary to take account of country and region specific inhibiting factors in the design of sustainable RES policies on European level. In the case of slow progress, additional costs for RES curtailment or national re-dispatch measures might occur in the future.

In this context, conflicting measures must be envisaged and tackled early to avoid adverse effects between actions and potential delays in development. One important issue in this

[5] It should be noted that, due to the limited number of case studies, the regional patterns for inhibitory factors should be validated by further research in order to allow for fully reliable statements on the transferability of the results.

Table 4
Measures and responsible actors to facilitate the integration of RES into future energy infrastructures.[a]
Source: Based on Klobasa and Boie (2011).

	Facilitating measures	Activities ongoing/ planned	Future measures to be considered	Main actors responsible			
	(A) Infrastructure development procedures			**EC**	**NG**	**NR**	**SO**
1	Develop a transnational institutional framework for planning, cooperation & coordination	☑	Granting of more decisive power to ACER	●	○	○	○
2	Establishment of a common planning procedure horizon (> 10 years)	☑	Identification of best practices across member states, development of harmonized guidelines for planning procedures	●	●	●	●
3	Support development of coherent network extension plans for the entire EU	☑		●	○		●
4	Develop a long term vision for offshore grid development	☑	Realization of stronger institutional cooperation and establishment of joint support instruments for offshore development	●	○		○
5	Simplify procedures for infrastructure development	☑	EU-wide definition of clear timelines and steps for implementation, clarify responsibilities, exploit past research on planning issues and support dissemination of best practices	○	●		
6	Support coordinated development processes and establish transnational cooperation platforms	☑	Specific support for transnational cooperation for OWE	○	●	●	●
7	Enhance regional planning structures and foster integration in national and transnational planning	☒	Create mechanisms and framework for integration of bottom-up inputs and regional participation in planning		●		○
8	Better coordinate national planning with other policy goals	☒	Create framework and institutions for integrated planning approach		●	●	
9	Integrate gas and electricity network planning	☒	Create framework and institutions for an integrated planning approach		●	●	●
10	Creation of incentives & regulations to minimize impacts of projects to enhance public acceptance in general	☑	Establishment of compensation and participation mechanisms, enhance informational activities, use innovative communication tools	●	●	●	●
11	Provide guidelines on harmonized planning procedures	☑	Provision of rules concerning timelines, responsibilities and compensation practice	●	○		
12	Better coordinate climate- and environment conservation goals with infrastructure planning	☑		●	●		
13	Simplify planning processes and develop efficient planning procedures	(☑)	Make broad use of standardized planning tools		●	○	○
14	Involve the public and NGO's early in the planning process to raise public acceptance (usage of standardized planning tools)	☑	Implementation of solutions developed on European level (use of standardizes criteria and principles)		●	●	●
15	Integrate strategic environmental assessment in planning procedure	(☑)	Introduce respective guidelines on European level		●	○	○
	(B) Infrastructure investment and financing			**EC**	**NG**	**NR**	**SO**
16	Enhance transnational cost allocation mechanisms for grid investments	(☑)	Enhancement of the existing ITC mechanism, development of a corresponding mechanism for gas infrastructure	●	○		
17	Increase funds for R&D and foster research on forecasting of renewable power production, smart grid- and storage technologies	☑		●	●		
18	Create sufficient incentives for offshore grid development	(☑)	Develop joint support instruments, enhance specifically targeted EU funding	●	●		
19	Create improved mechanisms for national grid financing	☑	Develop EU-wide guidelines for citizens' participation in infrastructure financing	○	●	●	
20	Establish compensation mechanisms for electricity transit communities (on regional level)	☑	Develop EU-wide guidelines for compensation mechanisms, conduct studies on social acceptability of different options	○	●	●	
21	Harmonize regulatory practices of the European member states	☑	Support diffusion of best practices through creation of communication platforms and -mechanisms	○	○	●	
	(C) Infrastructure management			**EC**	**NG**	**NR**	**SO**
22	Improve coordination of grid management between EU member states	☑		●	○	○	○
23	Foster efficient methods for capacity allocation and congestion management	☑	Implementation of a nodal pricing scheme, establishment of European ISOs	●		●	○
24	Harmonize grid codes	☑	RES participation in ancillary services, further pilot projects should be started	●	○	○	●
25	Develop legal framework and guarantee RES connection to the grid	(☑)	Coordinate respective measures and support diffusion of best practices across all European Member States	○	●	●	○
26	Foster adaptation of infrastructure to distributed generation and RES	☒		○	●	●	●
27	Enhance active network management	☑	Introduce market-based grid access in case of congestions in distribution grids			●	●
28	Ensure/foster active participation of the demand side and distributed generators	(☑)	Enhance aggregators for demand response and virtual power plants			●	●
29	Realize time variable grid tariffs and electricity prices for consumers	☒			○	●	●
30	Enhance transmission grid flexibility	☑		○			●
31	Harmonize balancing markets	(☑)	Create common rules for the participation of RES in balancing markets	○		●	●

[a] For details please refer to the respective sections in the paper.

regard will be the conflict between fast and efficient authorization procedures and a stronger involvement of local stakeholders, which usually prolongs the process significantly. In this respect, standardized planning tools can play an important role to achieve a well structured and focused development process which still allows for the integration of the public opinion. Further conflicts can arise between the need for infrastructure extensions and other policy goals, particularly objectives in the field of spatial planning and environmental protection. Here, a long-term, coordinated planning approach and the creation of respective coordinative institutions will contribute to the solution of future problems. In this sense, the activities of the EU commission and its related institutions (ACER, CEER, ENTSO-E and ENTSO-G) need the input and the support from national governments as well as national system operators and regulators. On distribution system level, associations such as the European Distribution System Operators (EDSO) will play a major role, especially for the broad diffusion of Smart Grid technologies. Ultimately, the implementation of activities has to be pushed on national level since the national stakeholders are required to translate the actions from EU level to national- and local level and integrate them into their respective planning procedures.

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References

ACER, 2011. Framework Guidelines on Capacity Allocation and Congestion Management for Electricity. Available from: ⟨http://www.acer.europa.eu/portal/page/portal/ACER_HOME/Communication/News/FG-2011-E-002%20%28Final%29.pdf⟩.
Arge Netz, 2012. Grüne Bürger Netzgesellschaft, Presentation of Dr. Martin Grundmann. Available from: ⟨http://www.arge-netz.de/78.html⟩.
Auer, H. et al., 2009. SUSPLAN D1.2 – Storyline Guidebook: Definition of a Consistent Storyline Framework.
BMU, 2012. Die Bürger sollen an der Energiewende verdienen, Interview with the German Minister of the environment, Peter Altmeier, Frankfurter Allgemeine Sonntagszeitung, 29.09.2012, Available from: ⟨ www.bmu.de/P1805 ⟩.
Borggrefe, F., Neuhoff, K., 2011. Balancing and Intraday Market Design: Options for Wind Integration – DIW Berlin Discussion Paper no. 1162. Available from: ⟨http://www.diw.de/documents/publikationen/73/diw_01.c.387225.de/dp1162.pdf⟩.
CEF, 2011. CEF – Connecting Europe facility. Website of the European Commission: Connecting Europe Facility. Available from: ⟨http://ec.europa.eu/energy/mff/facility/connecting_europe_en.htm⟩.
Cossent, R., et al., 2011. Distribution network costs under different penetration levels of distributed generation. Eur. Trans. Electr. Power 21 (6), 1869–1888.
Denholm, P., Hand, M., 2011. Grid flexibility and storage required to achieve very high penetration of variable renewable electricity. Energy Policy 39 (3), 1817–1830.
Deutsche Umwelthilfe, 2010. Plan N – Handlundsempfehlungen an die Politik. Deutsche Umwelthilfe, Available from: ⟨ http://www.duh.de/uploads/tx_duh downloads/PLAN_N_final_04012011.pdf ⟩.
Dii-Eumena, 2011. Dii Eumena website. Available from: ⟨http://www.dii-eumena.com/⟩.
EERP, 2012. EERP – European Energy Programme for Recovery. Regulation of the European Parliament to remedy the effects of the financial crisis and to grant financial assistance to the energy sector (663/2009), adopted 13.7.2009. Website of the European Commission: European Energy Programme for Recovery. Available from: ⟨http://europa.eu/legislation_summaries/energy/european_energy_policy/en0012_en.htm⟩.
EnLAG, 2009. EnLAG – Energieleitungsausbaugesetz vom 21. August 2009 (BGBl. I S. 2870), Available from: ⟨www.gesetze-im-internet.de/bundesrecht/enlag/gesamt.pdf⟩.
ENPI/NIF, 2012. European Neighborhood Partnership Instrument/Neighborhood Investment Facility. Website of the European Commission: European Neighborhood Policy. Available from: ⟨http://ec.europa.eu/world/enp/welcome_en.htm⟩.
ENTSO-E, 2010. Ten year network development plan 2010, ENTSO-E. Available from: ⟨https://www.entsoe.eu/system-development/tyndp-2010/⟩.
ENTSO-E, 2012. Ten-Year Network Development Plan 2012 Project for Consultation, Draft version. Available from: ⟨www.entsoe.eu⟩.
ERGEG, 2006. Guidelines of Good Practice for Electricity Balancing Markets Integration (GGP-EBMI). Available from: ⟨http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Electricity/2006/E05-ESO-06-08_GGP-EBMI_2006-12-06.pdf⟩.
ESTEEM, 2008. ESTEEM toolbox project website. ESTEEM – Engage stakeholders through a systematic toolbox to manage new energy projects. Available from: ⟨http://www.esteem-tool.eu/⟩ (accessed 09.06.11).
ETSO, 2007. Balance Management Harmonization and Integration, 4th Report. Available from: ⟨http://www.marketcoupling.com/document/1000/ETSO%20-%20Report%20on%20Balance%20Management%20Harmonisation%20and%20Integration.pdf⟩.
European Climate Foundation, 2010. Roadmap 2050: A practical guide to a prosperous, low-carbon Europe. Available from: ⟨http://www.roadmap2050.eu/attachments/files/Volume1_fullreport_PressPack.pdf⟩.
European Commission, 2008. Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources. Available from: ⟨http://ec.europa.eu/energy/index_en.htm⟩.
European Commission, 2010. Energy infrastructure priorities for 2020 and beyond – A Blueprint for an integrated European energy network – Impact Assessment. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52010SC1395:EN:NOT (accessed 12.07.11).
European Commission, 2011a. Energy roadmap 2050. Available from: ⟨http://ec.europa.eu/energy/energy2020/roadmap/doc/com_2011_8852_en.pdf⟩.
European Commission, 2007. Eur. Energy Transp. Trends 2030 – Update, 2007.
European Commission, 2011b. Proposal for a regulation on guidelines for trans-European energy infrastructure. Available from: ⟨http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0658:FIN:EN:PDF⟩.
European Commission, 2011d. Roadmap for Moving to a low-Carbon Economy in 2050 – Impact Assessment. Available from: ⟨http://ec.europa.eu/clima/documentation/roadmap/index_en.htm⟩ (accessed 06.07.11).
European Commission, 2006. TEN-E – Decision no. 1364/2006/EC of the European Parliament and of the Council of 6 September 2006 laying down guidelines for trans-European energy networks. Available from: ⟨http://ec.europa.eu/energy/infrastructure/tent_e/ten_e_en.htm⟩.
EWEA, 2008. European Grid Code Requirements for Wind Power Generation - Position Paper. Available from: ⟨http://www.ewea.org/fileadmin/ewea_documents/documents/publications/position_papers/080307_WGGCR_final.pdf⟩.
FP7-RTD, 2012. FP7-RTD - European Seventh Framework Programme for Promotion of Research and Technological Development, adopted 18th December 2006. Website of the European Commission: European Seventh Framework Programme. Available from: ⟨http://ec.europa.eu/research/fp7/⟩.
Frías, P., et al., 2010. D2.6 – Report from the regional study case: South-Western Europe (Spain). Univ. Pontif. Comillas.
Frías, P., Fernandes, Camilla, Cossent, Rafael, 2011a. D5.2 – Report on implementation strategies for technical and system solutions and recommendations for policy makers, Universidad Pontificia Comillas.
Frías, P., Fernandes, Camilla & Cossent, Rafael, 2011b. SUSPLAN D5.2 – Report on implementation strategies for technical and system solutions and recommendations for policy makers, Universidad Pontificia Comillas.
Gair, S. et al., 2010. SUSPLAN D2.1 – Report from the Regional Case Study: Islands (Island of Lewis, North West Scotland), University of Highlands and Islands Millennium Institute (UHI).
Graabak, I., et al., 2010. SUSPLAN D2.2 – Report from the regional case study: Northern Europe. SINTEF Energy Res..
Graabak, I. & Bakken, B., 2011. Scenarios for integration of large shares of renewable energy in Europe up to 2050, Presentation at the IEEE Trondheim Powertech, 2011, Trondheim, Norway.
Gross, C., 2007. Community perspectives of wind energy in Australia: The application of a justice and community fairness framework to increase social acceptance. Energy Policy 35 (5), 2727–2736.
IEA, 2010. Technology Roadmap – Solar Photovoltaic Energy. (Available from)http://www.iea.org/papers/2010/pv_roadmap.pdf.
Joode, J.de et al., 2011. SUSPLAN D3.1 – Report on transnational infrastructure developments on the electricity and gas market, Available from: ⟨http://www.susplan.eu/index.php?id=13096⟩.
Klobasa, M. & Boie, I., 2011. SUSPLAN D5.3 – Report on Infrastructure Development – Implementation strategies for decision makers.
Lanati, F., Gelmini, A., 2010. SUSPLAN D2.7 – Report From the Regional case study: Southern Europe (Italy), RSE S.p.A (former ERSE S.p.A).
Linnerud, J., et al., 2010. SUSPLAN D2.8 – Report from the Regional Case Study: Western Balkan Countries (Serbia), Statkraft Western Balkans (SWB).
Luxembourg, S., et al., 2010. SUSPLAN D2.3 – Report from the regional case study: Rhine Neckar Region (Germany), Energy Research Centre of the Netherlands (ECN).
Mateo, C., et al., 2010. A reference network model for large-scale distribution planning with automatic street map generation. IEEE Trans. Power Syst. 26 (1), 190–197.
Michalowska-Knap, K., et al., 2010. SUSPLAN D2.4 – Report from the regional case study: North Eastern Europe, Pomerania region in Northern Poland. Institute for Renewable Energy, PL.
Miglavacca, G., et al., 2011. The REALISEGRID cost-benefit methodology to rank pan-European infrastructure investments. IEEE Trondheim PowerTech, 2011. (Trondheim, Norway).
NABEG, 2011. NABEG – Netzausbaubeschleunigungsgesetz Übertragungsnetz vom 28. Juli 2011 (BGBl. I S. 1690), Available from: ⟨www.gesetze-im-internet.de/bundesrecht/nabeg/gesamt.pdf⟩.
Neuhoff, K., Hobbs, B., Newbery, D., 2011. Congestion Management in European Power Networks: Criteria to Assess the Available Options – DIW Berlin Discussion Paper No. 1161.
Niedersächsische Staatskanzlei, 2011. Restriktions- und Potenzialanalyse zum Ausbau des Höchstspannungsnetzes in Niedersachsen. Available from: ⟨http://www.netzausbau-niedersachsen.de/downloads/20110412-restriktions-und-potenzialanalyse-net.pdf⟩ (accessed 06.06.11).
Pieltain, L., et al., 2011. Assessment of the impact of plug-in electric vehicles on distribution networks. IEEE Trans. Power Syst. 26 (1).

Roland Berger Strategy Consultants, 2011. The structuring and financing of energy infrastructure projects, financing gaps and recommendations regarding the new TEN-E financial instrument. Available from: 〈http://www.gaslink.ie/files/Copy%20of%20library/20111014115946_The%20Structuring%20and%20Financing%20.pdf〉.

Schweizer-Ries, P., Rau, I. & Zoellner, J., 2010. Umweltpsychologische Untersuchung der Akzeptanz von Maßnahmen zur Netzintegration Erneuerbarer Energien in der Region Wahle – Mecklar (Niedersachsen und Hessen), Forschungsgruppe Umweltpsychologie. Available from: http://www.forum-netzintegration.de/uploads/media/Abschlussbericht_Akzeptanz_Netzausbau_Juni2010.pdf (accessed 06.06.11).

Tantareanu, C., Badi, L., Klobasa, M., 2010. SUSPLAN D2.5 – Report from the Regional Case Study: South-Eastern Europe (Romania), ENERO.

Trieb, F., Müller-Steinhagen, H., 2009. The DESERTEC concept – Sustainable Electricity and Water for Europe, Middle East and North Africa. Available from: 〈http://www.desertec.org/fileadmin/downloads/WhiteBook_Excerpt_Trieb_Steinhagen.pdf〉.

UfM, 2011. Union for the Mediterranean (UfM) website. Union for the Mediterranean (UfM) website. Available from: 〈http://www.ufmsecretariat.org/en/the-ufm-mediterranean-solar-plan-is-on-its-way/〉.

Vandezande, L. et al., 2008. Implementation of cross-border balancing in Europe, Presentation at the first International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), Rotterdam, Netherlands, 10–12 November 2008.

Weiss, B. et al., 2010. SUSPLAN D2.9 – Report from the Regional Case Study: Alpine Region (Austria), VERBUND – Austrian Hydro Power AG (AHP).

Van der Welle, A., et al., 2011. SUSPLAN D5.1 – Report on non-technical approaches for integration of renewable into infrastructures. Energy Res. Centre Nether. (ECN).