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1 INTRODUCTION

In the SUSPLAN project, nine different regions have been selected throughout Europe for comprehensive in-depth analyses of long-term grid integration of renewable electricity, heat and gas generation technologies. These analyses not only deal with future renewable deployment scenarios in different European regions up to the year 2050 but also take into account and quantify the corresponding grid infrastructure needs and cost (electricity, heat and gas grids) necessary to "absorb" different degrees of penetration of renewable generation. The major objective of the regional scenario studies has not been to describe the entire European territory in geographic terms but to study renewable grid infrastructure integration in completely different energy systems described by a variety of different dimensions. Moreover, the manifoldness of these dimensions has been the major selection criterion of a particular SUSPLAN region. Among others, selection criteria incorporate varying degrees of severity in geographical, structural, technical, economical, institutional, and political respect.

The nine different regions are as follows: (i) Island (Isle of Lewis, North-West Scotland), (ii) Northern Europe (Norway), (iii) Central/Western Europe (Rhine-Neckar Region), (iv) North-Eastern Europe (Pomeranian Region), (v) South-Eastern Europe (Romania), (vi) South-Western Europe (Spain), (vii) Southern Europe (Italy), (viii) Western Balkan Countries (Serbia), (ix) Alpine Region (Austria). The major results and policy recommendations of each of the regions are documented in nine separate reports (available as Deliverables D2.1-D2.9 on the SUSPLAN project website www.susplan.eu).

The aim of this synthesis report (Deliverable D2.10) is to present some highlights of the different regional scenario analyses, on the one hand, and to develop some synthesis of the different results in the different regions, on the other hand. The ambition of the synthesis is to treat grid integration challenges of renewable generation technologies on a more general level decoupled from a particular SUSPLAN regional scenario study.

This synthesis report is organised as follows:

- In Chapter 2 the renewable grid integration scenario generation philosophy based on the storyline approach is briefly described. This is important to get a better understanding of the methodology applied to derive the different regional scenario studies in the SUSPLAN project. Further on, the establishment of a consistent set of empirical data of key scenario parameters, relevant for several of the European regions, is briefly presented.
- Chapter 3 summarizes the selection criteria for the different European regions subject to comprehensive in-depth scenario studies on long-term grid infrastructure integration of renewable generation technologies. Further on, the main characteristics of the nine different regions are listed and the modelling approach for the regional scenario studies is outlined.
- In Chapter 4 selected results from the different regional scenario studies are presented, highlighting different important aspects to be considered in the context of grid infrastructure integration of renewable generation technologies both short-term and long-term. The presentation and discussion of the different illustrative results in the different regions provide the basis for the derivation of the synthesis of results in the next chapter.
- Chapter 5 presents the synthesis of results of the different regional scenario studies on grid infrastructure integration of renewable electricity, heat and gas generation technologies. As already stated above, the ambition of the synthesis is to treat several important issues on a more general level again, decoupled from a particular regional case.
- Concluding remarks in Chapter 6 close this report.

2 RENEWABLE (RES) GRID INTEGRATION SCENARIO GENERATION BASED ON THE STORYLINE APPROACH

2.1 Storylines and Scenario Generation Methodology

The SUSPLAN project not only deals with future renewable (RES) deployment scenarios (in terms of installed capacities and annual renewable electricity/heat generation) up to 2050 but also takes into account the corresponding grid infrastructure needs both on regional as well as transnational level. Furthermore, the analytical approach used in SUSPLAN is different from many other international scenarios studies applying neither an obvious Business-As-Usual (BAU) scenario nor alternative scenarios generated by variations of one or more parameters in relation to a BAU scenario.

Instead, in SUSPLAN the intention is to envisage and describe fundamentally different possible future “energy worlds” enabling also “structural breaks” in long-term scenario generation (e.g. due to breakthroughs of new technologies, discontinuous changes of energy policies and/or public attitudes, etc.). Moreover, this approach is qualified to study much higher future RES penetration rates in Europe than written down in binding energy policy documents today. The results from SUSPLAN scenario generation analyses, therefore, rather describe what kind of RES generation and network infrastructures are needed to integrate RES generation; and even more important, what kind of policies, incentives, regulations, etc. do we need to get the most appropriate RES potentials utilized and grid infrastructures in place: where, when and based on which terms and conditions.

> The scenario generation philosophy in SUSPLAN verbally can be characterized as *"What if a certain development occurs?"* rather than *"What is the optimal (or most likely) development according to a given set of assumptions?"* Thus, a number of assumptions are made ex-ante to create a set of sufficiently different possible, but alternative future developments of energy systems both on regional and trans-national (global) level.

The set of different assumptions defining the different cornerstones of possible regional and transnational energy systems in the future is reconciled in four so-called “Storylines”. The description of these storylines and also the quantitative results of corresponding analyses, however, can not be interpreted as the project’s recommended *“optimal”* development of a future energy system. Instead, the scenario results must be regarded as the project's assumptions of a “*possible”* future development. Moreover, it is important to note that in SUSPLAN analyses none of the storylines is considered to happen more likely than another one.

2.1.1 Possible Future “Energy Worlds”: Uncertainties and Options/Potentials

When further elaborating the different storylines, different categories of key “influence parameters” have to be structured such that they describe the different possible, but alternative future developments of energy systems both on regional and trans-national (global) level. In detail, a distinction is made between the following different dimensions of parameters:

- *Region-independent* versus *region-dependent* developments;
- *Uncontrollable uncertainties* versus *controllable options/potentials;*

Below selected examples of the most important candidates of parameters in each of the categories of "influence parameters" are listed which determine the cornerstones of SUSPLAN scenario analyses (see also Figure 2.1):

- ***Region-independent, uncontrollable uncertainties*** are global parameters and assumptions that cannot be directly controlled by the analyst or decision maker: Fossil fuel prices of crude oil, natural gas or coal; wholesale price of CO_2; wholesale price of biomass;[1] investment costs of new and renewable technologies; capital costs (e.g. interest rates); other parameters determining international climate policies and/or international energy market developments. These parameters are common for all SUSPLAN regions.
- ***Region-dependent, uncontrollable uncertainties*** are region-specific parameters and assumptions that cannot be directly controlled by the analyst or decision maker: National economic growth (regional GDP), national energy demand and load profile changes; national energy policy focus (e.g. favouring and/or phasing out/in of single technologies like nuclear, CCS, etc.); subsidizing of single fuel types (e.g. lignite); national energy policy goals (RES and energy efficiency) being more ambitious than international targets; venture capital access and availability; societal-economic aspects to increase public awareness and to favour public acceptance. These parameters are different in the SUSPLAN regions.
- ***Region-independent, controllable options*** are global actions/developments that can be taken/used by the decision maker: Availability and specification of several types of technologies for RES generation, end-use efficiency, network and network integration (incl. storage and load response). These options are common for all SUSPLAN regions.
- ***Region-dependent, controllable options*** are regional actions/developments that can be taken/used by the decision maker: Utilization of regional potentials (RES generation, end-use efficiency, network routes, network integration technologies) realised and/or implemented; regional/municipal grid infrastructure planning policies (e.g. gas distribution grids versus district heating grids); regional financial support policies of new RES and end-use efficiency technologies; regional grid regulation and system balancing policies; regional R&D budgets. These options are different in the SUSPLAN regions.

In Figure 2.1 the most important cornerstones of the scenario generation framework in SUSPLAN (following the nomenclature described above) are visualised:

- Each ***scenario*** on RES grid infrastructure integration in SUSPLAN consists of a possible, uncertain future development (described by ***storylines***) and a combination of controllable parameters describing the settings of different options/potentials for how to act within an uncertain future (***strategy/action plan)***).
- Each of the 4 different storylines in SUSPLAN consists of both region-independent (external) and region-dependent (internal) uncertain factors/development that cannot be directly controlled by the decision makers. On the contrary, each strategy/action plan contains a combination of technical, non-technical and other options which can be chosen, implemented and/or decided by decision makers.

[1] Although biomass fuel costs at present have a regional component (and might also have to some extent in the future), in the future an international biomass wholesale price most probably will be the reference price for biomass.

- In general, this methodology enables a high number of scenarios (i.e. number of uncertain future developments multiplied by the number of strategies/action plans) to be generated in a SUSPLAN region. For practical reasons and focused interpretation of results, however, the number of both storylines and strategies/action plans has to be limited in the different regional scenario studies.

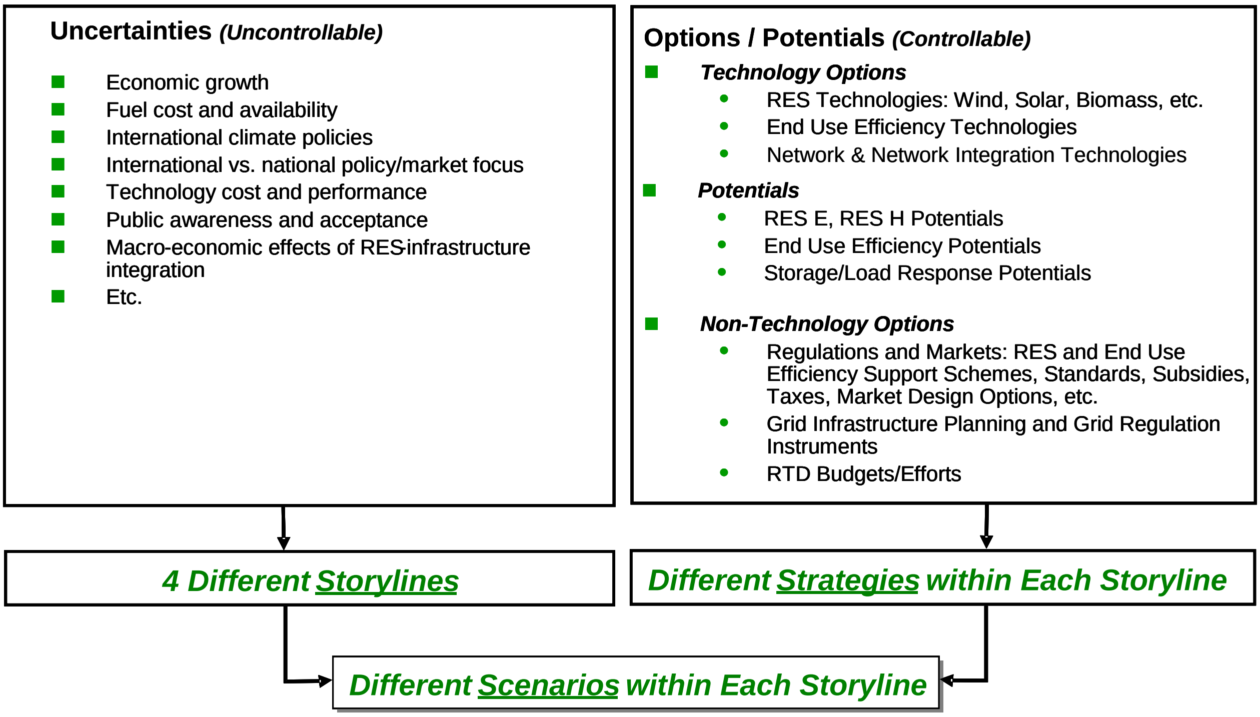

Figure 2.1 Scenario generation methodology in SUSPLAN

For scenario generation in SUSPLAN it is important to note that some settings of uncertainties and some options/potentials are mutual (i.e. the same) for all regions and levels, others are region specific. Thus, using this methodology in the scenario setup for the different regional RES grid infrastructure integration studies will ensure a consistent and comparable starting point for SUSPLAN scenario analyses in several regions of particular interest.

2.1.2 Description of SUSPLAN Storylines

As mentioned above, the combination of many uncontrollable, uncertain future developments (storylines) and settings of controllable parameters describing different strategies (action plans) would lead to a multitudinous number of combinations (scenarios). Therefore, we have chosen to limit the amount of scenarios in the regional analyses in SUSPLAN to be able to derive credible practical implementation plans for decision makers and stakeholders.

The most challenging task in this context is to limit the number of uncontrollable uncertain future developments. This is done by the identification of the primary driving forces according to degree of uncertainty and relevance for the task (i.e. in SUSPLAN the major task is to analyze the more efficient integration of RES generation into future grid infrastructures).

Assuming two main driving forces (typically a "hardware/technology" and a "soft" driver) opens a 2-dimensional space with four quadrants, see Figure 2.2. In each of the quadrants several uncertainties are combined into a single storyline. Therefore, there are four storylines in SUSPLAN in total. Within a storyline different scenarios can be established and analyzed by selecting the different strategies (action plans).

Before each of the four storylines is described more in detail, the basic assumptions and background information for the definition of the SUSPLAN storylines are listed below:

- There is a strong political intent in Europe to promote sustainable development and security of supply in the energy sector. This strong political intent results in the use of necessary incentives and regulations for increased deployment of RES generation technologies. According to the main focus of the project, there are no storylines that focus on nuclear or fossil/CCS as main technology developments.
- The share of RES in the future European energy system will be large. The use of conventional technologies like nuclear power plants and fossil fuel technologies (also with new CCS) will follow traditional infrastructure planning and operation strategies. Therefore, this already known aspect will not be explicitly analyzed in the SUSPLAN project in detail. However, in the different storylines different penetration rates and emphasis of these technologies are assumed.
- Hydrogen will not be applied as major energy carrier at distribution level in the given time perspective of SUSPLAN (up to 2050). If hydrogen is applied large-scale, it will be as bulk transport of energy or large-scale storage for the power sector. Electricity (e.g. electric vehicles) will turn out to be the most cost effective alternative to fossil fuels in the transport sector, but bio-fuels may in some storylines fill also a certain amount of the energy demand in the transport sector.
- SUSPLAN focuses on stationary energy production and consumption, i.e. the transport sector itself is not a part of the SUSPLAN project. However, electric vehicles and biofuels might influence the stationary energy balance (e.g. reduced bio-energy potentials for electricity and heat generation in case of biofuel use and applications in the transport sector).

The SUSPLAN project comprehensively addresses the aspect of large-scale integration of different types of RES generation technologies. This creates different needs for infrastructures on different levels and dimensions:

- Transmission grid expansion both onshore and offshore to enable the utilization of the economies of scale of large-scale RES-Electricity generation of technologies like onshore and offshore wind, wave and tidal, CSP (concentrated solar power), etc.;
- Distribution grid modernisation to enable the implementation of active grid elements and smart technologies interacting with several different kinds of grid users (smart grid concepts);
- Consideration of the interdependencies (and partly contrary objectives) between centralised top-down transmission grid infrastructure planning (favouring centralised RES-Electricity generation) and decentralised bottom-up smart grid concepts (favouring distributed RES-Electricity generation like PV, etc.);
- Consideration of the interdependencies between electricity, heat and gas grid infrastructures in case of combined-heat and power generation (e.g. biomass), on the one hand, and also switches of energy carriers "fuelling" particular energy services, on the other hand.

- Grid infrastructure to get spatial access to flexible electricity generation and storage technologies to balance high shares of variable and intermittent RES-Electricity generation.

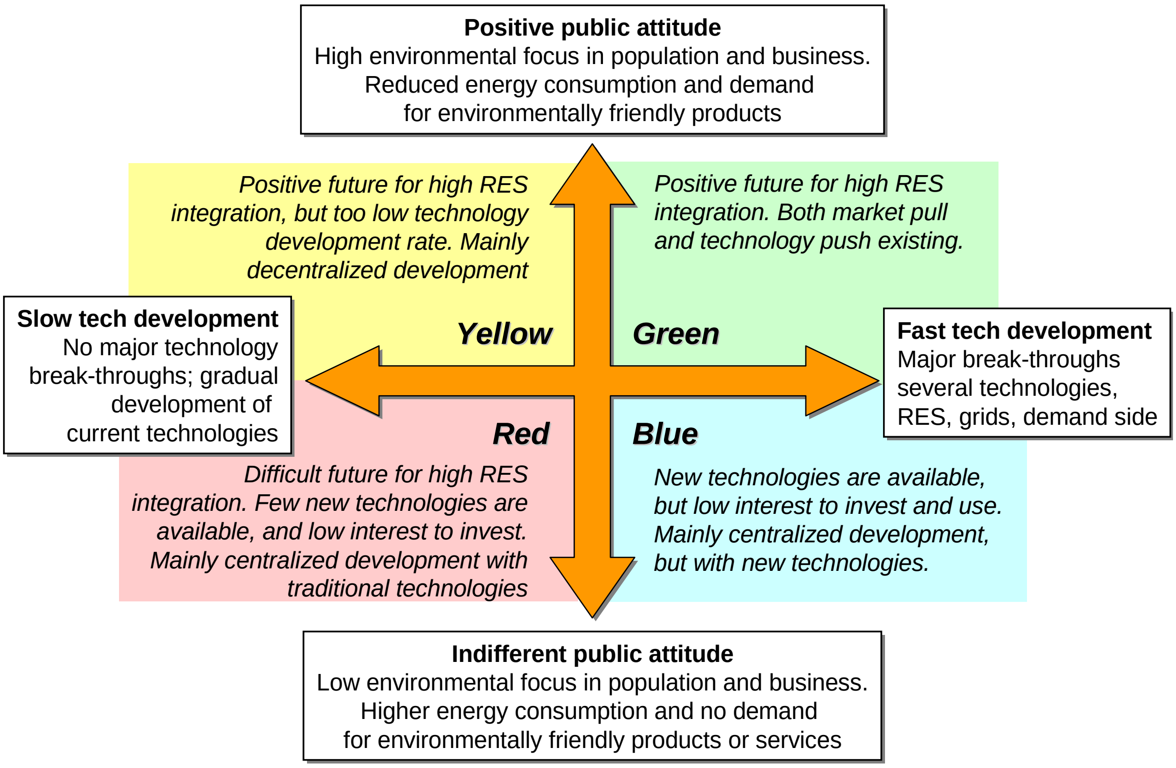

Figure 2.2 Overview of the four different storylines in SUSPLAN

In the following as well as throughout the entire SUSPLAN project, the four different Storylines are named "*Green*", "*Yellow*", "*Red*" and "*Blue*" respectively[2].

"Green" Storyline

In the *Green* storyline there is a very high focus in Europe on environmental challenges and the need for reduction of CO_2 emissions. The awareness applies to the politicians and authorities at all levels, European as well as national and regional. Furthermore, it applies to the consumers, and since the consumers are mainly asking for commodities from companies which are acting in an environmentally friendly way, also the industry has to reduce their emissions to a minimum. The *NIMBY*-factor[3] is hardly visible any more. Research and development of technologies relevant for reduction of CO_2 emissions have been given high priority for many years. The efforts have resulted in breakthroughs in many areas relevant for the energy sector.

In the *Green* storyline demand is low due to the consumers' concern about acting in an environmentally friendly way. Moreover, in *Green* all major technologies for RES generation are available at commercial level and large amounts of RES generation are possible at local, regional,

[2] The "colored" names of the storylines are based on the following principles: (i) easy to remember, (ii) having a meaning / logical interpretation, (iii) consistency and similarity among the names for the four different storylines.

[3] NIMBY: "Not In My Back-Yard"

national and trans-national level. The consumer has become a producer, and local production is very widespread.

In terms of grid infrastructures, in *Green* large-scale power grids are available to be implemented in an efficient way both onshore and offshore. On distribution level, Smartgrids are reality. Storage technologies for balancing variable and intermittency RES generation are available in terms of (pumped-)hydro power from the Alpine region as well as the Nordic countries. Also other new technologies are available and economically competitive for storage of energy both at local (end-user) as well as at aggregated level (e.g. different battery systems and also CAES[4]).

This storyline is named Green because it describes the most environmentally friendly future. The energy system is developing in a direction which will prevent or at least limit climate changes. An alternative way of regarding the Green storyline is by comparing with traffic lights. Green lights can be regarding as "continue in the same way". An even third interpretation is that biomass is utilized to large extent in this storyline.

"Yellow" Storyline

In the *Yellow* storyline there is a very high environmental concern among the consumers, which highly influences their demand for energy. This means that energy demand is low in the *Yellow* storyline. There have been limited breakthroughs in new technologies for RES generation as well as for transmission and distribution. However, due to the high environmental focus among people ("bottom-up" driver) there is a market pull for technologies for local production as well as for reduction of energy consumption.

However, since there are fewer new and innovative technologies compared to the *Green* storyline, in *Yellow* more of energy demand reduction is caused by changes in behavior and needs among consumers. In the transport sector there is also limited deployment of electric cars outside the main city centers, because there have been few breakthroughs in battery storage technology.

In *Yellow*, new RES-Electricity generation is dominated by distributed solutions like PV. In general, RES production is mainly based on technologies that have been mature for many years. There have not been enough technological breakthroughs to make new large-scale energy efficient power grids commercially attractive. However, there is some deployment of Smartgrids technologies due to the environmental focus among the consumers. Storage for balancing variable and intermittent RES generation is available in terms of (pumped-)hydro power from the Alpine region and to some degree from the Nordic countries. Also some decentralised solutions are available to contribute to balancing variable and intermittent RES production.

Compared to traffic lights, the color Yellow can be interpreted as "the time slot you have is limited". It is still possible to pass through or to change to a better direction towards sustainable energy systems. In addition, PV is specially mentioned as a significant part of the Yellow storyline, and the sun is yellow.

[4] CAES: "Compressed Air Energy Storage"

“Red” Storyline

The *Red* storyline represents the most difficult future to achieve sustainable energy systems with high shares of RES. There have been limited breakthroughs in technology for RES production, transmission and distribution as well as for energy demand reduction. New RES generation is mainly established at municipal level. There is very limited interest for local (micro-) production. Furthermore, there have not been any necessary breakthroughs to establish significant new large-scale RES production on trans-national level. Therefore, in *Red* RES production is mainly assumed to be based on technologies that have been known for many years.

In *Red*, energy demand is relatively high due to very low awareness among consumers. Some types of new technologies for demand reduction are available but the request for these technologies from consumers is very limited.

In terms of grid infrastructures, in *Red* large-scale offshore power grids are assumed to have no significant breakthroughs. Furthermore, smartgrids are not worth to mention because the interest for local production and customer participation in the market is very limited. The vision from the first years of the 21st century about the consumer also becoming a producer has not become reality. Storage technologies for balancing variable and intermittent RES generation are available in terms of (pumped-)hydro power from the Alpine region and to some degree from the Nordic countries. Eventually, at high enough electricity price levels the demand side may adjust their consumption to some extent in *Red* to contribute to balance intermittent RES generation.

Compared to traffic lights, the color of the Red storyline can be interpreted as “Stop! This is not a way to a sustainable future”.

“Blue” Storyline

In the *Blue* storyline, the development of the energy system in Europe is mainly driven by the politicians and authorities both European and national level. There has been a high focus on public R&D funding in the energy sector for many years. These efforts have finally resulted in the same level of breakthroughs in technology for RES production, transmission and distribution as in the *Green* storyline, but the investments have mainly been driven by authorities. Regarding technology for local production as well as energy reduction, the deployment is more limited due to low interest for the products. The *NIMBY* factor, furthermore, may be a barrier for the establishment of both new RES production and new grid infrastructures.

In *Blue*, energy demand is high, since energy is still mainly a low-interest product among the European public. High energy demand is a result of both low interest in environmental questions and rather low energy prices.

In terms of RES-Electricity generation, in *Blue* large-scale and centralised solutions of RES-E power plants are implemented (e.g. big offshore wind farms as well as CSP plants, etc.), supported by national and EU policy instruments.

Finally, in *Blue* large-scale power transmission grids are implemented and operated in an efficient manner both onshore as well as offshore. On the contrary, Smartgrids have a very limited deployment. Storage technologies for balancing variable and intermittent RES generation is available in terms of (pumped-)hydro power from Alpine countries as well as the Nordic countries. At high enough prices, the demand side reduces its consumption and flexible demand also contributes to balancing intermittency in RES production.

This storyline is named Blue because large-scale ocean energy and offshore-wind play an important part, and the ocean is blue. In this storyline renewable energy is mainly produced centralized, far away from consumers' sites. This introduces the problem that people do not get in touch with these sustainable technologies and also might not fully understand the need to behave environmental friendly. Thus, storyline Blue is also indicating that people live their lives without much concern for the situation tomorrow.

2.1.3 Time Horizon of SUSPLAN Analyses

As already mentioned in the introduction of this report, the SUSPLAN project addresses several long-term aspects of RES grid infrastructure integration in Europe both on regional and trans-national level. More precisely, the time period 2030-2050 is of particular interest in the different in-depth scenario analyses on RES grid infrastructure integration.

However, this does not mean that the SUSPLAN project neglects RES deployment and the corresponding infrastructure needs in the time period from 2010-2030. The time period 2010-2030 (and the already binding 20% targets on RES deployment and energy efficiency in the European Union in 2020) is treated as follows:

- Several existing studies analyzing the European dimension of the future development of the energy systems and/or RES deployment and energy efficiency (mainly up to 2020; some of them up to 2030) have been analyzed and incorporated in detail. A summary of the most important studies in this context is presented in [SUSPLAN, D1.1]. Moreover, the most important studies (e.g. [EC, 2007], [IEA, 2009], [Faber, 2007], others) also have been used as an input for the development of the four storylines in SUSPLAN, setting up the cornerstones of the different scenario analyses for the period 2030-2050.
- In the four storylines it is assumed that the EU2020 targets are met at different points in time between 2020 and 2030. To be more precise, this means that for the SUSPLAN analyses starting in 2030 it is not essential whether the EU2020 targets are met in year 2020 or there are some delays. E.g. in the least ambitious *Red* storyline the RES shares which should have been implemented in year 2020 are assumed for the starting year 2030 (assumption of a maximum 10 year's delay for the implementation of the EU-2020 targets). On the other hand, in the Green storyline it is assumed that the EU-2020 targets are met already in 2020.
- In the starting year 2030 of SUSPLAN analyses in the four different storylines four different RES shares are assumed to be implemented. As already mentioned above, the least ambitious starting point is allocated to the most conservative storyline *(Red)* assuming the EU2020 targets to be implemented with a 10 years' delay in 2030. Several other scenarios in the remaining three storylines assume more ambitious (i.e. higher) RES penetration in 2030 as a starting point.
- Finally it is important to note that in each of the four different storylines different RES deployment scenarios are analyzed (depending on the different strategy settings) for the time period 2030-2050. This means in particular, that within a storyline different scenario analyses on RES deployment and corresponding grid infrastructure needs are conducted. There is no inter-temporal "switch" between the different storylines in a single RES grid integration scenario analyses somewhere at a point in time in between 2030 and 2050.

Figure 2.3 below presents an overview of the development of RES shares in the 4 storylines in SUSPLAN scenario analyses up to 2050, indicating the different considerations of the different time periods (2010-2030, 2030-2050).

2.2 Establishment of a Consistent Set of Empirical Data Describing Region-Independent Parameters

For several of the scenario studies on both regional and trans-national levels it is important to agree on consistent empirical settings of the key region-independent parameters. However, in this context it is not important to consider a high number of parameters describing the external-driven cornerstones of the energy systems in the different regions. In the SUSPLAN project, the key parameters determining the cornerstones of energy supply and demand patterns (with or also without high shares of RES generation) are limited to a handful of candidates:

- RES/RES-electricity deployment
- Final energy/electricity demand development
- RES/RES-electricity technology cost development
- Development of fossil fuel-, CO_2- and biomass prices
- Development of wholesale electricity prices

In the following, the empirical settings of several of the key region-independent parameters described above - being of core relevance for SUSPLAN scenario analyses - are visualized and, furthermore, the most relevant references/sources and own assumptions are briefly explained [Auer, 2010].

2.2.1 RES/RES-Electricity Deployment up to 2050

For each of the four different storylines in SUSPLAN four different empirical sets of future developments for both RES generation as a share of final total energy demand and RES-electricity generation as a share of final total electricity demand are determined on aggregated European level up to 2050. Figure 2.3 and Figure 2.4 below present RES and RES-Electricity deployment in the four different SUSPLAN storylines on aggregated European level up to 2050 (Source: Green-X modelling results up to 2030 [Faber, 2007], [Auer, 2008]; extrapolated up to 2050 according to the long-term RES/RES-Electricity potentials and ambitions in energy efficiency in the different European counties).

2.2.2 Final Energy/Electricity Demand up to 2050

Similar to future RES/RES-electricity deployment the same sets have been established also for total final energy and total final electricity demand for each of the four storylines in SUSPLAN on aggregated European level up to 2050. Figure 2.5 below presents final energy demand (electricity demand is not shown here; but the source is the same) in the four different SUSPLAN storylines on aggregated European level up to 2050 (Source: Primes model runs up to 2030 [Capros, 2005]; extrapolated to 2050).

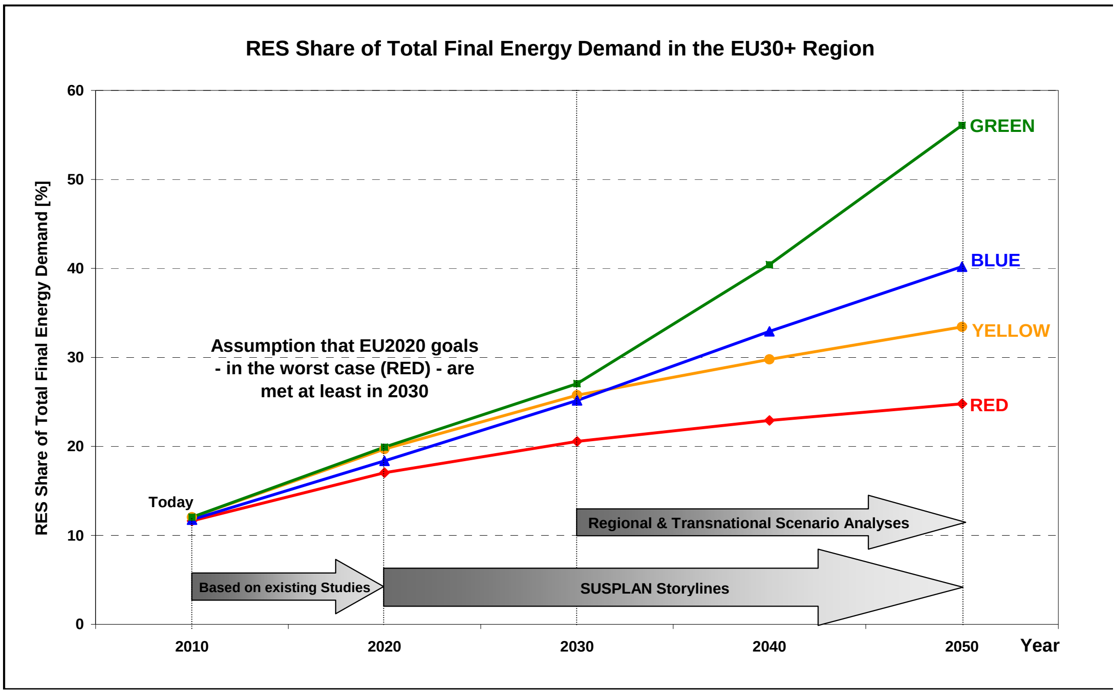

Figure 2.3 RES deployment as a share of total final energy demand on aggregated European level in the four different storylines in SUSPLAN

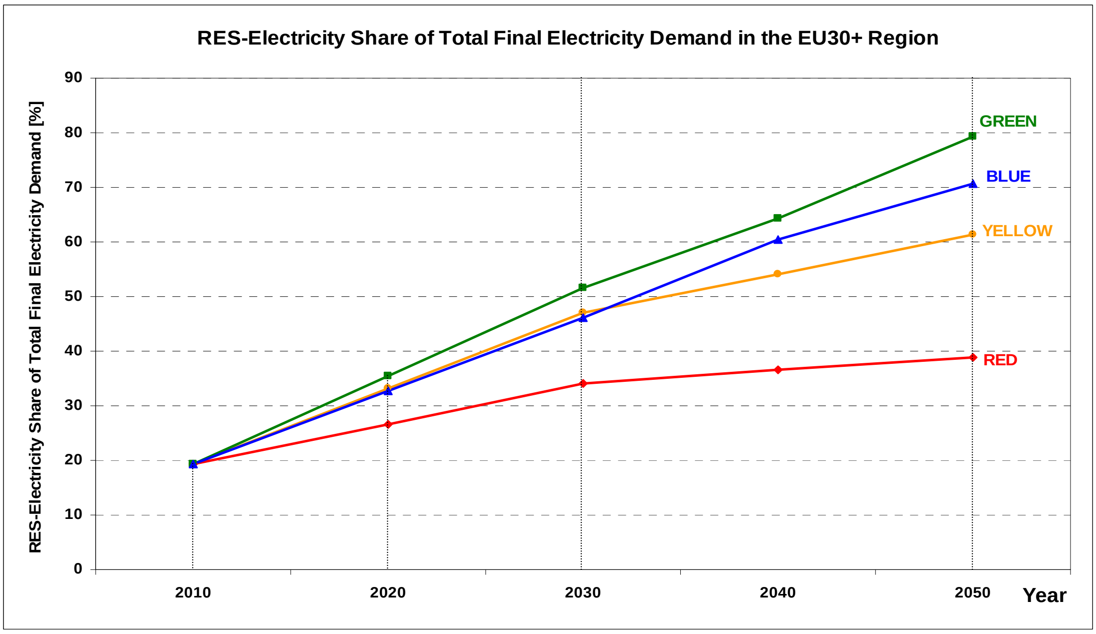

Figure 2.4 RES-Electricity deployment as a share of total final electricity demand on aggregated European level in the four different storylines in SUSPLAN

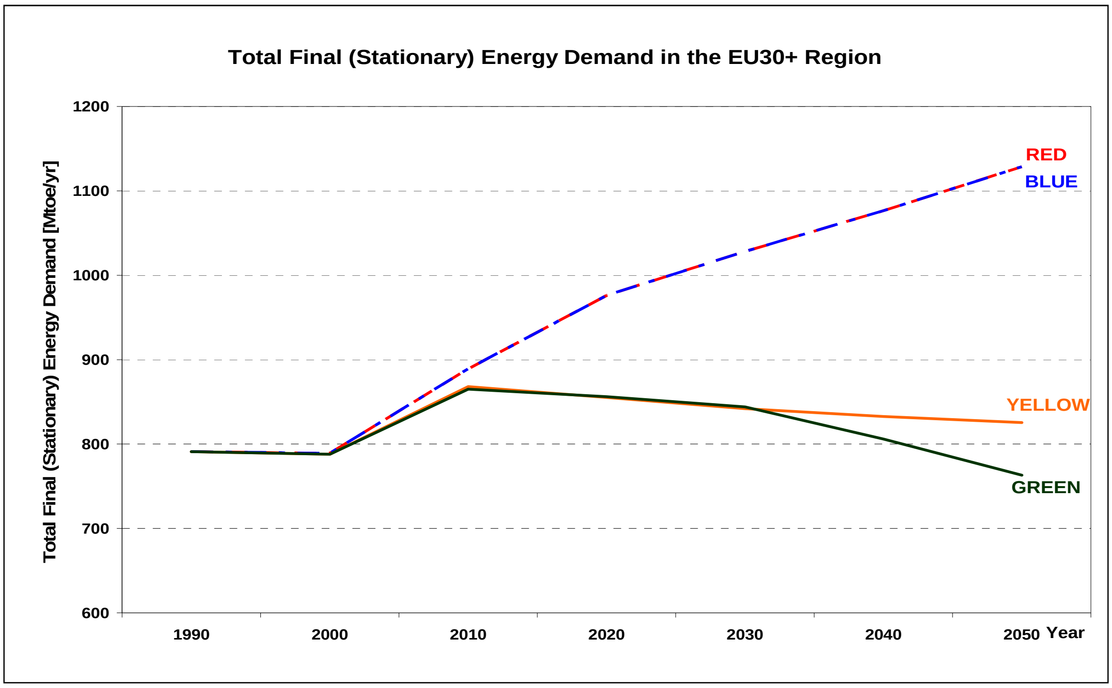

Figure 2.5 Total final stationary energy demand on aggregated European level in the four different storylines in SUSPLAN

2.2.3 RES/RES-Electricity Technology Cost up to 2050

Depending on global implementation rates of RES/RES-electricity generation technologies, their specific investment cost decrease accordingly (mainly due to economies of scale in manufacturing). Therefore, different cost trajectories per RES/RES-electricity technology and per storyline are considered up to 2050. As an example, Figure 2.6 and Figure 2.7 present the future development of RES generation technologies' investment cost for the *Red* and *Green* storyline based on Green-X model up to 2030 ([Faber, 2007], [Auer, 2008]) and extrapolation of gradients up to 2050. The reference year (100%) of technologies' investment cost is year 2010.

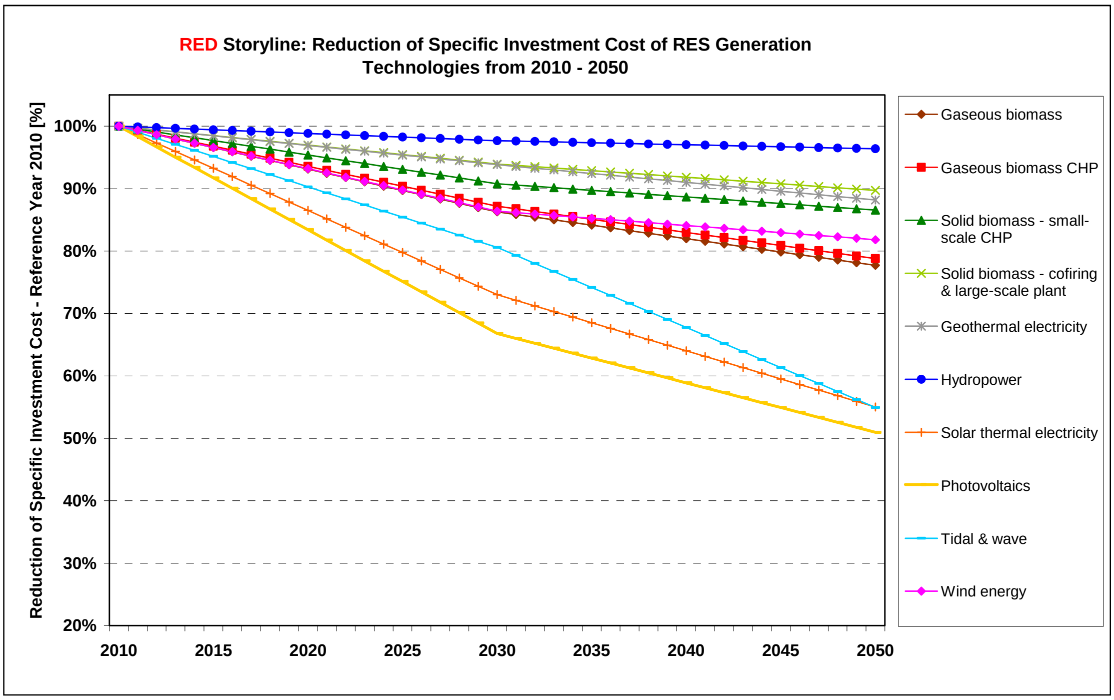

Figure 2.6 Development of the specific investment cost of different RES generation technologies in the *Red* storyline in SUSPLAN

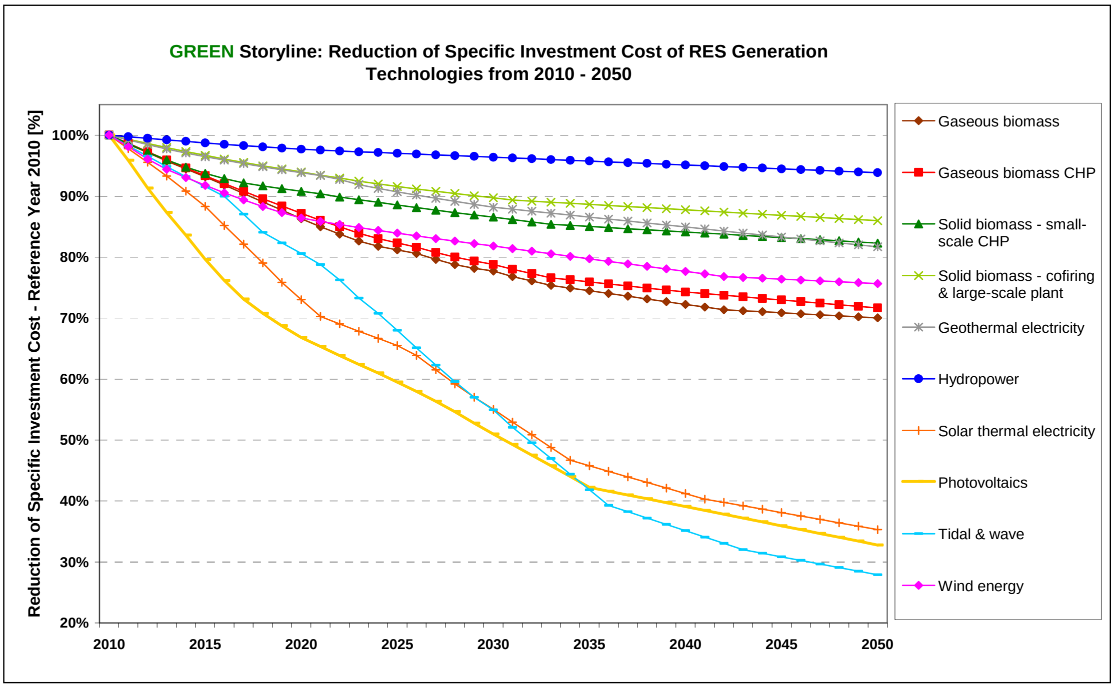

Figure 2.7 Development of the specific investment cost of different RES generation technologies in the *Green* storyline in SUSPLAN

2.2.4 Fossil Fuel-, CO_2- and Biomass Prices up to 2050

Consistent settings of future price scenarios for fossils, CO_2 and biomass in the different storylines are based on different empirical settings of future development of key parameters. However, they are not set independently; they are rather explained and justified in comparison to other relevant studies and publications on international level. The following Figure 2.8 and Figure 2.9 present the expected future development of the fossil fuel and CO_2 prices in the four different storylines in SUSPLAN up to 2050, on the one hand, and the biomass wholesale prices, on the other hand.

Fossil Fuel and CO2-Price Development up to 2050

In order to be able to set expected future price developments of fossil fuels and CO_2 in accordance with several other important international studies (e.g. *'European Energy and Transport Trends* of the European Commission [EC, 2007], *'World Energy Outlook'* of the International Energy Agency [IEA, 2009], *'Annual Energy Outlook 2009 - With Projections to 2030'* of the U.S. Energy Information Administration of the Department of Energy [DOE, 2009], others), the major results on these price scenarios have been studied and compared. This comparison has led to the conclusion that the future price scenarios (i.e. *'Reference Scenario'* and *'450 ppm Scenario'*) of the latest publication of the World Energy Outlook ([IEA, 2009]), in general, match with several other publications (small deviations can be explained by differences in assumptions in the different studies) and, therefore, are qualified to be used in SUSPLAN scenario analyses. Moreover, the empirical settings of the fossil fuel and CO_2 price scenarios of the WEO2009 are used in the SUSPLAN storyline context as follows:

- The two different price scenarios of the WEO2009 are implemented in the SUSPLAN approach according to the expected demand and importance of fossil and CO_2 products in the different storylines. As the demand patterns of the storyline two couples *Red/Blue* and *Yellow/Green* are similar, the four different storylines are combined to two storyline-clusters.
- *Yellow/Green:* Due to lower demand of fossil fuels and decreasing importance of CO2 instruments, the low price path of each of the two price scenarios of the WEO2009 is used.
- *Red/Blue:* Due to still high demand of fossil fuels and still high importance of CO2 instruments, the high price path of each of the two price scenarios of the WEO2009 is used.

Positive Public Attitude

WEO2009 "450 ppm Scenario" ($2008 Prices)	2008	2015	2020	2025	2030	2035	2040	2045	2050
IEA crude oil imports ($/bbl)	**97,2**	**86,7**	**90,0**	**90,0**	**90,0**	**90,0**	**90,0**	**90,0**	**90,0**
Natural gas imports ($/Mbtu PCS)	10,3	10,5	11,0	11,0	11,0	11,4	11,4	11,4	11,4
Natural gas imports ($/Mbtu PCI)	11,5	11,6	12,3	12,3	12,3	12,3	12,3	12,3	12,3
Natural gas imports ($/MWh PCI)	**39,2**	**39,7**	**41,9**	**41,9**	**41,9**	**41,9**	**41,9**	**41,9**	**41,9**
OECD steam coal imports ($/t)	120,6	85,6	80,1	72,5	64,8	57,2	49,6	41,9	34,3
OECD steam coal imports ($/MWh)	**16,5**	**11,7**	**10,9**	**9,9**	**8,8**	**7,8**	**6,8**	**5,7**	**4,7**

Lower demand of Fossils in Yellow/Green than Red/Blue -> Lower Price Level

WEO2009 "Reference Scenario" ($2008 Prices)	2020	2030	2040	2050
CO_2 Price [$/t$CO_2$]	43	54	65	76

Public adapts production and consumption of energy themselves in a sustainable way; CO_2 market less important instrument and, therefore, prices are lower

Slow Techn. Develop. ← → Fast Techn. Develop.

WEO2009 "Reference Scenario" ($2008 Prices)	2008	2015	2020	2025	2030	2035	2040	2045	2050
IEA crude oil imports ($/bbl)	**97,2**	**86,7**	**100,0**	**107,5**	**115,0**	**122,5**	**130,0**	**137,5**	**145,0**
Natural gas imports ($/Mbtu PCS)	10,3	10,5	12,1	13,1	14,0	15,0	15,9	16,9	17,8
Natural gas imports ($/Mbtu PCI)	11,5	11,6	13,5	14,6	15,6	16,7	17,7	18,8	19,8
Natural gas imports ($/MWh PCI)	**39,2**	**39,7**	**45,9**	**49,7**	**53,2**	**56,8**	**60,4**	**64,0**	**67,6**
OECD steam coal imports ($/t)	120,6	91,1	104,2	107,1	109,4	112,0	114,5	117,0	119,5
OECD steam coal imports ($/MWh)	**16,5**	**12,4**	**14,2**	**14,6**	**14,9**	**15,3**	**15,6**	**16,0**	**16,3**

Higher demand of Fossils in Red/Blue than Yellow/Green -> Higher Price Level

WEO2009 "450 ppm Scenario" ($2008 Prices)	2020	2030	2040	2050
CO_2 Price [$/t$CO_2$]	50	100	125	150

High CO_2 market price is important instrument (for authorities) to influence production and consumption of energy (due to indifferent „public")

Indifferent Public Attitude

Figure 2.8 Expected development of the fossil fuel (crude oil, natural gas, coal) and CO2 prices up to 2050 in the *Red/Blue* and *Yellow/Green* storylines in SUSPLAN

Biomass Price Development up to 2050

In SUSPLAN scenario analyses it is assumed that there will be a common European market for biomass in the medium- to long-term, resulting in a converging international biomass wholesale price. Derived from the *'RES2020'* project [RES2020, D4.2], where several relevant country-specific biomass fraction and cost data are available for all EU27 Member States (incl. Norway), an average biomass price of 6€/GJ is taken as starting point for 2010 for several of the four storylines in SUSPLAN. Moreover, roughly 80% of the biomass cost values in the different countries are within a range of 2 €/GJ to 9 €/GJ, with a decreasing trend for moderate biomass use towards the future.

In the SUSPLAN storyline context the empirical settings of the biomass wholesale prices up to 2050 have been set as follows (see Figure 2.9 in detail):

- Due to the fact that in the *Red* storyline demand for biomass is assumed to be the lowest (compared to other storylines in SUSPLAN), a linear price decrease from 6 €/GJ in 2010 to 5 €/GJ until 2050 is foreseen. In the *Blue* storyline demand on biomass is slightly higher than in *Red* and, therefore, a constant biomass price of 6 €/GJ remains until 2050.
- In the two other storylines, *Green* and *Yellow*, demand on biomass is significantly higher and, therefore, increasing biomass wholesale prices are expected until 2050 reaching price levels of 8 €/GJ and 10 €/GJ for *Green* and *Yellow* respectively.

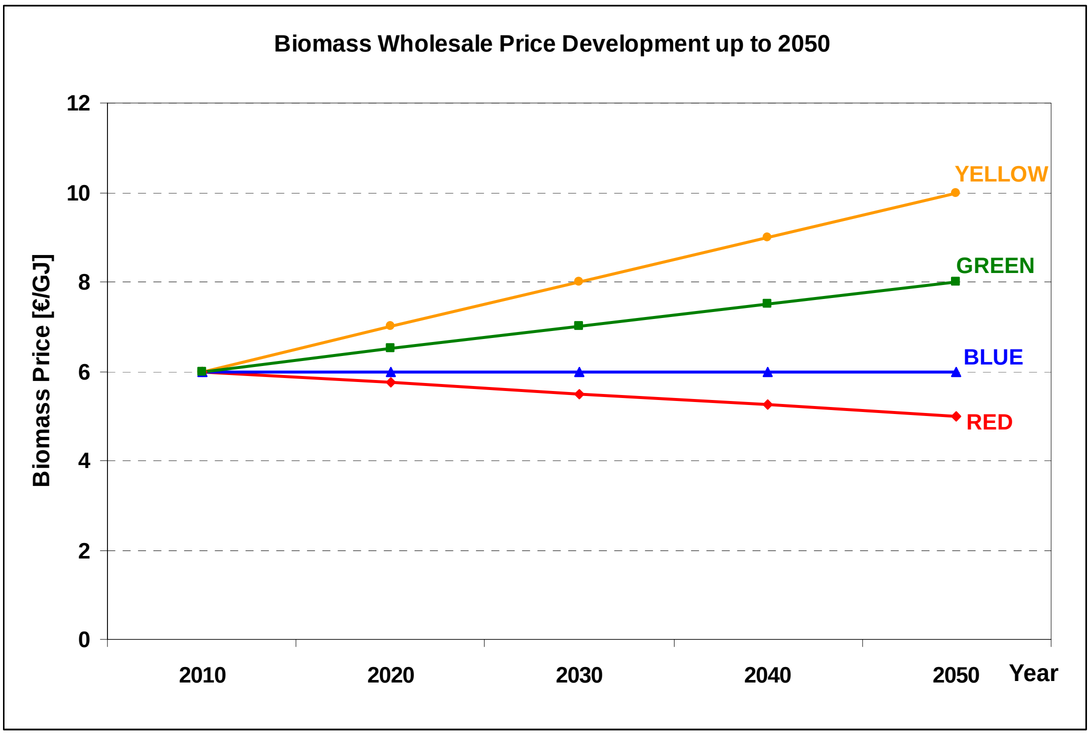

Figure 2.9 Expected development of the biomass wholesale prices up to 2050 in the four different storylines in SUSPLAN

2.2.5 Wholesale Electricity Prices up to 2050

In the SUSPLAN project, the wholesale electricity market price development in the four different storylines is not set exogenously; it is modelled endogenously with a European electricity market model where – among others – the empirical settings of parameters described above (like fossil fuel-, biomass- and CO_2 prices, RES-Electricity generation per technology, electricity demand on country-level, etc.) are used accordingly.

To establish a uniform starting point for the regional studies, the European electricity market up to 2050 has been modelled with the European Multi-area Power market Simulator *'EMPS'* for each of the four storylines (for a detailed description of this model it is referred to the *'Scenario Guidebook'* [SUSPLAN, D1.2]). The EMPS model is a socio-economic electricity system model that can handle systems with large shares of variable/intermittent electricity generation as well as long- and short-term storage options. Basically it is a stochastic optimization model which calculates a minimum cost strategy for the operation of an electricity system [Mo, 2005], [Wolfgang, 2009].

In the SUSPLAN application of the EMPS model each European country is considered as a single node (characterized by an endogenously determined internal supply and demand balance) with distinct import and export transmission capacities to the neighbouring countries, see Figure 2.10.

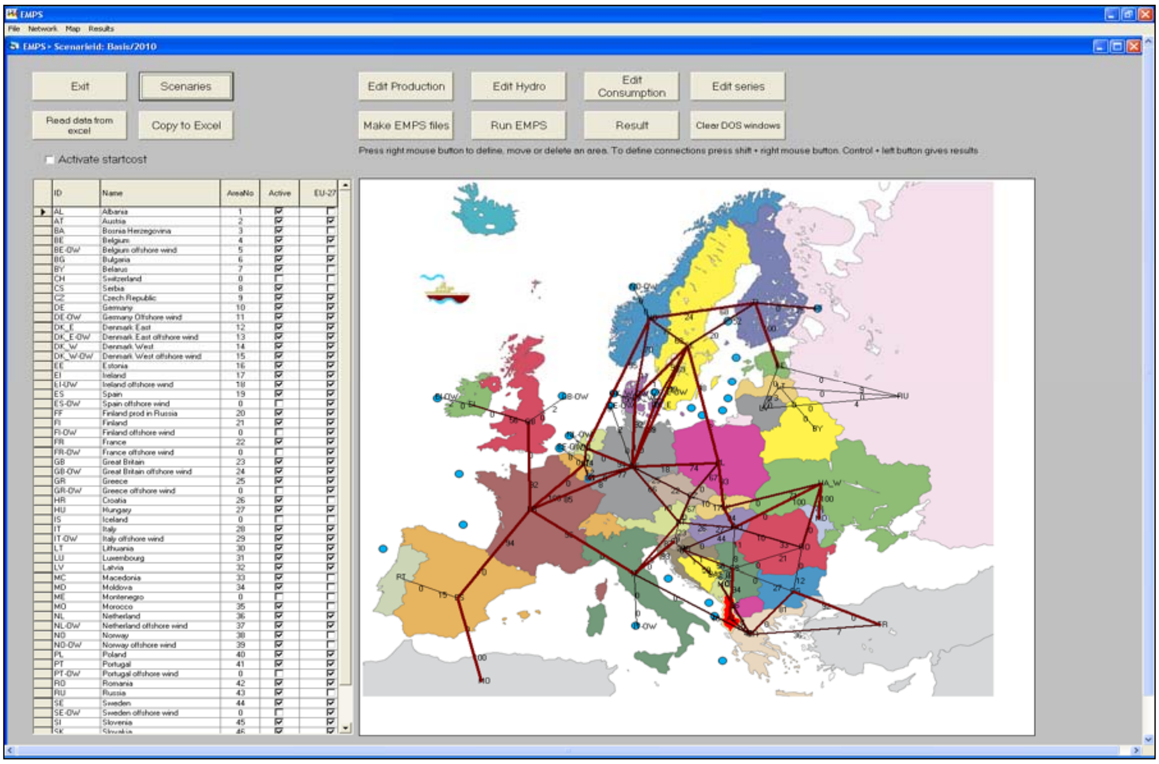

Figure 2.10 EMPS electricity market model for the regional scenario studies in SUSPLAN

Several empirical settings of the parameters in the *'EMPS'* model go in line with the overall philosophy of the different storylines in SUSPLAN. This means in particular, that e.g. several capacity settings both generation and cross-border transmission, are implemented in accordance with the overall description of the storylines. E.g. in the *Blue* storyline with large-scale, centralized offshore RES-Electricity generation higher cross-border transmission capacities are implemented in the model than for remaining storylines. As the major output, *'EMPS'* delivers per storyline a series of wholesale electricity prices on country-level up to 2050.

3 SELECTION CRITERIA FOR REGIONAL SCENARIO STUDIES

3.1 Objectives of the Regional Scenario Studies

The most innovative aspect of the SUSPLAN project is that each of the regional case studies plus the trans-national electricity and gas infrastructure studies in WP3 are all performed within the same 4 storylines with the same basic assumptions and parameters. Furthermore, the regional analyses not only determine RES supply/demand balances in a particular region and/or country but also study corresponding grid infrastructure integration needs and costs for the integration of renewable energy sources. In geographic terms the analysis is not restricted to the boundaries of a particular region and/or country but also determines the balances on the borders to neighboring regions and/or countries. This is also true for the grid infrastructure analyses, which are not restricted to the electricity grids but also analyses the role of gas and heat grids in this context and the interdependences between the different network infrastructures for an optimal RES deployment in the long-term. For details on quantitative and qualitative results for each of the different regional reports, see the respective deliverables [SUSPLAN, D2.1]-[SUSPLAN, D2.9]).

As already mentioned in the *"Scenario Guidebook"* [SUSPLAN, D1.2], where a consistent scenario framework for the SUSPLAN project is defined, the rational background to conduct different regional scenario studies is driven by two major considerations:

- Input to the overall SUSPLAN project: The complexity of RES grid infrastructure integration significantly depends on the existing structure of the energy system. Due to the fact that in the different European regions/countries there exist fundamentally different energy systems (e.g. in terms of flexibility of the power plant portfolio in the electricity sector, dominance and resource availability / corridors of natural gas in the electricity and heating sector, historically grown structures and dominance of fuels used in the heating sectors, etc.) therefore, a representative amount of regional case studies has to be conducted to be able to study several important aspects/dimensions of more efficient RES grid infrastructure integration into future energy systems. However, the number of regional scenario studies has to be limited in order to avoid redundancy of the major features describing the existing energy systems and RES resource availability.
- Stand-alone regional scenario study of RES grid infrastructure integration up to 2050: Each of the nine different regional scenario studies is also a comprehensive stand-alone study on RES grid infrastructure integration for the region itself under a variety of different possible future "environments" (i.e. scenarios) in the region up to 2050. In this context, the long-term perspective is important to be able to study possible "structural breaks",[5] on the one hand, and also to consider extremely long lead times of grid infrastructure planning and implementation necessary to absorb large amounts of RES generation, on the other hand. The policy recommendations and inputs for action plans for the different players in the region (decision makers, stakeholders, etc.) are prepared tailor-made for the region. Moreover, the regional scenario studies shall significantly support the development of regional RES grid integration strategies both short-term and long-term.

Based on the considerations stated above the major objectives of the regional scenario studies can be summarized as follows:

[5] E.g. phasing in and/or phasing out of new energy technologies and/or energy policies.

- Contribution *of the region* and the regional energy system and its resources to study the complexity of RES grid infrastructure integration under a variety of different constraints;
- Development of different RES grid integration strategies and recommendations *for the region* up to 2050.

3.2 Selection Criteria of the Nine European Regional Scenario Studies

Having in mind the existing energy systems in the European countries and the future potential of renewable energy sources all over Europe and in neighboring regions like the Atlantic Ocean and North-Africa, the criteria for the selection of the different European regions being representative to get sufficient insight to cover the most important cornerstones of interest in the SUSPLAN project has finally resulted in nine different regional case studies.

The main criteria determining the selection of different regions in the regional scenario analyses in SUSPLAN can be summarized as follows:

- Number of regional scenario studies: A critical number of regional scenario studies is necessary in order to cover several representative geographic regions all over Europe. The total number, however, shall be as small as possible in order to avoid overlapping analyses.
- Consideration of different status quo (starting points) of renewable integration: There exist considerable differences in the status quo of renewable deployment in different European countries, e.g. compare existing RES deployment in (i) "old" EU15 Member States (partly high RES shares are already implemented), (ii) "new" EU12 Member States (significant RES investment opportunities exist for the future) and (iii) Balkan Countries (although high RES shares less financial support instruments for RES implementation at present).
- Different characteristics of the energy systems: The different regional scenario studies describe different determinants, challenges and complexities of RES grid infrastructure integration being also transferable to other European regions and being characterized by similar features and constraints.
- Renewable/environmental policy, energy market maturity and macro-economic aspects: In different European regions there exist significant differences with respect to these different determinants. This has to be reflected in the selection of the regional scenario studies, too. There exist fundamental differences e.g. in terms of the political situation in general, environmental consciousness, maturity of the energy markets and also macro-economic developments.

3.3 Characteristics of the Nine European Regions

Below the main characteristics of the nine European regions are listed which have been subject to comprehensive scenario study analyses in the SUSPLAN project (see also Figure 3.1):

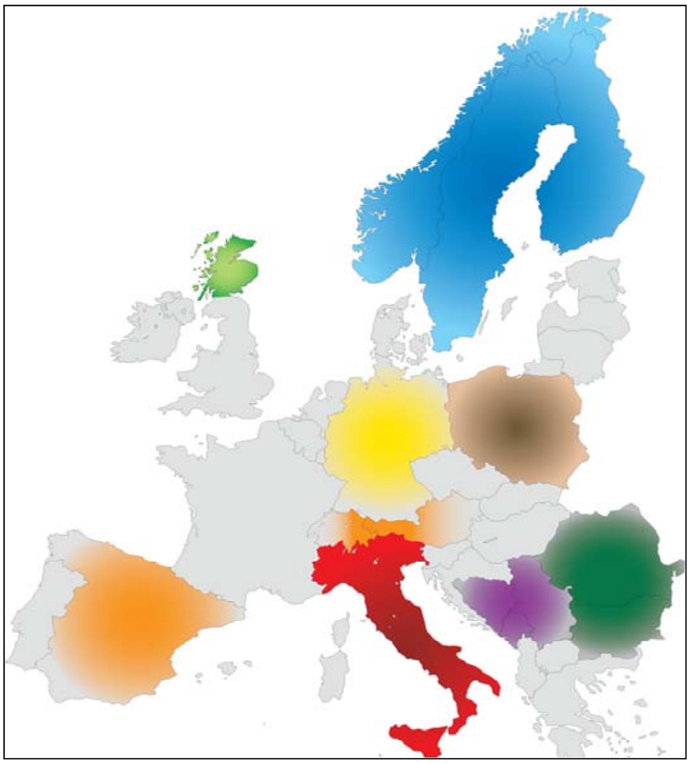

Figure 3.1 The nine SUSPLAN regions

- Islands (Isle of Lewis, North-West Scotland): Huge potentials of offshore renewable potentials (offshore wind, marine energy); isolated/weak grid connection points; low demand; potential for H_2 production and storage;
- Northern Europe (Norway): Well-functioning deregulated electricity market; large share of implemented low emission hydropower (and also future potentials); distinct mono-energy distribution of electricity; cold climate; high prosperity and environmental consciousness;
- Central/Western Europe (Rhine-Neckar Region): dense population; multiple grid infrastructures of electricity, heat and gas; high prosperity; high environmental consciousness;
- North-Eastern Europe (Pomeranian Region in Northern Poland): coal dependent electricity supply system (less flexibility); high wind-onshore and wind-offshore potentials; multiple grid infrastructure of electricity, heat and gas; expected massive investment in the modernisation of the energy infrastructure in the next decade; growing prosperity;
- South-Eastern Europe (Romania): centralised energy system with multiple, but to a large extent obsolete infrastructures; poor efficiency and environmental performance of the energy system; poor security of supply standards; low prosperity; deregulation of electricity markets in an early stage; significant RES potentials; massive investments in the modernisation of the energy infrastructure needed in the next decade;
- South-Western Europe (Spain): already large shares of wind generation in the system; weak transmission grids; deregulated, but isolated electricity market; warm climate (growing cooling demand, summer peak); still high potentials on wind and solar (PV, CSP) generation;

- Southern Europe (Italy): import dependent energy (electricity) system; candidate for important gas-hub (LNG) in Europe; deregulated electricity market; high potentials for wind and solar (PV, CSP); warm climate (growing cooling demand, summer peak);
- Western Balkan Countries (Serbia): region supposed to be part of the European Union in the future; politically still unstable; poor energy infrastructure; ongoing energy market liberalisation; growing demand; significant RES potentials (mainly hydro power); financial support of renewable energy started recently;
- Alpine Region (Austria): similar characteristics of the energy system like Central/Western Europe; incl. significant storage and variability/intermittency mitigation option due to pumped-hydro storage power plants; significant electricity hub in Continental Europe (North/South; East/West); still not utilized potentials for hydro power; significant influence of implementation of Water Framework Directive on future hydropower generation;

3.4 Modelling Approach for Regional Scenario Studies

The overall modeling approach is already described in general in the '*Scenario Guidebook*' [SUSPLAN, D1.2], and in detail in each of the final reports of the regional scenario analyses ([SUSPLAN, D2.1]-[SUSPLAN, D2.9]). Therefore, it is referred to the corresponding documents for details, while only a brief summary is included in this synthesis report.

The key steps of the modeling approach in several of the regional scenario studies can be summarized as follows:

- Step 1: Identification of the long-term 2050 technical potentials of the different RES generation technologies; calculation of a least-cost merit order; and trade-off against a key parameter for the different end-uses (e.g. the wholesale electricity market prices in case of RES-Electricity generation technologies); determination of least-cost RES deployment for different points in time in the future;
- Step 2: Incorporation of a variety of different existing barriers and constraints into the determination process of utilizable RES potentials as well as grid infrastructure routes in the different storylines; estimation and incorporation of the future potential for removal of several of the different barriers and constraints; Figure 3.2 below presents the different barriers and constraints considered in the regional scenario analyses;
- Step 3: based on the possible grid infrastructure routes in the different storylines finally the grid infrastructure cost are quantified for different RES penetration rates and barrier/ constraint settings for different points in time in the future;

One of the most important results in the different regional scenario studies is the quantification of grid infrastructure cost over RES deployment in the different storylines up to 2050.

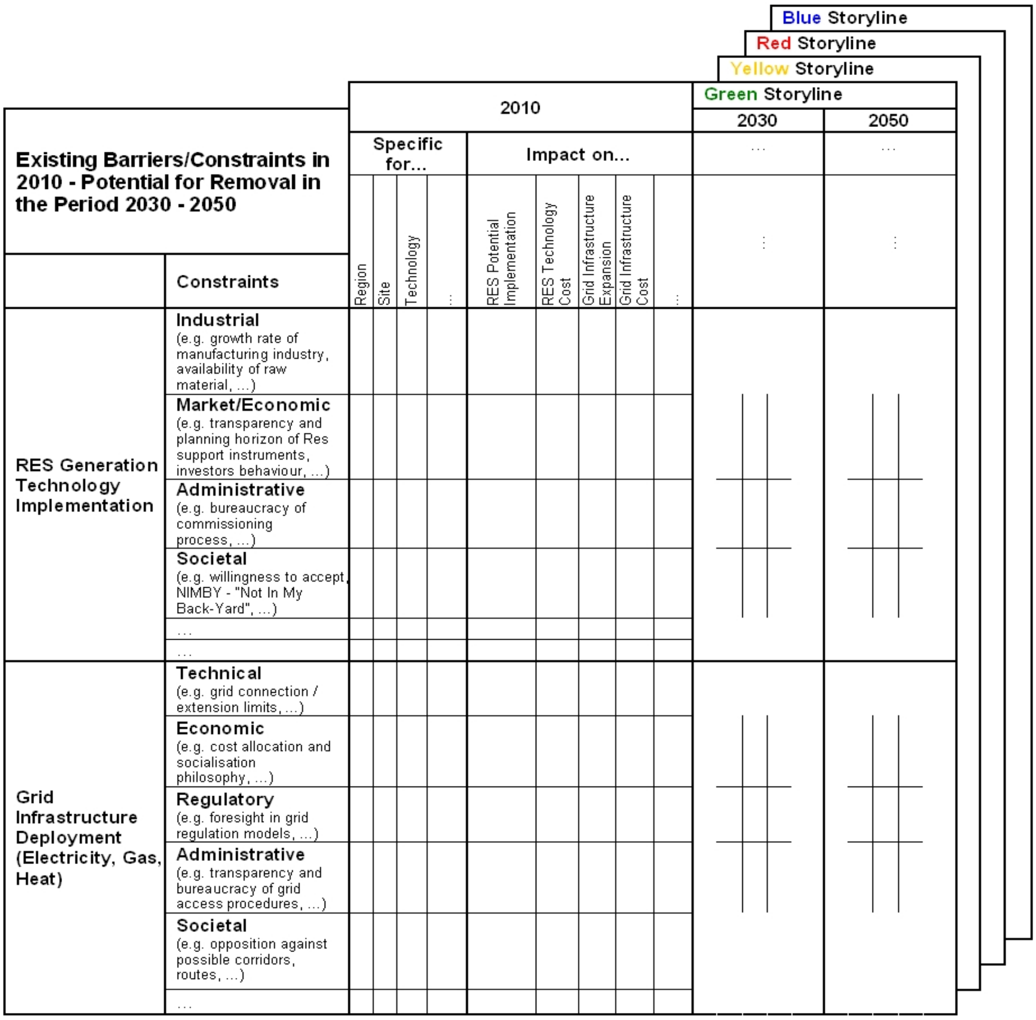

Figure 3.2 Existing barriers/constraints for RES grid infrastructure integration and future potential for removal in the four different storylines

4 SELECTED RESULTS FROM DIFFERENT REGIONAL SCENARIO STUDIES

In the following, for each of the nine regional scenario studies one illustrative result is presented highlighting at least one important aspect having to be considered in RES-E integration. Also for RES-Heat and RES-Gas integration results from selected regions are presented in section 4.2. Detailed results from each region can be found in the specific case reports ([SUSPLAN, D2.1] – [SUSPLAN, D2.9]).

4.1 Grid Integration Results of RES-Electricity Technologies (All Regions)

4.1.1 Islands (Isle of Lewis, North-West Scotland)

In the Isle of Lewis RES-Electricity integration progresses significantly but public acceptance of these devices are relatively low. There is a high level of the *'Not In My Backyard (NIMBY)'* factor. Therefore, the deployment of large-scale wind-onshore developments becomes less likely with a preference for wind-offshore developments that exists outside the region's population areas. One of the biggest challenges, however, is to reach major load areas in case of utilization of the huge amount of marine energy (offshore-wind, wave and tidal energy) in the medium to long-term.

Moreover, in order to meet the ambitious future RES-E generation targets in Europe with minimal total system cost (i.e. cost of RES-E generation and grid infrastructure), it is important to utilize RES-E generation on those sites where energy yields are highest; then only economies of scale of RES-E generation can be exploited. In almost all cases attractive RES-E potentials are far away from load centres in terms of geographical distances. Even more, in many cases the existing electricity grid infrastructure is not sufficiently dimensioned to absorb large amounts of RES-E generation. The Island case is a typical example of this challenge.

Figure 4.1 presents the Isle of Lewis case in the Blue storyline up to 2050. It can be seen that the huge amount of offshore electricity generation (wind, marine) by far exceeds gross electricity demand in the region. It will only be possible to exploit these vast amounts of renewable energy in a trans-national context. Dense load centres in this case either can be in the southern part of England (London region) or in Continental Europe. Therefore, massive transmission investments, onshore and offshore, are needed to integrate these huge amounts of offshore RES-E potentials in the energy supply of Europe.

Further details from the Islands case study can be found in [SUSPLAN, D2.1].

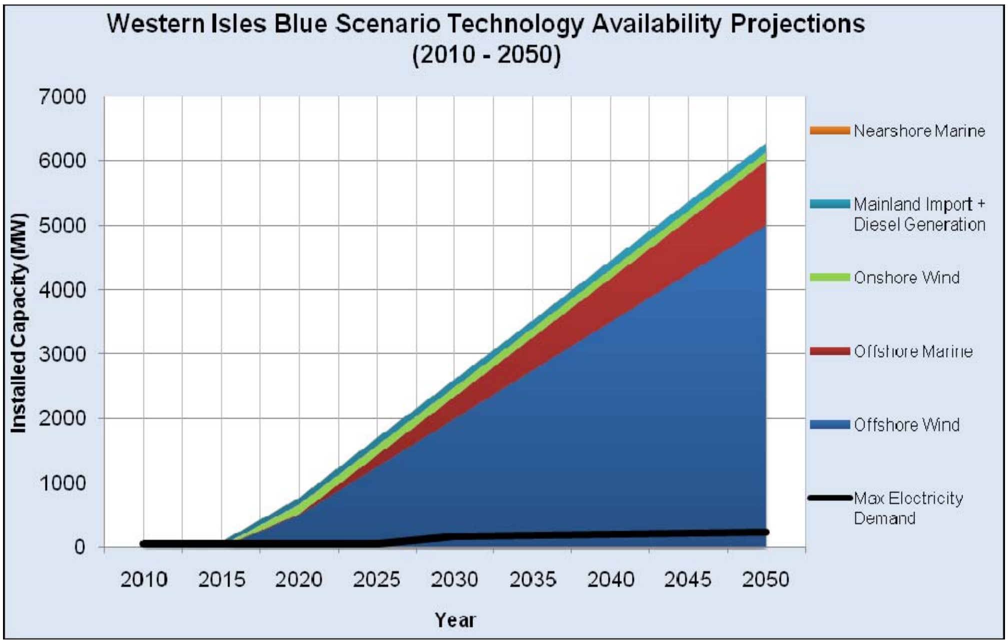

Figure 4.1 Development of installed RES-E capacities and gross electricity demand in the Isles of Lewis in the Blue-Storyline up to 2050

4.1.2 Northern Europe (Norway)

In the north, the Central and Eastern European countries have at present limited access to the Scandinavian electricity system. Due to the high share of flexible hydro power (in Norway in particular) this is another major resource in a trans-national context to balance future electricity systems with high shares of variable and intermittent RES-E generation to replace less flexible power plant portfolios. In order to do so, further transmission grid upgrades, expansions and also new transmission routes are necessary.

The Norwegian TSO has already developed comprehensive scenarios for grid development up to 2030 (the starting point of SUSPLAN analyses). These scenarios proved to be robust also in the SUSPLAN storylines up to 2050, with the exception of development of a large-scale offshore grid in the Blue storyline. Figure 4.2 shows the starting point of the analyses in 2030 based on existing TSO scenarios, while Figure 4.3 presents further extension to a full-scale offshore transmission grid in the Blue storyline up to 2050. In this case, the offshore grid will channel all RES production outside the national grid, and no further expansion is necessary onshore.

In terms of future RES-E potentials, Norway is characterised – beside still available hydro power potentials – by huge wind-offshore potentials along the coast line of the country. Depending on the distance to shore, wind-offshore potentials are quantified in the range of hundreds of TWhs. But the problem is that the Norwegian public, in general, has no interest to implement wind-offshore potentials at all; at least not as long as Norwegian end-users have to pay offshore-grid expansion in their grid tariffs. Moreover, at present Norwegian electricity generation is based on almost 100% hydro-power generation that is cheap, and ensures flexibility to their own system and for exports.

Nonetheless, in the Blue storyline of the SUSPLAN project the case of large-scale wind-offshore implementation has been analysed up to 2050. In Figure 4.3 a possible structure of a large-scale wind offshore grid is presented for the year 2050. But the problem is, that as long as there do not exist fitting business models, Norwegian offshore-wind may not be fully exploited. It is clear that the overarching goal to implement low cost wind-offshore generation in a European context will demand overarching (business-) models on trans-national level. Then only, first best solutions for the energy supply of Europe will be possible. Further details from the Norwegian case study can be found in [SUSPLAN, D2.2].

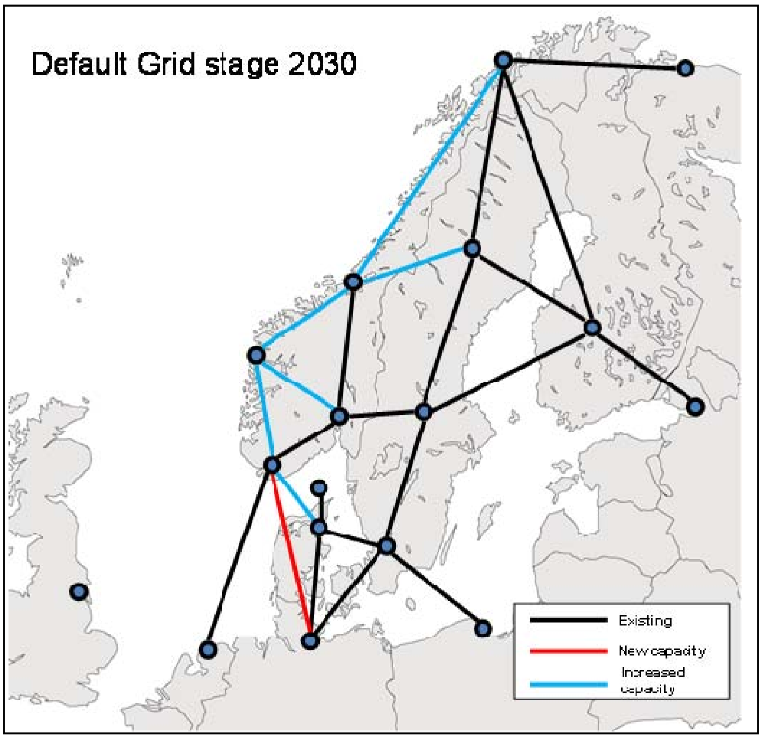

Figure 4.2 Starting point for SUSPLAN analyses based on existing TSO scenarios

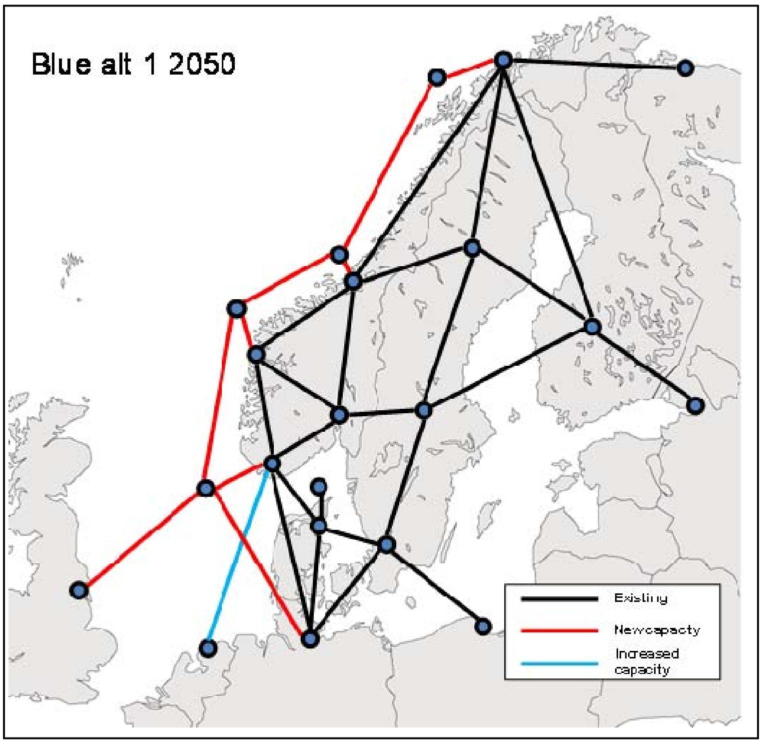

Figure 4.3 Development of full-scale offshore grid in the Blue storyline in 2050

4.1.3 Central/Western Europe (Rhine-Neckar Region)

The electricity sector of the Metropolitan Region Rhine-Neckar (MRN) has two main characteristics today: (i) limited potentials for RES-Electricity generation within the region (mainly PV) and (ii) a big coal-fired power plant *(Großkraftwerk Mannheim (GKM))* already in operation and covering more than 40% of total electricity demand in the region. Moreover, GKM currently is the largest coal-fired installation in the MRN region and almost all of the coal used for electricity generation in the MRN region is used by this power plant. GKM will remain the most dominant generation capacity also in the future (see Figure 4.4), even though its electricity generation might be reduced by replacing one or more of the blocks by gas-fired units to bring more flexibility into the system.

Figure 4.4 presents the electricity generation portfolio of the different generation technologies in the MRN for the period 2030-2050 in the Green storyline. It can be seen that electricity generation based on natural gas technologies (mainly industrial CHP power plants) has the most significant decrease, from around 21 TWh in 2030 to 7 TWh in 2050. As an immediate consequence of energy efficiency implementation on the demand side, the reduction in heat demand in the MRN region (assumed to decrease 3% annually for both process and space heating) also impacts electricity generation from industrial CHP plants. Therefore, the reduction of natural gas demand for electricity generation originates from the reduction in heat demand. In addition, Figure 4.4 indicates that the continuous growth of RES-E generation technologies (especially PV) exceeds this reduction resulting in a decrease of electricity generation from residual resources (e.g. coal) if imports are assumed to be constant.

An overview of future development of RES-Heat generation in the MRN region is presented in section 4.2.1.Further details from the MRN case study can be found in [SUSPLAN, D2.3].

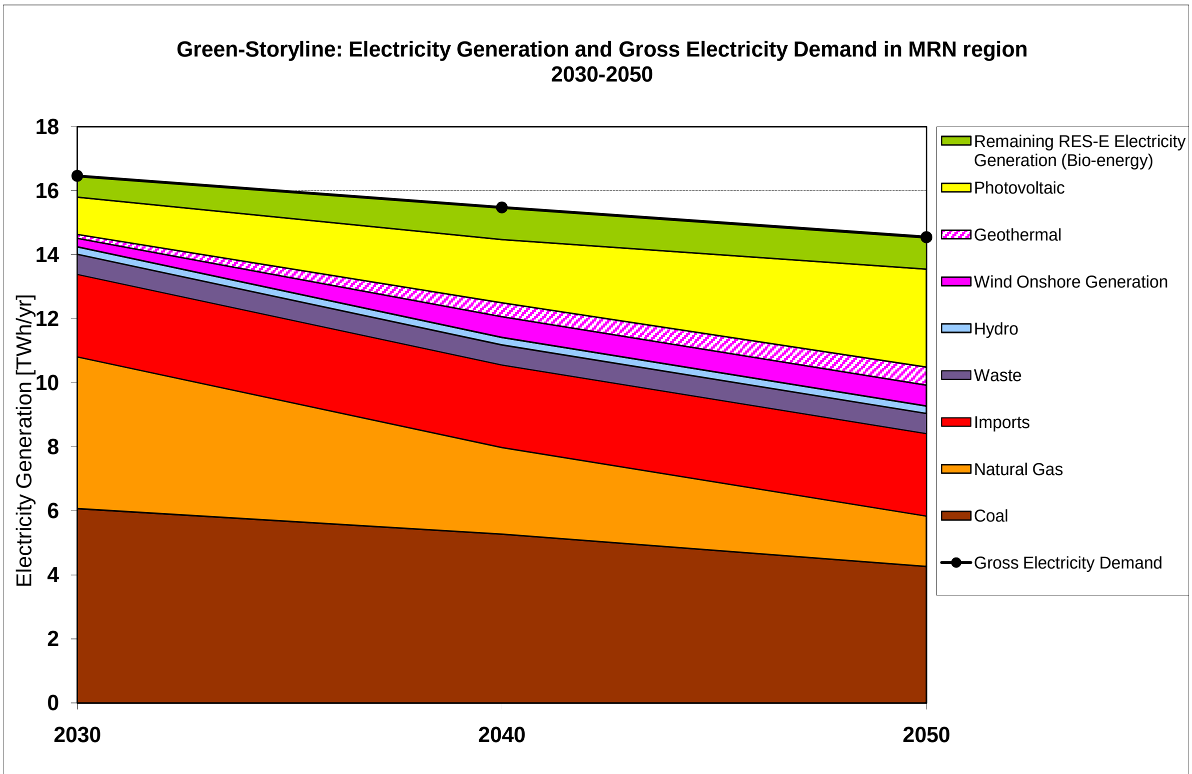

Figure 4.4 Electricity generation and gross electricity demand in the Metropolitan Region Rhine-Neckar (MRN) in the Green storyline up to 2050

4.1.4 North-Eastern Europe (Pomeranian Region)

The Pomeranian region in the northern part of Poland is rich on RES-E resources, not least due to significant wind-offshore potentials in the Baltic Sea. As in many regions throughout Europe, also in the northern part of Poland load density is rather low, compared to other Polish regions towards south. Therefore, long distances in geographic terms have to be overcome to connect attractive RES-E potentials with corresponding load centres. In many cases the existing electricity grid infrastructure is not sufficiently dimensioned to absorb large amounts of RES-E generation. The reason simply can be that network capacities are limited because load density in the area/region is also low.

Figure 4.5 presents the development of electricity generation and gross electricity demand in the Pomeranian region in the Blue (top) and Green (bottom) storylines up to 2050. Both figures show that the Pomeranian region may become a major net-exporter to the interior of Poland and – most probably – also to neighbouring countries. Therefore, adequate transmission investments and routes towards dense load centres have to be ensured. However, the public being confronted with new transmission lines and routes, but having no immediate benefit of it, must be convinced (and most probably compensated somehow).

One of the major differences between the Red and Blue storyline in the Pomeranian region is nuclear power. In the Red storyline it is assumed that Poland phases in nuclear power in the near future (before 2030). However, the nuclear capacity expected to be implemented in the Pomeranian region exceeds electricity load in this region both in the short-term and long-term. Therefore, remaining conventional and RES-E generation is expected to be entirely exported to other regions.

On the other hand, in the Green storyline the entire electricity generation in the region is renewable-based, most notably wind-offshore. Again, major shares of RES-E generation are exported to other regions. Balancing of such an electricity system is possible if synergies of and access to flexible neighbours are used (e.g. pumped-hydro capacities in Scandinavia and the Alps (section 4.1.9)).

Further details from the Pomeranian case study can be found in [SUSPLAN, D2.4].

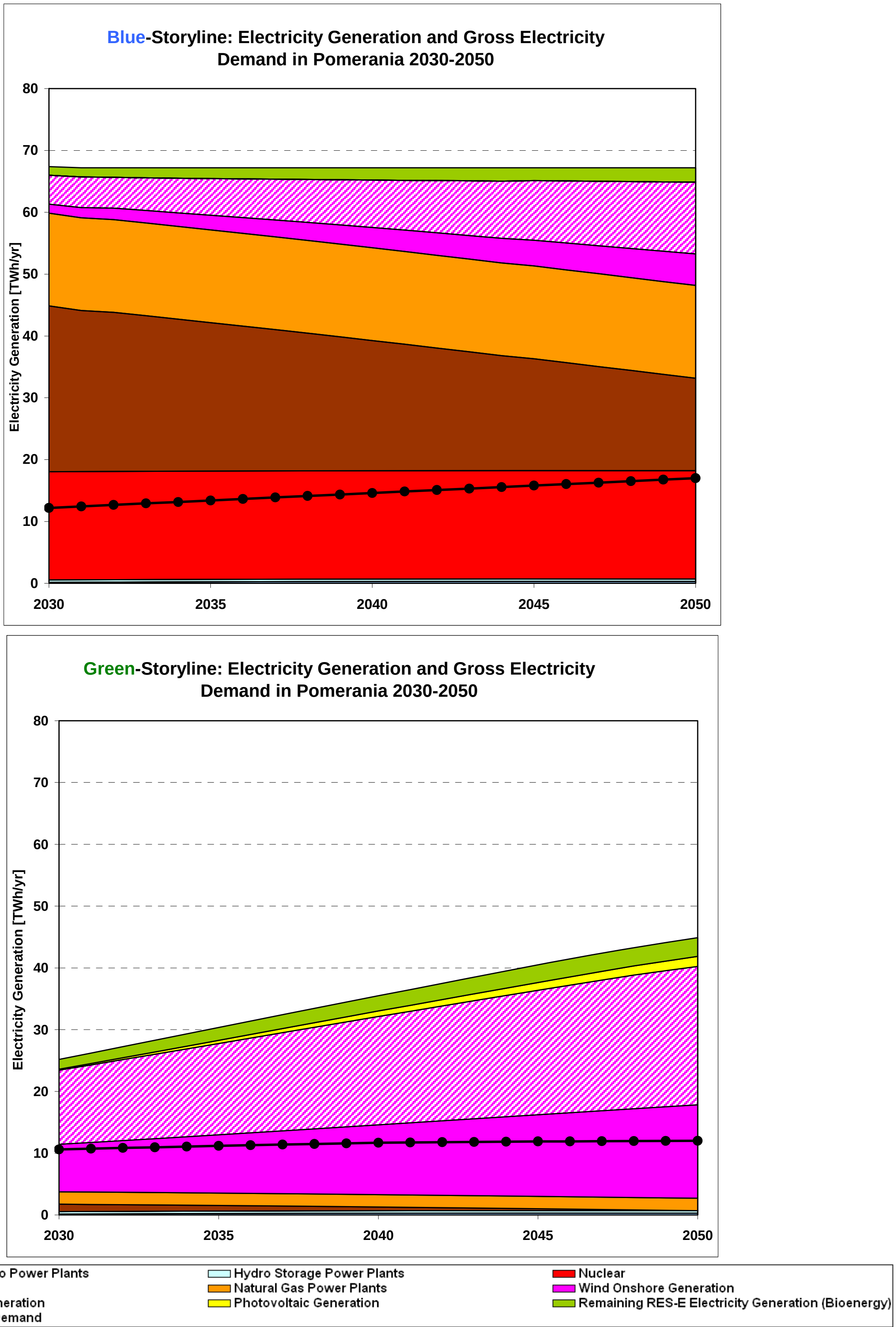

Figure 4.5 Development of electricity generation and gross electricity demand in the Pomeranian region in the Blue (top) and the Green (bottom) storyline up to 2050

4.1.5 South-Eastern Europe (Romania)

In the long-term, on the Romania territory the spatial dispersion of RES-Electricity generation is quite balanced due to the fact that hydro, wind (onshore and also offshore in the Black Sea) and biomass resources are the main contributors. This balanced pattern is most obvious in the long-term analyses in the Green storyline where thermal electricity generation phases out in 2037 (in the remaining three storylines thermal electricity generation, besides hydro and nuclear, plays an important role also in the long-term). Clearly, adequate transmission grid investments – depending on RES-E penetration in the different storylines – are required. This is indicated on the bottom of Figure 4.6, where **c**umulated transmission grid investments over annual RES-E generation are drawn for several of the four different storylines for different years in the future up to 2050.

Figure 4.6 (bottom) shows that to some extent the same amount of RES-E generation may be obtained in the different storylines, but with higher transmission grid cost towards the Red storyline and, of course, over a longer time period. E.g. RES-E generation of 40 TWh/yr may be obtained in the Green storyline by year 2024 with €3.7b cumulated transmission grid investments, while in the Yellow storyline the same amount is obtained by year 2037 with €6.3b.

On the top of Figure 4.6, average annual investments into the transmission grid over RES-E capacity expansion are shown, starting with around €200m per year (today's annual rate of investments into the transmission grid). This is an insufficient transmission grid investment rate, close to the Red storyline in the future. According to the results obtained in the quantitative Romanian analyses in the different storylines, the required average annual rates of transmission grid investments are: €225m/yr in Red, €270m/yr in Yellow, €330m/yr in Blue, and €400m/yr in Green.

In a short-term perspective in Romania, i.e. up to 2020/2025 horizon, wind-onshore development in the Dobrogea area will create significant congestion problems in the transmission grid. Even more, expected electricity produced in Dobrogea by wind-onshore and nuclear in the near future (Cernavoda nuclear power plant with two new 710 MW units foreseen by 2018) badly needs better transmission infrastructures in the region. In this respect the strategic development plan for the Romanian transmission grid up to 2020 includes corresponding investments into transmission facilities as well as further transmission interconnections with Bulgaria. Another important project is the submarine cable in the Black Sea to Turkey. This cable will contribute to meet higher electricity demand in Turkey as well as to capitalise and export "green" electricity from projects mainly developed and implemented in the Dobrogea region.

Further details from the Romanian case study can be found in [SUSPLAN, D2.5].

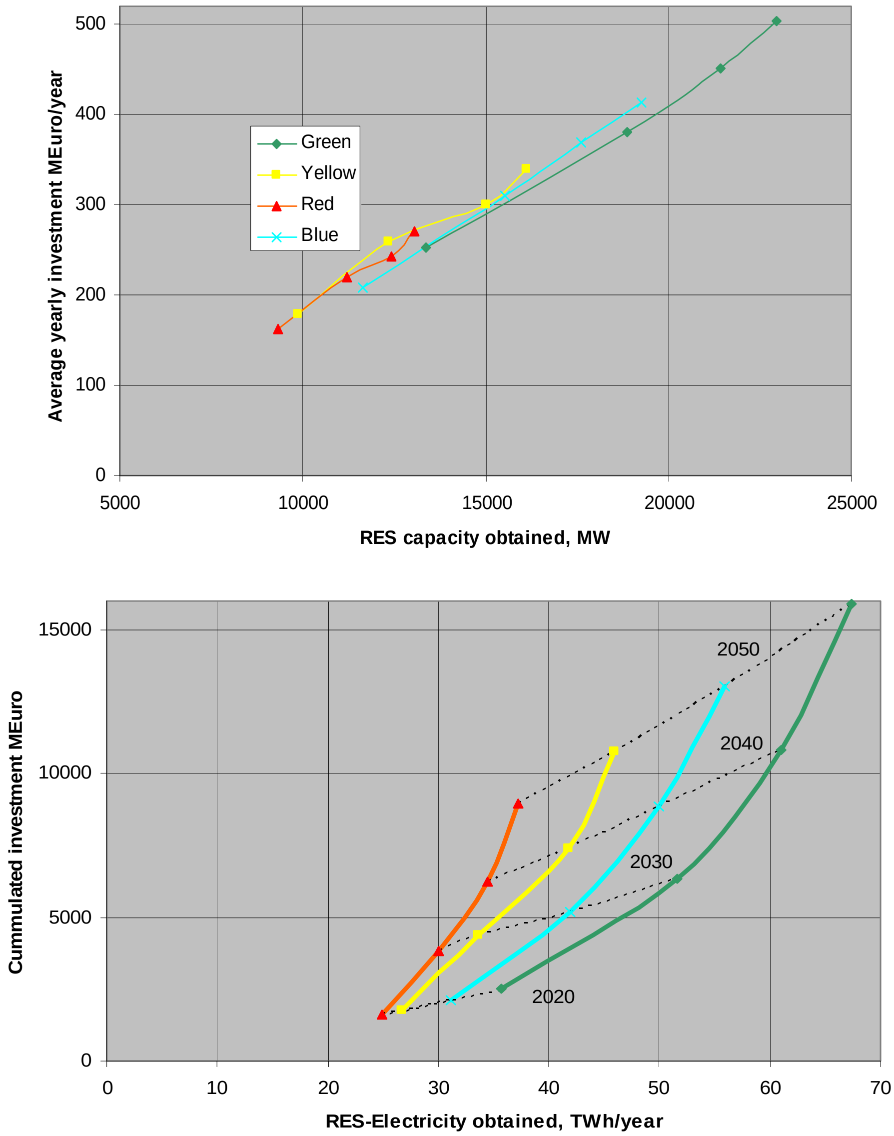

Figure 4.6 Average annual investments in the transmission grid versus RES-E capacity expansion (top); cumulated transmission grid investments versus annual RES-E generation obtained for different years in the future up to 2050 (bottom)

4.1.6 South-Western Europe (Spain)

The results of the regional scenario analyses in Spain demonstrate that different assumptions about the future of the Spanish electricity system provide significant differences in the composition of the generation mix in terms of RES-E and conventional generation portfolio as well as associated investment cost, expected carbon emissions, power system operation, and network investment requirements. The major outcomes and recommendations for an effective and efficient integration of RES-E resources in Spain up to 2050 are as follows:

- The huge potential for RES-E generation in Spain, most notably solar, and wind to a lower degree.

- Despite the beneficial effect of RES-E penetration on carbon emissions and fuel cost, the realizations of scenarios with a high share of RES-E generation technologies - up to 80% of total electricity generation in the Green storyline by 2050 - would create important challenges in the operation of the power system. Changes caused by large shares of RES-E in power system operation, such as higher levels of RES-E generation surpluses, higher operational reserve needs and also energy not supplied (in case of periods of non-availability of renewable resources), would give raise to higher system cost. This cost should be minimized with the integration of backup conventional (gas-fired) electricity generation, electricity storage options (hydro pumping units in the Pyrenees, battery systems of electric vehicles, etc.), new interconnection capacity to neighbouring countries, and/or other flexible resources.
- The installation of high shares of RES-E will modify currently existing regional-based transmission infrastructure planning criteria. The additional drivers for transmission investment to be considered in future scenarios will be the connection of offshore-wind farms and the need to increase transmission interconnection capacity to neighboring countries.
- A main concern in Spain will be the reduction of possible intermittent generation spillages and/or curtailment, which can be achieved by using flexible generation/demand strategies and also by increasing transmission interconnection with France. For the expected levels of RES-E generation in the different storylines, results show that there will be a need to increase the interconnection capacity with France in the range of 6 GW to 26 GW by 2050, depending on the storyline. The cost of increasing the interconnection capacity could be fully recovered by the various benefits brought by this additional capacity, including the avoided RES-E spillages within this period.

Figure 4.7 and Figure 4.8 finally present two selected quantitative results to underpin above statements: Installed RES-E capacities in the four different storylines up to 2050 and total cumulated transmission grid investment cost over RES-E penetration in the four different storylines up to 2050.

Further details from the Spanish case study can be found in [SUSPLAN, D2.6].

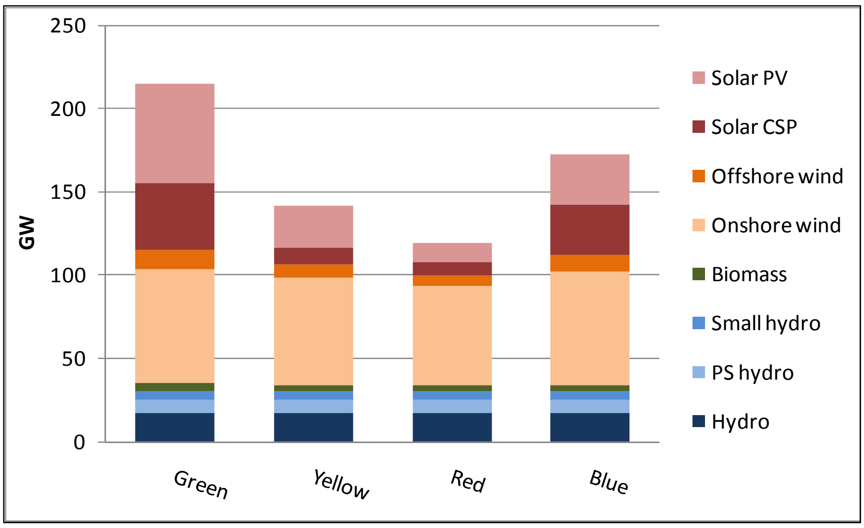

Figure 4.7 Installed RES-E capacities in Spain in the four different storylines up to 2050

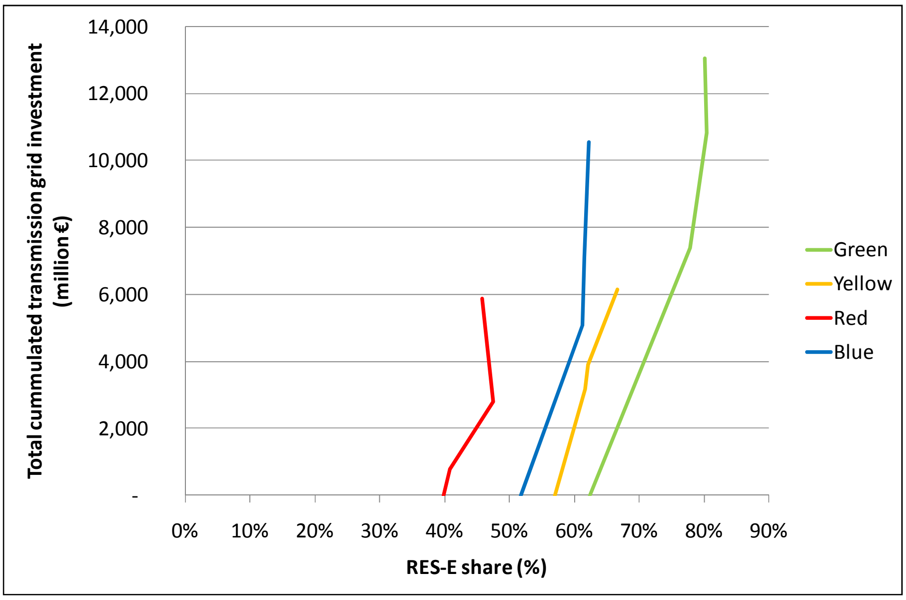

Figure 4.8 Total cumulated transmission grid investment cost over RES-E penetration in the four different storylines up to 2050

4.1.7 Southern Europe (Italy)

Representing the Italian case, Figure 4.9 shows the electricity generation portfolio (RES-E and Non-RES-E) in the four different storylines up to 2050, while Figure 4.10 shows expansion requirements and annual investments of both the trans-regional (between regions) and intra-regional (within regions) transmission grid. RES-E generation is highest in the Green storyline and lowest in Red for several different points in time in the future, but Italy remains a net importer of electricity in all storylines. In terms of trans-regional transmission investment needs (Italy consist of 20 regions), a similar pattern can be observed for all storylines; this means in particular that the highest transmission investment needs are required in the Green storyline, the lowest in Red. On the contrary, for the intra-regional transmission investment requirements the situation is vice versa.

In Italy, the large potentials for RES-E generation are located in the southern part of the country. In this area, however, load is generally low and the electrical system is weakly developed, so it is necessary to built new transmission lines to connect new RES-E plants to the grid properly. In addition, RES-E generation is often not located near load centres, so there is a substantial change of power flow distributions, with the consequence to strengthen the national transmission grid.

Further details from the Italian case study can be found in [SUSPLAN, D2.7].

	RED		YELLOW		BLUE		GREEN	
PRODUCTION (TWh)	2030	2050	2030	2050	2030	2050	2030	2050
Biomass	14.5	15.9	14.9	16.1	15.2	17.5	15.2	17.5
Hydroelectric	42.1	42.1	42.8	45.7	42.1	42.1	42.8	45.7
Wind onshore	18.3	18.2	21.7	21.6	18.3	18.2	21.7	21.6
Wind Off-shore	2.9	3.7	5.0	5.8	4.5	14.6	5.8	15.8
Solar PV	6.3	7.6	7.6	9.8	8.8	23.9	9.8	26.1
Solar CSP	1.6	3.4	1.6	3.4	3.4	5.8	3.4	5.6
Geothermal	7.5	7.5	7.5	7.5	8.5	8.5	9.8	9.8
Pumped storage	6.3	6.3	6.3	6.3	6.3	6.3	6.3	6.3
Waste (not RES)	3.8	4.0	4.2	5.0	4.4	5.0	4.4	5.0
CCGT	80.2	193.5	21.8	40.9	60.7	98.2	34.1	49.0
Other natural gas	86.3	47.1	89.6	60.7	86.2	50.4	86.1	52.8
Oil & derivatives	8.9	0.5	8.9	0.5	8.9	0.5	8.9	0.5
Coal	77.1	75.5	77.2	75.5	64.0	60.2	47.9	44.1
Coal with CCS	-	-	-	-	2.2	2.2	35.1	35.1
Nuclear	-	-	18.9	51.0	38.3	89.3	-	-
Res Production	*93*	*98*	*101*	*110*	*101*	*131*	*108*	*142*
Non Renewable Prod.	*263*	*327*	*227*	*240*	*271*	*312*	*223*	*193*
TOT PRODUCTION	356	425	328	350	372	443	331	335

Figure 4.9 RES-E & Non-RES-E generation portfolio in Italy in the four different storylines in 2030 and 2050

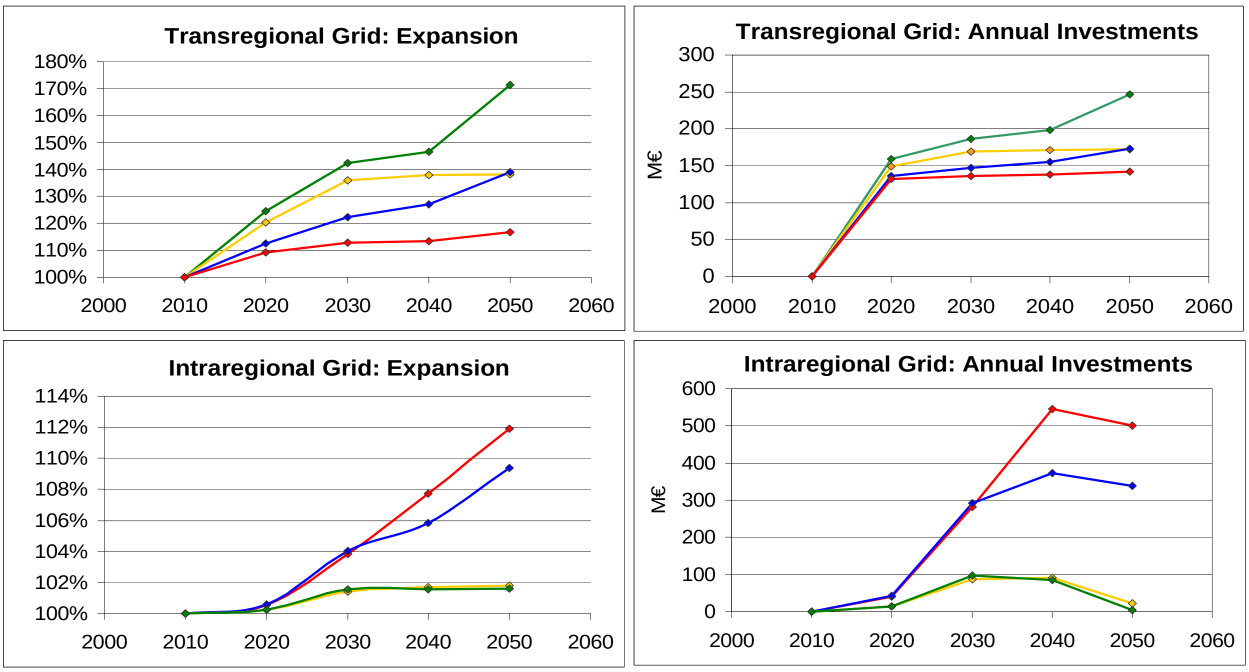

Figure 4.10 Expansion and annual investments of the trans-regional and intra-regional transmission grid in Italy in the four different storylines up to 2050

4.1.8 Western Balkan Countries (Serbia)

As a representative Western Balkan country, in the SUSPLAN regional scenario studies Serbia has been selected. Besides the other countries in the region, Serbia's energy industry is subject to a fundamental new setup (partly from scratch) in the upcoming years and decades. This is true for several segments of the supply chain: Electricity generation (RES-E, Non-RES-E), transmission, distribution, and customer supply. Furthermore, Serbia as well as the majority of other Western Balkan countries are characterised by still high and economically attractive potentials of hydro power, currently not utilized in their electricity systems.

Figure 4.11 (left) presents not only the spatial dispersion of existing and future RES-E potentials (most notably hydro power and wind-onshore) but also the main load centres and expected new transmission grid routes in Serbia. Moreover, the existing plan to strengthen the national transmission grid as well as cross-border interconnectors to the neighbouring countries in the different directions is most beneficial for RES-E integration in Serbia's electricity market. This means in detail, that major future investments into the transmission network are needed to establish robust market structures in Serbia as well as in the entire Western Balkan region. These synergies can be used to integrate relatively high shares of RES-E generation potentials with rather low total and specific cost for transmission expansion.

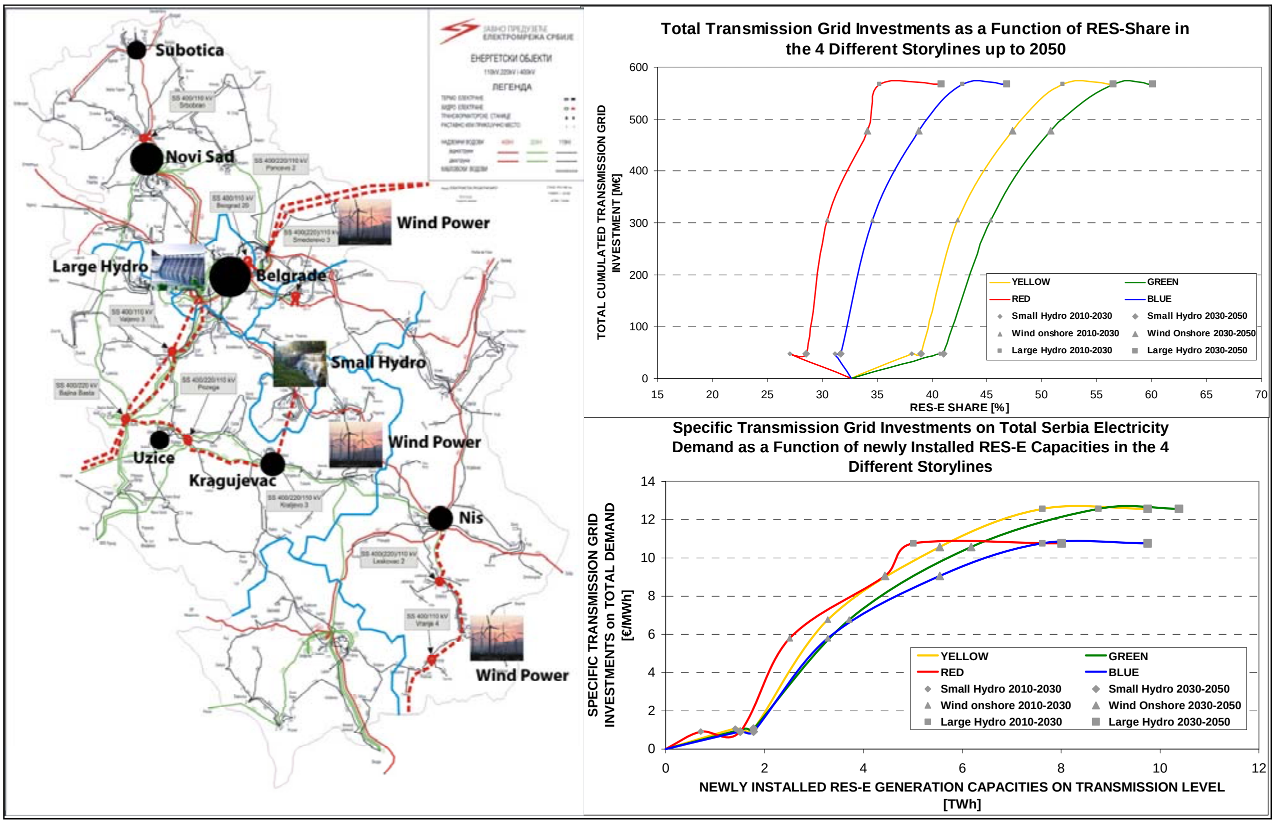

Figure 4.11 Spatial dispersion of RES-E potentials, load centers and transmission grid routes in Serbia (left); total transmission grid investments as a function of RES-E share (upper right) and specific transmission grid investments as a function of newly installed RES-E capacities (lower right) in the four different storylines in Serbia up to 2050

In this context, Figure 4.11 presents total transmission grid investments as a function of RES-E shares (upper right) and specific transmission grid investments as a function of newly installed RES-E capacities (lower right) in the four different storylines in Serbia up to 2050. Mainly due to differences in the assumption of future development of electricity demand (higher in Red/Blue compared to Yellow/Green), RES-E shares are different in the different storylines, despite quite similar penetration of RES-E generation and transmission investments in the different storylines. For the same reason, specific transmission investment costs are quite similar.

Further details from the Serbian case study can be found in [SUSPLAN, D2.8].

4.1.9 Alpine Region (Austria)

Large amounts of Austria's RES-Electricity generation potentials are expected to be already developed until the year 2030. The only remaining major RES-E potentials will be new (pumped) hydro power and PV installations. Wind generation can be expanded by repowering measures of existing systems only, since the most attractive sites are already taken in the near future.

Figure 4.12 presents the total cumulated transmission grid investments in Austria as a function of RES-E deployment in the four different storylines from 2010-2050. All storylines have the same starting point of a RES-E share of about 69% in 2010. In the Red storyline it can be observed that this share decreases continuously (high demand, low deployment of remaining RES-E) and remains below the 2010 value until 2050; despite additional integration of wind and hydro generation from 2010-2050. Also in the Blue storyline the RES-E share indicates a negative development at the beginning, but the high additional wind and hydro generation increases it to about 78% in 2050. Compared to Red and Blue, Yellow and especially Green show a continuously increasing RES-E development. In the Green storyline more than 100% are reached in 2050, indicating that Austria becomes a net exporter of "green" electricity.

When studying the vertical axis of Figure 4.12, it can be seen that both storylines Red and Yellow show a similar growth rate in the total cumulated transmission grid investments and also reach a similar value in 2050. This indicates that both have about the same need for transmission grid expansion, but the reasons are different: in the Red storyline some of the transmission investment needs are also triggered by higher electricity demand increases and not exclusively by new RES-E generation. The much higher RES-E share of the Yellow storylines, however, is due to the higher share of PV generation, which does not trigger new transmission grid investments in the analysis. The same is true for Blue and Green, also here comparable transmission grid investment needs are seen, but again in the Blue storyline these new transmission lines are not fully exploiting RES-E generation. The higher transmission grid investments in Green/Blue (compared to Red/Yellow) are triggered by higher amounts of integrated shares of wind and hydropower as well as the need to upgrade transmission routes to neighbouring countries to export electricity.

Further details from the Austrian case study can be found in [SUSPLAN, D2.9].

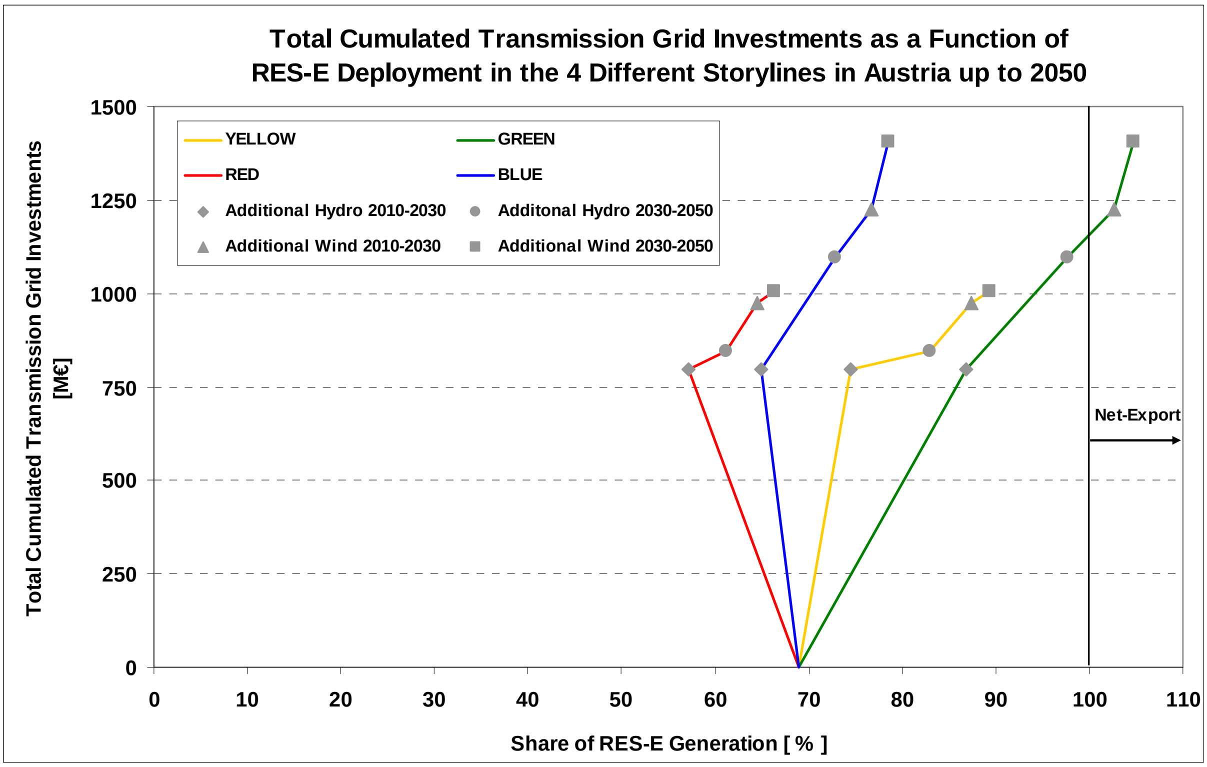

Figure 4.12 Total cumulated transmission grid investments as a function of RES-E deployment in the four different storylines in Austria up to 2050

4.2 Grid Integration Results of RES-Heat and Gas Technologies in Selected Regions

As opposed to electricity, heat infrastructures are regional and thus case specific. In general, the construction of new heat infrastructures for RES-Heat distribution is not cost-efficient compared to RES-Electricity, so only those regions that already have an existing large scale heat infrastructure have considered development of RES-Heat solutions.

Gas infrastructures, on the other hand, are both regional and trans-national and are analysed both in selected regions here in WP2 and trans-nationally in WP3.

4.2.1 Central/Western Europe (Rhine-Neckar Region)

Figure 4.13 below presents the total end-use heat demand in Metropolitan Region Rhine-Neckar (MRN) region from 2030 to 2050 in the four different storylines (Further details from the MRN case study can be found in [SUSPLAN, D2.3]). The total heat demand in MRN is assumed to decrease in all four storylines. In the household and commercial sector the use of "fossils" (natural gas, oil) for heat production is reduced significantly in all storylines, except in Red. In detail, in Green/Yellow in 2040 several oil stoves are replaced by biomass, heat pumps and solar collectors; also in Red/Blue oil heating completely phases out until 2050.

Also interesting, in Green/Yellow the district heating (DH) system does not expand any more and remains at its 2010 share of 15% also in the long-term; contested by energy efficiency implementation (e.g. wall isolation of households, etc.) and also distributed combined heat and power (CHP) generation. The biggest contribution (80%) to the DH heating system comes from Großkraftwerk Mannheim (GKM). A partial fuel-switch is expected to take place at GKM in all four storylines in the medium to long-term, resulting in a 'greener' fuel mix. E.g., in the Green storyline in 2050 only 12.5% of primary fuels for heat production of GKM come from coal.

Furthermore, in the industrial sector decreasing process heat demand and the further penetration of RES-Heating technologies (biomass, geothermal CHP plants, etc.) is assumed to reduce coal demand first and, subsequently, gas demand. As a result, industrial coal demand vanishes until 2050 in several of the storylines, except in Red. Gas, on the other hand, still covers a majority of industrial heat demand in 2050 in several of the four storylines. However, in the Green storyline already 50% of industrial heat demand is covered by RES-Heating technologies in 2050.

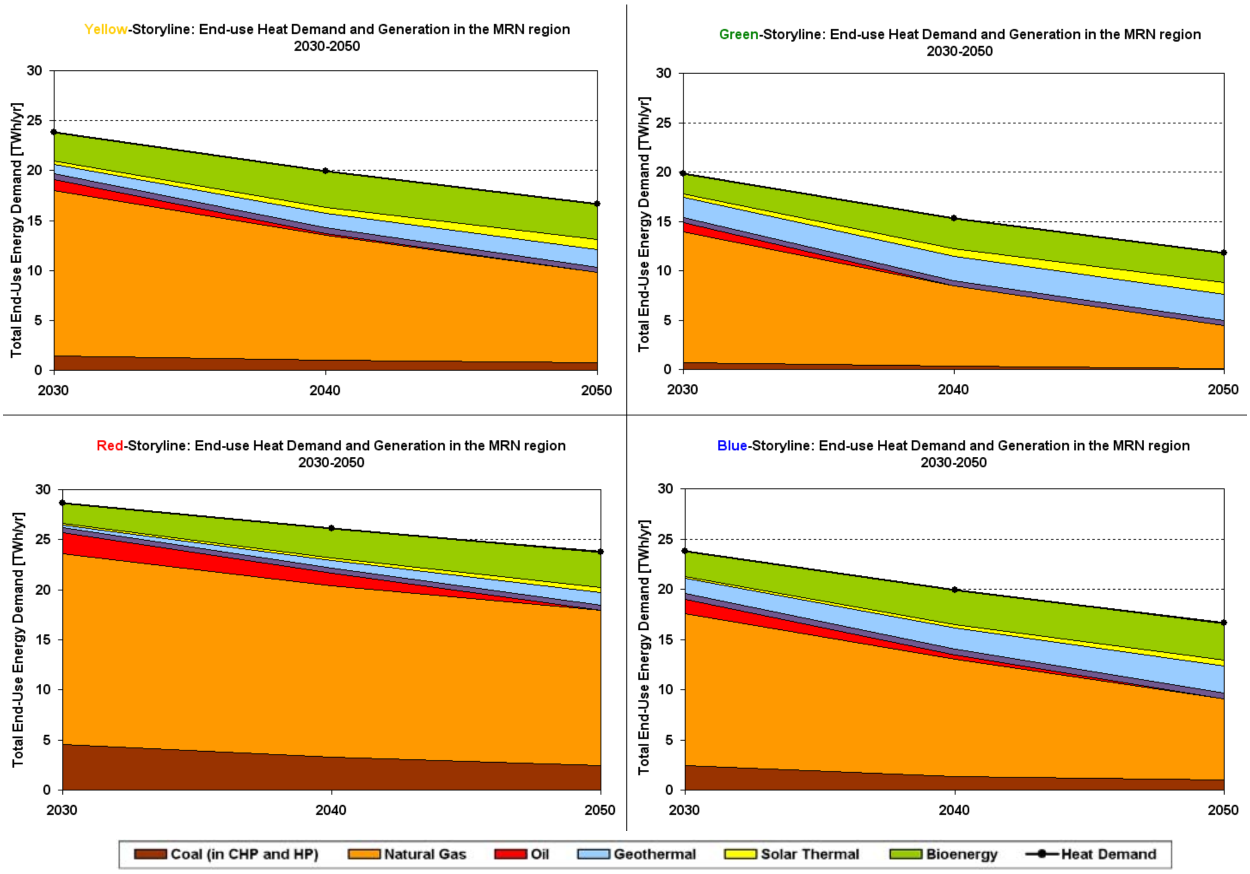

Figure 4.13 Total end-use heat demand (residential, industrial, tertiary sector) in the Metropolitan Region Rhine-Neckar (MRN) in the four different storylines up to 2050

4.2.2 South-Western Europe (Spain)

The analysis in the Spanish case study has not been restricted to detailed considerations of RES-Heating only, but the role of gas supply and corresponding gas infrastructure needs in the domestic and industrial sector also have been investigated in detail [SUSPLAN, D2.6]. Moreover, the Spanish analysis in this context assumes that future gas infrastructure needs have the following drivers: (i) RES-Electricity penetration, significantly impacting the production of gas-fired thermal electricity generation, and (ii) domestic and industrial gas consumption meeting different end-uses.

Currently, almost all of Spanish domestic gas consumption is demanded by household gas heating systems; they are, however, assumed to be replaced by heat pumps in the Green and Blue storyline. In the Red and also the Yellow storyline domestic gas consumption still increases (and corresponding grid infrastructure is built) until majority of Spanish households have access to gas.

Using year 2010 as a reference, Figure 4.14 (left) presents a comparison of the maximum and/or additional gas supply capacity required in Spain in the four different storylines in 2020, 2030 and 2050. This comparison also takes into consideration several important gas network design criteria, including a 10% supply margin required for the secure operation of gas networks. Interestingly, compared to the status quo in 2010, in several of the four storylines there is no need to significantly extend the gas grid infrastructure network in Spain in the near future. Moreover, gas supply can be met with the existing gas infrastructure in the next 10-15 years.

In the medium to long-term, however, the Red storyline indicates steadily increasing gas consumption and, subsequently, gas grid infrastructure capacity and investment needs (also due to a higher share of CCGT units in operation for electricity generation and low environmental concern in this storyline). Also in the Blue and Yellow storyline further gas infrastructure capacity and investment expansions are needed (see Figure 4.14 (left)) beyond 2030. However, beyond 2040 some of these expansion measures are supposed to remain excess capacities in the long-term future (2050 and beyond) because gas demand is decreasing or remains stable in the Blue and Yellow storyline respectively beyond 2040. And finally, the Green storyline does not expect any gas infrastructure expansion measures any more. Moreover, in Green in the medium to long-term, parts of the already existing gas infrastructure are already obsolete.

Figure 4.14 (right), finally, presents total cumulated gas infrastructure cost over RES-E shares. As already stated above, Green does not expect any investments any more. On the contrary, lower RES-E penetration certainly requires new investments in gas capacities and infrastructures, being very high in the case of low technical developments and low "green" conscience (Red storyline).

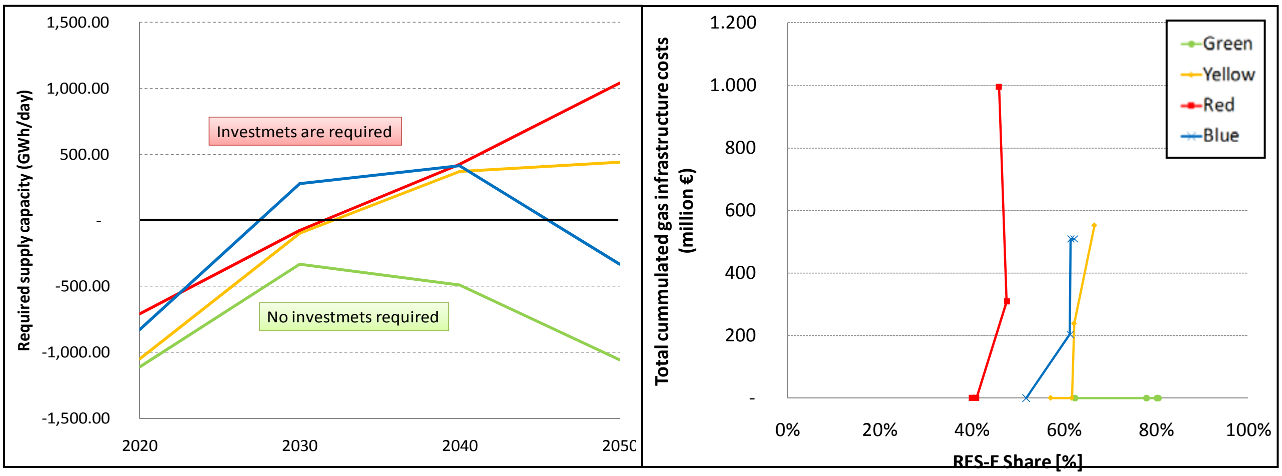

Figure 4.14 Required gas capacity over time (left) and total cumulated gas infrastructure costs over RES-shares (right) in the four different storyline in Spain from 2030 to 2050

4.2.3 Southern Europe (Italy)

In 2008, Italian renewable heat production is estimated at nearly 1.4 Mtoe in the industrial sector (around 1 Mtoe from industrial combined heat and power (CHP) generation; 0.4 Mtoe biomass heat production) and about 1.8 Mtoe in the residential and tertiary sector. Solar thermal production was limited to about 100 ktoe in 2008. However, in year 2020 and beyond, a large penetration of solar thermal heat and hot water technologies is expected in Italy. Further on, for the future also breakthroughs of other technologies like geothermal heat pumps are expected.

In the residential sector, the following three RES-Heating technologies are considered to meet at least some of the demand for heating and hot water: (i) district heating networks (fuelled partly or entirely from biomass), (ii) stand-alone solid biomass heating systems and (iii) heat pumps.
In the industrial sector it is assumed that at least four industries are able to increase renewable energy demand in their use of process heat: wood, paper, food and cement industry. Consequently, it is assumed that about 10% of heating consumption in these industries can be met by using renewable energy in the medium to long-term. In quantitative terms, this commitment

would amount to a heat consumption of about 1 Mtoe in the three storylines Green, Yellow and Blue. In the Red storyline, however, it is assumed that renewable heat generation in the industrial sector remains at the present value (about 0.5 Mtoe).

Figure 4.15 and Figure 4.16 present the results of total RES-Heating consumption and RES-Heating shares as of total heat consumption in the four different storylines in Italy in 2030 and 2050. Further details from the Italian case study can be found in [SUSPLAN, D2.7]

RES-H Technology		RED		BLUE		YELLOW		GREEN	
	Sector	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
SOLAR THERMAL	RES	0.7	0.8	0.7	0.8	0.9	1.3	1.2	1.6
	TER								
	IND								
	AGR								
	TOT	**0.7**	**0.8**	**0.7**	**0.8**	**0.9**	**1.3**	**1.2**	**1.6**
BIOMASS	RES	4.1	4.2	4.1	4.1	4.3	4.3	4.3	4.1
	TER								
	IND	0.5	0.5	0.9	1.0	1.0	1.0	0.9	1.0
	AGR	0.1	0.2	0.1	0.2	0.1	0.2	0.2	0.2
	TOT	**4.7**	**4.9**	**5.1**	**5.3**	**5.4**	**5.5**	**5.4**	**5.3**
AERO-GEO-THERMAL	RES	1.1	1.4	1.2	1.4	1.4	1.8	1.5	1.9
	TER	0.9	0.9	0.9	0.9	1.1	1.3	1.1	1.4
	IND								
	AGR								
	TOT	**2.0**	**2.3**	**2.1**	**2.3**	**2.5**	**3.1**	**2.6**	**3.3**

Figure 4.15 RES-Heating consumption (Mtoe) per technology and sector in Italy in the four different storylines in 2030 and 2050

	2030			2050		
YELLOW	RES-H	TOT-H	RES/TOT	RES-H	TOT-H	RES/TOT
RES	6.8	21.3	32%	7.4	20.7	36%
TER	1.1	7.7	14%	1.3	8.0	16%
IND	1.0	24.7	4%	1.0	24.8	4%
AGR	0.2	2.1	10%	0.2	1.9	11%
TOT	9.1	55.8	16%	9.9	55.4	18%

	2030			2050		
GREEN	RES-H	TOT-H	RES/TOT	RES-H	TOT-H	RES/TOT
RES	7.0	21.3	33%	7.6	20.3	37%
TER	1.1	7.7	14%	1.5	8.0	19%
IND	1.0	23.5	4%	1.0	23.0	4%
AGR	0.2	2.1	10%	0.2	1.7	12%
TOT	9.3	54.6	17%	10.3	53.0	19%

	2030			2050		
RED	RES-H	TOT-H	RES/TOT	RES-H	TOT-H	RES/TOT
RES	6.0	22.8	26%	6.4	23.1	28%
TER	0.9	8.4	11%	0.9	8.7	10%
IND	0.5	27.7	2%	0.5	28.9	2%
AGR	0.2	2.4	8%	0.2	2.0	10%
TOT	7.6	61.3	12%	8.0	62.7	13%

	2030			2050		
BLUE	RES-H	TOT-H	RES/TOT	RES-H	TOT-H	RES/TOT
RES	6.0	22.7	26%	6.3	22.8	28%
TER	0.9	8.4	11%	0.9	8.7	10%
IND	1.0	26.3	4%	1.0	26.6	4%
AGR	0.2	2.4	8%	0.2	2.0	10%
TOT	8.1	59.8	14%	8.4	60.1	14%

Figure 4.16 RES-Heating share as of total heat consumption per sector in Italy in the four different storylines in 2030 and 2050

4.2.4 Alpine Region (Austria)

In Figure 4.17 below the results of end-use energy demand in the residential heating sector in Austria are presented for the four different storylines up to 2050 [SUSPLAN, D2.9]. It can be seen that the residential heating demand decreases moderately (Red/Blue) or even significantly (Green/Yellow) in all storylines up to 2050. Moreover, in all four storylines oil heating systems are increasingly replaced by RES-Heating technologies; resulting in a complete phase out of oil heating systems in the Austrian residential sector in 2050 in Green and Yellow.

Furthermore, it can be observed that gas heating systems in Austria stay more or less constant (Red/Blue), decrease (Yellow) or even phase out (Green) until 2050. Therefore, no extension of the gas distribution grid in Austria is needed in the future to supply the residential sector. Even more, in the Green storyline, where also gas heating completely phases out in the residential sector in Austria until 2050 the question arises: What to do with the existing, but obsolete gas distribution grid in the residential sector in Austria in 2050?

Also residential district heating (DH) does not indicate any increase in the four different storylines up to 2050. The reason for this is that large-scale district heating grids - supplied by heat from CCGTs, waste and/or biomass combustion technologies - are limited in its implementation to niche markets like dense areas and municipalities/cities. Small-scale grid-connected biomass heating shows moderate/significant extension in the different storylines until 2050, but it is also limited to dense areas and municipalities/cities. Nonetheless, competitors for both heating grid systems are energy efficiency (see Section 5.3) and also innovative heating technologies such as solar thermal collectors, ambient heat and heat pump systems.

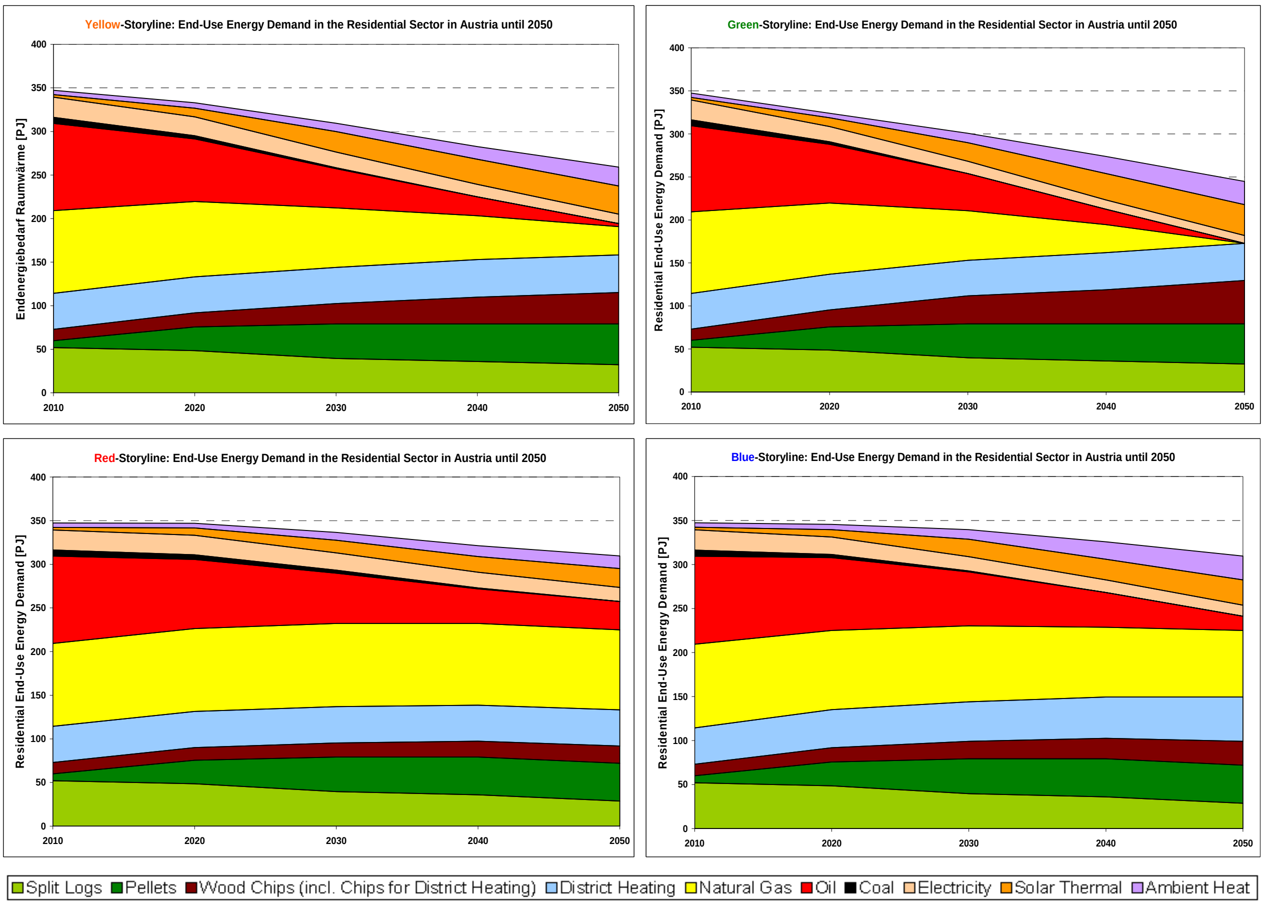

Figure 4.17 Total end-use heat demand in the residential sector in Austria in the four different storylines up to 2050

5 SYNTHESIS OF RESULTS

A synthesis of the scenario studies performed in nine different European regions provides the basis for the identification of success criteria for integration of large shares of renewable energy under a variety of different geographical, structural, technical, economical, institutional, and political framework conditions. The regional case studies have confirmed huge potentials of unexploited renewable resources in Europe. The potentials are local (e.g. Solar PV in Italy, Rhine-Neckar), regional (e.g. onshore wind in Spain, Pomerania) as well as trans-national (e.g. offshore wind in the North Sea and coast of Scotland) in its character.

Several regions may develop a huge surplus of renewable energy to export to other regions given the future conditions, e.g. the coast of Scotland may export energy produced from wind, Norway may export energy produced from offshore wind or power for balancing intermittent production in Europe, the Pomeranian region may export a large surplus of electricity produced by wind, etc. Even the Rhine-Neckar region with limited resources for power production may under favourable conditions export electricity (Solar PV in the summer).

Many regions in southern Europe have good conditions for utilization of the sun for power production in the form of PV and thermal CSP. Even in the geographical region of Rhine-Neckar (appr 5600 km2) it is a potential of about 3 TWh/y of production from PV in the future conditions in the Green storyline. Thus, given a favourable development of PV technology, solar production may be an important part of the power production in Europe in the future.

5.1 Main characteristics of the regions

The results from the regional studies indicate that all regions are able to integrate larger shares of renewable energy sources, but non-RES sources will also be present in varying degree in most regions. However, very different infrastructures will be needed at regional (and also trans-national) level dependent of “type of future” in the different storylines. Especially futures like Green and Blue will require other infrastructure development paths compared to current strategies of regional Security of Supply and centralized generation. The following bullets highlight the main characteristics of each region:

- **Islands** (Isle of Lewis, Scotland [SUSPLAN, D2.1])
  - Very high offshore wind and marine resources
  - Barriers to development of onshore resources
  - Low local demand, weak connection to main UK grids
  - No major RES development possible when region is seen isolated, needs connection to central grids and load areas to fully exploit its resources
- **Northern Europe** (Norway [SUSPLAN, D2.2])
  - High on-shore and off-shore RES potentials
  - Existing TSO scenarios for onshore grid development robust
  - Weak national drivers to further develop RES generation
  - Further RES exploitation should be as part of joint, trans-national grid development
- **Central Europe** (Rhine-Neckar [SUSPLAN, D2.3])
  - Multiple grid infrastructures of el, heat and gas
  - Reduced energy demand expected in all storylines

- No grid expansion necessary, but SmartGrid/control equipment may be necessary for more variable local production (PV)
- May export electricity from solar PV during summer under favourable conditions
- Existing gas and heat infrastructures may be converted to biogas/bioheat
- Still dominant coal fired production unit (CHP) in the area, large shares of RES must be imported from other regions

- **North-Eastern Europe** (Pomerania [SUSPLAN, D2.4])
  - Huge RES potentials (mainly wind)
  - Current policies focus on Security of Supply, not particularly on RES
  - Significant investments in infrastructure are needed, but not necessarily triggered by integration of RES
  - Major decisions made now and up to 2020 may limit large development of RES
  - Region becomes a major exporter in all storylines, but not necessarily of RES

- **South-Eastern Europe** (Romania [SUSPLAN, D2.5])
  - Balanced energy supply of fossil, nuclear and hydro power
  - National strategy needed to develop cogeneration based on biomass
  - Focus on national supply and storage/balancing, no major energy exchange
  - Stronger regional interconnections with Bulgaria and Turkey needed to exploit onshore and offshore wind potentials

- **South-Western Europe** (Spain [SUSPLAN, D2.6])
  - Large potential for solar and wind generation
  - Challenges related to intermittency and balancing; parallel strategy of gas fired CCGT
  - Stronger interconnection with rest of Europe (France) needed
  - No further need for domestic gas investments if RES-E shares exceed 70%
  - Trans-national gas interconnections with Europe positive in all storylines

- **Southern Europe** (Italy [SUSPLAN, D2.7])
  - Region remains a net energy importer in all storylines
  - Energy efficiency measures needed to reach current RES targets
  - Major wind and solar resources in the south, main load centres in the north; considerable infrastructure developments needed both between regions (highest in Green storyline) and inside regions (highest in Red storyline)
  - Further expansion of gas grid only through the role as European gas hub

- **Western Balkans** (Serbia [SUSPLAN, D2.8])
  - Abundant local lignite resources utilized in all storylines together with hydro power
  - Due to current development, major resources are assumed to be utilized before 2030
  - Current under-investment in infrastructure and low purchase power among consumers; mainly development of small-scale RES generation and storage foreseen, combined with demand side management and SmartGrid technologies at low cost
  - Fossil generation present in all storylines; based on local lignite and CCGT connected to the planned South Stream gas pipeline project

- **Alpine** (Austria [SUSPLAN, D2.9])
  - Already high national shares of RES
  - Only solar PV resources still available beyond 2030, most other hydro and wind potentials already exploited

– Further development of pumped storage and international exchange capacity possible to supply balancing to neighbouring countries
– Major transition from fossil to RES-Heat technologies expected, but no further expansion of heat or gas infrastructures needed

5.2 Grid Integration of RES-Electricity Technologies

The outcomes of the nine in-depth regional scenario studies on grid infrastructure integration of RES-Electricity generation technologies in different European regions teach us a variety of lessons. In many cases today, RES-E in Europe is integrated in the energy system on a project-by project basis and not according to an overall plan, while many of the case studies show that the full potential of a region can only be exploited in a trans-national context. To obtain the most effective utilization of RES from a Pan-European perspective (in terms of reduction of CO_2 emissions, minimum economic costs and sufficient Security of Supply) and to be able to develop infrastructures in the most appropriate way, harmonized planning is important. The regional case studies in SUSPLAN have shown that the future may look very different dependent of which RES sources are utilized for energy production and also in which sequence they are included in the energy system.

In the following, the most important criteria for successful grid integration of RES-Electricity generation technologies are briefly outlined:

- Due to the fact that natural resources for RES-E generation in many cases are site specific, *"artificial borders" (political, institutional, etc.) shall be avoided wherever it is possible;* simply because the operation of electricity systems is governed by physical laws.
- *Utilize economies of scale of RES-E generation both in a regional and in a Pan-European context*; i.e. the most attractive sites shall be chosen first. In case of low electric load density in an area or region also transmission connection to fitting load centres with sufficient load density outside the region shall be considered.
- *Develop inter-regional (European-wide) business and cost remuneration models for transmission investments*, if they are needed to utilize low-cost RES-E generation and to fulfil other energy policy objectives like the further integration of the European electricity market and/or improvement of security of supply. E.g. the Norwegian end-users are supposed not to be interested in increases of grid tariffs in case the Norwegian TSO implements offshore grids to enable the utilization of low-cost offshore-wind generation on the Norwegian coastline, one the one hand, and Norwegian end-users and policy makers might not be interested to push large-scale wind integration due to almost 100% hydro power generation and still not exploited, attractive onshore potentials, on the other hand. All over Europe, in many regions similar situations can be cited (e.g. Isle of Lewis (Scotland) regional case study).
- *Enable access to efficient and effective system balancing and reserve capacity provision technologies in a Pan-European context*. There is a significant difference whether each single European country is exclusively responsible to be flexible enough to manage their electricity system or if countries can also "rely" on the power plant portfolios of their neighbours. E.g., a country like Poland (with an inflexible, mainly coal-fired power plant mix) may get access to flexible pumped-hydro power generation via transmission links to Scandinavia (subsea cable) and the Alps (via Czech Republic and Slovakia to Austria) whereas countries like Spain, UK, Italy (partly) and also others may need a national "gas-strategy" in case of a

further significant increase of variable/intermittent wind-onshore and wind-offshore penetration in order to be able to maintain flexibility of their electricity systems (e.g. with Combined Cycle Gas Turbines (CCGTs)).

- *Harmonize legislative and regulatory frameworks in the context of grid infrastructure integration of RES-E generation technologies* in the different European Member States and/or regions in order to enable better compatibility for "common" RES-E projects directly affecting more than one European Member State and/or region. As an example, fundamental differences and non-harmonized approaches can be found in grid integration charging of RES-E generation technologies in the different European Member States (e.g. "deep", "shallow", "hybrid" charging models).
- *Involve local/regional people and communities as well as several important other stakeholders and decision makers already from the beginning of the planning phase of a RES-E and grid infrastructure project* and start an interactive dialog between them in order to be able to figure out several concerns, barriers and also anxieties.
- *Develop business-models where local/regional people and communities also benefit somehow if they "accept" to use "their lands" for a certain RES-Electricity and grid infrastructure project* (e.g. monetised in terms of shareholders of a particular project holding minority shares, cooperation with the local/regional tourism industry, non-monetised beneficiary models like cooperation with the education sector, etc.).

Concluding, the lessons learnt from the nine regional scenario studies have further improved our understanding for first best solutions of grid infrastructure integration of RES-Electricity generation technologies under a variety of different constraints in the short-term and long-term. We refer to the separate region-specific final reports [SUSPLAN, D2.1]-[SUSPLAN, D2.9] for further success criteria that have been identified in the different regional scenario studies.

5.3 Grid Integration of RES-Heat/RES-Gas Technologies

In this section, a synthesis of results of grid infra-structure integration of RES-Heating/RES-Gas generation technologies is conducted. Decoupled from individual regional scenario studies, Figure 5.1 below summarizes the most important aspects and statements quoted in this context.

Regardless which kind of heat grid infrastructure (or stand alone technology/technology combination) currently exists in a region, a crucial long-term aspect in the further development of the entire portfolio of heating/hot water technologies and corresponding grid infrastructures is the future ambition of the implementation of end-use energy efficiency technologies on the demand side. End-use energy efficiency implementation influences the economics of the different energy carriers in the local/regional heat market and the corresponding network infrastructures. In this context, fundamentally different ambitions have been assumed in each of the four different storylines in SUSPLAN.

Today, in almost all regions throughout Europe there is rather low awareness on (thermal) energy efficiency measures. In the Red and Blue storylines it has been assumed that this situation does not change in the long-term, meaning that in the period 2030-2050 end-use energy efficiency measures are still not implemented systematically and on large-scale. Moreover, high energy demand increase in these two storylines in general is a key indicator for "indifferent public attitude/behaviour" (negative part of vertical axes in the SUSPLAN storyline scheme in Figure 2.2) in terms of energy efficiency awareness.

In a future "energy world" according to the Red or Blue storylines, similar to the situation right now in year 2010, in almost all regions throughout Europe there exist favourable conditions (i.e. significant heat loads) for

- *heat network infrastructures* like gas distribution grids (e.g. fed by natural gas, LNG and also biogas) both in dense and rural areas;
- *district heating grids* (e.g. heat decoupled as a by-product from combined heat and power generation technologies fuelled by natural gas, waste, biomass/biogas, others) in dense areas (cities) and also for smaller heat grids in less dense municipalities and communities;
- *direct electric heating*, having tradition in some European regions (e.g. Norway). Although direct electric heating was implemented also in other European regions in the past (e.g. Austria), this technology type is controversial from the environmental point-of-view in case of non-renewable electricity generation. Innovative heat technologies like heat pumps (operating most efficient and effective with low inflow temperatures into the heat delivery systems) are no option in energy systems characterised by poor thermal efficiency standards (expecting very high inflow temperatures).
- *stand alone heat technology options* (e.g. solid biomass (split logs, coal), being used simply due to necessity. Innovative technologies like biomass (chips) and/or pellets in combination with solar thermal collectors are no option in energy systems characterised by poor thermal efficiency standards (the same explanation like for heat pumps above).

However, end-use energy efficiency standards in the long-term period 2030-2050 should be much more ambitious, as reflected in the Yellow and Green SUSPLAN storylines. Having in mind the merit order curve of CO_2 abatement cost, energy efficiency measures are characterised by negative CO_2 abatement cost; meaning that they shall get highest priority for implementation as soon as possible. In order to mitigate at least parts of the CO_2 emission problem in the heating sector it is expected that in a long-term perspective the development will be characterized by much more ambitious end-use efficiency strategies. In detail, in a world of significantly decreasing heat loads the situation is as follows:

- In general, several *grid connected heating technologies* and technology combinations are increasingly confronted with significant troubles; except electricity grids supplying innovative technologies like heat pumps (direct electric heating is supposed to be the least elegant technology solution in a sustainable energy world)[6]. High energy efficiency standards are, furthermore, also favouring innovative stand alone solutions like biomass (chips) and/or pellets in combination with solar thermal collectors in less dense and rural areas.
- In particular, conditions for *gas distribution grids* (supplying the residential and tertiary sector) may become increasingly difficult in many regions. They are simply not needed any more in the long-term; at least not in the Green and Yellow storyline (see e.g. corresponding analyses for Austria, Spain, etc.). So already at present a further extension of gas distribution grids for domestic consumption may be a wrong strategy in many cases. At this point it is

[6] When talking about sustainable energy systems, one strong argument against direct electric heating is the fact that electricity is the energy carrier with the highest degree of refinement. Furthermore, with the exception of hydro-power dominated electricity supply systems another strong opposing argument is the low total efficiency (and, subsequently, negative environmental balance) of the chain of conversions from primary energy to end-use energy services.

important to note, however, that corresponding gas infrastructures supplying the industrial and power generation sector are not included in this assumption.

- *District heating*, finally, has an ambiguous future. On the one hand, competitors like energy efficiency, solar thermal collectors and others contest market shares of heat loads in areas with medium/average density but, on the other hand, district heating is supposed to be still the first best solution in dense areas like cities and bigger municipalities.

Preferable Heating Strategies Depending on End-use Efficiency Ambition up to 2050			Expected End-use Efficiency Implementation 2030 - 2050: Low	Expected End-use Efficiency Implementation 2030 - 2050: High
Stand Alone	**Non grid connected RES-H** (e.g. stand alone biomass in less dense & rural areas,Solar thermal collectors)		O	+
Network Infrastructure	**Electricity Distribution Grid**	Direct electric heating (e.g. Norway)	O	-
		„Innovative“ electric heating (e.g. heat pumps)	-	+
	Heat Distribution Grid	CHP-based RES-H (e.g. Biomass / Biogas in dense areas / municipalities)	+	- / o
		District heating (e.g. various fuels in dense areas / municipalities)	+	- / o
	Gas Distribution Grid	RES-G fed into gas distribution grid	+	-
		Natural gas and LNG fed into gas distribution grid	+	-

+…Preferable Strategy **O…Indifferent** **-…Non Preferable Strategy**

Source: Auer (2010)

Figure 5.1 Preferable heating strategies depending on the end-use energy efficiency ambition in the heating sector up to 2050

6 CONCLUSIONS

This synthesis report has demonstrated the complexity and diversity of dimensions having to be considered when trying to integrate large amounts of RES-Electricity, RES-Heating and RES-Gas technologies into the corresponding grid infrastructures of Europe. The case study processes themselves, the interactions with the local/regional actors in this context as well as the outcomes of the nine different regional scenario studies throughout Europe have significantly contributed to further improve our common understanding how best to “tackle” the challenges inherently linked to the continuous transformation process towards more sustainable energy systems.

One of the most novel aspects of the nine regional energy systems’ analyses has been the quantification of both RES-Electricity, RES-Heating and RES-Gas technology penetration and corresponding grid infrastructures needs/cost in a long-term time horizon up to 2050, on the one hand, and also the identification of interdependences and partly competing drivers between different renewable resources and corresponding grid infrastructures qualified to serve different energy services, on the other hand.

It is important to note, however, that it neither has been the intention of the nine regional scenario studies nor of this synthesis report to draw a full picture of solutions and/or best-practise examples of grid infrastructure related aspects of RES-Electricity, RES-Heating and RES-Gas technology integration under a variety of different constraints and settings, being of geographical, structural, technical, economical, institutional, and political nature. It rather has been a first attempt to further structure the discussion on grid infrastructure related challenges and problems having to be mitigated and overcome, respectively, to enable the absorption of large amounts of RES-Electricity, RES-Heating and RES-Gas on several time scales short-term and long-term.

Especially the emphasis on the long-term time perspective up to 2050 in the regional and trans-national SUSPLAN analyses, demonstrates that there exist significant interdependences between short-term energy policy decisions and long-term options to integrate large amounts of RES-Electricity, RES-Heating and RES-Gas technologies into the different network infrastructures. Once capital-intensive network infrastructures are implemented, the corresponding investments are definitely sunk and, subsequently, the implemented network infrastructures inherently predetermine the pattern of a particular regional energy system not only for years but for decades. This heavily affects any kind of renewable policy decisions in the future.

Last but not least, it is important to note, that the important insights and results of the nine regional scenario studies provide valuable inputs, qualitatively and quantitatively, for the subsequent work packages of the SUSPLAN project.

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