IEW TENTATIVE PROGRAM

2011 INTERNATIONAL ENERGY WORKSHOP PROGRAM

JULY 6-8, 2011

STANFORD UNIVERSITY

Tentative Agenda - Plenary Program

- ***Tuesday, July 5 - Welcoming Reception (6:30 PM)***

- List of **Presentations** (/docs/273)
- List of Presentations by **Author** (/docs/274)
- List of Presentations by **Session** (/docs/275)

Time	**Wednesday, July 6**	**Thursday, July 7**	**Friday, July 8**
8:00 AM	Registration	Registration/Information	Registration/Information
	Continental Breakfast	Continental Breakfast	Continental Breakfast
9:00 AM	**Plenary Session**: *Energy Modeling and the IEW: An Historical Perspective* **Chair**: Geoff Blanford ***Speakers:*** ***John Weyant*** Stanford University ***Richard Richels*** Electric Power Research Institute ***Kenneth Arrow*** Stanford University	**Plenary Session**: *Global Energy Technology* **Chair**: Bob van der Zwaan ***Speakers:*** ***Sally Benson*** Stanford University ***Andreas Schäfer*** Cambridge/Stanford University ***Keywan Riahi*** International Institute for Applied Systems Analysis	**Plenary Session**: *Climate and Energy Policy* **Chair:** Massimo Tavoni ***Speakers:*** ***James Sweeney*** Stanford University ***Joseph Aldy*** Harvard University Concluding Panel TBA

11:00AM	Morning Break	Morning Break	Morning Break
11:30AM	Parallel Sessions • **Energy Efficiency and End-Use Demand (1)** (/docs/276) • **International Policy Negotiations** (/docs/277) • **Technology Risk in the Electric Sector** (/docs/278) • **Renewable Energy(1)** (/docs/279) • **Bioenergy Potential** (/docs/280)	Parallel Sessions • **Integrated Assessment: Cost-Benefit Analysis** (/docs/291) • **China Climate Policy** (/docs/292) • **R&D Investments** (/docs/293) • **Renewable Energy (4)** (/docs/294) • **Biomass and Emissions Mitigation** (/docs/295)	Parallel Sessions • **Integrated Assessment: Climate Stabilization** (/docs/306) • **Energy-Economy Projections** (/docs/307) • **International Technology Issues** (/docs/308) • **Energy Security** (/docs/309) • **Transportation Modeling: Emissions Mitigation** (/docs/310)
12:45PM	Lunch	Lunch	Lunch
2:00 PM	Parallel Sessions • **Energy Efficiency and End-Use Demand (2)** (/docs/281) • **EU and Japan Climate Policy** (/docs/282) • **Learning and R&D** (/docs/283) • **Renewable Energy (2)** (/docs/284) • **Forestry Modeling** (/docs/285)	Parallel Sessions • **Integrated Assessment: Mitigation and Adaptation (1)** (/docs/296) • **International Trade** (/docs/297) • **Electricity Markets** (/docs/298) • **Oil Markets, Unconventional Oil, and Climate Policy** (/docs/299) • **Transportation Modeling: Alternative Vehicles** (/docs/300)	Parallel Sessions • **Multiple Policy Instruments** (/docs/311) • **Energy-Economy Policy Interactions** (/docs/312) • **Energy Technology Modeling** (/docs/313) • **Electricity Grids and Transmission Infrastructure** (/docs/314) • **Transportation Modeling: Urban Studies and Willingness to Pay** (/docs/315)
3:15 PM	Afternoon Break	Afternoon Break	Afternoon Break
3:45 PM	Parallel Sessions • **Energy Efficiency and End-Use Demand (3)** (/docs/286) • **Permit Trading Schemes** (/docs/287)	Parallel Sessions • **Integrated Assessment: Mitigation and Adaptation (2)** (/docs/301) • **Sustainable Development** (/docs/302)	Final session TBA • Special Session on OSeMOSYS (Open Source Energy Modelling System)

	- **Technical Change and Innovation** (/docs/288) - **Renewable Energy (3)** (/docs/289) - **Cross-cutting Land Use Issues** (/docs/290)	- **Environmental Policy** (/docs/303) - **Resources and Emissions Mitigation** (/docs/304) - **Transportation Modeling: Consumer Choice** (/docs/305)	
5:00 PM	Meeting Concludes	Meeting Concludes	
5:15 PM	**Informal Reception at Ford Garden**	**Tour of New Science and Engineering Quad**	
6:30 PM		**IEW Conference Reception & Dinner**	

LONG-TERM GRID INFRASTRUCTURE INTEGRATION STRATEGIES OF RENEWABLE ELECTRICITY GENERATION TECHNOLOGIES IN EUROPE UP TO 2050

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Abstract

Within the EU-FP7-project "SUSPLAN", long-term grid integration of renewable electricity, heat and gas generation technologies has been analyzed in nine different European regions. This paper focuses on grid integration of RES-Electricity technologies.

Scenario generation is based on storylines: Four possible futures were established and for each of the storylines several uncertain key parameters influencing RES grid integration (RES-technology costs, fuel-prices etc.) are described. For modelling, the models *GreenNet* (least-cost RES-Electricity deployment) and *eTransport* (multi-grid infrastructure investment) were used to establish RES-deployment and corresponding infrastructure costs from 2030-2050.

The novelty is the quantification of grid infrastructure cost over RES deployment in the different storylines and up to 2050. Selected highlights are: (i) Identification of lack of business models: Norway has huge wind-offshore potentials, but no interest to deploy it; (ii) Need of access to load centres: The Western Isles have massive marine energy potentials, but dense load centres are far away; (iii) Need of access to balancing power: In Pomerania balancing power needs to be imported; (iv) Need of simultaneous gas-strategy: Spain needs to develop a "gas-strategy" for balancing its intermittent RES-Electricity capacities;

Overall, the analyses improved our understanding of grid infrastructure integration of RES-Electricity generation technologies in Europe under different constraints.

1. Introduction

Up to now, almost all scenario studies in the energy sector in Europe (e.g. like Primes, WEO, *Green-X*, etc.) have been conducted on the basis of country-specific balances of conventional and/or renewable energy sources (RES)-based supply and demand. Cross-country interdependences between neighbouring energy systems, on the one hand, and corresponding grid infrastructures needs (within a country as well as cross-border) for RES system integration, on the other hand, usually are not taken into account.

Within the EU-FP7-project “SUSPLAN” (“SUStainable PLANing”), 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 consider the lacking aspects mentioned above and, therefore, 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 (of electricity, heat and gas grids) necessary to “absorb” different shares of renewable generation. Moreover, the major objective of the regional scenario studies has been to study renewable grid infrastructure integration under a variety of different geographical, structural, technical, economical, institutional, and political framework conditions. This paper focuses on the grid integration of renewable electricity (RES-Electricity) technologies.

The nine different analysed regions are as follows: (i) Island Case (Isle of Lewis, North-West Scotland), (ii) Northern Europe (Norway), (iii) Central/Western Europe (Rhine-Neckar Region, Germany), (iv) North-Eastern Europe (Pomeranian Region, Poland), (v) South-Eastern Europe (Romania), (vi) South-Western Europe (Spain), (vii) Southern Europe (Italy), (viii) Western Balkan Countries (Serbia) and (ix) Alpine Region (Austria).

2. Method

2.1 Storylines

The renewable grid integration scenario generation philosophy is based on a storyline approach: two main driving forces were identified, public attitude and technological development, which open a 2-dimensional space with four quadrants. In each of the four quadrants several key, but uncertain parameters influencing RES grid integration (like RES technology cost, electricity demand, fossil fuel-, biomass-, CO_2-prices, etc.) are described in a single storyline. Therefore, there are four different storylines in SUSPLAN in total: *Red*, *Yellow*, *Green* and

Blue, whereas the *Green* storyline represents the most positive one in terms of RES-grid integration and the *Red* storyline the most negative one (see Figure 1 for more details). Within a storyline different scenarios are established and analyzed by selecting different strategies (i.e. varying different key parameters).

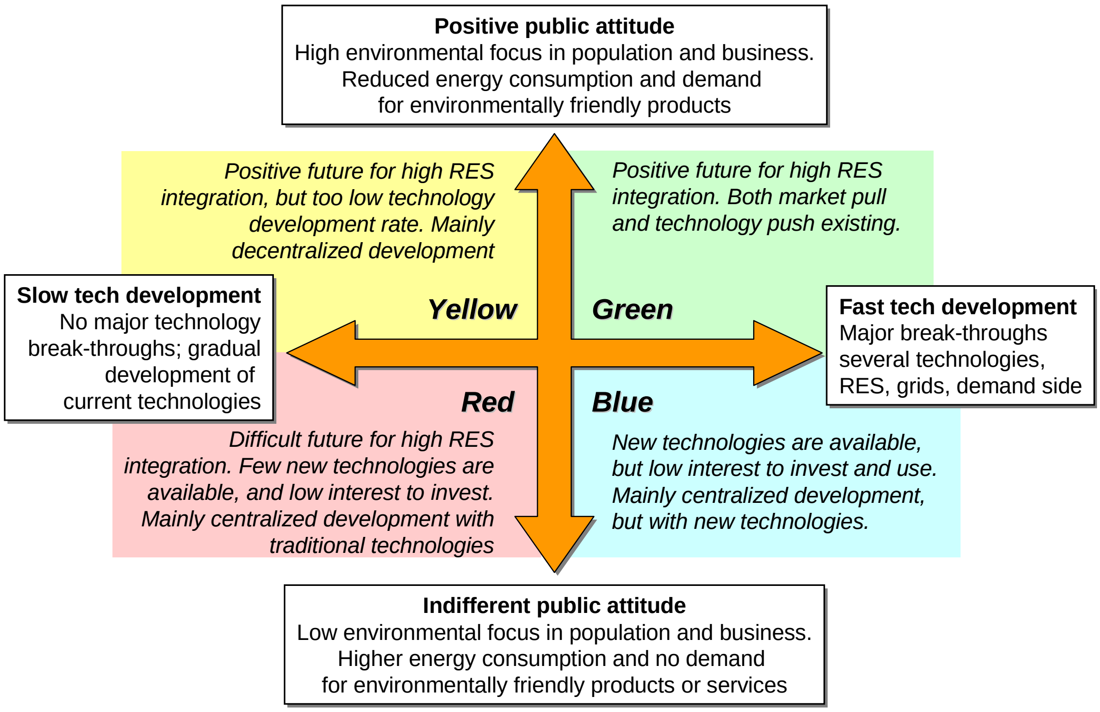

Figure 1: Overview of the four different storylines in SUSPLAN

2.2 Establishment of a consistent Set of empirical Data describing uncertain Parameters

In the SUSPLAN regional scenario studies the key parameters determining the cornerstones of energy supply and demand patterns (with or also without high shares of RES generation) comprise in particular:

- 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 based on *Green-X* modelling results up to 2030 and own assumptions according to the long-term RES/RES-Electricity potentials and ambitions in energy efficiency implementation up to 2050 in the different European counties.
- 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 (based on *Primes* model runs up to 2030; own assumptions up to 2050).

- RES/RES-Electricity Technology Cost up to 2050: Depending on global implementation rates of RES/RES-Electricity generation technologies also their specific technology 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 based on the *Green-X* model (up to 2030) and extrapolation of gradients up to 2050.

- Fossil Fuel-, CO_2-Prices 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 Outlook*' of the European Commission, '*World Energy Outlook*' of the International Energy Agency, '*Statistical Information*' of the U.S. Energy Information Administration of the Department of Energy, 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 (WEO2009), 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 (see Figure 2):

  - 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 CO_2 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 CO_2 instruments, the high price path of each of the two price scenarios of the WEO2009 is used.

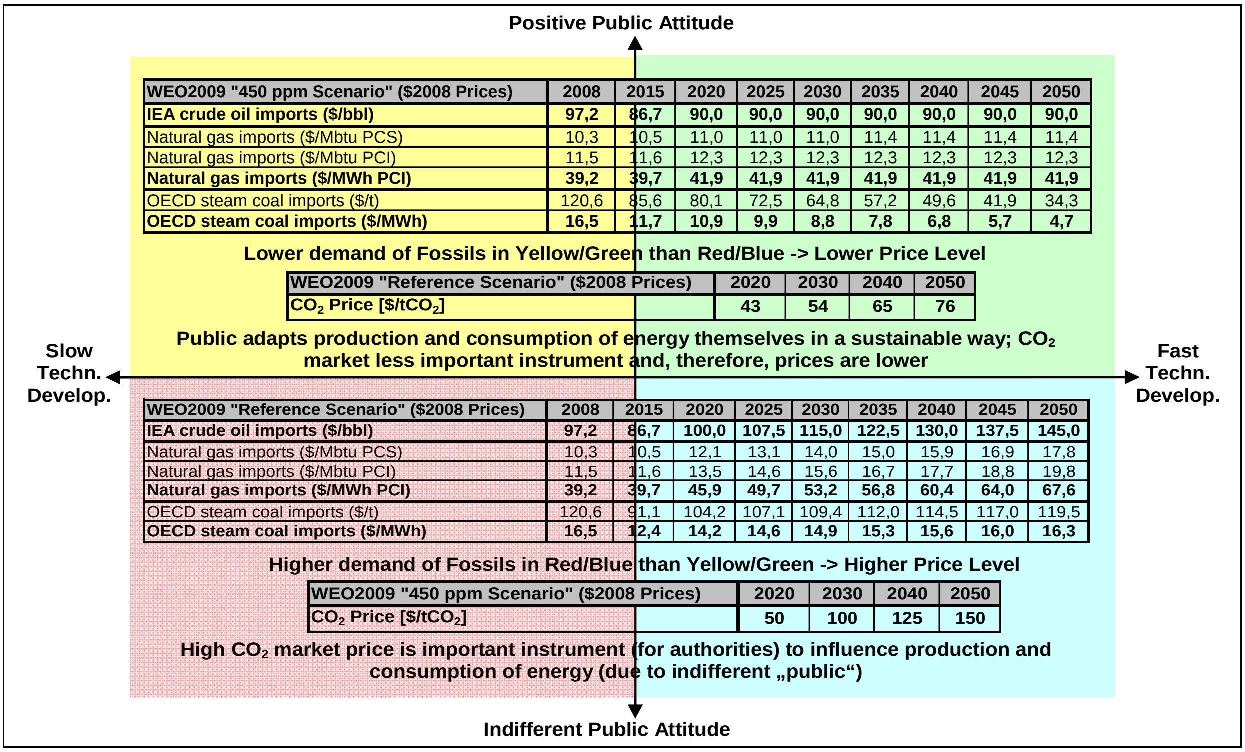

Figure 2: Expected development of the fossil fuel (crude oil, natural gas, coal) and CO_2 prices up to 2050 in the Red/Blue and Yellow/Green storylines in SUSPLAN

- Biomass-Prices up to 2050: In the 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 (see www.res2020.eu), 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. 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 3 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.

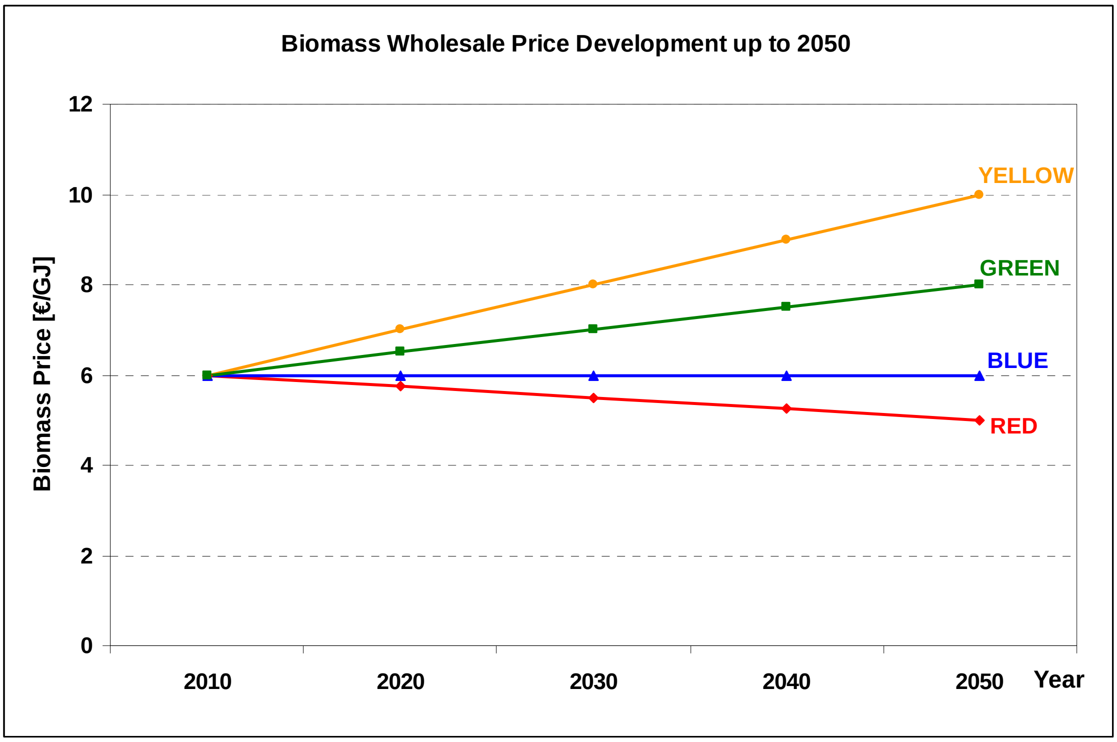

Figure 3: Expected development of the biomass wholesale prices up to 2050 in the four different storylines in SUSPLAN

- <u>Wholesale Electricity Prices up to 2050:</u> In the SUSPLAN project, wholesale electricity market price development in the four different storylines is not set exogenously; it is modelled endogenously based on a European electricity market model where – among others – the empirical settings of parameters like fossil fuel-, biomass- and CO_2 prices, RES-Electricity generation per technology, electricity demand on country-level, etc. are used accordingly. The modelled wholesale electricity market prices in the different regions, subsequently, are used as key benchmarks determining the economics and phase-in levels of non-competitive RES-Electricity generation technologies. Even more, deployment of RES-Electricity generation technologies and its integration into the grid infrastructures is also based on least-cost principles, indicating that the best available sites for the utilization of RES-Electricity generation are given priority.

2.3 Modelling Approach

The key steps of the modelling 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 in the region; calculation of a least-cost merit order and then the trade-off against a key parameter for the different end-uses (e.g. the wholesale electricity market price level 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;
- Step 3: Based on the spatial dispersion of the utilizable RES potentials and load centres as well as 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.

For the execution of this modelling approach the models *GreenNet*, a least-cost RES-Electricity simulation tool, and *eTransport*, a multi-grid infrastructure investment modelling tool, were used in sequence in the majority of the regional scenario studies.

2.4 Time Horizon of the Analyses

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 RES deployment and the corresponding infrastructure needs in the time period from 2010-2030 are neglected. 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 (compare Figure 4):

- 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. Moreover, the most important studies (e.g. EC-EET2007, WEO2009, *Green-X*, 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 different storylines it is assumed that the EU2020 targets are met at different points in time between 2020 and 2030.
- In the starting year 2030 of SUSPLAN analyses in the four different storylines four different RES shares are assumed to be implemented according to the ambitions in the storyline.
- Finally it is important to note, that in SUSPLAN 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.

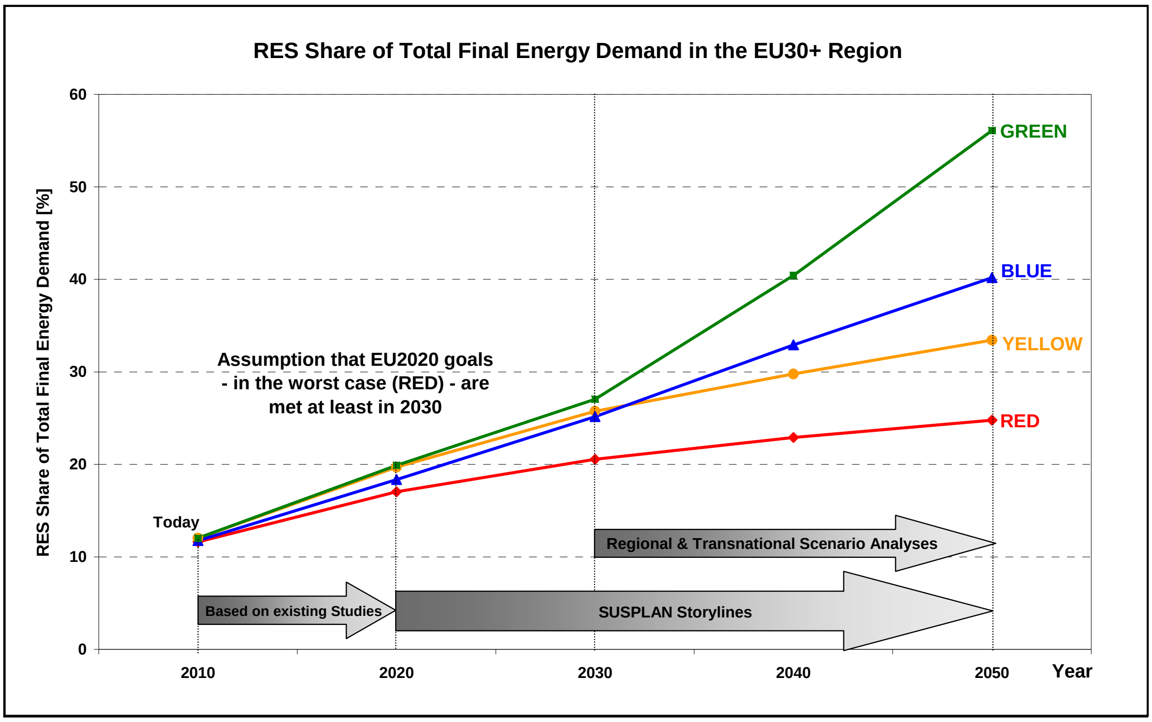

Figure 4: RES deployment as a share of total final energy demand on aggregated European level in the four different storylines in SUSPLAN

3. Results

Besides a variety of other quantitative and qualitative results, 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. Some selected highlights are presented in the following chapters.

3.1 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 resource in a wider context to balance future electricity systems with high shares of variable and intermittent RES-E generation. In order to do so (and to release to some extent those countries with rather inflexible power plant portfolios) further transmission grid upgrades, expansions and also new transmission routes are necessary.

Figure 5 presents the expected transmission grid measures in the Scandinavian transmission grid in this context: (i) expected transmission grid development up to 2030 on the left and (ii) further expected extension of the transmission grid in the *Blue* storyline up to 2050 on the right.

In terms of future RES-E potentials, Norway is characterised – beside still high 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 Norway, 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.

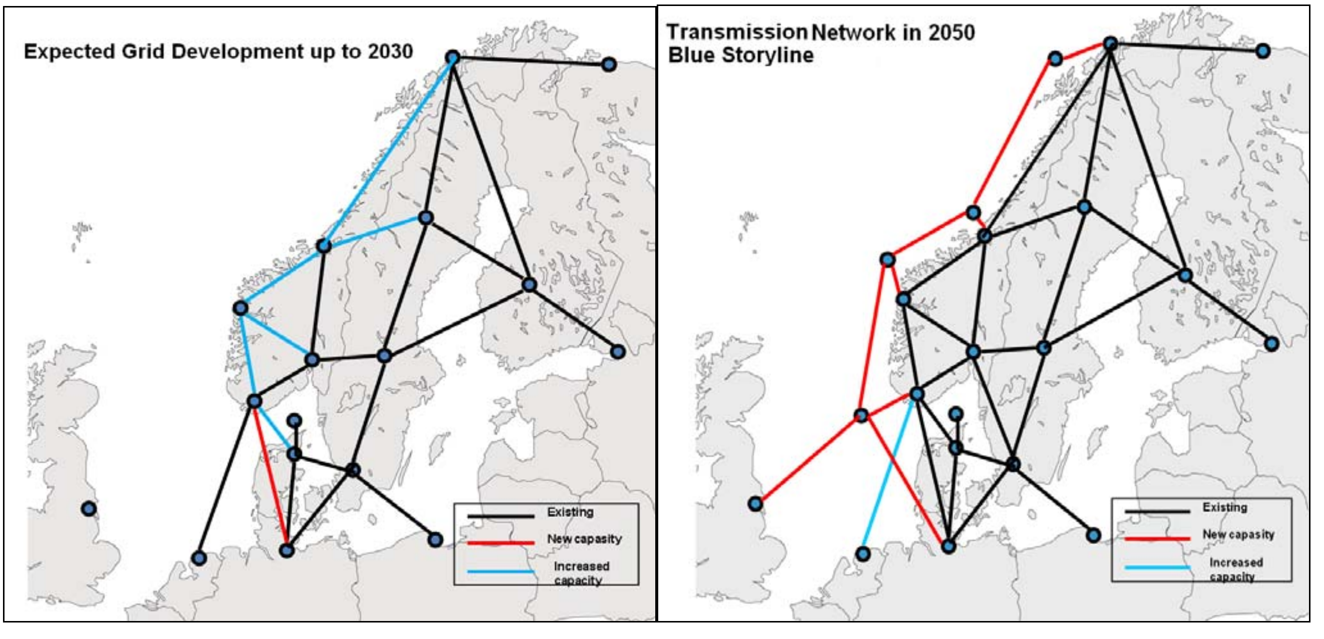

Figure 5: Expected transmission network development up to 2030 (left) and further extension in the Blue storyline in 2050 (right)

Moreover, at present Norwegian electricity generation is based on almost 100% hydro-power generation. Norway, furthermore, has plenty of currently not implemented, cheap hydro-power potentials. So hydro-power is supposed to be preferred for two reasons: (i) its cheap, and (ii) brings flexibility to the own system and for exports.

Nonetheless, in the *Blue* storyline of the SUSPLAN project the case of large-scale wind-offshore implementation has been analysed up to 2050. On the right hand side in Figure 5, a possible structure of a required 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 will be rather fiction than reality. It is supposed to be clear, that overarching goals (i.e. to implement low cost wind-offshore generation in a European context) demand overarching (business-)models being not restricted to national thinking. Then only, first best solutions are possible.

3.2 Island Case (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 “find” loads 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 nearest connection point to the existing electricity grid infrastructure is not necessarily the nearest fitting connection point qualified to absorb large amounts of RES-E generation.

Figure 6 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. 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 Scottish North West.

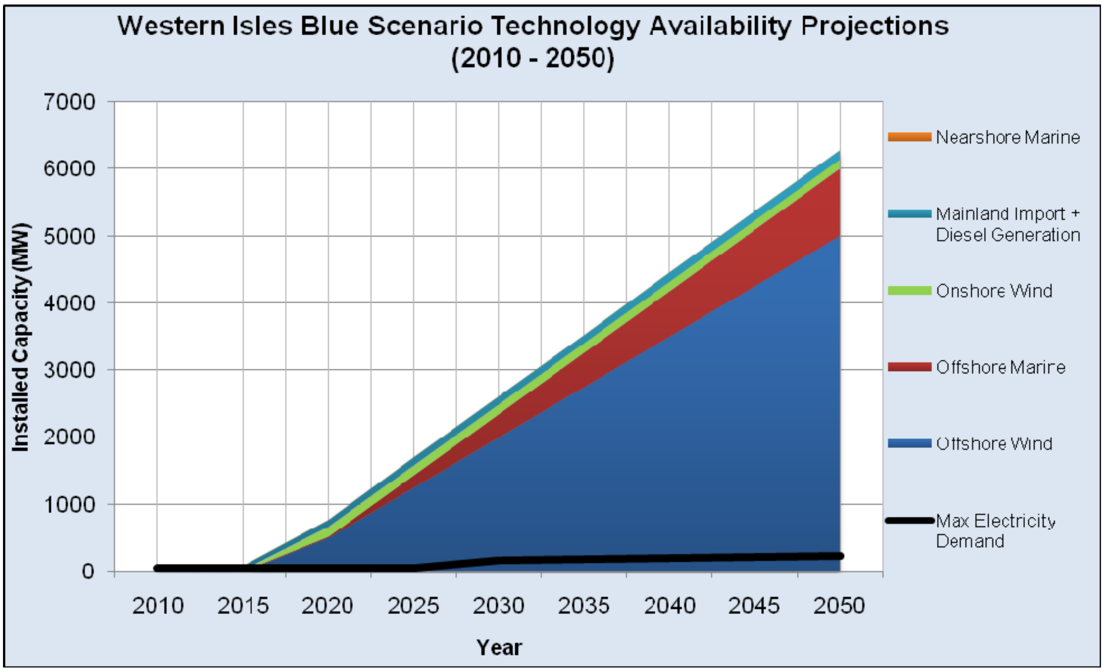

Figure 6: Development of installed RES-E capacities and gross electricity demand in the Isles of Lewis in the Blue-Storyline up to 2050

3.3 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 overcome to connect attractive RES-E potentials with corresponding load centres. Even more, in many cases the nearest connection point to the existing electricity grid infrastructure is not necessarily the nearest fitting connection point qualified to absorb large amounts of RES-E generation. The reason simply can be that network capacities are not sufficient because load density in the area/region is also low. This is also the case for the Pomeranian region.

Figure 7 presents the development of electricity generation and gross electricity demand in the Pomeranian region in the *Blue* (left) and *Green* (right) storyline up to 2050. Both figures impressively show that the Pomeranian region becomes an exorbitant net-exporter to the interior of Poland and – most probably – also to neighbouring countries. Therefore, adequate transmission investments and routes towards dense load centres are supposed to be straightforward. However, the public being confronted with new transmission lines and routes, but having no immediate benefit of it, must be convinced (and most probably compensated somehow).

One of the major differences between the *Blue* and *Green* storyline in the Pomeranian region is nuclear power. In detail, in the *Blue* storyline it is assumed that Poland phases in into nuclear power in the near future (already before 2030). However, the currently discussed nuclear capacity expected to be implemented in the Pomeranian region already exceeds electricity load in this region 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 contrary, the *Green* storyline in the Pomeranian region treats the current nuclear debate as a straw-fire subject to deflagration again. In *Green*, furthermore, a significant reduction of coal-fired electricity generation is assumed in the Pomeranian region. Moreover, entire electricity generation in the region is renewable-based, most notably wind-offshore. Again, majority shares of RES-E generation are exported to other regions. Balancing of electricity systems like that is no problem if synergies of and access to flexible neighbours are used (e.g. pumped-hydro capacities in Scandinavia and the Alps (section 3.4)).

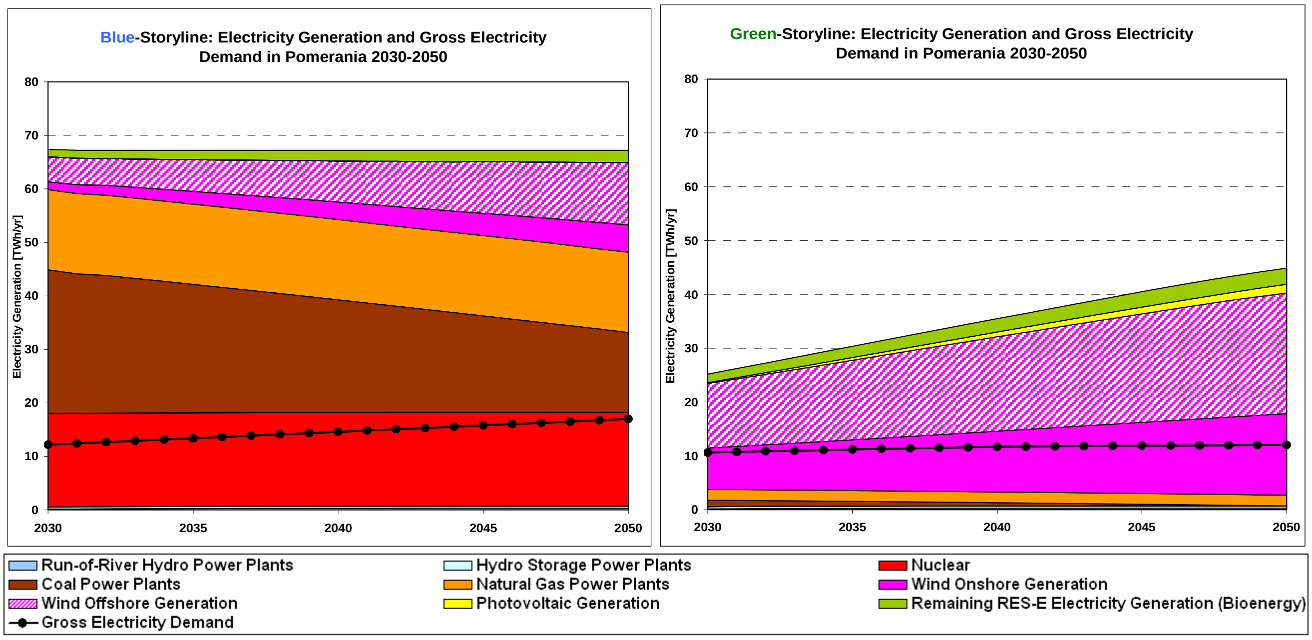

Figure 7: Development of electricity generation and gross electricity demand in the Pomeranian region in the Blue (left) and the Green (right) storyline up to 2050

3.4 Alpine Region (Austria)

Austria's pumped-hydro power plants have been playing an important role already in the last decades due to the fact that they guarantee a high degree of flexibility of the electricity systems not only in Austria but also in the neighbouring countries (e.g. economically attractive "peak-base" exchange contracts with Germany). In the future, the provision of flexible reserve capacities and balancing power demanded by large-scale wind integration into the Central and Eastern European electricity systems is expected to enable further attractive business opportunities for additional pumped-hydro power generation capacities if the corresponding transmission grid needs are fulfilled. In this respect, Figure 8 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.

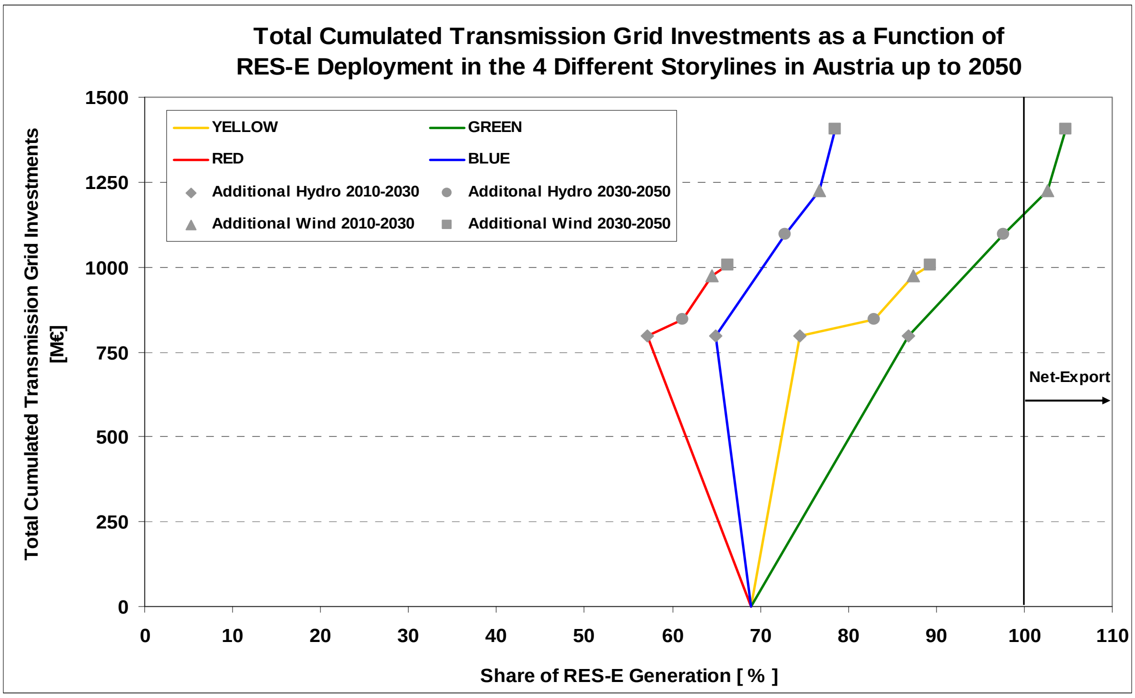

Figure 8: Total cumulated transmission grid investments as a function of RES-E deployment in the four different storylines in Austria up to 2050

When studying the vertical axis of Figure 8, 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.

3.5 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, has to be continuously integrated in the future.
- 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 reserves needs and also energy not supplied (in case of periods of non-availability of renewable resources), would give raise to higher system cost. These 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 neighbouring countries.

- A main concern in Spain will be the reduction of possible intermittent generation spillages, 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 9 finally presents two selected quantitative results to underpin above statements: installed RES-E capacities in the four different storylines up to 2050 (left); total cumulated transmission grid investment cost over RES-E penetration in the four different storylines up to 2050 (right).

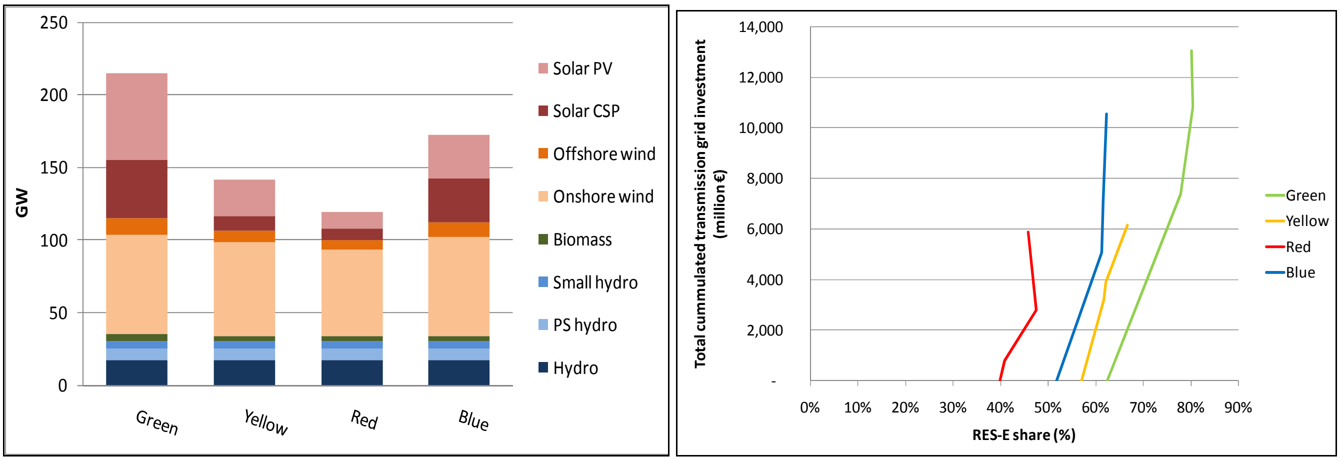

Figure 9: Installed RES-E capacities in Spain in the four different storylines up to 2050 (left); total cumulated transmission grid investment cost over RES-E penetration in the four different storylines up to 2050 (right)

4. Conclusions

In the following, some of the most important criteria for successful grid integration of RES-Electricity generation technologies are briefly outlined. They are based on the outcomes and experience of regional scenario analyses in the SUSPLAN project:

- Due to the fact that natural resources for RES-Electricity 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.
- Try to utilize economies of scale of RES-Electricity generation; i.e. the most attractive sites shall be chosen first. In case of low electric load density in an area also transmission connection to fitting load centres with sufficient load density 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-Electricity generation and to fulfil other energy policy objectives like the further integration of the European electricity market and/or improvement of security of supply.
- Try to enable access to efficient and effective system balancing and reserve capacity provision technologies in an inter-regional European context.
- Harmonize legislative and regulatory frameworks in the context of grid integration of RES-E generation technologies in the EU27+.
- Involve local/regional people/communities from the beginning of a planning phase; develop business/participation models for them.

Concluding, the lessons learnt from the nine regional scenario studies have further improved the understanding for first best solutions of grid infrastructure integration of RES-Electricity generation technologies in Europe under a variety of different constraints in the short-term and long-term.

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