e-HIGHWAY 2050

Modular Development Plan of the Pan-European Transmission System 2050

Contract number	308908	Instrument	Collaborative Project
Start date	1st of September 2012	Duration	40 months
WP 1	**Setting the boundary conditions for 2020-2050 grid planning**		
D 1.2	**Structuring of uncertainties, options and boundary conditions for the implementation of EHS**		

Revision: 5.2

Due date of delivery: 24 May 2013

		Date & Visa
Written by	Daniel Huertas-Hernando, Bjørn Bakken /SINTEF	
Validated by	Bjørn Bakken / SINTEF	24.05.2013
Approved by	Gérald Sanchis / RTE	28.05.2013

Project co-funded by the European Commission within the Seventh Framework Programme		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document information

General purpose

The main purpose of Deliverable D1.2 as final deliverable of Work Package 1 of e-Highway2050 is to summarize the main findings from the different tasks in the work package and present recommendations for the following work in e-Highway2050. This document structures uncertainties/futures, options/strategies and corresponding boundary conditions for the implementation of EHS that were identified in the different tasks of WP1, in particular technological, economical, political, socio- political and environmental uncertainties and options. The reports from the different WP1 Milestones are confidential but can be accessible upon request to the Coordinator.

Change status

Revision	Date	Changes description	Authors
V1.0	20.01.2013	Draft layout of document	Bjørn Bakken
V2.0	08.02.2013	Content from D1.1 added	Bjørn Bakken
V2.1	10.02.2013	Content from M1.1, M1.2, M1.4 and T1.5 added	Daniel Huertas-Hernando Bjørn Bakken
V2.2	12.02.2013	Content from M1.3 added	Bjørn Bakken
V2.3	14.02.2013	Recommended Futures for e-Highway2050 added	Bjørn Bakken
V3.0	04.03.2013	Scenario building process added	Daniel Huertas-Hernando Bjørn Bakken
V4.0	26.03.2013	Deliverable updated according to feedback from e-Highway2050 partners	Bjørn Bakken
V5.0	26.04.2013	Review of national policies and relevant scenario studies updated. Verbal summary of scenarios updated. EHSP discussion paper added in Annex 1.	Bjørn Bakken Daniel Huertas-Hernando
V5.1	27.04.2013	Verified by WP Leader	Bjørn Bakken
V5.2	24.05.2013	Selection of 5 final scenarios added	RTE, Technofi, Bjørn Bakken

EXECUTIVE SUMMARY

Work Package 1 (WP1) of the e-Highway2050 project establishes a comprehensive set of Boundary Conditions to inform all participants of the opportunities and limitations that are required to bring about a successful transition from today's solutions to the next generation of infrastructure needed to support an integrated power system with electricity generation driven predominantly by renewable energy sources in 2050.

A detailed bottom-up approach is necessary to ensure transparency and efficient communication of Boundaries to the other WP's. Thus, the definition of Boundary Conditions starts with a bottom-up process where we distinguish between *uncontrollable Uncertainties* which are important for the development of an Electricity Highways System (EHS) but which the decision maker(s) cannot control, and *controllable Options* which can be chosen by the decision maker(s). Any combination of Uncertainties will create the boundaries for a possible *Future* in which the EHS will be implemented, while the decision maker(s) choice of one or more Options will combine into a possible *Strategy* on how to implement EHS. Different *Scenarios* for e-Highway2050 are then established by choosing an appropriate set of Strategies and testing those under different Futures.

In this process we define *Boundary Conditions (BC)* as the upper and lower limits of the Uncertainties and the Options. However, since WP1 is only the starting point of the scenario building and following analyses in e-Highway2050, not all boundaries can be specified in numerical values in this report. In particular, the Options will mostly be described verbally since these will be the outcome of later analyses of the project.

The following Boundary Conditions have been assessed and documented in separate tasks in WP1: *Technological BC, Economic and financial BC, Political, socio-political and environmental BC and Research, development and deployment BC*. Through careful review by the project partners and feedback from stakeholders, the most relevant uncertainties and options have been identified in each category. These are used to establish a reduced set of Boundary Conditions for the e-Highway2050 Scenarios. Furthermore, two questionnaires have been distributed by ENTSO-E to European transmission system operators (TSOs). The first questionnaire enquired about expected developments of load, generation and transmission and the second about national policies and codes. These will also be useful input to the following work in e-Highway2050.

Through the scenario building process, qualitative definitions of 5 possible Futures and 6 Strategies were established by assigning possible ranges to the most relevant Boundary Conditions. Second, the list of 5 x 6 possible Scenarios was reduced through elimination to a final list of *5 relevant e-Highway2050 Scenarios*. This is a feasible number of scenarios to perform detailed analyses in the following work packages, but may be further reduced during the numerical quantification in WP2.

The tentative descriptive names for these 5 scenarios are as follows:

- *100% RES*
- *Big & Market*
- *Large fossil fuel with CCS and nuclear*
- *Large scale RES & no emission*
- *Smal and local*

We emphasize that the e-Highway2050 scenarios are neither predictions nor forecasts about the future. We do not conclude that one scenario will be more likely to happen than another, nor that one scenario is more preferred or "better" than another. Rather, each e-Highway2050 scenario is one alternative image of how the future of European Electricity Highways (EHS) could unfold.

Table of Contents

1 Introduction

1.1 Objective and tasks

Work Package 1 (WP1) of the e-Highway2050 project establishes a comprehensive set of Boundary Conditions to inform all participants of the opportunities and constraints that are to be addressed in order to bring about a successful transition from today's solutions to the next generation of infrastructure needed to support an integrated power system with electricity generation driven predominantly by renewable sources in 2050.

A successful transition requires coordinated progress on many fronts – finance, technology, research and development, the establishment of adequate supply chains as well as significant changes in the generation mix and in evolving grid capability throughout Europe. It is therefore vital that the e-Highway2050 Consortium agrees on a set of boundary conditions that adequately define the design and operation of the pan-European Electricity Highways System and sets a detailed framework for the work that needs to be undertaken in order to develop a unified approach to the considerable task in hand.

WP1 produces two Deliverables and four Milestones, as illustrated by the green boxes in Figure 1.1. D1.1 is a dedicated deliverable from Task 1.1, while Tasks 1.2-1.4 each produces a Milestone in the form of written reports. Milestone M1.2 defines the general assumptions that will be input to the scenario building process which continues in WP2/Task 2.1. Task 1.5 does not have a separate Milestone, but also delivers a written report.

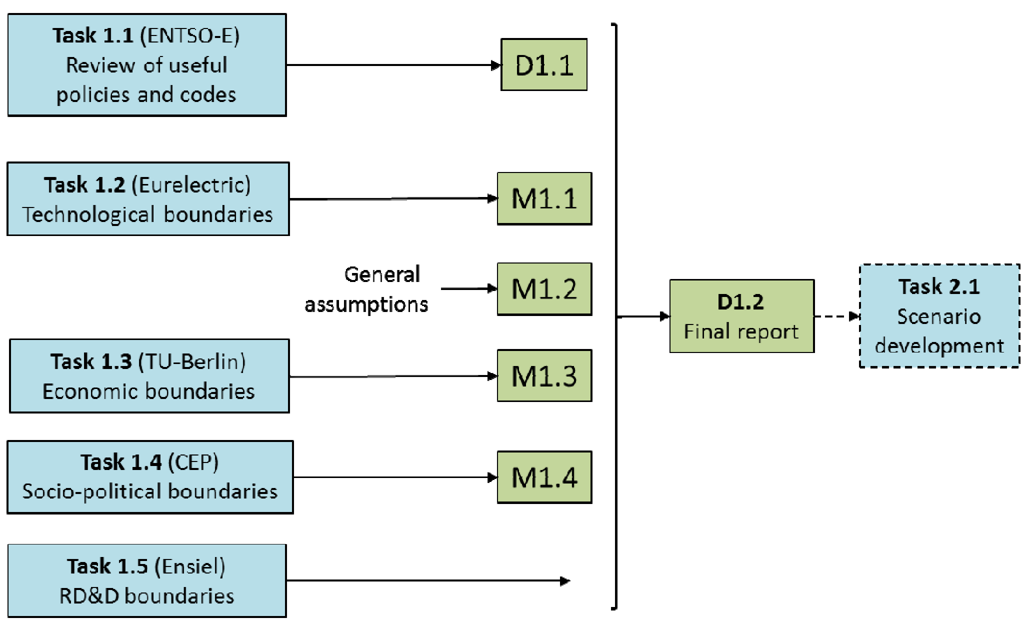


Figure 1.1 Task, milestones and deliverables in WP1

This deliverable D1.2 summarizes the main findings from each of these tasks and is structured in the following way: The next section 1.2 briefly explains the methodology used and defines the terminology of *Uncertainties, Options, Boundary Conditions, Futures* and *Strategies* that are the main building blocks for the e-Highway2050 Scenarios. Chapter 2 presents a summary of the review of relevant studies and policies which are documented in greater detail in Deliverable D1.1. Chapter 3 summarizes the Technology Boundary Conditions, Chapter 4 the Economic and Financial Boundary Conditions, Chapter 5 the Political, Socio-political and Environmental Boundary Conditions, and finally, Chapter 6 summarizes the Research, Development and Deployment Boundary Conditions. Each of these chapters is documented in detail in the separate milestones as shown in Figure 1.1. Finally, the process to establish relevant and coherent Scenarios for e-Highway2050 is elaborated in Chapters 7 and 8. Further specification and numerical quantification of the Scenarios will continue in WP2/Task 2.1.

It is neither possible nor practical to repeat here in full detail the work that is performed in each of the WP1 tasks. A deeper knowledge about approach, assumptions and conclusions is included in the separate milestones that are produced by each task.

1.2 Methodology

WP1 is the starting point for the work in e-Highway2050. A detailed bottom-up approach is necessary to ensure transparency and efficient communication of the assumptions and the resulting conclusions to the other WP's. Thus, the definition of boundary conditions for the e-Highway2050 scenarios starts with a bottom-up process where we distinguish between ***uncontrollable Uncertainties*** which are important for the development of EHS but which the decision maker(s)[1] cannot control, and ***controllable Options*** which can be chosen by the decision maker(s).

In this process we define ***Boundary Conditions*** as the upper and lower limits of the Uncertainties and the Options. However, since WP1 is only the starting point of the scenario building and following analyses in e-Highway2050, the boundaries are specified in numerical values (min, max, average etc.) in this report for the relevant Uncertainties, while the Options will mostly be described verbally since the values of these will be the outcome of later analyses throughout the project. The following work packages will improve the numerical specification/limitation of both Uncertainties and Options, and may also add, modify or remove some Uncertainties and/or Options.

Any combination of Uncertainties will create the boundaries for a possible ***Future*** in which the EHS will be implemented, while the decision makers' choice of one or more Options will combine into a possible ***Strategy*** on how to implement an Electricity Highways System (EHS).

[1] In this report, we use the term "decision makers" to denote all decision making entities related to design and operation of the electricity system: Politicians, Directors of regulatory bodies, TSO's or DSO's, CEO's of generating or manufacturing companies etc

This is illustrated in Figure 1.2. Different scenarios for EHS will be established by choosing an appropriate set of Strategies in combination with different Futures.

At this stage we also introduce the term *Assumption*, indicating an Uncertainty that does not change between the different Futures (or Option that does not change between Strategies). In that case, it is no longer an Uncertainty but a *fixed Assumption for all the Scenarios*.

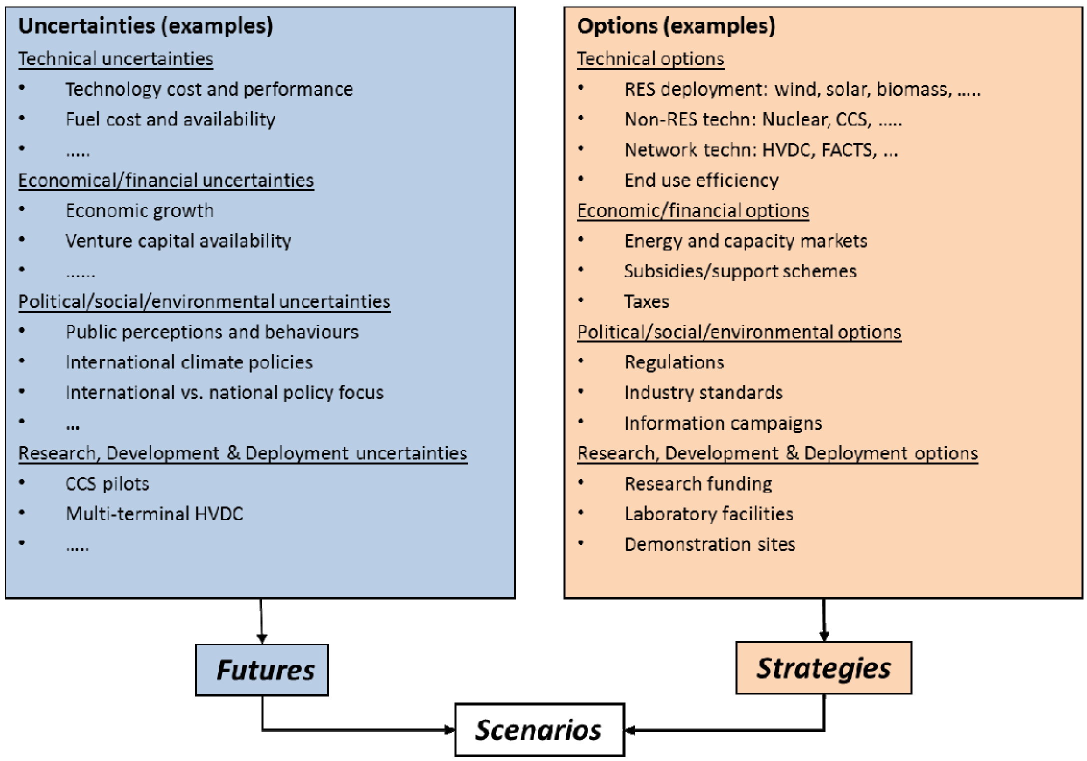


Figure 1.2 Construction of Scenarios from Uncertainties and Options

The e-Highway2050 scenarios are neither predictions nor forecasts. We do not conclude that one scenario will be more probable to happen than another, nor that one scenario is more preferred or "better" than another. Rather, each scenario is one alternative image of how the future could unfold, based on a combination of Options and Uncertainties.

The scenario building process in e-Highway2050 (including both WP1 and WP2 work) is performed in seven main steps (see Figure 1.3).

1. First, a detailed bottom-up specification of all relevant Uncertainties and Options with corresponding Boundary Condition is performed. This step is performed in each task in WP1 and documented in separate Milestones, and is only summarised in this deliverable.

2. To limit the possible combinations to a feasible number, we need to identify and assess the *main Uncertainties and Options* that will create the relevant Futures and Strategies for e-Highway2050.
3. The main Uncertainties are combined into *possible Futures* that we narrate in a verbal way without giving specific numbers for each uncertainty..
4. In parallel, the main Options are combined into *relevant Strategies* for implementation of EHS in different possible Futures.
5. In this step, *coherent Futures and Strategies* are combined into possible *Scenarios*. In this step, coherence means that related Uncertainties and Options should match – e.g. in a Future where CCS is not commercially available we cannot have CCS as an Option..
6. The resulting number of Scenarios (= Futures x Options) from Step 5 will be too high for the analyses in following work packages of e-Highway2050. Thus, an extra step is performed to reduce the number of possible scenarios. First, a more detailed check for inconsistencies is performed; between the different Uncertainties, between the different Options and between Uncertainties and Options. Second, we assess how each scenario is assumed to impact on the development of EHS in terms of Generation, Demand and Exchange (G/D/E). Scenarios that have a similar impact on G/D/E developments can be combined into one scenario. This reduction process aims at selecting the *most challenging* scenarios from the point of view of grid development and the implementation of EHS.
7. Finally, after a detailed process of evaluation, selection and elimination involving the full e-Highway2050 consortium, a set of agreed *e-Highway2050 scenarios* is proposed. Typically, we aim for a number between 5 and 10 to enable a detailed numerical analysis of each scenario in the following work packages.

The various Boundary Conditions that are identified in this work package will act as *limits* or *bounds* in the process of building coherent Futures and Strategies into a feasible number of relevant Scenarios in steps 3, 4 and 5. As an example, the effect of various Boundary Conditions is shown in Figure 1.4 for the wind generation potential in a given country. The level and order of the different boundaries may of course change from country to country and from scenario to scenario.

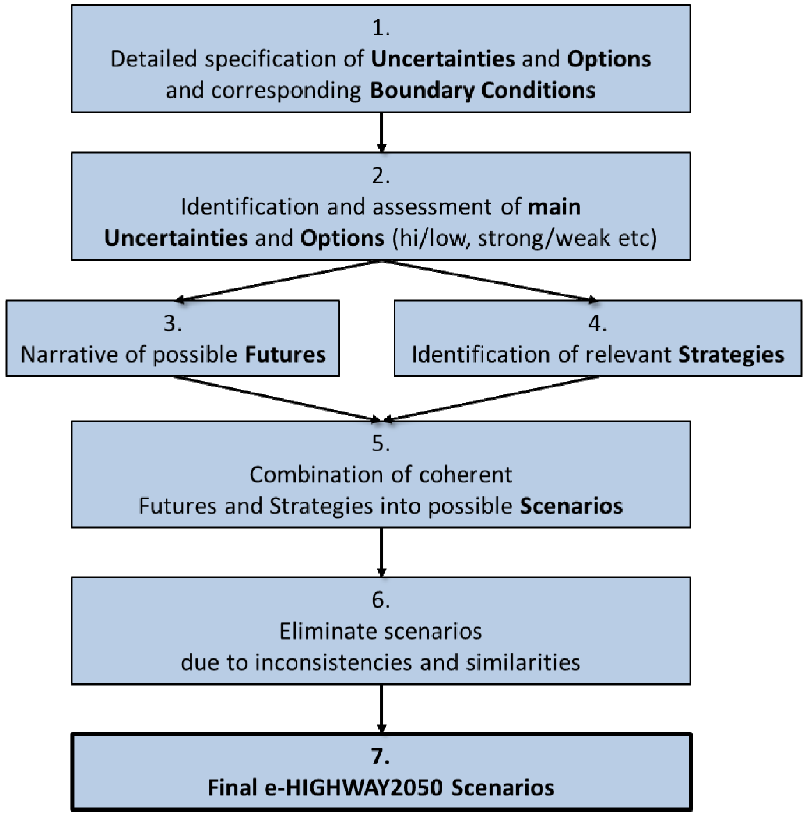


Figure 1.3 Scenario building process of e-Highway2050

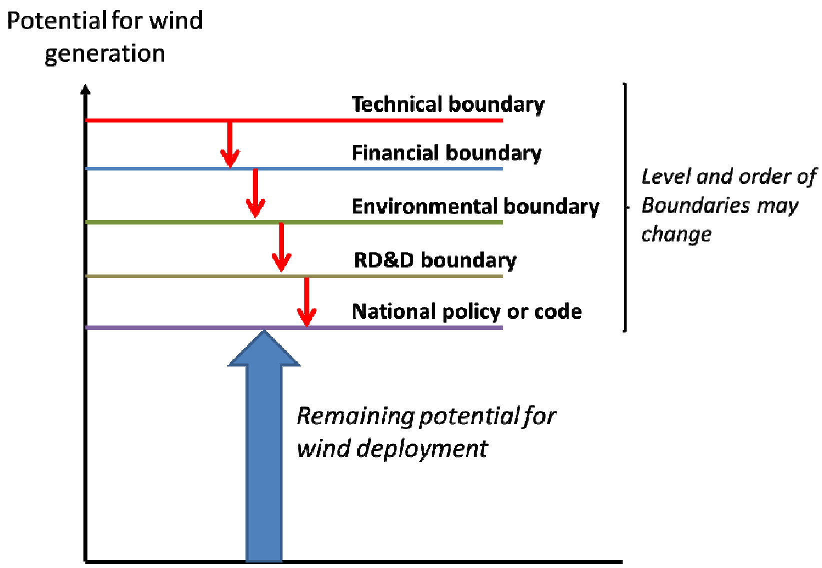


Figure 1.4 Example of how different boundary conditions may influence the potential for wind generation in a given country

2 Review of relevant studies and policies

2.1 Approach

In the first task of WP1 (1.1), background data useful for the assessment of the e-Highway2050 scenarios were collected. In this respect, two questionnaires were developed by the TSOs involved in the project and sent to all members of ENTSO-E. The data from these enquiries will constitute a baseline reference for the energy scenarios that will be built and used throughout the e-Highway2050 project.

In the first questionnaire, national data regarding load, generation and transmission developments were collected (presented in D1.1b, confidential report). The second questionnaire inquired about national policies and also national studies of interest for e-Highway2050. Detailed reports of this questionnaire are found in Deliverable D1.1a [1]. The following section provides a brief overview of the main findings of the second questionnaire of national policies and codes. Finally, Section 2.3 presents an overview of existing scenario studies of relevance to e-Highway2050.

2.2 Review of existing policies

The second questionnaire sent to all members of ENTSO-E was divided into four major parts covering the topics *Energy demand and efficiency*, *Generation*, *Storage* and *General framework*. In addition, a summary of relevant national studies was also requested.

Although this exercise reflects the diversity of European countries, it is possible to draw some general conclusions. All European countries are faced with comparable challenges concerning energy, electricity and environment, and very often comparable policies on energy efficiency and demand side management, generation and storage exist – within the national context – to cope with those challenges.

Moreover, it is important to realize that the national reviews only provide a snapshot of the current situation in European countries. The market situation can change rapidly and policies can change as well within the existing long term framework. The current national policies in the EU countries with a major impact on the development of energy economics could be further improved to address the 2050 timeframe. This will be the topic for further research in WP5.

A detailed summary of the answers and a comprehensive list of national studies are found in Deliverable D1.1a [1]. The present document only includes the summary tables for each topic as input to the further work in e-Highway2050.

Table 2.1 Summary of national policies on energy efficiency and demand side management

Blank : no policy or no answer

++ : existing operational measure(s)

+ : existing policy or politically desired

	Energy efficiency	Thermal insulation in buildings	Electric space heating devices	Electric vehicles	Other electric devices	Demand Side Management
Austria	++	++	++	++	++	++
Belgium	++	++	++	++	++	++
Bosnia and Herzegovina	+					
Bulgaria						
Croatia						
Cyprus						
Czech Republic	+	++	++	++	++	++
Denmark	++	++	++	++	++	++
Estonia						
Finland						
France	++	++	++	++	++	++
Germany	++	++		++		++
Greece	++	++		++	++	+
Hungary						
Iceland						
Ireland						
Italy	+	++	+	+	+	+
Latvia						
Lithuania	+	+				++
Luxembourg						
FYR Macedonia	+	+			++	
Montenegro						
Netherlands						
Norway	++	++	++	++	++	++
Poland	++	++				++
Portugal	++	+	+		++	++
Romania	+	+	+	++	+	++
Serbia	+	+				
Slovak Republic						
Slovenia						
Spain	++	++	+		++	++
Sweden	++	++	+	++	++	++
Switzerland	++	++	++	+	+	+
United Kingdom	++	++	++	++	++	

Table 2.2 Summary of measures on energy efficiency and demand side management

	Energy efficiency	Thermal insulation in buildings	Electric space heating devices	Electric vehicles	Other electric devices	Demand Side Management
Austria	Statutory regulations to increase energy efficiency	Promotion of renewable energy systems in the building sector Stronger focus of housing support on thermal remediation	linked to housing support and further initiatives at regional and local levels.	Tax reduction and exemption NoVA greening – tax reduction for low CO2-emission vehicles	Strategy	Strategy
Belgium	Tax relief	Subsidies	Tax reduction	Tax reduction	Labelling system	R&D programs
Czech Republic		Low energy standards, Regulation	Heat pumps replace local coal	Support of R&D	Labelling system	Support of smartgrids
Denmark	Subsidies, taxes and regulations	Subsidies, taxes and regulations	No more oil fired burners, Subsidies	Tax reduction	Subsidies	Smart meter, Regulation
France	Regulation, incentives, energy saving certificates	Regulation, incentives for low energy building	Regulations, subventions	Promotions incentives	Energy saving certificates	Balancing mechanism
Germany	Subsidies	Subsidies		Subsidies		Subsidies
Greece		Tax incentives				
Italy		Incentive				
Lithuania		Promotion of buildings modernization				
FYR Macedonia	Decree for program plans, promotion, obligations for big consumers	Decree for program plan	Decree for program plan		Labelling decree of eco design of products	
Norway	Financing, active advice	Recommendations	Tax reduction			Metering system
Poland	White certificates	Subsidies		Tax reduction, incentives		
Romania	Subsidies	Subsidies		Purchase incentive		
Serbia	Green passport					

	Energy efficiency	Thermal insulation in buildings	Electric space heating devices	Electric vehicles	Other electric devices	Demand Side Management
Spain		Program plan		Promotion		Contracts with large consumers
Sweden	Tax reduction			Tax reduction	Labelling system	Hourly balancing
Switzerland	Building efficiency standards	Regulation, tax reduction, green certificate	Regulations	Regulation, certificates	Regulations, information campaigns, promotions and energy labels.	
United Kingdom	Taxes, obligations building design standards.	Loan	Subsidy	Purchase incentive	Energy efficiency labelling	

Table 2.3 Summary of targets for energy efficiency and demand side management

	Energy efficiency	Thermal insulation in buildings	Electric space heating devices	Electric vehicles	Other electric devices	Demand Side Management
Austria	Reductions in energy consump-tion -22 % for transport, 12 % for heating and cooling, 5 % for electricity	In the part of the building code / technical rules, there are general requirements on energy savings and thermal insulation:		Applicants / tax-privileged individuals Vehicles with environmentally friendly power supply motors * maximum bonus € 500 per vehicle		
Denmark	Increase energy efficiency in buildings and in transport	strict requirements to new buildings regarding insulation reduction of energy consumption in older buildings	Oil fired burners are to be phase out by 2030 and should be replaced by district heating, heat pumps or other RE heating solutions	Promotes the use of electric Vehicles Test schemes for electric vehicles research scheme for EV DKK 53 m Green transport policy DKK 180 m		demand-side management and active demand-side participation in markets, increased DG and domestic storage (e.g. electric cars) with active management of distribution networks
France	combat climate change and improve energy performance	reduction of energy consumption in older buildings	reduce the development of Joule effect space heating	2 million electric and plug-in hybrid electric vehicles in 2020	345 TWh of savings (2011-2013)	
Lithuania	1.5 % annual savings of the total final energy consumption	reduction of the heat consumption by 30–40 % in buildings by 2020				
FYR Macedonia	at least 9% energy savings by 2018	greater exploitation of RES for energy supply in households and service sector			The energy-related products fulfilling prescribed criteria /conditions according to the Decree on eco design of products put on the market	

	Energy efficiency	Thermal insulation in buildings	Electric space heating devices	Electric vehicles	Other electric devices	Demand Side Management
Poland	Energy saving > 9% of the national average energy consumption per year. Use of White certificates	Preparing energy characteristic as certificates Subsidies for those who decrease building energy consumption				
Romania	Elimination subsidies to households with district heating systems	Reduction of heating and hot water bill by 40-60%				
Serbia	Limit in consumption of electrical energy in new buildings will be 65 kWh/m2.					
Switzerland	Improvement of building efficiency standards, reduction of CO2 Emissions, reduction of electricity demand per appliance.	Reducing building energy consumption by 28 TWh (of which 12 TWh electricity)	From 2020 onwards, New buildings autonomous concerning yearly heat production New buildings shall not require more than 60 kWh/(m²*year) for heating	By 2015, the average CO2 emissions per vehicle shall not exceed 130 g CO2/km and by 2020 the value will be at 95g CO2/km.	The estimated efficiency improvement potential of best-available-technologies compared to present techn is 25-30%.	
United Kingdom	CRC mandatory carbon reductions for business	reduce CO2 targets by 0.5M ton/year by 2015	funding cap for each year			

Table 2.4 Summary of national policies on generation

++ : existing operational measure(s)

\+ : existing policy or politically desirable

\- : existing policies or measures not in favour of the technology

blank : no answer or no policy

	Centralized Thermal units	Nuclear power plants	Hydro Power Units	PV	Wind	Biomass	Other Res	CHP
Austria			++	++	++	++		
Belgium	++	-		++	++	++	++	
Bosnia and Herzegovina			+	+	+			
Bulgaria								
Croatia								
Cyprus								
Czech Republic	++			+		+		
Denmark					++	++		
Estonia								
Finland								
France	++		+	++	++	++		++
Germany		-		++	++	++	++	++
Greece			+	++	++	++	++	++
Hungary								
Iceland								
Ireland								
Italy			++	++	++	++	++	++
Latvia								
Lithuania		++	+	+	+	+	+	+
Luxembourg								
FYR Macedonia			++	++	++	++	++	
Montenegro								
Netherlands								
Norway			++		++	++		
Poland	++	++	++	++	++	++		++
Portugal			++	+	+	+	+	
Romania	++	++	++	++	++	++	++	
Serbia	++		++	++	++	+		
Slovak Republic								
Slovenia								
Spain			++	++	++	++	++	++
Sweden		++		++	++	++	+	
Switzerland	++	-	++	++	++	++	++	++
United Kingdom				++	++	++	++	

Table 2.5 Summary of measures for generation

	Centralized Thermal units	Nuclear power plants	Hydro Power Units	PV	Wind	Biomass	Other Res	CHP
Austria	All restrictions and guideline must be respected	no nuclear power in Austria	Subsidies	Subsidies, feed-in-tariffs; Time frame: 2020	Subsidies, feed-in-tariffs; Time frame: 2020	Subsidies, feed-in-tariffs; Time frame: 2020		
Belgium	Capacity payments (or some related mechanisms) and/or tendering processes may be considered	Taxation on the incomes nuclear rente		Support in investment	Green certificates mechanism with guaranteed minimum price	Support in investment	Support in investment	CHP certificates; Premiums for heating networks
Bosnia and Herzegovina	None	no nuclear	Subsidies for small hydro	Subsidies	Subsidies		None	None
Czech Republic	Support of co-generation and high efficiency of units	Support of nuclear	support of new Pumped Storage	Support of roof installations only	Support tailored according to economic possibilities, natural conditions and limitations in protection areas	Special support of large units of 10 - 100 MW	After fulfillment of Czech RES obligations, gradually no RES subsidies	Heat pumps preferred to classical sources
Denmark	Coal used as fuel on central power plants should be phased out by 2030 and replaced by biomass	no nuclear	no hydro	supported by a PSO (Public Service Obligation) scheme		Biomass will replace coal in the central power plants by 2030		Electricity and heat systems should be based on RES by 2035
France	no transposition law in France for the moment	objective to reduce the share of nuclear in electricity production to 50% in 2025	Official law concerning concessions	Subventions for PV (installation and feed-in-tariff)	Subsidies for on- and offshore wind (installation and feed-in-tariff)			

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Germany	Revenues achievable in the energy market	Nuclear phase-out by 2022		Subsidies	Subsidies	Subsidies	Subsidies	Subsidies
Greece	modernization and upgrading of existing thermal power plants along with the reinforcement of the transmission system at 400 kV voltage level	encouraged but there are severe environmental obstacles	priority in dispatch and are remunerated by a fixed Feed in Tariff (FIT).	priority in dispatch and are remunerated by a fixed Feed in Tariff (FIT).	priority in dispatch and are remunerated by a fixed Feed in Tariff (FIT).	priority in dispatch and are remunerated by a fixed Feed in Tariff (FIT).	++ priority in dispatch and are remunerated by a fixed Feed in Tariff (FIT).	CHP of high efficiency (<50 MW) are treated by the existing legislation equally to RES plants
Italy	permitting procedure (for construction and operation is subject to environmental impact assessment (EIA) and, with power more than 300 MW, to single authorization procedure	no nuclear		Incentives and simplified authorization (PV and grid connection) procedures	Incentives and simplified authorization (Wind Farm and grid connection) procedures	Incentives and simplified authorization (biomass plant and grid connection) procedures	Incentives and simplified authorization procedures	Incentives and simplified authorization procedures
Lithuania	Encourage new biofuel-fired Thermal power plants		introduction of suitable and clear market conditions	introduction of suitable and clear market conditions	introduction of suitable and clear market conditions	introduction of suitable and clear market conditions	introduction of suitable and clear market conditions	encourage small-scale CHP installation closer to the users.
FYR Macedonia		Strategy for nuclear development envisaged but no further elaboration	feed-in tariffs for electricity produced from SHPP (<10 MW)	feed-in tariffs for electricity produced from PV (<1 MW)	feed-in tariffs for wind electricity preferential if (<50 MW)	feed-in tariffs	feed-in tariffs	issuing of guarantee of origin of electricity produced by CHP

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Norway	No thermal gas production without CCS	Not accepted	Positive development of small and medium hydro; Included in Green certificate market	No policies	Included in Green certificate market, but not sufficient for offshore development	Positive to biomass; Included in Green certificate scheme; time frame: 2020	Encourage RES development up till 13.6 TWh	No new CHP without CCS
Poland	Ministry of Environment regulation on the installation of emission standards reduce air pollution and GHG emission	Atomic Law Act Act on the preparation and implementation of investment in nuclear power facilities and associated investment 6000 MW until 2030	Energy Law Act with amendments Draft Law on RES	Energy Law Act with amendments Draft Law on RES	Energy Law Act with amendments Draft Law on RES	Energy Law Act with amendments Draft Law on RES	Energy Law Act with amendments Draft Law on RES	
Portugal	no policy (beyond already licensed capacity)	no nuclear	undergoing national plan (launched in 2007) is been implemented in order to explore national hydro power resources Capacity payments	Other mechanisms than feed-in tariffs shall be used to further developments (details to be published)	Feed-in tariffs or other shall be used to further developments (details to be published)	Feed-in tariffs or other shall be used to further developments (details to be published)	Other mechanisms than feed-in tariffs shall be used to further developments (details to be published)+	

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Romania	Strategy: installing new units and retrofitting of the old ones	Strategy: necessity of building two new units	For energy produced in SHPP (< 10 MW): 3 certificates / MWh if plants are new and 2 certificates / MWh if plants are retrofitted	6 certificates / MWh of solar energy generated and delivered	2certificates by 2017 and 1 certificate from 2018 / MWh generated and delivered by wind energy producers	3 certificates / MWh of biomass energy produced and delivered	3 certificates / MWh ++	Strategy
Serbia	Strategy: continue building new units	moratorium on building nuclear units till year 2015	Feed-in tariff SHPP (0.2 to 30 MW) are in range from 7 - 13.7 c€/kWh.	Feed-in tariff for PV (0.03 MW and above) are in range from 16 - 21 c€/kWh, depending of the size of the units	Feed-in tariff for offshore WPP is currently 9.2 c€/kWh	Feed-in tariff for biomass is currently in range from 8- 13.8 c€/KWh, depending on the size of units		Feed-in tariff for production of electrical energy from small CHP units is currently in range from 8- 8.9 c€/kWh, depending on the type of fossil fuel
Spain			RES support schemes have been cancelled for new installations	RES support schemes have been cancelled for new installations	RES support schemes have been cancelled for new installations	RES support schemes have been cancelled for new installations	RES support schemes have been cancelled for new installations	
Sweden	No special policies	allow investments in new nuclear reactors when the old reactors come to end-of-life	No special policies	investment subsidy for PV, where up to 35 % of the investment cost can be financed	30 TWh electricity yearly coming from wind power generation	No special policies	No special policies	

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Switzerland	Full CO_2 compensation required with at least 50% done nationally. The remainder e.g. via ETS (provided CH becomes eligible to the ETS);	currently pursuing a phase-out of nuclear power plants	Feed-in tariffs for SHPP (<10MW), acceleration of permit granting procedures and identification of priority areas suitable for power plants	Feed-in tariffs for larger PV plants (>10 kW), 30% coverage of investment costs for small PV plants (<10kW), improved land use planning	Feed-in tariffs, acceleration of permit granting procedures and identification of priority areas suitable for power plants	Feed-in tariffs	Financial support for research: e.g. coverage of investment guarantees; financial support for pilot projects	Financial support of plants 350kW-20MW provided all the produced heat is used in one form or other
United Kingdom	Electricity Market Reform (EMR)	Electricity Market Reform (EMR)	EMR, Feed-in Tariffs (FITs), Renewable Obligation Certificates (ROCs)	Feed-in Tariffs (FITs)	Renewable Obligation Certificates (ROCs)	Renewable Obligation Certificates (ROCs)	Feed-in Tariffs (FITs)	

Table 2.6 Summary of targets for generation

	Centralized Thermal units	Nuclear power plants	Hydro Power Units	PV	Wind	Biomass	Other Res	CHP
Austria	Topics: environmental impact (geology, biology, hydro, etc.), human medicine, project description including constructions, energy economic use, technical alternative, etc		Encouraging the construction of hydro generation and facilitate market competition; plus 1000 MW	Encouraging the construction of PV generation and facilitate market competition; plus 1200 MW	Encouraging the construction of wind generation and facilitate market competition; plus 2000 MW	Encouraging the construction of biomass generation and facilitate market competition; plus 200 MW		
Belgium				13% of energy consumption in 2020 to be from renewable sources	13% of energy consumption in 2020 to be from renewable sources	13% of energy consumption in 2020 to be from renewable sources	13% of energy consumption in 2020 to be from renewable sources	
Bosnia and Herzegovina					350 MW of wind by 2019, 640 MW by 2023			
Czech Republic	50 - 60% generation share						18-25% generation share	
Denmark	Coal used as fuel on central power plants should be phased out by 2030 and replaced by biomass				50% wind power in the electricity system by 2020	Biomass will replace coal in the central power plants by 2030.		

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
France	Around 4 GW of oil units and 3,6 GW of hard coal units will shut down between 2012 and 2015 because of this directive.	An announced objective is to reduce to 50% the share of nuclear in electricity production in 2025.		5.4 GW of solar for 2020	- Onshore wind : 19 GW - Offshore wind : 6 GW	3 GW of biomass for 2020		
Germany		-	80% of energy consumption in 2020 to be from renewable sources 2050	80% of energy consumption in 2020 to be from renewable sources 2050	80% of energy consumption in 2020 to be from renewable sources 2050	80% of energy consumption in 2020 to be from renewable sources 2050	80% of energy consumption in 2020 to be from renewable sources 2050	
Italy		no nuclear	target 2020: Hydro 17,8 GW; (ref. PdS)	target 2020: Solar 8,6*GW (ref. PdS)	target 2020: Wind 12,7 GW (ref. PdS)	target 2020: Biomass 3,8 GW (ref.PdS)		
Lithuania			In 2020 Lithuania should have at least 141 MW installed capacity of hydro power plants.	In 2020 Lithuania should have at least 10 MW installed capacity of solar power plants.	In 2020 Lithuania should have at least 500 MW installed capacity of wind power plants.	In 2020 Lithuania should have at least 355 MW installed capacity of biomass power plants.		
Norway			70% of national hydro power resources to be explored until 2020: 9000 MW (total)		Encourage RES development up till 13,6 TWh	Encourage RES development up till 13,6 TWh	Encourage RES development up till 13,6 TWh	
Poland		6000 MW until 2030						

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Portugal		no nuclear	70% of national hydro power resources to be explored until 2020: 9000 MW (total)	PV: 500 MW in 2020 Solar Thermal: 50 MW in 2020	5300 MW in 2020	Biomass + Biogas + renewable CHP: 750 MW in 2020	6 MW in 2020	
Serbia	By the year 2025, the plan is to have 2.3 GW of new thermal capacity. Also 1.2 GW of old capacity is planned to be mothballed.		By the year 2025, the plan is to have approximately 0.8 GW of new hydro capacity.		By the year 2030, the plan is to have approximately 1000 GW of new onshore wind capacity, but that is very much dependent on economic conditions, feed-in tariffs, and amount of reserve in our power system. We still, don't have strategy beyond year 2030.	The plan in years to come is to introduce the biomass in some gas power plants instead of fossil fuel.	By the year 2025, the plan is to have 2.3 GW of new thermal capacity. Also 1.2 GW of old capacity is planned to be mothballed.	
Spain		55,600 GWh of annual production in 2020	11,676 MW in 2020 (hydro >10 MW without storage)	7,250 MW (pv) and 4,800 MW (Solar Thermal) in 2020	35,000 MW (onshore) and 750 MW (offshore) in 2020	1,950 MW in 2020	Geothermal: 50 MW in 2020 Waves: 100 MW in 2020	
Sweden					30 TWh electricity yearly coming from wind power generation			

	Centralized Thermal	Nuclear power	Hydro Power	PV	Wind	Biomass	Other Res	CHP
Switzerland	1 CCGT by 2020, as many as 9 in total depending on pursued energy strategy and supply&demand developments (incl. RES)	Existing nuclear power plants are to be decommissioned and 'replaced' with non-nuclear alternatives	Max +3.16 TWh	Feed-in tariffs for larger PV Promotion of onshore wind; +4 TWh plants (>10 kW), 30% coverage of investment costs for small PV plants (<10kW), improved land use planning	Promotion of onshore wind; +4 TWh	+1.1 TWh	Research and development of the technology for implementation; +4.4 TWh (tentative);	Promotion of CHP plants, in particular from industrial processes, large buildings and district heating areas; +3.4 TWh (of which 2 TWh by 2025);

Table 2.7: Overview of national policies for storage

++ : existing operational measure(s)

\+ : existing policy or politically desirable

blank : no answer or no policy

	Pump Storage Plants	Batteries	Other kinds of Storage
Austria	+		
Belgium		++	
Bosnia and Herzegovina			
Bulgaria			
Croatia			
Cyprus			
Czech Republic	+	+	+
Denmark			+
Estonia			
Finland			
France			
Germany			++
Greece	+	+[2]	+
Hungary			
Iceland			
Ireland			
Italy	+	+	+
Latvia			
Lithuania	+		
Luxembourg			
FYR Macedonia			
Montenegro			
Netherlands			
Norway			
Poland			++
Portugal	++		
Romania	+	+	+
Serbia	+		
Slovak Republic			
Slovenia			
Spain	++	++	
Sweden			
Switzerland	++		
United Kingdom			

[2] Only for very small isolated systems in islands

Table 2.8 Summary of main measures for storage

	Pump Storage Plants	Batteries	Other kinds of Storage
Austria	Increase public acceptance		
Belgium	Improve land use conditions	Positive business case	
Czech Republic	support of pump storage facilities	R&D support	R&D support
Denmark		Improve business plan	The trend is to integrate electricity and gas systems and then use the storage capabilities of the gas system as long term electricity storage. In shorter periods demand side management is seen as the "storage".
Germany			R&D support
Greece	Encourage the construction of Pump Storage Plants (PSP)	Pilot projects for small stand-alone systems (in islands of Kythnos and Ikaria) that incorporate energy storage in batteries and PSPs respectively).	
Italy		TSO include batteries and other kinds of storage in the Development National Plan	TSO include batteries and other kinds of storage in the Development National Plan
Lithuania	analysis whether it is appropriate or not to extend the Kruonis pumped storage power plant by placing additional turbine		
Norway	No restrictions concerning pump storage plants		
Poland		Energy Law for PSP Batteries and other kind of storages	Energy Law for PSP Batteries and other kind of storages
Portugal	An undergoing national plan is implemented in order to explore national hydro power resources including pumped-storage ~3000 MW of new hydro installed capacity until 2020 is to be pumped-storage hydro		

	Pump Storage Plants	Batteries	Other kinds of Storage
Romania	Strategy to build a Pumped Storage Plant around 2020		
Serbia	Plan, till year 2025 is to have new 1.28 GW in Pump Storage Plants		
Sweden	No planned pumped storage projects		
Switzerland	+4.0 TWh of pumped storage by 2020 +7.5 TWh (including the +4.0) by 2050		
United Kingdom	No policy		

2.3 Review of existing scenario studies

2.3.1 Reviewed studies

The scenario studies that were reviewed for e-Highway2050 are grouped according to the following categories:

- *Global scenario studies:* BP Energy Outlook 2030 [2], Greenpeace Energy [R]evolution [3], IEA Energy Technology Perspectives 2012 [4], IEA World Energy Outlook 2011 [5], Shell Energy Scenarios 2050 [6];
- *European* scenarios studies: EU Energy Roadmap 2050 [7], IRENE-40 [8], EURELECTRIC's Power Choices [9], ECF Roadmap 2050 [10], [33], ECF Power Perspectives 2030 [11], REALISEGRID [12], [13], SUSPLAN [14] and LinkS [15], Getting in the right Lane for 2050 [16], Northern European Solar and Wind Intermittency Study (NEWSIS) [17], EREC RE-thinking 2050 [27], PWC Roadmap to 2050 for Europe and North Africa [28], PWC Moving towards 100% renewable electricity in Europe & North Africa by 2050 [29];
- *Regional/ national studies:* A comprehensive list of national studies is found in Annex of Deliverable D1.1 [1];
- Other relevant studies about specific possibilities/challenges etc: Energy Corridors [18], FENIX [19], ICOEUR [20], Medgrid [21], MedRing [22], NSCOGI [23], OffshoreGrid [24], UCTE-IPS study [25], WindSpeed [26], TWENTIES [30], EWIS [31], Feature of an electricity supply system based on variable input [32].

A more detailed summary of these studies is found in Deliverable D1.1 [1].

2.3.2 Summary of key findings

Key findings of the different global, European and other studies and their relevance for e-Highway2050 are summarized in Table 2.9. Table 2.10 summarizes the main ideas behind the scenarios that are used in the global and the European studies [1].

Table 2.9 Overview of key findings in the scenario studies

Title of the Study	**Relevance for eHighway2050**
Global studies	
BP Energy Outlook 2030 [2]	Limited relevance. Global trends to 2030.
Energy [R]evolution [3]	Limited relevance. Global scenarios and information given as "OECD Europe" and "Eastern Europe/Eurasia". A lot of specific cost information for different technologies. No nuclear or CCS technologies. Based on IEA WEO to 2035.
IEA Energy Technology Perspectives 2012 [4]	Global scenarios. Main interest for e-Highway2050 is information related to different technologies. Separate section for Europe, but limited information compared to European studies.
IEA World Energy Outlook 2011 [5]	Updated version in 2012. Development of global fuel prices to 2035, several European figures in 3 scenarios: CO2 prices, demand, power generation and capacity by source. Electricity consumption per sector, cumulative power retirement by source 2012-2035, cumulative gross capacity addition 2012-2035. Furthermore, additional possibilities for energy efficiency in Europe beyond already announced policies.
Shell Energy Scenarios 2050 [6]	Limited relevance. Global trends with aggregated data.
European studies	
EU Energy Roadmap 2050 [7]	Very relevant low carbon emission scenarios including evaluation of impacts on infrastructure (table 29). Detailed overview of policy measures. Confirmation of the central role the eletricity will play in decarbonisation of transport, industry and buildings. Learning curves for technologies.
Getting in the right Lane for 2050 [16]	Discussing the future EU Energy system in a broader context.
IRENE-40 [8]	Concludes that Europe needs a supergrid and that an overlay HVDC network is the prefered solution due to lowest costs, best control possibilities and highest expected public acceptance. Recommendations related to coordination of network control. WP3 should consider the technology database of IRENE-40.
Northern European Solar and Wind Intermittency Study (NEWSIS) [17]	The study considers the effects of interconnection and smart energy on the system, with detailed analysis of wind correlation and plant operation. The study investigates the impact of weather in the future with large amounts of weather dependent renewables (especially wind and solar).
EURELECTRIC's Power Choices [9]	1. Scenarios (very relevant) 2. Key findings 3. Investment in transmission lines
ECF Power Perspectives 2030 [11]	Very relevant scenarios for transmission grid development to 2030. Based on the objective to reduce domestic greenhouse gas emissions by at least 80% below 1990 levels in 2050.

Title of the Study	Relevance for eHighway2050
REALISEGRID [12], [13]	Technology Roadmap for the integration of promising innovative power transmission technologies. Scenario studies to 2030. Framework for cost-benefit analysis of transmission expansion investments.
ECF Roadmap 2050 [10]	Based on a target of a nearly decarbonized power sector in 2050. Alternative realization compared to "EU Energy Roadmap 2050". Includes analysis of need for expansion of transmission capacities. The dedicated policy recommendations in Volume 2 are relevant for the policy analyses in e-Highway2050 WP5 [33].
SUSPLAN [14] /LinkS [15]	1. Scenario methodology and scenarios to 2050 2. Need for cross border capacities dependent on type of RES to 2050 [15] 3. Policy recommendations [34]
RE-thinking 2050 [27]	Only one scenario: 100% renewable energy system by 2050. Relevant input to e-Highway2050 scenario "100% RES".
100% renewable electricity: Roadmap to 2050 for Europe and North Africa [28] / Moving towards 100% renewable electricity in Europe & North Africa by 2050 [29]	Limited relevance for the scenario analyses since there are no numerical results presented, but relevant for the policy analyses in e-Highway2050 WP5.
Other studies	
Energy Corridors [18]	From 2007. Analysis of need for electricity corridors and capacity between European Union and neighbouring countries up to 2030.
FENIX [19]	Boosts distributed energy resources by maximizing their contribution to the electric power system, through aggregation into Large Scale Virtual Power Plants (LSVPP) and decentralized management.
ICOEUR [20]	1. Synchronous interconnection ENTSO-E – IPS/UPS long term alternative 2. Asynchronous connection may be a mid-term solution
Medgrid [21]	1. Volume of possible import from Africa 2.Plans for interconnections Africa/Europe
MedRing [22]	Linking Europe with the Southern Mediterranean through electricity and gas interconnections.
NSCOGI [23]	At least two plausible scenarios comprising a) radial offshore wind connections and b) an integrated offshore grid solution will be produced. Related to the European supergrid as Norwegian hydropower plants act as a giant battery and several HVDC interconnection between countries link renewable energy sources across northern seas of Europe to the rest of Europe.

Title of the Study	Relevance for eHighway2050
OffshoreGrid [24]	Concepts for combined development of offshore wind farm connections and cross border interconnectors
UCTE-IPS [25]	1. Non-synchronous HVDC coupling between UCTE-IPS and UPS recommended 2. Limited possibilities for power exchange due to the internal congestions in the systems concerned
WindSpeed [26]	Potential for 135 GW offshore wind in the Central and Southern North Sea in 2030. Coordinated North Sea Policies between involved nations including spatial planning with integration of Offshore Wind Energy, incorporating near shore and further from shore developments, offshore grid implementation. Recommendations related to offshore grid development and TSOs role.
TWENTIES [30]	6 demonstration projects to evaluate the contributions from intermittent generation and flexible load to system services and flexibility of the transmission grid that could be important input to the technology assessment and grid analyses of e-Highway2050. No scenario studies or analyses of future grid development.
EWIS [31]	Focus on the immediate network related challenges from large scale wind integration by analysing detailed representations of the existing electricity markets, network operations and the physical power flows and other system behaviours. No scenario studies or analyses of future grid development towards 2050, but could be relevant input to the technology assessment and grid analyses of e-Highway2050.
Feature of an electricity supply system based on variable input [32]	Not directly relevant for the scenario studies, but could be relevant input to the following technology assessment and grid analyses of e-Highway2050.

Table 2.10 Description of the different scenarios in relevant studies

Title of the Study	Scope	Scenario titles	Main ideas
Energy [R] evolution	World	Reference	-
		Energy [R] evolution	Consistent fundamental pathway for how to protect our climate: Getting the world from where we are now to where we need to be by phasing out fossil fuels and cutting CO2 emissions while ensuring energy security.
IEA ETP 2012	World	2DS	The 2DS scenario represents a vision of a sustainable energy system of reduced GHG emissions, consistent with the globally agreed objective of limiting average temperature rise to 2^{o}C
		4DS	The 4^{o}C scenario reflects pledges by countries to cut emissions and boost energy efficiency.
		6DS	The 6^{o}C scenario reflects a scenario where no new energy or climate policies are introduced

Title of the Study	Scope	Scenario titles	Main ideas
IEA WEO 2011	World	Current Policies	Policies enacted by mid-2011 remain unchanged: including ETS covering power, industry and aviation; Energy Performance of Buildings Directive, emission standards for LDVs, 20% of reduction in emissions by 2020 and 20 % of renewables to reach share in energy demand.
		New Policies	Recent commitments and plans, not necessarily adopted and implemented, including ETS covering power, industry and aviation; new LDV standards.
		450	Anticipative (back-casting) scenario: Energy pathway that is consistent with a 50% chance of meeting the goal of limiting the increase in average global temperature to 2° including 30% reduction of emissions by 2020, ETS strengthened in line with 2050 roadmap
Shell Energy Scenarios 2050	World	Scramble	The energy policies are segmented and dominated by national energy security concerns. Competition between national governments for favourable terms of energy supply.
		Blueprint	Internationally harmonised framework for carbon-trading, addressing for climate change mitigation. Fuel efficiency requirements in USA, stricter CO_2 emission allowances in EU
EU Energy Roadmap 2050	EU27	Reference	Long-term projections of current trends in economic development (GDP growth 1.7% pa) and policies implemented *by March 2010*. Takes into account rising fossil fuel prices. The 2020 targets for GHG reductions and RES shares will be achieved but no further policies and targets after 2020 (besides the ETS directive) are modeled. Sensitivities: a) a case with higher GDP growth rates, b) a case with lower GDP growth rates, c) a case with higher energy import prices, d) a case with lower energy import prices.
		Current Policy Initiatives	Includes several new initiatives adopted or being proposed by the EC *after March 2010*, mainly outlined in the Communication "Energy 2020 - A strategy for competitive, sustainable and secure energy". This scenario analyses the extent to which measures adopted and proposed will achieve the energy policy objectives. It includes additional measures in the area of energy efficiency, infrastructure, internal market, nuclear, energy taxation and transport. Technology assumptions for nuclear were revised reflecting the impact of Fukushima and the latest information on the state of play of CCS projects and policies were included.
		Energy Efficiency	Driven by a political commitment of very high primary energy savings by 2050 and includes a very stringent implementation of the Energy Efficiency plan. It includes further and more stringent minimum requirements for appliances and new buildings; energy generation, transmission and distribution; high renovation rates for existing buildings; the establishment of energy savings obligations on energy utilities; the full roll-out

Title of the Study	Scope	Scenario titles	Main ideas
			of smart grids, smart metering and significant and highly decentralized RES generation to build on synergies with energy efficiency.
		Diversified Supply Technologies	Decarbonization pathway where all energy sources can compete on a market basis with no specific support measures for energy efficiency and renewables. Assumes acceptance of nuclear and CCS as well as solution of the nuclear waste issue. Significant penetration of CCS and nuclear as they necessitate large scale investments and does not include additional targeted measures besides carbon prices (Technologies compete on their economic merits alone)
		High RES	Aims at achieving a higher overall RES share and very high RES penetration in power generation, mainly relying on domestic supply.
		Delayed CCS	Similar approach to the Diversified supply technologies scenario but assumes difficulties for CCS regarding storage sites and transport while having the same conditions for nuclear as scenario 3. It displays considerable penetration of nuclear.
		Low Nuclear	Similar approach to the Diversified supply technologies scenario but assumes that public perception of nuclear safety remains low and that implementation of technical solutions to waste management remains unsolved leading to a lack of public acceptance. Same conditions for CCS as scenario 3. Considerable penetration of CCS.
IRENE-40	EU27	BAU	-
		CCS	Substantial contribution from CCS to attain 80% goal
		Efficiency	Lower electricity demand than in the other scenarios
		RES	High contribution of RES to 80% goal. Assumptions for RES from ECF 2050 Road Map
		DESERTECH	Similar to RES but with import from Africa. Assumptions for RES from ECF 2050 Road Map
Power Choices	EU27	Baseline	-
		Power Choices	The EURELECTRIC Power Choices should be seen as compass to indicate the way to carbon-neutral electricity in Europe by 2050.
Roadmap 2050	EU27 +NO, CH	Baseline	-
		80% reduction of CO2 emissions	Goal: To realize an economy-wide GHG reduction of 80%. The pathways range in share of renewable energy sources (RES, from 40% to 80%) versus fossil CCS and nuclear energy. Additionally, a pathway with 100% RES is assessed, and sensitivities on the relative shares of fossil with CCS and nuclear are performed.
Power Perspectives	EU27 +NO, CH		Power specific study related to Roadmap 2050, Models current plans up to 2020 and further projects a power mix in 2030 in line with the emission reduction trajectory for the power sector in the EC 8th March 2011 communication, 1 main scenario + 9 sensitivities

Title of the Study	Scope	Scenario titles	Main ideas
REALISEGRID	EU27 +NO, CH, Balkan	Optimistic	High technological improvement, economic & population growth; Strong climate mitigation; Bounded electricity interties.
		Competing	High technological improvement, economic & population growth; Strong climate mitigation; Free electricity interties.
		Centric	Low technological improvement, economic & population growth; Strong climate mitigation; Free electricity interties.
		Pessimistic	Low technological improvement, economic & population growth; Weak climate mitigation; Bounded electricity interties.
SUSPLAN	Europe +surroun-ding countries	Red	Low-tech, Indifferent public attitude. Mainly centralized development with traditional technologies.
		Blue	High-tech, indifferent public attitude. Many advanced technologies but low interest from public and commercial actors. Mainly large-scale developments driven by governmental regulations and agreements. DESERTEC and North Sea Grid realized in this scenario.
		Green	High-tech, positive public attitude. Many advanced but mainly distributed technologies for RES energy.Reduced growth in energy demand.
		Yellow	Low-tech, positive public attitude. Reduced growth in energy demand, mainly achieved through changed behaviour of consumers as there are fewer advanced technologies to “help” energy efficiency improvements.
Getting in the right lane for 2050	EU27	Vision for 2050	Goal: Produce food for a global population of nine billion while minimizing biodiversity loss; mitigate climate change while enhancing energy security for the EU; practical and workable solutions for an EU transport system that is low carbon, including a power grid that would allow citizens to become electricity producers and would help ensure a dependable supply of electricity.
Northern European Solar and Wind Intermittency Study (NEWSIS)	Northern Europe Countries	Target Met	Wholesale market prices in some countries will have become highly volatile and driven by short term weather patterns, thermal generation becomes ‘intermittent’ in its operation. CO_2emission limit: 100 g CO_2/kWh.
		Capacity Payment	Price volatility is reduced by modelling a capacity payment mechanism.
		Offshore Grid	Interconnectors to Nord Pool become increasingly valuable in high wind scenarios asthere is a rise in demand for hydro to balance wind generation
		Flexible Demand	There is considerable potential in the demand-side to mitigate intermittency, and it is the most effective of the measures investigated.
		Reduced Renewables	CO_2emission limit: 150 g CO_2/kWh.
		Reduced Renewables (low CO_2)	CO_2emission limit: 100 g CO_2/kWh.

Title of the Study	Scope	Scenario titles	Main ideas
		Germany N-S Split	
RE-thinking 2050	EU27	100% Renewable Energy Vision	Presents a possible pathway towards a 100% renewable energy system for the EU
100% renewable electricity: A Roadmap to 2050 for Europe and North Africa	Europe + North Africa	-	Not a scenario study but a policy roadmap towards a 100% renewable electricity system in Europe and North Africa.
Moving towards 100% renewable electricity in Europe & North Africa by 2050	Europe + North Africa	-	Follow-up of the above with review of current policies, TYNDP and NREAP's.

2.3.3 Recommendations for further use

The main findings from the studies can be summarised in the following way:

Global scenario studies: The main relevant information for e-Highway2050 from these studies is development of fuel prices, CO_2 prices, GDP and population. Furthermore, expected development of different technologies (learning curves) is available from these studies and constitutes an important input to further work.

European scenarios studies
There are mainly two types of European studies that are of interest to e-Highway2050:

i. Studies analysing how the European energy or electricity system should develop to obtain low carbon emissions, e.g. "EU Energy Road Map 2050", "Power Perspectives 2030" and "Power Choices".
ii. Studies focusing on a specific issue related to decarbonisation of the energy or power system, e.g. IRENE-40 (what kind of a pan-European grid is preferred in a long term perspective in Europe), EWIS (network related challenges from large scale wind integration) and TWENTIES (contributions from intermittent generation and flexible load to system services and flexibility of the transmission grid) etc.

Both in the global and in the European studies there are several trends related to scenarios focusing on a low carbon society in 2050 and these trends should be considered in the further e-Highway2050 work:

- The GHG emissions from the power sector is low (less than 20%) in 2050 compared to 1990

- The percentage reduction of GHG compared to 1990 is larger in the power sector than in other sectors
- The electricity consumption increases in all scenarios, also in "Energy Efficiency" scenarios, although to a lesser degree. Important factors that increase the electricity consumption are electrification of the transport and the heating sectors
- A combination of several efforts is used in many scenarios: Increased share of RES, nuclear, CCS and energy efficiency. One of the efforts may be omitted, but at least two are always included.
- The share of RES is high in all scenarios
- Energy efficiency is a cost efficient contribution to reducing GHG emissions
- Grid upgrades/expansions will be necessary

Several of the reviewed studies have the same time perspective as e-Highway2050 and analyses alternatives for a European power system with very low emissions of CO_2. Especially the "*EU Energy Road Map 2050*" is reflecting the EUs aims about a low carbon energy system in 2050 and with reduction of GHG emissions by 80-95% by 2050 compared to 1990 levels. The Road Map has five scenarios for how the low carbon future may be achieved and provides consistent and quantitative information related to the alternatives.

The two European Climate Foundation (ECF) studies "*Roadmap 2050*" and "*Power perspectives 2030*" and Eurelectric's "*Power choices*" provides alternative scenario analysis compared to "EU Energy Road Map 2050" and should be used to complement the knowledge basis for the further e-Highway2050 work. These studies should be used when quantifying the boundaries for various technical options (e.g. deployment of different types of generation technologies). The detailed quantification of scenarios is outside the scope of WP1, however, and continues in WP2 based on these and other relevant sources.

Global developments and macro-economic projections (GDP, population, labour force, economic efficiency etc) are out of scope for the e-Highway2050 consortium which has its main focus and competence on the development of the European electricity system up to 2050. Thus, the boundaries for these kinds of uncertainties should be taken from large-scale global studies, typically the IEA Energy Technology Perspectives and World Energy Outlook, from the PRIMES/PROMETHEUS models used for the EC's Energy Roadmap 2050 and Eurelectric's Power Choices, and from ECF's Roadmap 2050 study.

3 Technological boundary conditions

3.1 Sources and methodology

This chapter provides an overview of the work conducted in Task 1.2 and reported in Milestone M1.1 *Summary of Technology Boundary Conditions*, a key milestone of WP1 which focuses on defining the technological uncertainties and options that should be considered throughout the project by 2050 [33]. For a detailed overview of Technology Boundary Conditions we refer to this Milestone including a comprehensive Excel spreadsheet of Uncertainties and Options.

When assessing information on technology costs and performances it is important to first define the concepts of uncertainties, options and associated boundary conditions. We have ranked these items as follows:

- **Technology options** are all possible technologies on the generation, storage, demand-side and transmission
- **Boundary conditions for options** are the main constraints and potential for the implementation of relevant technologies on generation, storage, demand-side and transmission
- **Uncertainties** are a selection of relevant variables influencing the development and the performances of technologies over time
- **Boundary conditions for uncertainties** are the limitations and/or opportunities set as extreme values (both quantitative and qualitative) for each of the variables considered, including costs, efficiencies and other performances

Milestone M1.1 presents data and information on generation, storage and demand-side technologies for both today and 2050. The data provided should be used to give estimates of relative comparisons of the different technologies for today and 2050 rather than to make technology choices. As mentioned in the different sources, the estimations for 2050 are inevitably subject to high uncertainty and should be considered as ranges.

With the aim of gathering a wide range of industry opinions and to ensure study balance and objectivity, the data collection process included expert contributions from key relevant industry stakeholders as well as a selection of publicly-available sources. Most of the publications used were also identified in the e-Highway2050's description of work as well as in Section 0 of this report.

For *generation technologies*, industry expertise included contributions from VGB Power Tech e.V., the European Technical Association for Power and Heat generation, EWEA, the European Wind Energy Association, ESTELA, the European Solar Thermal Electricity Association and EPIA, the European Photovoltaic Association. VGB Power Tech provided current and future estimates on costs, efficiency, and full load hours for almost all generation technologies, while ESTELA, EWEA and EPIA provided information on concentrated solar thermal (CSP), wind power and photovoltaic (PV), respectively.

For *storage technologies*, industry experts' opinions include information from EASE, the European Storage Association and other expert interview. EASE provided data according to the following energy storage segmentation: large-bulk energy storage, grid storage and end-use storage. As the information of the different storage technologies did not differ much in terms of capacity, the EASE data were integrated into the milestone's table according to the classification of energy storage into centralised and decentralised.

The information provided for *demand-side technologies* is based on literature sources listed in the explanatory document M1.1 Summary of Technology Boundary Conditions [33].

The selection of publicly-available studies covering estimates for 2050 for generation and storage technologies includes:

- **IEA Energy Technology Perspectives 2010 and 2012** [4] presents data on investment costs, fixed operational and maintenance costs as well as efficiency assumptions for selected technologies in the United States.
- **The European Commission's "Energy Roadmap 2050"** [7] contains figures on capital costs for a set of generation technologies but other important variables such as operating costs or plant efficiencies are not available in this publication. In order to ensure comparability, the cost assumptions remain consistent across the study's various scenarios.
- **Greenpeace/EREC "Energy [r]evolution"** [3] study does not contain information on CCS nor on nuclear power which is considered phased-out in its scenarios. Its reference scenario is based on the IEA's World Energy Outlook assumptions to 2035 which is extended to 2050 by extrapolating their key macroeconomic and energy indicators.
- Assumptions from the **Renewable Electricity Futures Study** (RE Futures) [36], a report published by the National Renewable Energy Laboratory (NREL) of the US Department of Energy. The publication evaluates the implications and challenges for the grid at high levels of renewable generation – from 30% up to 90%, with a focus on 80% - in 2050.
- Schroeder et al., **Draft paper on current and prospective production costs of electricity generation** [37] by e-Highway2050 partner TU-Berlin compiles different current and future cost estimates in the electricity sector, covering renewable and conventional generation and seeks to provide a unified dataset that can be used for model comparisons. In addition to costs, the paper also presents data on efficiencies.
- **Cost and performance data for power generation technologies**, a report produced by Black and Veatch for the National Renewable Energy Laboratory [38]. The data refers to some plants in the US.

3.2 Technology Options

Three main technology areas are considered as Technology Options:

- **Generation** including both centralised and decentralised generation technologies, as well as centralised **storage**
- **Transmission** including passive and active transmission technologies
- **Consumption** including decentralised storage and demand-side technologies

M1.1 presents an assessment of an exhaustive list of **generation technologies** including both renewables and thermal generation [33]:

- Photovoltaic
- Concentrated Solar thermal Power (CSP)
- Wind offshore
- Wind onshore
- Geothermal
- Hydro without reservoir (run-of-river)
- Hydro with reservoir
- Gas turbines (OCGT, CCGT)
- Hard coal generation
- Lignite generation
- Oil for power generation
- Carbon Capture and Storage (CCS)
- Nuclear power
- Biomass
- Biogas
- Marine technologies
- Combined heat and power
- Any other distributed generation (incl. hydrogen fuel cells, etc.)
- Nuclear fusion

Storage technologies are able to maintain excess energy produced by variable sources such as wind and solar, e.g. at night when consumption is low so the energy can be used later in peak-load periods. Additionally, they represent an important flexibility solution to improve grid stability, to reduce temporary mismatch between supply and demand and to support the power system performance against the variable nature of (some) renewable energy sources.

Storage services at the network level include capacity support to shift load from peak to base load periods, contingency grid support and reactive power compensations as well as load levelling, thus contributing to reduced line losses and increased energy savings. Storage facilities also allow for “peak shaving” for industrial customers.

An increased generation based on variable renewables could trigger the need for additional storage facilities at both the transmission and the distribution level. For instance, storage capacity provided by "classical" hydropower plants connected to the high-voltage grid could be complemented by smaller-scale storage facilities at the transmission and distribution level such as: Compressed air energy storage (CAES), flywheels, super-capacitors and superconducting magnetic energy storage (SMES).

Milestone M1.1 classifies electricity storage into two main categories: *Centralized* and *Decentralized* storage technologies. The following technologies are considered:

- *Centralized storage:* Pumped hydro-storage, Compressed Air Energy Storage (CAES), Batteries, Redox flow batteries, Hydrogen storage, Molten Salt, Power to gas, Pumped Heat Energy Storage, Liquid Air Energy Storage, Other power storage
- *Decentralized storage:* Batteries, Redox flow batteries, Hydrogen storage, Other power storage (SMES, supercapacitors, flywheel)

Transmission technologies[3] are classified in two main parts: *Passive* and *active* transmission technologies. The following are considered:

- *Passive technologies*: HVAC overhead lines, HVDC overhead lines, HVAC Cables (submarine and underground), HVDC Cables (submarine and underground), Upgrading of existing routes, High Temperature Conductors (revamping of existing transmission systems), Gas insulated lines, Supraconductor, High Temperature Superconducting (HTS) cables
- *Active technologies*: CSC (Current Source Converters for HVDC), VSC (Voltage Source Converters for HVDC), Combination of HVAC/HVDC transmission, Offshore HVDC substations design, System level protection and control, Phase Shift transformers, Static Var Compensator, FACTS (Flexible AC Transmissions Systems), Transformers with tap changer, System level protection and control (at substations), Other HVDC substation equipment

Overhead transmission lines are likely to remain the key power transmission technology over the coming years. However, at voltages above 420 or 550 kV overhead lines occupy a wide corridor of land that may represent a constraint for their realization in densely populated areas. Upgrading of existing routes may facilitate grid extension, but public acceptance still needs to be taken into consideration. Moreover, the transmission of very high power in one single transmission line may represent a serious problem for grid stability.

The HVDC cable transmission technology is one of the most promising technologies nowadays which covers long distances both for submarine and land interconnections and when overhead lines are not practicable. The voltage level is currently in the range of 320 kV, but an increase in voltage over the next years can be expected both for VSC and LCC HVDC systems. Mass-impregnated cables will still remain a valuable solution at the highest voltage levels especially for submarine cables where a reduced number of factory joints are necessary.

[3] Note that transmission technologies will be researched in greater detail in following work packages in e-Highway2050, so WP1 only classifies these technologies without quantifying boundary conditions.

Demand-side technologies are technologies whose development in the decades to come (2020 to 2050) could significantly impact the load on the future pan-European electricity network. Note that this chapter only deals with the technologies themselves. The public attitudes towards these technologies, including behavioural changes that influence demand, are treated in Chapter 5. The set of technologies includes:

- New electricity consuming devices and processes such as heat pumps or electric vehicles
- Demand-side management (DSM) technologies
- Controlling devices, i.e. ICT infrastructures needed to perform observation of the consumption in real time and remote control of some of the electricity consuming devices and processes

Demand-side management should include both energy efficiency and load management:

- *Energy efficiency* means the technological improvement of processes and devices that can help to reduce their overall consumption.
- *Peak shaving*, i.e. the reduction of electricity consumption during peak hours that can be achieved either by substituting appliances used at peak hours (i.e. convectors) by other equipment or technologies (passive peak shaving) or by remote control at large scale of devices such as heat pumps in buildings.
- *Load shifting* can be achieved for instance by shifting the use of electric water heaters after peak hours.

3.3 Technology Uncertainties

The analysis in Task 1.2 identified the following set of uncertainties that will influence the development and the performances of technologies from now until 2050. Note that these uncertainties are based on the maturity of the technology and not on the acceptance of the technology. The latter is dealt with in Chapter 5.

Uncertainties for Generation and Storage technologies:

- Capital costs and (fixed) operational and maintenance costs
- Efficiency
- Environmental variables and regulations
- Technology breakthroughs
- Level of RES variability
- Reliability
- Load factor
- Contribution to system flexibility
- Scale-up and replication
- Contribution to system services
- Manufacturing capabilities
- Research, Development and Deployment capabilities

Uncertainties for Demand-side technologies:

- *Cost of deployment of ICT and smart appliances* especially in industrial and commercial sectors where their profitability has to be assessed in the framework of the envisaged business models.
- *Controllability of ICT devices* at large scale will be an uncertainty since appropriate and standardized communication infrastructures are required.
- *Energy efficiency potential*, especially in large scale commercial and industrial sectors, since further advanced technologies are needed e.g. in water and space heating and cooling to make them more efficient.
- *Electrification of heating and transport* will be a major uncertainty since more infrastructures and advanced technologies are needed for the transport sector, like EVs, inductive charging, etc.
- *Replacement rates of appliances and social acceptance* can be an issue since the replacement rate based on future technologies also depends on social approval e.g. the application of white goods in residential sector.
- *Interoperability, reliability and cyber security of ICT devices* will be uncertain. Considering the reliance on two-way wireless connections the availability, integrity, and confidentiality of unprecedented volumes of data will require a new set of technologies.

Uncertainties for Transmission technologies:

- Capital and operating costs
- Interoperability (including multi-vendor solutions)
- Cyber-security
- TSO/DSO interface
- Observability, bulk-power and system controllability
- Technology breakthroughs
- Environment variables and regulations
- Reliability of technologies
- Scaling laws
- Standardisation
- System services
- Manufacturing capabilities (including skilled manpower availability)
- Human-Machine Interface (HMI) for operators (only for active transmission)

Transmission technologies will be further researched in other work packages in e-Highway2050 and will not be elaborated here.

3.4 Boundary Conditions for main technical Uncertainties and Options

Milestone M1.1 [33] presents boundaries for all listed Technology Uncertainties in spreadsheets. In this document, we only summarize the uncertainties and options that are considered to be *most relevant by 2050* based on the research in Task 1.2 and the feedback received during and after the Stakeholder workshop in Brussels the 23rd of January 2013.

3.4.1 Main technical uncertainties for 2050 and related boundary conditions

MAIN UNCERTAINTIES	IMPORTANCE	MINIMUM	MAXIMUM
Cost of Carbon Capture & Storage (Hard coal with CCS as example)	High	CAPEX[4]: 1 863 (k€/MW)	CAPEX: 2 700 (k€/MW)
		OPEX[1]: 20 (€/MWh)	OPEX: 61 (€/MWh)
Commercial availability of new centralised storage (except PHS)	High	Technology-specific data given in M1.1	
Cost of new nuclear due to limited building experience	High	CAPEX[1]: 2 500 (k€/MW)	CAPEX: 5 360 (k€/MW)
		OPEX[1]: 12 (€/MWh)	OPEX: 68 (€/MWh)
Managing renewables variability	High	Will be further researched in other WPs	
Network integration and interoperability of decentralised generation, storage and demand	Medium	Will be further researched in other WPs	

The cost of CCS is a major source of uncertainty against the development of the technology as it still needs to be demonstrated at a commercial scale. While the cost of CCS is an important factor, the extent to which society will accept the storage of CO_2 will also play a major role. This is further elaborated in Chapter 5.

There is also an uncertainty surrounding the future costs of nuclear power plants as there is limited experience with building new nuclear power plants in Europe. Similar to CCS, the development of nuclear also depends to a large extent on public acceptance. E.g. if another accident like Fukushima should take place, society's acceptance might decrease rapidly. On the other hand, there might be a push for nuclear technology dependent on the availability of other fuels.

[4] Note that minimum and maximum CAPEX and OPEX values are not correlated – minimum CAPEX does not imply minimum OPEX for the same technology. See the tables in Milestone M1.1 for details. The data refers to the nuclear technology G13 in the milestone (generation 3). The costs show ranges based on a variety of sources with different methodologies and given the long-term time horizon these estimates remain subject to great uncertainty.

Finally, electricity produced from variable renewable energy sources such as wind and solar depending on local weather conditions results in an uncertain hourly feed-in – although techniques to forecast variable renewable generation patterns are presently the subject of much research and investigation.

The development of nuclear fusion is not considered as a “main uncertainty” since it remains unlikely that the technology will be in operation at a commercial level by 2050. Furthermore, shale gas development in Europe is not considered as a *technical uncertainty* but is treated in other tasks (under Socio-political constraints in Chapter 5).

Main technology uncertainties should be seen in terms of the extent to which technology deployment will happen. It is unclear for instance how storage will exactly develop but the current estimates show that there will be significant development. Similarly, while efficiency is set to increase, alongside with the ability to shift the load for demand-side technologies, the level of demand-side management cannot be precisely predicted. While an increased in the share of decentralized units (demand, storage or generation) can be expected, coordination of these units remains an important issue to be considered in the future.

3.4.2 Main technical options for 2050

The following technology options are considered as playing the most important part of the power system by 2050:

OPTIONS	IMPORTANCE
Deployment of centralized renewables	*High*
Deployment of distributed energy sources	*High*
Fossil fuel plants with CCS	*High*
Deployment of centralized storage	*High*
Deployment of decentralized storage	*High*
Deployment of nuclear	*High*
Increase of demand-side management with energy efficiency, load shifting and peak shaving	*High*

These options will used in the scenario building process in chapter 8.

4 Economic and financial boundary conditions

The objective of this chapter is to collect and describe economic and financial Uncertainties and Options with corresponding boundary conditions until 2050 which may have an impact on the European power system and consequently on an adequate transmission infrastructure [40]. The boundary conditions for the Uncertainties shall be described using quantitative data when they are available, otherwise qualitative considerations are given. The Options are in general presented mostly as verbal descriptions.

4.1 Economic and financial uncertainties

Milestone M1.3 identifies the following main economic and financial uncertainties [40]:

- **Population**: Long-term projections are found at country level from UN 2011 [41] and Eurostat/EUROPOP2010 [42], while regional data are available for the NUTS 2 regions (Nomenclature of Territorial Units for Statistics) [43]
- **GDP**: Projections are available from OECD (not all EU27+ countries included) [45] and from EU [46].
- **Fuel costs**: Relevant sources for fuel cost estimates up to 2050 include IEA ETP [4], IEA WEO [5], US Energy Information Administration [47] and the PROMETHEUS model used in EC/PRIMES studies [7].
- **CO_2 Emission allowance costs**: Relevant sources include PRIMES model results from Eurelectric's Power Choices study [9] and EC Energy Roadmap 2050 [7].
- **Cost of capital** (the cost of borrowing money to finance a project): Relevant source is the PRIMES data from EC Energy Roadmap 2050 [7].
- **Construction costs** including labour and materials (but excluding cost of land and transaction costs such as permits, legal costs etc)
- **Level of European integration**: Included in Chapter 5 on political, socio-political and environmental boundary conditions

4.2 Economic and financial options

Milestone M1.3 identifies the following main economic and financial options [40]:

- **Energy efficiency**: A large variety of policy instruments exists to improve the diffusion of energy efficient technologies. Generally a distinction can be made between imposing standards, issuing and trading certificates, paying subsidies, introducing taxes and stipulating labelling.

- **Power System governance and regulation**: Economic (monopoly) regulation can, on a very high level, be distinguished by the risk allocation that is implied by the regulation. One generic type of regulation is cost-based regulation (or profit regulation). In this set-up, the regulator allows the regulated company to recover its operational and capital costs, and still earn fair returns on the capital employed. Cost-based regulation can either be:

    i) *Rate-of-return regulation*: A reasonable rate of return on capital is issued by the regulator and it cannot be exceeded by the regulated company; or

    ii) *Cost-plus regulation*: Revenues are limited to a certain mark-up on effective production costs**.** A stricter regulation can be realized by imposing an *ex-ante* fixed cap either on the total revenue of the regulated company (Revenue cap) or on the price per unit sold (Price cap).

- **Capacity mechanisms**: The measures addressing support schemes and instruments affecting technological change of the demand side can be characterized by three dimensions:

    i) *Spatial aspects*: Load-centred, no spatial differentiation, other spatial differentiation

    ii) *Technology specificity*: Promotion of RES-E, Promotion of low-carbon-technologies, Promotion of indigenous primary energy carriers, Promotion of flexibility

    iii) *Impact level*: Low vs. High

- **Electricity market design:**

    There is a clear EU position that the market is the framework of the future, especially when more and more RES are included into the power mix [48]. There is an almost as clear EU position that the market has strong benefits not only for trading electricity on the basis of existing generation sources, but also for market-driven investments in new generation. Neither the energy nor the generation investment markets can function if very large portions of the overall market are subsidised. The benefits from market-driven investment decisions could be argued to be especially strong when there are large uncertainties about the cost structures of different generation technologies.

    The rules for Capacity Allocation and Congestion Management (CACM) are currently under review at ACER. The market settings could be changed in order to introduce new fixed or variable prices zones. Furthermore, different mechanisms for market coupling could be used. Volume coupling or price coupling could be introduced to link different market areas. Additionally the assessment of the available transfer capacity could be changed from net transfer capacity (NTC) to flow based.

    Discussion on a future Target Model (TM) for electricity is still at the beginning. Capacity mechanisms are implemented in some countries and other countries plan to do the same. It is also discussed whether such mechanisms should remain interim solutions until elements of a new market design become clearer. The impact on the e-

Highway2050 scenarios resulting from different cross-border balancing schemes and new markets for the integration of large amounts of volatile and stochastic generation such as e.g. capability or flexibility markets will need to be analysed.

4.3 Recommendations for Boundary Conditions

4.3.1 Uncertainties

To set boundaries for the economic and financial uncertainties, we propose to use the absolute values which were identified in the studies mentioned above. The figures are sufficiently recent and offer a wide range in order to provide for a good robustness of the network planning process to be envisaged as outcome of the e-Highway2050 project.

Population

Figure 4.1 shows the estimated European population in 2050 in some scenario studies reviewed in D1.1 [1], compared with 499 million in 2010 as estimated in EU Energy Roadmap [7]. The ECF Roadmap 2050 expects almost no increase in population while the other 3 have 2-3% increase.

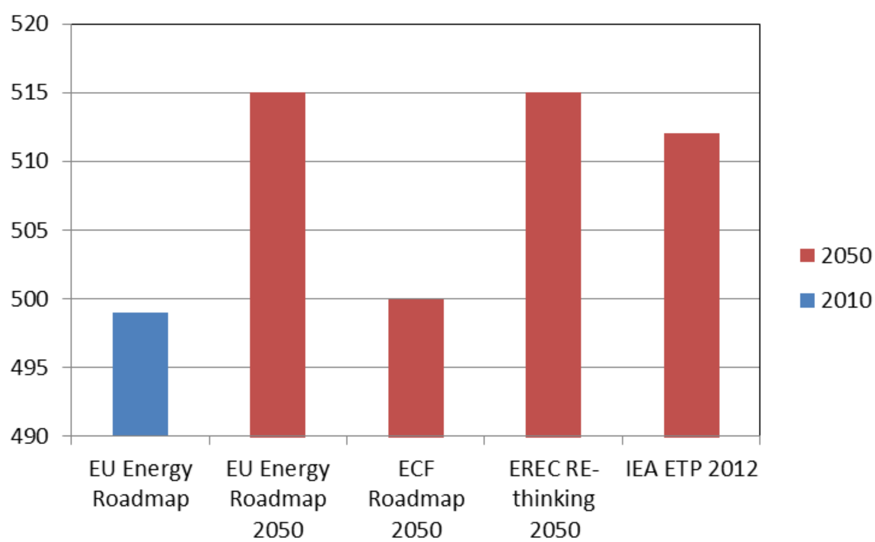


Figure 4.1 Population in Europe in 2050 (million) [1]

Minimum and maximum numbers for the population in each European country based on references [41] and [42] are given in Table 4.1. It is interesting to note that these values sum up to a minimum and maximum range which is far outside the expected population development in the scenario studies shown above, even though Figure 4.1 shows values for EU27 while Table 4.1 includes Norway and Switzerland. Furthermore, the add-on from external areas and the shrinking European population will result in stable population numbers [48]. *Therefore, we recommend the use of 500 million (current population) for the "Migration only" Futures and 515 million for the "Growth" Futures.*

Table 4.1 Recommended minimum and maximum Boundaries for Population (in Thousands).

EU28+CH+NO	MIN	MAX
Austria	6554	8969
Belgium	9082	13126
Bulgaria	4669	5901
Croatia	3187	4028
Cyprus	793	1090
Czech Republic	7600	10668
Denmark	4685	6038
Estonia	584	1213
Finland	4390	5727
France	57070	73184
Germany	70322	88876
Greece	8720	11576
Hungary	6743	9177
Ireland	4439	6207
Italy	39873	65915
Latvia	1183	1797
Liechtenstein	39	39
Lithuania	2244	2837
Luxembourg	636	804
Malta	357	451
Netherlands	15064	19039
Norway	4349	6366
Poland	29325	37062
Portugal	8021	10598
Romania	16049	20284
Slovakia	4396	5556
Slovenia	1394	2115
Spain	33174	52688
Sweden	7730	11231
Switzerland	5162	9313
United Kingdom	58790	76406
SUM	**416 624**	**568 281**

GDP is generally given in annual growth rates, so we provide average yearly per capita growth rates to 2050, related to 2005 PPPs[5]. GDP developments are far less predictable in the EU and around the world than population forecast. For the main reference cases of the e-Highway2050 project, it should be assumed that the period of large-scale economical crises is solved [48].

[5] PPP = Purchasing Power Parity

Table 4.2 shows the boundaries of growth rates for the time period from 2013 to 2050 based on references [45] and [46]. The average minimum and maximum values from the Table 4.2 are 1.915% and 2.325%, respectively. In comparison, average economic growth in EU27 up to 2050 ranges from **1.7% p.a** in EU Energy Roadmap 2050, **1.8% p.a** in Power Choices and ECF Roadmap 2050, to **2.0% p.a** in IEA WEO [1]. As with population, we suggest to use the absolute highest/lowest values for the modelling/scenario development. *Therefore, minimum growth rate is assumed to be 1.7% p.a. and maximum growth rate is assumed to be 2.3% p.a.*

Table 4.2 Recommended min and max boundaries for average yearly GDP per capita growth rates from 2013 to 2050 [%].

EU28 + CH + NO	max	min
Austria	1.30	1.09
Belgium	1.60	0.97
Bulgaria	3.55	3.55
Croatia	N/A	N/A
Cyprus	N/A	N/A
Czech Republic	2.86	2.19
Denmark	1.45	1.07
Estonia	4.60	2.64
Finland	1.63	1.23
France	1.37	1.13
Germany	1.50	1.00
Greece	2.06	1.47
Hungary	3.00	2.30
Ireland	1.07	1.03
Italy	1.19	0.58
Latvia	5.16	5.16
Lithuania	4.74	4.74
Luxembourg	1.06	0.93
Malta	2.63	2.63
Netherlands	1.60	1.13
Norway	1.65	1.29
Poland	3.19	1.86
Portugal	1.76	1.50
Romania	3.68	3.68
Slovakia	N/A	N/A
Slovenia	N/A	N/A
Spain	1.72	1.43
Sweden	1.59	1.29
Switzerland	0.63	0.63
United Kingdom	1.55	1.36

Fuel costs

For fuel costs up to 2050, available studies lead to a wide range of prices, as illustrated in Figure 4.2. As with the other uncertainties, in Table 4.3 we propose to use absolute maximum/minimum values of numbers available in order to have a sufficient level of variance. The unit is 2010 USDs per barrel of oil equivalent (boe, 1.7 MWh).

Table 4.3 Recommended min and max boundaries for fuel costs [4], [7]

Fuel	max [2010 USD/boe]	min [2010 USD/boe]
Oil	149	70.84
Nat. Gas	99.17	46.41
Hard Coal	34.41	12

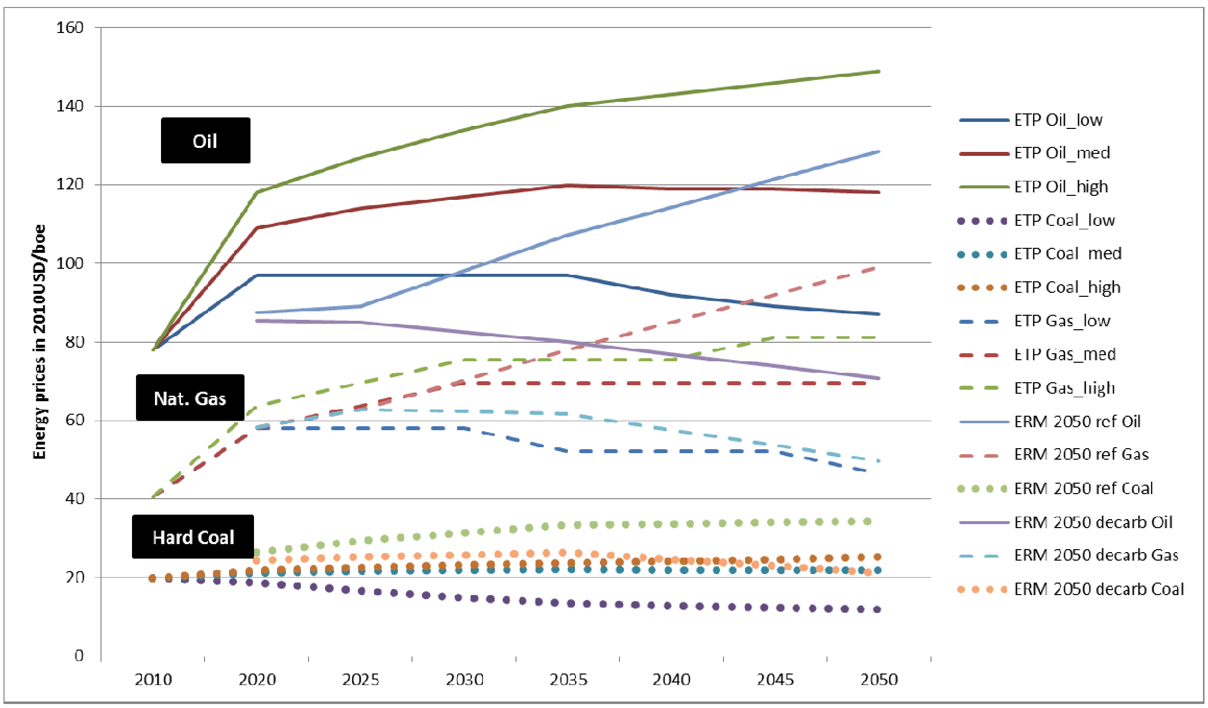


Figure 4.2 Price developments for Oil, Hard Coal and Natural Gas (the latter for supply in Europe)
(ETP = IEA's Energy Technology Perspectives [4], ERM = EC's Energy Roadmap 2050 [7])

Other costs

Other costs considered in this Task cover CO_2 emission allowances and costs of capital. However, costs of building power plants were also discussed but for respective boundaries, we refer to the outcome of Milestone 1.2. Emission allowance costs exhibit a large variance, depending on the study used. This is illustrated in Figure 4.3.

The respective maximum value is **310 $€_{2008}/t_{CO2}$**, the minimum value assumed **42.3 $€_{2008}/t_{CO2}$**.

Costs of capital are very hard to determine and are to a large extent depending on the general economic development, including GDP growth. We therefore refer to the qualitative discussion in [40].

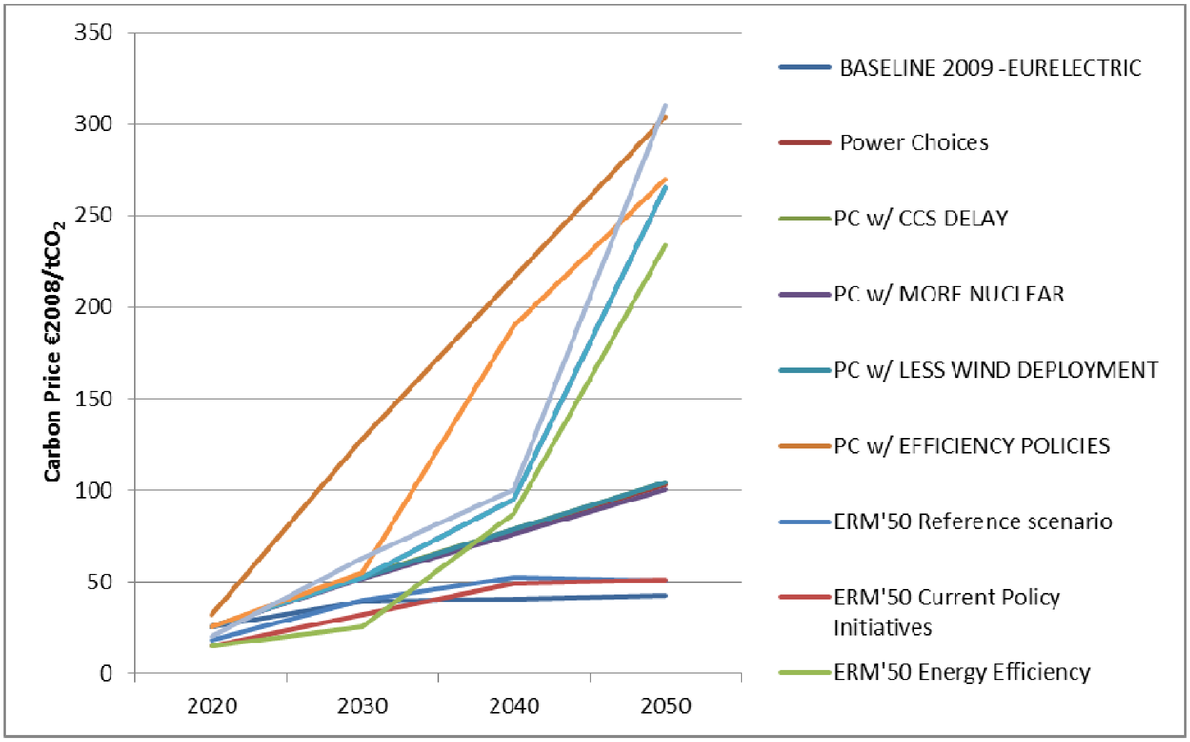


Figure 4.3: Carbon price cost paths. Source: EURELECTRIC, EC.
(PC = EURELECTRIC's PowerChoices [9], ERM'50 = EC's Energy Roadmap 2050 [7])

4.3.2 Options

Most *Options* considered in this Task are qualitative; therefore, the boundaries are in those cases simply presented in a verbal way.

Energy Efficiency

As boundaries on Energy Efficiency, we may consider the 0% savings as a natural lower bound even though objectives can be expected to be higher. As an upper bound, one could assume 3% of annual reduction from 2020 to 2050: it doubles the value that is included in the EU’s recent Energy Efficiency Directive. A qualitative dimension of Energy Efficiency is linked to the sector it relates to; for example:

- ***Industry***
- ***Residential, SMEs***
- ***Transport.***

Power System Governance and Regulation

Concerning the regulation, it may be appropriate to distinguish between (a) **cost-based** regulation and (b) **cap-based** regulation. Ownership of the transmission system can also be expected to be important in that respect, the general distinction can be broken down to (a) **state ownership** and (b) **private ownership**. A central issue would be recovery of cost for cross-border projects as these are not covered by national tariffs and congestion rents are not used to finance interconnection investments.

Capacity mechanisms (including RES-E)

Capacity mechanisms may be applied in manifold ways and they may address various technologies. Therefore we suggest that capacity mechanisms (as they are an option, not an uncertainty) should be chosen at the mean level. Those are:

1. Spatial aspects,
2. Technology specificity,
3. Impact level.

Renewable support mechanisms

In the future, RES-E should be cost-competitive and less subsidized, e.g. by feed-in tariffs. Feed-in tariffs heavily influence the behaviour of the electricity market and thus have a major impact on the dispatch of generation. ENTSO-E suggests that integrated European wholesale and retail electricity markets should have no subsidies beyond 2025 / 2030 for established RES (wind, PV, biomass and hydro). However, other types of RES may have to be supported after 2025/30 [48]. Especially on cost-competitive scenarios with a very high share of RES-E (up to 100%) and with very limited price-setting fossil production, alternative market mechanisms may have to be taken into account (e.g. based on total cost). Therefore, the treatment of RES-E will probably have to differ among the scenarios. For instance, one could imagine two kinds of scenarios:

1. Scenarios with a very high RES-E generation on a system level (up to 100%), including some kind of market competition based on total cost.
2. Scenarios with lower levels of RES-E generation, including support schemes at least in some countries.

4.3.3 Interrelations between different Uncertainties and Options

When designing scenarios one might wonder whether all combinations of uncertainties exhibit the same likelihood of occurrence. This is certainly not the case, but very little can be said in general. However, it can be assumed that the general economic performance may limit the action space of politics. On the contrary, it can in general not be expected that the economic performance of a single country or even the EU is sufficiently able to influence world market developments, although those are not independent. This leads to the result, that prices for emission allowances and all other options are more or less determined by the economic capabilities of the country and/or the EU's capabilities. Concerning emission allowances and options related to long-term measures (such as energy efficiency, capacity payments for high-cost, new-technology generation and the like), it may happen that those instruments are used less ambitiously in times of tight public finance and weak economic performance. Concerning fuel prices and other costs, one could expect those to be more independent of such developments (this argument is derived from the idea of a more globalised economy). GDP growth figures in this report are given in per capita numbers which generally makes them independent from assumptions on population developments.

A more in-depth assessment of interrelations between different financial and economic uncertainties would require the use of complex macro-economic models which is beyond the scope of the e-Highway2050 project. Thus, we refer to other studies as source for these uncertainties as explained in Section 2.3.3.

5 Political, socio-political and environmental boundary conditions

5.1 Approach

The aim of Task 1.4 *Political, socio-political and environmental boundary conditions* is to identify and specify potentially important uncertainties and options and corresponding boundary conditions related to political, social and environmental issues [49]. The interpretation of these concepts within Task 1.4 is as follows:

- **Uncertainties** - set of relevant characteristics or variables e.g. demographic change, biodiversity and climate change impacts.
- **Boundary conditions for uncertainties** - qualitative or quantitative range for each characteristic e.g. predicted population increases, frequency of extreme climatic events etc
- **Options** - potential choices such as policies, regulations, standards, etc.
- **Boundaries conditions for options** - levels of regulation, policy priorities / options etc.

The initial list of potential political, socio-political and environmental uncertainties and options were identified as a result of brainstorming exercise amongst the project team and recorded in a mind map. The uncertainties and options were then clustered under “SLEP” – Social, Legal, Environmental and Political categories – a modification of STEEP(L)[6] drivers since Technological and Economic (costs) are considered by other tasks within WP1. Further details on the approach are given in Milestone M1.4 [49].

5.2 Key Uncertainties, Options and Boundary Conditions

The list of potential Uncertainties and Options identified as part of the scoping exercise are listed in Figure 5.1. Each of the potential uncertainties and options were qualitatively “scored” as either of *High*, *Medium* or *Low* importance – two scores were given to distinguish between the importance of the uncertainty / option for generation, storage, consumption and exchange and for transmission and grid development (see Table 5.1).

[6] STEEP(L): Social, Technological, Economic, Environmental, Political and Legal drivers

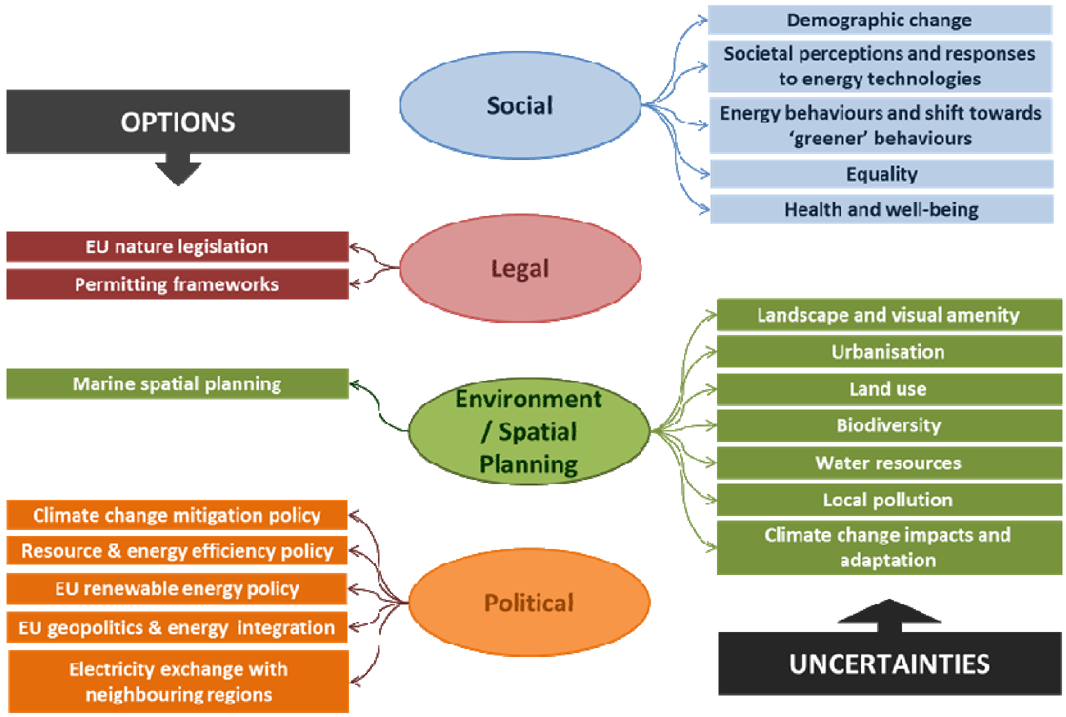


Figure 5.1 Social, socio-political and environmental Uncertainties and Options

Table 5.1 Assessment of the importance of social, socio-political and environmental uncertainties and options

Potential uncertainties and options	Generation, consumption, storage and exchange	Transmission / grid development
Social		
Demographic change	*Medium/High*	*High*
Societal perceptions and responses to energy technologies	*High*	*High*
Institutional and citizen's energy behaviours and shift towards 'greener' behaviours	*High*	*Medium*
Equality (distribution of benefits and costs)	*Low*	*Medium/High*
Health and well-being	*Medium*	*Medium/High*
Legal		
EU nature legislation	*High*	*High*
Permitting frameworks	*High*	*High*
Environment / Spatial Planning		
Landscape and visual amenity	*High*	*High*
Urbanization	*High*	*High*
Land use	*High*	*Medium*
Biodiversity	*Medium*	*High*

Marine spatial planning	*High*	*High*
Water resources	*High*	*Medium*
Local pollution	*Low/Medium*	*Low*
Climate change impacts and adaptation	*High*	*High*
Political / Policy		
Climate change mitigation policy	*High*	*Low*
Resource and energy efficiency policy	*High*	*Low/Medium*
EU renewable energy policy	*High*	*Low*
EU geopolitics and integration	*High*	*High*
Electricity exchange with neighboring regions	*High*	*Medium/High*

5.3 Recommendations

Regarding potential political, social and environmental boundary conditions, three recommendations on how the uncertainties and options should be considered within the e-Highway2050 project are identified:

- Key Uncertainties that should be included as a variable in developing the scenarios;
- Key Assumption to consider in developing the scenarios;
- Other topics to consider in other Work Packages.

5.3.1 Key political, socio-political and environmental Uncertainties to include in scenario development

Having identified the most important Uncertainties and Options, the next step considered which of these should be included as a Boundary Condition within the scenario development process. To be a Boundary Condition within the scenarios it was assumed that the qualitative or quantitative range or values for their characteristics in 2050 had to be expected to vary reasonably significantly. Some Uncertainties or Options and their associated Boundary Conditions may be very important and influential over generation, storage, consumption and/or exchange, but if they can be confidently predicted then they can be taken as an *Assumption or constant rate* across all the scenarios rather than a variable between them. In addition, others may be more relevant to inform the impact assessment (to be developed in WP4) or indicators development (to be developed in WP6) rather than be included as a Boundary Condition within the scenarios.

Another factor that was considered in describing the key boundary conditions was geographical scale. The EU scale was of primary interest, but where considerable regional variations and changes within the EU to 2050 that could significantly affect grid planning were identified these were highlighted.

The key social, legal, environmental and political boundary conditions to include in the scenario development were identified as follows:

- **Societal perceptions and responses to energy technology** – opposition and negative perceptions to certain technologies is potentially a significant constraint on generation and grid build-out.
- **Energy behaviours and shifts towards 'greener' behaviours** – institutional and citizens' consumption and efficiency behaviours are critical factors in meeting energy objectives.
- **Permitting frameworks and nature conservation legislation** – permitting is a key driver in generation and grid developments and nature conservation legislation is one of the main reasons for conflicts and eventual delays in permitting.
- **Land use and urbanisation** – changing land use and the competing demands for land could pose a significant constraint on generation and grid build-out and urbanisation has a direct effect on consumption patterns.
- **Landscape and biodiversity** – together with health, landscape and biodiversity represent values that lead social perceptions and could block generation and grid build-out.
- **Climate change impacts** – the implications of a changing climate pose significant and potentially uncertain risks to energy systems and could significantly change power system patterns.
- **EU geopolitics and integration** - the level of market integration and heterogeneity of approaches to energy between countries will significantly affect spatial distribution of generation and future levels of electricity trading.
- **Electricity exchange with neighbouring regions** - the extent of electricity imports and exchange from outside the EU will significantly shape future grid architectures.

5.3.2 Key political, socio-political and environmental Assumptions to include in scenario development

The important Boundary Conditions that we list below are recommended to be included as *Assumptions* that are "fixed" across all the scenarios. Note that some also represent Options (e.g. different policy approaches for achieving something that will affect power consumption and generation).

- **GHG emissions target** - the move to a resource-efficient, low-carbon economy is a central priority for Europe and leaders have agreed on an economy-wide target of 80-95% greenhouse gas emissions reductions by 2050. *This target should be treated as an Assumption, while mechanisms for meeting the target should be treated as Options.*
- **Climate mitigation policy** - while it is recommended that *the 80-95% economy wide greenhouse gas reduction target is treated as an Assumption common to all scenarios*, there are different policy Options for achieving this which will affect power consumption and generation, including complementary measures to support renewables, energy efficiency and other low carbon technologies.

- **Demographic change** - there is a potential for significant demographic changes within Europe by 2050 (including an ageing population, increasing numbers of households, internal migration and migration from outside the EU) with variation in the population changes predicted between regions. This will potentially have significant implications for generation, consumption and grid build-out. In addition there is a risk of "big surprises" from global events causing unexpected immigration and population change. However, these factors are already being considered within the scenario development process as part of predicting future consumption, since this is a critically important factor in shaping future grid architectures. *It is therefore recommended that demographic change from a socio-environmental political point of view it is not included as a critical Boundary Condition, but rather an Assumption within the scenario development process.*
- **Equality** – it is recommended that equality - which includes issues such as the affordability of energy / fuel poverty and the just distribution of the costs/benefits and impacts of energy and energy infrastructure development - is treated as an Assumption as part of the scenario development process. *All the scenarios will be equitable in the distribution of impact and benefits and those that are most vulnerable will not be disproportional affected.*
- **Health and well-being** - it is recommended that the health and well-being implications of different energy infrastructures and technologies on Europe's current and future human populations are treated as assumptions as part of the scenario development process – i.e. that *none of the scenarios will lead to a deterioration of health and well-being, and ideally an improvement.*
- **Maritime spatial planning** – this could be taken as an assumption, however the extent to which activities will develop in maritime spatial areas in different Member States are likely to vary. Uncertainties are common to those related to biodiversity but applied off-shore, including habitats and birds sensitivity and public perceptions.

5.3.3 Other political, social and environmental topics to consider in other Work Packages

In addition to the important boundary conditions that are recommended to be included as either key variables or assumptions in developing the scenarios discussed above, also other political, social and environmental uncertainties and options identified from task 1.4 (such as water resources and local pollution) will also be important to consider and inform other Work Packages within the e-Highway project outside WP1. For example, climate change impacts / resilience should be considered in grid planning (WP2) and EU geopolitics should be considered in WP5 on governance and regulation.

These and the other uncertainties and options will also be potentially key environmental or social effects (critical decision factors) to include in the impact assessment (WP4) and / or potentially key environmental or social effects to inform the indicators selected as part of the Cost Benefit Analysis (CBA) / Multicriteria Analysis (MCA) (WP6). For example, equality and health and well-being are potentially key social effects that should be included in the impact assessment (WP4.2) and in the CBA/MCA in WP6.2 as is climate change impacts / resilience.

6 Research, development and deployment boundary conditions

6.1 Methodology

Technological development will be essential for the successful transition of today's infrastructure into the Electrical Highways System (EHS) of the future. Task 1.5 identifies *Challenges* that Research, Development and Deployment (RD&D) has to face as a reference point for the identification of *Uncertainties*, which can prevent or slow down the transition of the current system to the EHS of the future, and of *Options*, which identify possible actions to be implemented to mitigate the Uncertainties and more easily overcome the Challenges [50].

Within Task 1.5, *Challenges*, *Uncertainties* and *Options* are assessed regarding:

i) Value-chain challenges;
ii) Requirements for proof-of-concept of new technologies;
iii) Conditions for creation of industrial and commercial value.

To ensure a consistent assessment, the following terminology and approach is defined for the RD&D analyses:

- the *Challenges* are the main critical aspects to be addressed by RD&D in the transition from present system to the EHS 2050;
- the *Uncertainties* for RD&D refer to the adequacy of the responses needed to address the relevant challenges
- the *Options* are the RD&D means to reduce the uncertainties

In the Electrical Energy Value Chain, the analysis is developed considering a multi-layer hierarchical structure, see Figure 6.1:

- the first layer refers to the *Primary and Enabling Activities* of the value chain;
- for each *Activity* there is a list of *RD&D Challenges* to be addressed;
- each *RD&D* C*hallenge* is broken down into the corresponding *Uncertainties;*
- each *RD&D Uncertainty* is broken down into the corresponding *Option* which can be repeated for more than one Uncertainty

In the described approach, the options are classified according to four categories: *Research, Demonstration, Development* and *Deployment*, distinguished by the reference colours which are represented in the figure. Figure 6.2 illustrates this approach with an arbitrary example for multi-terminal HVDC systems.

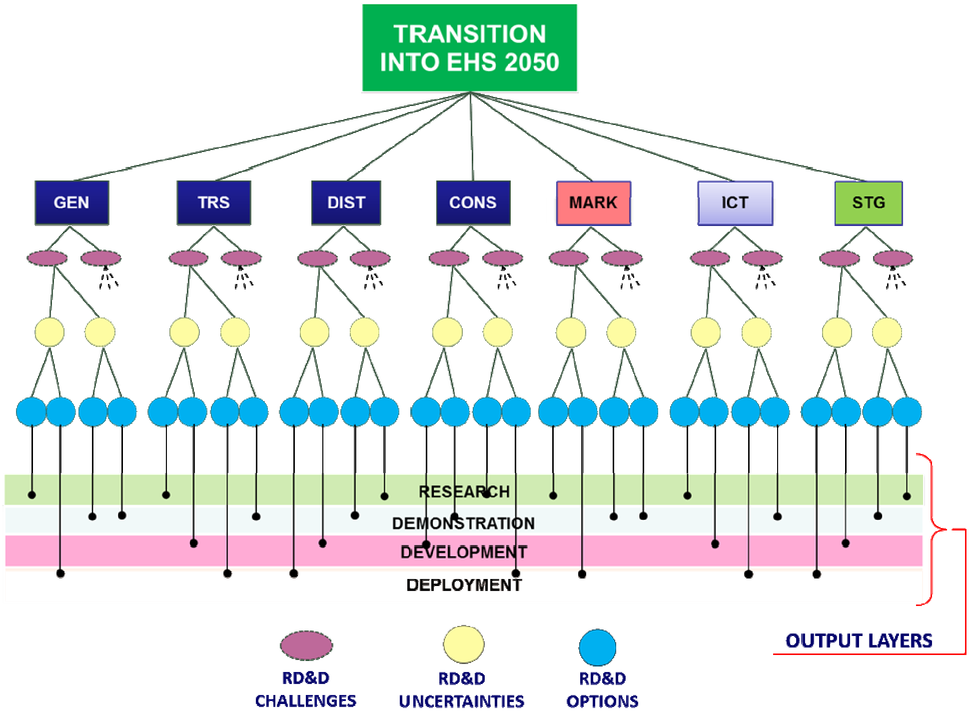


Figure 6.1 Hierarchical structure for Electrical Energy Value Chain analysis

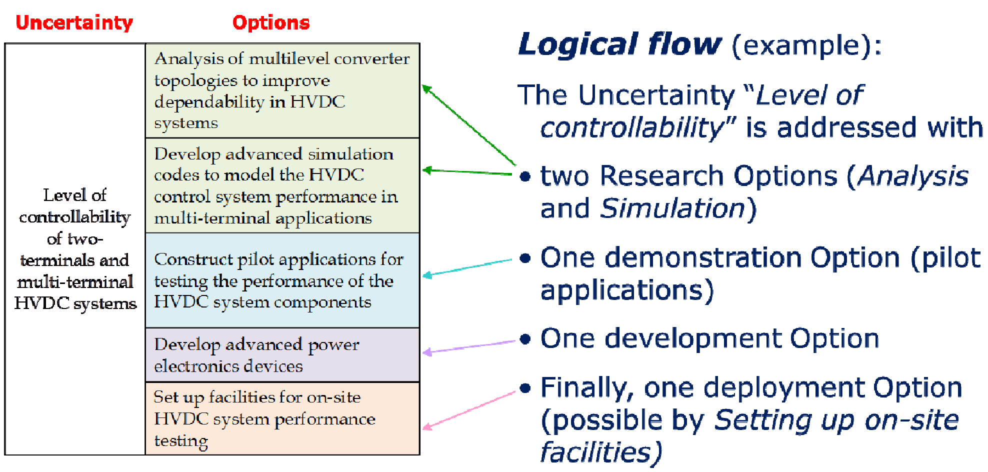


Figure 6.2 Example of construction of RD&D Uncertainties and Options

6.2 Main RD&D uncertainties, options and boundary conditions

The main Boundary Conditions for RD&D were identified as the following: *Budget, Human resources, Research groups, Laboratory requirements, Pilot experiments, National goal, European goal and Privacy degree*. In the following tables qualitative assessments will also be included since they mirror the relative importance of uncertainty and relative options.

Table 6.1 Main Generation RD&D Uncertainties

Generation Uncertainties	Descriptions	Boundary conditions
Generation cost of different technologies	Evaluate the impact of technological research on the generation cost	Budget, human resources, laboratory requirements, number of pilot projects
Variability of primary sources	Estimate the best strategy for integration of non programmable generation	Budget, human resources, number of pilot projects, European goal, national goal
Reliability (e.g. CCS & nuclear plants)	Evaluation of reliability of generation plants and of new technologies from the system point of view	Budget, human resources, laboratory, experiments, number of demonstration projects, European goal, national goal.
Long-term availability of primary sources	Evaluate the impact of the long-term availability of primary sources	Budget, human resources, laboratories, number of development projects, European goal, national goal.

Table 6.2 Importance of Generation RD&D Uncertainties for Scenario building and grid development

Generation Uncertainties	Importance for scenario building	Importance for grid development
Generation cost of different technologies	*High*	*High*
Variability of primary sources	*High*	*High*
Reliability (e.g., CCS plants, nuclear plants)	*High*	*High*
Long-term availability of primary sources	*High*	*High*

Table 6.3 Main Transmission RD&D Uncertainties

Transmission Uncertainties	Description	Boundary conditions
Level of controllability of two/multi-terminals HVDC systems	Analysis and simulation of controlled converter topologies, with pilot applications and testing	Budget, human resources, laboratory requirements, number of pilot and demonstration projects
Adequate refurbishment or replacement of HVAC systems	Study of new structures, maintenance strategies for refurbishment and HVAC replacement	Budget, human resources, national goal, Laboratories, number of development and pilot projects.
Adequate research and testing for managing new technologies to reinforce the network and Dynamic Thermal Rating calculation	Research and testing of various technologies and methodologies to calculate dynamic thermal rating and to repower existing lines with different conductors and mixed lines (overhead, cable, sea cable).	Budget, human resources, laboratory requirements, number of experiment and demonstration project.
Level of development in the substations	Assist offshore substation design, study the detailed operation of transformers and protection systems and formulate interoperability standards.	Budget, human resources, laboratory requirements, number of experiment and demonstration project.
Adequate system-level protection and control	Advanced methods for preventive and corrective control, assessment of the causes of blackout and models for adaptive protection.	Budget, human resources, laboratory requirements, number of experiments.
Adequate coordination of grid codes and transnational rules	Develop pan-EU and regional rulemaking and harmonise the independent national rules	Budget, human resources, Laboratories, number of development projects, European goal, national goal
Adequate large-scale simulation	Develop equivalents for portions of the system and study the application of pervasive computing	Budget, human resources, Laboratories, number of demonstration projects.
Level of risk of future investments	Develop risk-based decision making tools to assess investments in operational and expansion planning	Budget, human resources, Laboratories

Table 6.4 Importance of Transmission RD&D Uncertainties for Scenario building and grid development

Transmission Uncertainties	Importance for scenario building	Importance for grid development
Level of controllability of two/multi-terminals HVDC systems	*Low/Medium*	*High*

Adequate refurbishment or replacement of HVAC systems	*Medium*	*High*
Adequate research and testing for managing new technologies to reinforce the network and Dynamic Thermal Rating calculation	*High*	*Medium/High*
Adequate system-level protection and control	*Medium/High*	*High*
Level of development in the substations	*Medium*	*High*
Adequate coordination of grid codes and transnational rules	*High*	*Medium/High*
Adequate large-scale simulation	*Low/Medium*	*High*
Level of risk of future investments	*High*	*Medium/High*

Table 6.5 Main Distribution RD&D Uncertainties

Distribution Uncertainties	Description	Boundary conditions
Network loading levels	Research on load forecasting advanced tools, demand side management and policies for load behavior conditioning.	Budget, human resources, research groups, laboratory requirements, pilot experiments, national goal.
Level of renewable generating capacity installed	Research on generation capacity forecasting advanced tools, management policies for generators behavior conditioning, storage systems technologies.	Budget, human resources, research groups, laboratory requirements, pilot experiments, national goal.
Effectiveness of protection system	Research and pilot projects for testing the coordination of diagnostic, monitoring, control, protection and automation systems.	Budget, human resources, research groups, laboratory requirements, pilot experiments
Adequate participation of active customers	Analysis of the evolution of distribution networks with increasing levels of active customers.	Budget, human resources, research groups, laboratory requirements, pilot experiments, national and European goal.
Level of integrated management of transmission and distribution networks	Research on fully integrated network planning and operation for transmission, distribution and storage accounting for forecasting models of distribution networks behavior. Effective integration between TSO and DNO.	Budget, human resources, research groups, laboratory requirements, number of pilot experiments, national and European goal.
Adequate interfacing of electrical stations (HV/MV).	Research on new criteria for coordination between transmission and distribution automation through fast/highly performing protection devices, SCADA and station automation systems.	Budget, human resources, research groups, laboratory requirements, pilot experiments.

Table 6.6 Importance of Distribution RD&D Uncertainties for Scenario building and grid development

Distribution Uncertainties	Importance for scenario building	Importance for grid development
Network loading levels	*High*	*Medium*
Coordination of decentralised units	*High*	*High*
Level of renewable generating capacity installed	*High*	*Medium*
Effectiveness of protection system	*Low*	*High*
Adequate participation of active customers	*High*	*Medium*
Level of integrated management of transmission and distribution networks	*High/Medium*	*High*
Adequate interfacing of electrical stations (HV/MV)	*Medium/Low*	*High*

Table 6.7 Main Storage RD&D Uncertainties

Storage Uncertainties	Description	Boundary conditions
Fixed and operating costs	Evaluation of how decreasing costs could impact on the power system operation	Budget, human resources, laboratory requirements, research groups, number of pilot projects.
Toxic material treatment	Evaluation of the impact of difficulties in treating waste material from batteries could limit their use for storage	Budget, human resources, laboratory requirements, number of pilot experiments, National goal
Production costs for H2	Development of fuel cells could be affected by this costs	Budget, human resources, laboratory requirements, number of pilot experiments.
New materials	Development of new materials (nanotechnologies included) can change the impact of storage on the power system	Budget, human resources, research groups, laboratory requirements, number of pilot experiments and projects.

Table 6.8 Importance of Storage RD&D Uncertainties for Scenario building and grid development

Storage Uncertainties	Importance for scenario building	Importance for grid development
Fixed and operating costs	*High*	*High*
Toxic material treatment	*Medium/High*	*Low*
Production costs for H2	*Low/Medium*	*Medium*
New materials	*High*	*Medium*

7 Synthesis of the relevant criteria for scenario identification

A systematic bottom-up definition of Uncertainties and Options has been performed in the different tasks of WP1. Furthermore, a ranking of these Uncertainties and Options has been performed, from more to less important. The main criterium used during this process has been to select the most relevant Uncertainties and Options for the Scenarios to be defined in the project. The main criteria for relevant eHighway2050 Scenarios are:

i. *An e-Highway2050 Scenario is relevant when it challenges todays' power system, not only the grid*
ii. *The e-Highway2050 Scenarios should be substantially different from each other, within the total scope of the identified boundary conditions*
iii. *Some of the e-Highway2050 Scenarios defined should challenge the grid in a different way than today.*

Based on a careful review of the recommendations for main Uncertainties and Options from each of the WP1 tasks, a first set of coherent Futures was presented at a workshop with external Stakeholders in Brussels 23rd January 2013. Further feedback from Stakeholders was received after the workshop. A summary of the most relevant Uncertainties and Options as outcome of this process is presented below for the following different categories: *Technological*, *Economic & financial* and *Political, socio-political & environmental*. Possible ranges of values are indicated in parenthesis. These Uncertainties and Options are the building blocks in the scenario process elaborated in Section 8.

7.1 Technology criteria

- ***Options:***
  - Deployment of centralized renewables (High/Medium/Low)
  - Deployment of decentralized renewables (including CHP and biomass) (High/Medium/Low)
  - Deployment of nuclear plants (High/Medium/Low/No)
  - Deployment of fossil fuel plants with CCS (High/Medium/No)
  - Deployment of fossil fuel plants without CCS (Medium/Low/No)
  - Deployment of centralized or decentralized storage (High/Medium/Low)
- ***Uncertainties:***
  - Electrification of Transport, Heating and Industry (Residential/Large scale/All)
  - CCS technology maturity (Yes/No)
  - Storage technology maturity (Small scale/Large scale/All)
- ***Assumption (fixed across all scenarios):***
  - Maturity of RES and DSM technologies

7.2 Economic and financial criteria

- ***Uncertainties:***
    - Demographic change (European Growth/Migration)
    - GDP growth (High/Medium/Low)
    - Fuel Costs (High/Medium/Low)
    - Emission allowance costs /CO2 costs (High/Medium/Low)

7.3 Political, socio-political & environmental criteria

- ***Uncertainties:***
    - International climate agreement (Global Agreement/EU alone)
      This Uncertainty includes aspects of *Climate change impacts and adaptation*
    - Joint transnational initiatives (Difficult / Common)
      This Uncertainty includes *European geopolitics and integration*
    - Public perception to RES technologies (Positive/Indifferent)
    - Public perception to nuclear energy (Positive/Indifferent/ Negative)
    - Public perception to shale gas (Positive/Indifferent/Negative)
      These three Uncertainties are derived from *Societal perceptions and responses to energy technologies,* and include aspects of *Landscape and visual amenity, Urbanisation, Land use, Biodiversity, Water resources* and *Local pollutions*
    - Shifts towards ‘greener’ behaviours (Major shift/Minor shift)
    - Dependency on fossil fuels from outside Europe (High/Medium/Low)

- ***Options***
    - Increase of Energy efficiency (High/Medium/Low)
      This assumption includes aspects of *Resource and energy efficiency policy*
    - Electricity imports from neighbouring regions (High/Medium/Low)
    - EU permitting framework (Convergent and Strong/Heterogeneous)
      This Option includes aspects of *EU geopolitics and energy integration, Permitting frameworks* and *EU nature legislation*

- ***Assumptions (fixed across all scenarios):***
    - GHG emissions target: High – 80-95% GHG reduction targets compared to 1990
      This assumption includes aspects of *Climate change impacts* as well as *Climate mitigation policy, Resource and energy efficiency policy* and *EU renewable policy*

8 Scenario building process

The Uncertainties, Options and related Boundary Conditions that are identified in WP1 serve as input to the scenario building process for WP2/Task 2.1. *It is worth emphasizing that the work performed in WP1 and documented in this Deliverable is only the start of this process, and that further specification, modifications and adaptations will continue in the following work packages.* The general process can be summarized in the following way (starting from Step 3 in Figure 1.3):

3. Combine Uncertainties into possible and relevant e-Highway2050 **Futures**
4. Combine Options into relevant e-Highway2050 **Strategies**
5. Define relevant e-Highway2050 **Scenarios** = Future *x* Strategy

Since this approach creates a large number of *possible* e-Highway2050 scenarios, we perform two additional selection steps in order to reduce the number of scenarios to a feasible set for the analyses to be performed in WP2, WP4 and WP6:

6. Identify contradictions between Futures and Strategies to remove infeasible scenarios
7. Identify which scenarios will have similar impacts on Generation, Demand or Exchange (G/D/E) to disregard scenarios with an overlapping impact.

Based on a careful review of the recommendations for main Uncertainties and Options from each of the WP1 tasks, a first set of coherent Futures was presented at the Stakeholder workshop in Brussels on the 23rd of January 2013. The discussions at the workshop and the additional feedback after the event allowed the team[7] to build a set of *five relevant Futures* (as combinations of main uncertainties) and *six relevant Strategies* (as combinations of main options) for e-Highway2050. The Futures are described in more detail in Section 8.1 and summarized in Table 8.1, while the Strategies are described in Section 8.2 and summarized in Table 8.2. *The names assigned to the different Futures and Strategies are highly tentative.*

8.1 Relevant e-Highway2050 Futures

8.1.1 Verbal description of Futures

- ***Future 1: "Green Globe"***
  Energy and Climate Policy: A global agreement for climate mitigation is achieved and a global carbon market is established. Europe still imports some energy from outside the EU, but fossil fuel consumption is generally low worldwide. Common agreements/rules for

[7] Participants in the brainstorming workshop on scenario development, SINTEF, Trondheim, 11th February 2013: N. Masia – RTE, J. Gaventa – E3G , M. Wilk – IEN, E. Peirano – TECHNOFI, B. Betraoui – RTE, B. Bakken – SINTEF, D. Huertas-Hernando – SINTEF. Feedback 12th February 2013: D. Orlic – EKC.

transnational initiatives regarding the functioning of an internal EU market, EU-wide security of supply and coordinated use of interconnectors for transnational energy exchanges exist. Fuel costs are relatively low since there is a reduced demand for fossil fuels. On the other hand, CO_2 costs are high due to the existence of a global carbon market.

Technological development: We consider relevant RES and DSM technologies as mature in ALL futures. In addition, in this Future both small scale/decentralized and large scale/centralized storage technologies are assumed to be mature. CCS technology is assumed to become mature on a global scale, so it is considered competitive in this Future. Electrification of transport, heating and industry is considered to occur both at centralized (large scale) and de-centralized (residential) level.

Economic: The demographic change trend towards 2050 is assumed to be growth at EU level. GDP growth in the EU is assumed strong. This indicates an overall strong economic activity, which has facilitated the successful global climate agreement.

Socio-political perceptions: Public attitude to the deployment of RES technologies is positive in this Future. It is assumed that in relation to a successful global climate agreement and generally high focus on climate mitigation and environmental challenges, attitudes towards nuclear and shale gas as energy sources are negative in Europe. Moreover a clear shift towards 'greener' behaviours is experienced in this Future compared to e.g. present practices (focus and active involvement towards more energy efficiency, focus and active involvement towards more use of sustainable energy by the general public).

- ***Future 2: "Green EU"***

  Energy and Climate Policy: A global agreement for climate change mitigation does not exist in this Future. Still Europe is fully committed to its target of 80-95% GHG reduction. As a consequence, Europe's energy dependency from outside is low, since it is assumed that the energy portfolio outside the EU is dominated by fossil fuels. Common agreements/rules for transnational initiatives regarding the functioning of an internal EU market, EU-wide security of supply and coordinated use of interconnectors for transnational energy exchanges in the EU exist. Fossil fuel demand is medium to high worldwide which makes global fuel prices high. In addition CO_2 costs in the EU are high due to the existence of strict climate mitigation targets in the EU.

  Technological development: We consider RES and DSM technology as mature in ALL futures. In this Future both small scale/decentralized and large scale/centralized storage technologies are assumed to be mature. CCS is considered as non-mature in this Future. Electrification of transport, heating and industry is considered to occur both at centralized (large scale) and de-centralized (domestic) level in EU.

  Economic: Demographic change trend towards 2050 is assumed to be growth at EU level. GDP growth is expected to be medium. This indicates a difference between the EU's position with respect to energy and climate policies and the position of other industrialized countries such as the USA and China which still rely on fossil fuels (coal, gas and oil) as main parts of their energy strategy. Economic growth worldwide is still linked mainly to the use of fossil fuels. This gap correlates with the fact that a global climate agreement was not successful.

Socio-political perceptions: Public attitude towards the deployment of RES technologies is positive in this Future. It is assumed that despite lack of a global climate agreement, attitudes towards shale gas as energy source are negative in the EU while attitudes to nuclear energy are indifferent. Moreover a clear shift towards 'greener' behaviours is experienced in this Future compared to present practices (active involvement towards more energy efficiency and towards more use of sustainable energy by the general public).

- ***Future 3: "EU-Market"***

  Energy and Climate Policy: A global agreement for climate change mitigation does not exist. Still Europe is fully committed to its target of 80-95% GHG reduction. The internal EU market (version of 2050) is well functioning and in this Future it is considered as the main instrument for the development of the EU energy system. Beyond that, neither common agreements nor rules/incentives are in place, and EU-wide coordination for the use of interconnectors for transnational energy exchanges is not established. Fossil fuels consumption is generally medium to high worldwide which makes fuel prices high. In addition CO_2 costs in the EU are low since RES technologies are able to compete equally with other technologies in the market and there is no global carbon market. European energy dependency from outside the EU is medium, although the energy portfolio outside the EU is moderately dominated by fossil fuels.

  Technological development: We consider RES and DSM technology as mature in ALL futures. In this Future all storage technologies are assumed as mature, and also CCS technology is mature and competitive in the market. Electrification of transport, heating and industry is considered to occur both for domestic and large scale demand.

  Economic: GDP growth in the EU is assumed to be high, mainly due to strong market-driven industrial activities, and this supports the trust in market mechanisms as main instruments for development. Regarding energy, RES and non-RES sources play an equal role in the energy market. The demographic change trend towards 2050 is assumed to be migration only, as a consequence of the strong market-driven development in the EU. Economic growth worldwide is still linked to a large extent to the use of fossil fuels. This gap correlates with the fact that a global climate agreement was not successful.

  Socio-political perceptions: The development of the European energy system is basically market-driven in this Future, thus the public attitude towards environmental issues and RES technologies is indifferent in the EU. Equally, there is an indifferent attitude regarding the use of nuclear and shale gas as energy sources. Moreover only a minor shift towards 'greener' behaviours is experienced in this Future compared to e.g. present practices (poor involvement towards more energy efficiency or more use of sustainable energy by the general public). In general, the public is somewhat passive and everything is left to the actors in a market-driven energy system.

- ***Future 4: "Big is beautiful"***

  Energy and Climate Policy: In this Future a global agreement for climate change mitigation has been successfully reached. Common agreements/rules for transnational initiatives regarding the functioning of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges in EU exist, but in this Future there is a general support for large scale centralized solutions for RES deployment and storage. This facilitates e.g. the establishment of an offshore grid in the North and Baltic Seas and realization of the Desertec project in North Africa. Fuel costs are low since there is a very low demand for fossil fuels. On the other hand, CO_2 costs are high due to the existence of a global carbon market.

  Technological development: We consider relevant RES and DSM technologies as mature in ALL futures. In this Future, focus is on large-scale solutions so predominantly large-scale storage (pumped hydro storage, compressed air, etc.) technologies are assumed as mature. CCS technology is also assumed mature in this Future. Electrification of Transport, Heating and Industry is considered to occur mainly at centralized (large scale) level.

  Economic: Demographic change trend towards 2050 is assumed to be growth at EU level. GDP growth is assumed medium, which has facilitated the successful achievement of a global climate agreement. However, RES technologies are still subsidized and national and European authorities are actively supporting the international initiatives needed for large scale solutions to be realized.

  Socio-political perceptions: Public attitude towards deployment of RES technologies is indifferent in the EU. Energy strategy is deployed from a top-down approach at EU level with coordinated trans-national approach based on a strong framework for policy and incentives, supporting the market functioning. Attitudes towards nuclear and shale gas as energy sources are positive as being preferred to de-centralized local solutions. Moreover only a minor shift towards 'greener' behaviours is experienced in this Future compared to present practices. In general, the public is somehow passive and everything has to be coordinated at high level following a top-down vision.

- ***Future 5: "Small things matter"***

  Energy and Climate Policy: In this future, a global agreement for climate mitigation does not exist. Still Europe is fully committed to its target of 80-95% GHG reduction. Common agreements/rules for transnational initiatives regarding the functioning of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges in EU do not exist. On the contrary, most of the focus is on de-centralized solutions dealing with de-centralized generation and storage and smart grid solutions at transmission and mainly distribution level. Due to a somehow heterogeneous European landscape of energy strategies, energy dependency from outside EU is medium, and some countries still rely on imports from outside the EU. The energy portfolio outside EU is moderately dominated by fossil fuels. Fossil fuels consumption is generally medium to high worldwide which makes fuel prices high. ETS is primarily controlled by national authorities. The supply of CO_2 allowances in the market is high and CO_2 prices in the EU are low.

Technological development: We consider RES and DSM technologies as mature in ALL futures. In this Future, focus is on small-scale solutions so predominantly small-scale storage solution technologies are assumed as mature. CCS technology is not mature in this Future. Electrification of Transport, Heating and Industry is considered to occur mainly at residentical/small scale level.

Economic: In this Future, GDP growth in EU is assumed low, mainly due to an inhomogeneous economic activity landscape among Member States. Demographic change trend at EU level towards 2050 is assumed to be migration only. Economic growth worldwide is still linked mainly to the use of fossil fuels. This gap correlates with the fact that a global climate agreement was not successful and the energy policy situation in EU is heterogeneous.

Socio-political perceptions: Public attitude to deployment of local de-centralized RES technologies is positive in EU. Although political targets are clear and there is a common commitment on sustainability and energy independency, Member States in coordination with the EC develop their energy strategies from a nationally-driven point of view. Attitudes towards nuclear and shale gas are generally negative as these solutions are considered large-scale centralized and non-sustainable energy technologies. A major shift towards 'greener' behaviours is experienced in this Future compared to e.g. present practices (active involvement towards more energy efficiency and towards more use of sustainable energy by the general public). In general, the public is very active and most of the development occurs on a local de-centralized level.

8.1.2 Table of Futures

The following table summarizes the five relevant e-Highway2050 Futures.

Table 8.1 Summary of the five e-Highway2050 Futures

Main Uncertainty	Possible Values	Future 1 Green Globe	Future 2 Green EU	Future 3 EU-Market	Future 4 Big is beautiful	Future 5 Small things matter
Energy and Climate Policy						
International Climate Agreement	Global agreement / EU alone	Global agreement	EU alone	EU alone	Global agreement	EU alone
Dependency on fossil fuels from outside Europe	High/Medium/Low	Medium	Low	Medium	Medium	Medium
Joint transnational initiatives	Difficult/Common	Common	Common	Difficult	Common	Difficult
Fuel Costs	High/Low	Low	High	High	Low	High
CO2 cost	High/Low	High	High	Low	High	Low
Technological development						
Storage technology maturity	Small scale/Large scale/All	All tech mature	All tech mature	All tech mature	Large-scale	Small-scale
CCS maturity	Yes/No	Yes	No	Yes	Yes	No
Electrification in Transport - Heating - Industry	Residential/Large scale/All	All	All	All	Large scale (commercial, industry&freight)	Residential (Homes, person vehicles)
Economic						
Demographic change	Growth/Migration only	Growth	Growth	Migration only	Growth	Migration only
GDP growth in EU	High/Medium/Low	High	Medium	High	Medium	Low
Socio-political perceptions						
Public perceptions to RES	Positive/Indifferent	Positive	Positive	Indifferent	Indifferent	Positive
Public perceptions to Nuclear	Positive/Indifferent/Negative	Negative	Indifferent	Indifferent	Positive	Negative
Public perceptions to Shale gas	Positive/IndifferentNegative	Negative	Negative	Indifferent	Positive	Negative
Shift towards 'greener' behaviours	Major shift/Minor shift	Major	Major	Minor	Minor	Major
Assumptions - Constant Uncertainties						
RES technology / DSM technology	Mature	Mature	Mature	Mature	Mature	Mature

8.2 Relevant e-Highway2050 Strategies

8.2.1 Verbal description of Strategies

The following six strategies were identified by combining the Options identified in Chapter 7.

- ***Strategy 1: "Market led"***
  This strategy implies technology neutrality so both RES and Non-RES technology are allowed to compete between each other on a market-led basis. It can be considered as a diversified technology mix or market-led strategy. Similarly, there are no particular priorities between centralized or de-centralized solutions.

  Deployment of centralized RES: Medium

  Deployment of de-centralized RES (including CHP and Biomass): Medium

  Deployment of centralized Storage: Medium

  Deployment of de-centralized Storage: Medium

  Deployment of nuclear plants: Medium

  Deployment of fossil fuel plants with CCS: Medium

  Deployment of fossil fuel plants without CCS: Gradual decommissioning from current level.

  Increase of energy efficiency (include DSM and flexibility of EV): Investments in energy efficient solutions are assumed to compete with RES and Non-RES supply technologies on market-based principles so there is a medium increase of its deployment compared to present level.

  Increase of funds and better coordination of RD&D activities (at EU level): Since Large Scale solutions are envisaged, increased coordinated RD&D activities at EU level are assumed.

  Electricity imports: A well-functioning competitive EU market combining RES and Non-RES is assumed which makes the needs for energy/electricity imports medium to low at EU level.

  Permitting framework (incl EU nature legislation): Convergent and strong frameworks are considered so deployment/development of profitable RES potential is possible at EU level.

  EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

- ***Strategy 2: "Large-scale RES solutions"***
  Deployment of centralized RES: High. This strategy has a main focus on deployment of large-scale RES technologies, e.g. large scale offshore wind parks in the North Sea and Baltic Seas and the Desertec project in North Africa.

  Deployment of de-centralized RES (including CHP and Biomass): This strategy has low focus on deployment of de-centralized RES (including CHP and Biomass) solutions.

  Deployment of centralized Storage: This strategy has high focus on the development of centralized storage solutions (pumped hydro storage, compressed air, etc…) that is complementary to the large-scale RES deployment.

  Deployment of de-centralized Storage: This strategy has low focus on deployment of de-centralized storage solutions since these will be insufficient to support the large-scale RES deployment.

  Deployment of nuclear plants: Nuclear technology is a centralized technology from a deployment point of view so nuclear technology is included in this strategy. However, no development in new nuclear technologies is assumed beyond the current level of deployment which is maintained according to standard decommissioning rates for present nuclear plants up to 2050.

  Deployment of fossil fuel plants with CCS: Since this strategy has focus on large scale RES solutions the development of fossil fuel plants with CCS is not given priority as an option to reach GHG reduction targets.

  Deployment of fossil fuel plants without CCS: Decommissioning from current level.

  Increase of energy efficiency (include DSM and flexibility of EV): In this Strategy, political focus is mainly on the supply side. Thus, low increase in energy efficient solutions (including DSM and flexibility of electric vehicles) is assumed. Large amounts of RES will make investments in energy efficiency solutions less attractive.

  Increase of funding and better coordination of RD&D activities (at EU level): In this Strategy, since large scale solutions are sought, increased coordinated RDD activities at EU level are needed. This is a very important component in this Strategy to allow successful deployment of these large scale solutions.

  Electricity imports: Due to the focus on large-scale RES solutions, high import of RES from North Africa – Desertec project is included.

  Permitting framework (incl EU nature legislation): Convergent and strong frameworks are needed to ensure large-scale deployment/development of the available RES potential at EU level.

EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

- ***Strategy 3: "Local solutions"***
  Deployment of centralized RES: This strategy has a low focus on the development of centralized large scale RES.

  Deployment of de-centralized RES (including CHP and Biomass): This strategy has a high focus on deployment of de-centralized RES solutions (including CHP and Biomass).

  Deployment of centralized Storage: This strategy has a low focus on the development of centralized storage.

  Deployment of de-centralized Storage: This strategy has a high focus on the development of de-centralized storage.

  Deployment of nuclear plants: Nuclear technology is a centralized technology that is not considered as an option for further development in this Strategy.

  Deployment of fossil fuel plants with CCS: CCS technology is a centralized technology that is not considered as an option in this Strategy.

  Deployment of fossil fuel plants without CCS: Decommissioning from current level.

  Increase of energy efficiency (include DSM and flexibility of EV): This Strategy has a high focus on the deployment of energy efficient solutions (including DSM and flexibility of electric vehicles).

  Increase of funds and better coordination of RD&D activities (at EU level): The development of de-centralized solutions occurs at a rather local/domestic scale, so the coordination of RD&D activities at EU wide / trans-national level is Low.

  Electricity imports: Due to a somehow inhomogeneous development of different de-centralized solutions, some countries might still require imports from outside EU, so this option is set as medium.

  Permitting framework (incl EU nature legislation): A de-centralized development with national initatives is likely to be correlated to a heterogeneous framework at EU level.

  EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

- ***Strategy 4: "100% RES"***
  Deployment of centralized RES: High. This Strategy includes ONLY RES production technologies.

  Deployment of de-centralized RES (including CHP and Biomass): High. This Strategy includes ONLY RES production technologies.

  Deployment of centralized Storage: High.

  Deployment of de-centralized Storage: High.

  Deployment of nuclear plants: No Nuclear since this Strategy includes ONLY RES production technologies.

  Deployment of fossil fuel plants with CCS: No CCS since this Strategy includes ONLY RES production technologies.

  Deployment of fossil fuel plants without CCS: Total decommissioning.

  Increase of energy efficiency (include DSM and flexibility of EV): High. These solutions provide reduction of energy demand as well as complementary flexibility and storage to account for variability of RES production from PV and Wind.

  Increase of funds and better coordination of RD&D activities (at EU level): The phase out of fossil fuel technologies will fundamentally change the way the power system is operated. High focus on increased coordination of RD&D activities at EU level is assumed for generation, storage and grid technologies. This is a very important component in this Strategy to allow successful transition to a 100% renewable electricity system.

  Electricity imports: No fossil fuels imports; Only RES-E from Desertec PV/CSP in North Africa and, possibly, other RES-E from FSU region.

  Permitting framework (incl EU nature legislation): Convergent and strong frameworks are essential to ensure successful deployment/development of all available RES potential at EU level.

  EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

- ***Strategy 5: "Carbon free CCS & Nuclear"***
  This Strategy aims for a carbon free electricity system in Europe but is not based on renewable generation. Instead, carbon free technologies like CCS and nuclear are chosen.

  Deployment of centralized RES: This strategy has low focus on deployment of centralized RES as part of a carbon free electricity system.

Deployment of de-centralized RES (including CHP and Biomass): Low.

Deployment of centralized Storage: Low.

Deployment of de-centralized Storage: Low.

Deployment of nuclear plants: High. In this strategy nuclear plays a pivotal role in achieving the 80-95% GHG targets without large scale RES deployment.

Deployment of fossil fuel plants with CCS: High. In this strategy fossil fuel plants with CSS play a pivotal role in achieving the 80-95% GHG targets without large scale RES deployment.

Deployment of fossil fuel plants without CCS: Decommissioning from current level.

Increase of energy efficiency (include DSM and flexibility of EV): Since nuclear and CCS will be heavily deployed in this Strategy, energy efficient options (including DSM and flexibility of electric vehicles) are deployed only at medium to low level with a main purpose of reduction of energy demand. In this Strategy no further complementary flexibility is needed since variability of RES production from PV and wind is low.

Increase of funds and better coordination of RD&D activities (at EU level): Medium coordination is needed with main focus on CCS research and development.

Electricity imports: Due to the development of large scale generation technologies, the need for import to Europe is low.

Permitting framework (incl EU nature legislation): Heterogenous. There is no need to develop fully coordinated frameworks since the geographical distribution of the generation portfolio will not change drastically with this Strategy.

EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

- ***Strategy 6: "No nuclear"***
  This Strategy is a special variant of Strategy 1 but without any nuclear generation in Europe. This will create an increased need for alternative options.

  Deployment of centralized RES: This strategy has high focus on the deployment of centralized RES.

  Deployment of de-centralized RES (including CHP and Biomass): This strategy has high focus on the deployment of de-centralized RES.

  Deployment of centralized Storage: High

Deployment of de-centralized Storage: High

Deployment of nuclear plants: No Nuclear power will remain in Europe.

Deployment of fossil fuel plants with CCS: Fossil fuel plants with CSS will play an important role in achieving the 80-95% GHG targets together with large RES deployment, as both are used to cover the gap created by the absence of nuclear power.

Deployment of fossil fuel plants without CCS: Decommissioning from current level.

Increase of energy efficiency (include DSM and flexibility of EV): Since nuclear is not available in this Strategy, high increase in energy efficient solutions (including DSM and flexibility of EV) is included since these options provide reduction of energy demand and complementary flexibility to balance variable RES production that replaces less variable nuclear power as base load.

Increase of funds and better coordination of RD&D activities (at EU level): Since large deployment of RES solutions substitute nuclear power in this strategy, increased coordinated RD&D activities at EU level are needed. This is a very important component in this strategy to allow successful deployment of these large scale solutions while maintaining security of supply and system adequacy.

Electricity imports: Medium import of RES-E is needed, and possibly from North Africa and/or FSU region.

Permitting framework (incl EU nature legislation): Convergent and Strong frameworks are in place so deployment of the available RES potential is possible at EU level.

EU policy targets for GHG reduction emissions: High – 80-95% GHG reduction target as fixed assumption.

8.2.2 Table of Strategies

The following table summarizes the six relevant e-Highway2050 Strategies.

Table 8.2 Summary of the six e-Highway2050 Strategies

Main Options	Strategy 1 MARKET LED	Strategy 2 LARGE SCALE RES	Strategy 3 LOCAL SOLUTIONS	Strategy 4 100% RES	Strategy 5 CARBON FREE CCS & NUCLEAR	Strategy 6 NO NUCLEAR
Deployment of centralized RES	Medium	High	Low	High	Low	High
Deployment of de-centralized RES (including CHP and Biomass)	Medium	Low	High	High	Low	High
Deployment of centralized Storage	Medium	High	Low	high	Low	High
Deployment of de-centralized Storage	Medium	Low	High	High	Low	High
Deployment of nuclear plants	Medium	Medium	Low	No	High	No
Deployment of fossil fuel plants with CCS	Medium	No CCS	No CCS	No CCS	High	High
Deployment of fossil fuel plants without CCS	Medium	Low	Low	No	Low	Low
Increase of energy efficiency (include DSM and flexibility)	Medium	Low	High	High	Low	High
Increase of funds and better coordination of RDD activities (at EU level)	Medium	High	Low	High	Medium	High
Electricity imports from outside Europe	Medium	High RES (Desertec)	Medium	High RES (Desertec)	Low	Medium
Permitting framework (incl EU nature legislation)	Convergent and Strong framework	Convergent and Strong framework	Heterogeneous framework at EU level	Convergent and Strong framework	Heterogeneous framework at EU level	Convergent and Strong framework
Assumptions - Constant Option						
EU Policy for GHG reduction emissions	Strong	Strong	Strong	Strong	Strong	Strong

8.3 Identification and selection of e-Highway2050 scenarios

The selection process and resulting energy scenarios is provided to represent the challenges the Pan-European power system may have to face by 2050. On the basis of a four-step filtering approach, it is suggested that five scenarios can be retained, which can be used all along the project to identify, for each of them, the most robust and sustainable grid architectures by 2050.

The Green paper published by the European Commission on March 27th 2013 [51] goes beyond the 2020 objectives and frames the policy environment within which Europe ought to design its whole energy system in the 2030-2050 timeframe. This 2050 perspective was first laid out in 2011 [52], and then continued through the Energy Roadmap 2050 [7] and the Transport White Paper [53]. Each of these key policy papers has seen a parent European Parliament Resolution [54], [55], [56].

This document stands within the same context and summarises a first set of results obtained by the EC supported e-Highway2050 project. This research and development work started on September the 1st of 2012 to meet the following overarching goal:

> *"To develop a **top-down** planning methodology which provides a first version of a modular and robust expansion of the European Network from 2020 to 2050, in line with the European energy policy pillars"*

The initial e-Highway2050 work is composed of a detailed methodology to build possible energy scenarios and the selection of those that will be used during the whole project.

8.3.1 Policy assumptions

The present scenario development work is based on two major policy assumptions set at EU level to shape a challenging 2050 horizon:

- **Reducing GHG emissions between 80-95% by 2050,** compared to the estimated 1990 levels,
- **Assuming that renewable energy, energy efficiency and smarter energy infrastructures are the key driving forces in technology options** for transforming the European energy system in accordance with the three pillars of the European energy policy, i.e. to ensure the security of the supply, energy market efficiency and sustainability.

These policy options have led to the following set of 2020 targets, which are reviewed by the mentioned 2013 Green Paper in order to check that they coherently support the decarbonisation orientations within the above three policy pillars:

- 20% GHG reduction target (set in relation to 1990 figures) involves two instruments: Emission Trading Scheme (ETS) and Effort Sharing Decision. Yet, the European Commission pinpoints trends towards policy fragmentation within EU 27 exhibiting significant differences between Member States. These trends may jeopardize or undermine the role of the ETS and any new measure between 2013 (16% GHG reduction achieved in 2012) and 2020,

- 20% renewable energy target (in gross final energy consumption) requires new measures, in such a way that most of the Member States meet their national targets set for 2020. They include, for instance, innovative market designs to accommodate large scale renewable deployment, as well as the upgrading and development of infrastructures including electricity grids,
- The target of a 20% decrease of the EU primary energy consumption (compared to projections made in 2007) is not legally binding: yet the 2012 Energy Efficiency Directive proposes a legislative framework at EU level for energy efficiency[8],
- Lastly, the Third Energy Package (2010), together with the Regulation on Trans-European Energy Infrastructure Guidelines, has addressed market competitiveness and infrastructure issues: it should ease the deployment of new energy generation and consumption patterns, which in turn will impact electricity costs and security of supply.

Most EU27 Member States have implemented the Directives[9] related to the above 2020 targets. Yet, there is currently, a need to go beyond the 2020 horizon since the development of energy systems is characterized by long investment cycles and specific risks (regulation, economy, international agreements on GHG emissions and so on): planning future developments over the 2020-2050 period should help energy system policy makers and stakeholders make decisions in support of the long-term 2050 decarbonisation goals.

As a first step, the public consultation launched by the EC with the 2013 Green Paper aims at setting the future 2030 binding targets on the route to decarbonisation, while highlighting the critical uncertainties under which electricity network operators must plan the pan-European expansion of the transmission networks by 2050.

8.3.2 An innovative methodology to select the most challenging scenarios for the electricity network by 2050

The proposed scenario building approach developed by the e-Highway2050 project is a four-step filtering process. While assuming that the above policy framework holds true over the 2020-2050 periods, it scans through a plethora of possible *controllable Options* and *uncontrollable Uncertainties*, before sorting out the selected Scenarios to be dealt with by the study project.

[8] even though the EC brings doubts about its implementation to help reaching the above targets
[9] ETS, Renewables, EE, Building, eco-design, wastes, etc.

8.3.3 Step 1: possible scenarios

The first step sets the foundations for scenario building by answering three questions[10]:

- ***What are the Options that decision makers have in hands to shape the energy Strategies in line with the 2050 policy positioning?*** *These Options may be technical, socio-economic or political: some of them need R&D investments to clarify and validate candidate Options before their real life deployment occurs within a time frame to be defined.*
- ***What are the Uncertainties that decision makers may have to cope with in order to allow for the proper implementation of the defined Strategies?*** *These Uncertainties also have technical, socio-economic or political content: they may affect the R&D investment results or outcomes within the same time frame.*
- ***What are the Boundary Conditions that narrow down the Options available to build Strategies and the Uncertainties expected to build possible Futures?*** *These boundary conditions impact the potential of the listed options and futures.*

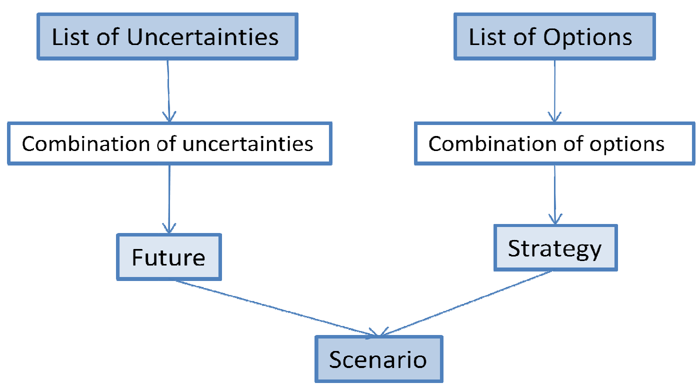


Figure 8.1 Construction of Scenarios from Uncertainties and Options

This process has been defined with the active contribution of the e-Highway2050 partners that include Transmission System Operators (TSOs) and non TSO (Research Institutes, Industrial Associations, Universities, Consultants...). A thorough scanning of uncertainties and options has been performed according to their ranking, decreasing order of importance. The main criteria used during this ranking process read as follows:

1. *An e-Highway2050 Scenario is relevant when it challenges the entire existing European electricity system, not just the grid,*
2. *The selected e-Highway2050 Scenarios should substantially differ from each other, after having accounted for the identified boundary conditions*
3. *Some of e-Highway2050 Scenarios should challenge the electricity system in a way which differs from the current state of affairs.*

---

[10] See Chapter 1.2 for a definition of the terminology.

A resulting first set of coherent Futures and Strategies was discussed at a workshop with external stakeholders held in Brussels on January 23rd 2013. Further feedback from the participating stakeholders led to identifying the most relevant Uncertainties and Options. Overall, five Futures and six Strategies were identified as presented in Sections 8.1 and 8.2, therefore defining the set of thirty potential Scenarios which the pan-European transmission network may have to face.

8.3.4 Step 2: eliminating spurious scenarios

The combination of 5 Futures and 6 Strategies gives 30 possible Scenarios. The Step 2 aims at eliminating the spurious scenarios that involve contradictions between the defined futures and strategies. They can be cancelled from future scrutiny, since unfeasible according to the following four criteria:

- *NUC: such scenarios cannot occur due to conflicts between the public perception of nuclear electricity generation in the futures and nuclear deployment in the strategies*
- *CCS: such scenarios cannot occur due to conflicts between the public perception of CCS technology in the futures and CCS deployment in the strategies*
- *No Policy: such scenarios are unlikely to occur within a predominantly market-driven future since the corresponding strategy implementation requires a strong policy framework*
- *Illogical: such scenarios are eliminated since a large-scale strategy does not fit in a future with predominantly small-scale local preferences and vice versa.*

This process leads to a remaining set of **15 possible scenarios**.

Table 8.3 The 15 remaining scenarios

Futures	Strategies	Strategy 1 MARKET LED	Strategy 2 LARGE SCALE RES SOLUTIONS	Strategy 3 LOCAL SOLUTIONS	Strategy 4 100% RES	Strategy 5 NUCLEAR & CCS	Strategy 6 WITHOUT NUCLEAR
Future 1	Green Globe	NUC	X-1	X-2	X-3	NUC	X-4
Future 2	Green EU	CCS	X-5	X-6	X-7	CCS	CCS
Future 3	EU- Market	X-8	No Policy	X-9	No Policy	No Policy	No Policy
Future 4	Big is beautiful	X-10	CCS	Illogical	X-12	X-13	X-14
Future 5	Small things matter	NUC/CCS	Illogical	X-16	X-17	NUC	CCS

8.3.5 Step 3: towards the most challenging 2050 scenarios

Grid architecture will be developed within the e-Highway2050 project for each energy scenario selected. However, the construction of grid architectures requires time and resources. The number of scenarios therefore has to be optimized in order to respect the requirements, and the predetermined schedule for the project.

The purpose of the step 3 is to identify the representative scenarios, that cover the whole set of 15 scenarios, as illustrated in the following picture:

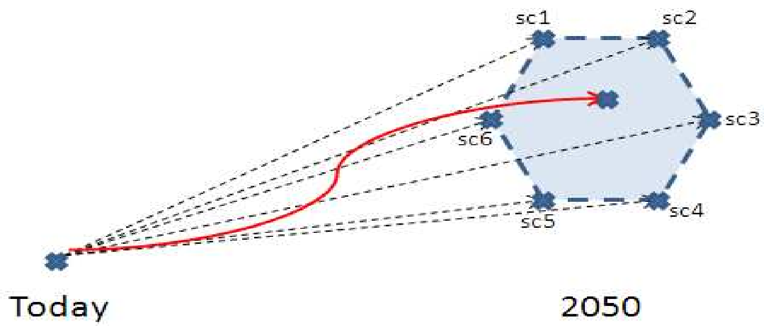


Figure 8.2 Representative Scenarios

In this way, step 3 aims to define the impacts of the different scenarios on the transmission grid, in order to analyze the possibility of reducing the number of scenarios selected in the previous step. The redundancies are identified, and the opportunity to merge certain scenarios is considered, in order to select the most relevant ones for the project.

The key levers for the development of transmission grid are: Generation, Demand (load), and Exchange (i.e. power exchanges within Europe or beyond its borders).

The third step of the scenario selection process aims to:

- **Keep scenarios with contrasted impacts.** The selected scenarios should indeed differ enough from each other, in order to encompass a wide range of possible situations in 2050, while setting the limits, or the boundary conditions of the possible long term transmission grids.
- **Assess the impacts of the different scenarios on the transmission grid**, to merge the scenarios that will lead to similar impacts.
- **Pinpoint the most impacting trends** which the pan-European transmission system may face up to 2050. TSOs should aim at keeping the vulnerability of the entire electricity system to a minimum, assuming that they are able to explore all the plausible and predictable threats which challenge conventional wisdom in order to minimize consequences for society. It has been assumed that only trends coming from generation, demand, and power exchanges within the ENTSO-E or beyond its borders) are addressed.

The resulting scenario selection process relies on the following two assumptions:

1. The chosen grid architectures coping with the selected e-Highway2050 challenging scenarios should be able to launch any possible energy scenario by 2050,

2. The independent parameters depicting the scenarios are linked to generation demand and levels of power exchange: all the other factors (such as socio-economic variables, policies, etc) are embedded in the above independent parameter (with various types of dependencies).

All criteria (options and uncertainties) are combined and limited to **10 relevant parameters** for the development of the long-term planning transmission grid.

Table 8.4 below shows the correlations between the remaining options and uncertainties and the parameters. For instance, the first parameter (level of decentralized renewable energy) depends on Decentralized storage, CO_2 prices, Public attitude towards RES technologies and international GHG targets. Other levels and their types of dependencies read as follows:

- The **level of centralized renewable energy**, depends on:
  - CO_2 prices,
  - Public attitude towards RES technologies,
  - International GHG targets.
- The **level of Nuclear energy**, depends on:
  - Public attitude towards nuclear power generation,
  - International GHG targets.
- The **level of fossil fuel energy**, depends on:
  - The use or not of CCS, according to CCS maturity,
  - Fossil fuel prices,
  - CO_2 prices,
  - Public attitude towards shale gas exploitation.
- The **level of centralized storage**, including the EU permitting framework
- The **level of electricity exchanges outside Europe**, which includes:
  - The energy dependency,
  - The EU permitting framework.
- The **level of transnational initiatives inside Europe**, which includes:
  - The attitude towards the deployment of interconnections,
  - The EU permitting framework.
- The **level of GDP and population**
- The **level of demand according to new uses**, which includes:
  - Electrification in Transport,
  - Electrification of heating systems,
  - Shifts towards greener behaviour in terms of Demand Side Management.
- The **level of energy efficiency**, which includes the Shift towards greener behaviour.

Table 8.4 Correlations between the parameters and the set of Options and Uncertainties

Criteria	Option	Uncertainty	1	2	3	4	5	6	7	8	9	10
Deployment of centralized renewable	o1	-	X									
Deployment of decentralized renewable	o2	-		X								
Deployment of renewable	-	**u15**	X	X								
Deployment of Fossil fuel plants with CCS (CCS maturity)	o6	-				X						
Deployment of Fossil fuel plants without CCS	u7/**o11**											
Nuclear acceptance / deployment of nuclear plants	o5/u12					X						
Deployment of centralized storage	o3	-					X					
Deployment of decentralized storage	o4	-		X								
Deployment of storage	o3/o4	-		X			X					
Electrification in transport and Heating	-	u8									X	
Fuels Costs	-	u4				X						
Emission allowance costs (CO2 costs)	-	u5	X	X		X						
Population (demographic changes)	-	u9								X		
GDP growth	-	u10										
Public attitude towards RES technology	-	u11	X	X	X							
Shale gas acceptance	-	u13				X						
Dependency on fossil fuels / Electricity imports from outside Europe	o9/u2								X			
Joint transnational investment initiatives	-	u3							X			
EU permitting framework	o10						X	X	X			
Energy efficiency	o7	-										X
International GHG emissions target	**o12**/u1		X	X	X	X	X					
Shift towards greener behaviour		u14									X	X

For further characterization of the remaining scenarios, metrics have to be defined in order to measure of the intensity of each parameter and to be able to compare the scenarios. These metrics are given in Table 8.5. The different values of the parameters can be displayed by using a radar graph representation as shown below (the 15 radar graphs are detailed in Annex).

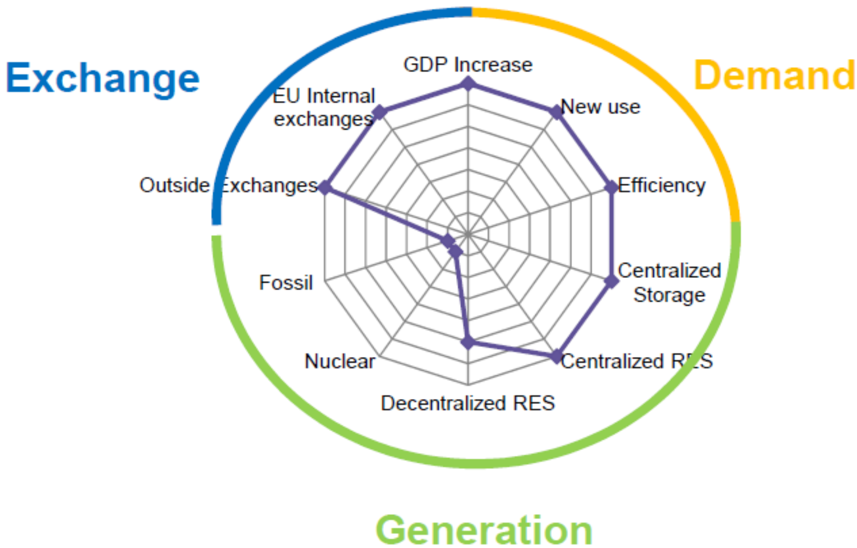


Figure 8.3 Radar diagram of the 10 relevant parameters

The different colours specifically show the different fields concerned: generation field (in green), demand field (in yellow) and exchange (in blue). These three families of parameters provide answers to the following questions:

- *How much does generation change /where and how is generation changing (spatial distribution and variability)?*
- *How much does demand change / where and how is demand changing (volume and flexibility)?*
- *How do power exchanges within EU (27+2) member states and with third countries change (internal and external exchanges)?*

Table 8.5 Summary of the Generation/Demand/Exchanges data of the scenarios selected in Step 2. Generation (in green), Demand (in yellow), and Exchange (in blue)

Criteria (options / uncertainties)	x-1	x-2	x-3	x-4	x-5	x-6	x-7	x-8	x-9	x-10	x-12	x-13	x-14	x-16	x-17
	Large Scale RES, Green Globe	Local solutions & Green globe	100% RES, Green globe	Green revolution & no nuclear	Large Scale RES & No emission	Local solutions	"100% RES"	Pure Market	local solutions & market	Big & Market	100% RES, Big EU	Big, Nuc & CCS	No nuc & Big	"Small and local"	100% RES & small
Level of centralized renewable	60%	20%	60%	40%	60%	20%	60%	30%	20%	40%	60%	30%	40%	25%	40%
	High	Low	High	M/H	High	Low	High	Medium	Low	M/H	High	L/M	M/H	Low	M/H
Level of decentralized renewable	20%	60%	40%	40%	15%	60%	40%	20%	60%	20%	40%	5%	20%	60%	60%
	M/L	High	High	High	Low	High	High	M/L	High	M/L	High	Low	M/L	High	High
Level of renewable	80%	80%	100%	80%	75%	80%	100%	50%	80%	60%	100%	35%	60%	85%	100%
Level of Fossil fuel plants with CCS	0%	0%	0%	15%	0%	0%	0%	20%	0%	15%	0%	30%	30%	0%	0%
	No	No	No	Medium	No	No	No	Medium	No	Medium	No	Yes-High	Yes-High	No	No
Level of Fossil fuel plants without CCS			0%	5%	5%		0%	10%		5%		5%		5%	
			Low	Low	Low		Low	Medium		Low		Low		Low	
Level of Fossil fuel	0%	0%	0%	20%	5%	0%	0%	30%	0%	20%	0%	35%	30%	5%	0%
Level of nuclear	20%	20%	0%	0%	20%	20%	0%	20%	20%	20%	0%	30%	0%	10%	0%
	Medium	Med	No	No	Medium	Medium	No	Medium	Medium	Medium	No	High	No	Low	No
Level of centralized storage	High	Low	High	High	High	Low	High	Medium	Low	Medium	High	Low	High	Low	High
Enabling EU international exchanges	High	Medium	High	Medium	High	Medium	High	Medium	Medium	Medium	High	Low	Medium	Medium	High
New use emerging (including DSM)	High	Low	High	High	High	Low	High	Medium	Low	Medium	High	Medium	High	Low	High
New use	High	High	High	High	High	High	High	High	High	High	High	High	High	Low	Medium
Population (demographic changes)	Growth	Growth	Growth	Growth	Growth	Growth	Growth	Migration only	Migration only	Growth	Growth	Growth	Growth	Migration only	Migration only
GDP increase	High	High	High	High	Medium	Medium	Medium	High	High	Medium	Medium	Medium	Medium	Low	Low
Energy efficiency	Low	High	High	High	Low	High	High	Medium	High	Medium	High	Low	High	High	High

Finally, a close review of the remaining scenarios and the comparison with other long-term energy planning studies, lead to five groups of scenarios, in which one scenario has been selected to represent the whole group.

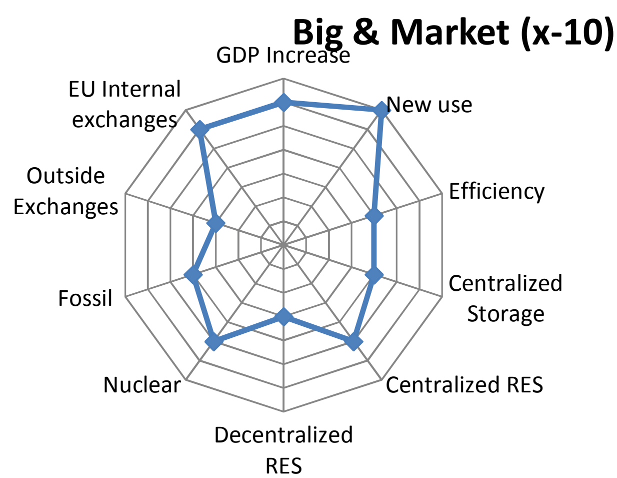
- ***x-5:*** *Large scale RES and no emissions, out of group 1, i.e. {x1, x4, x5, x14},*
- ***x-7:*** *100% RES, out of group 4, i.e. {x3, x7, x12, x17}*
- ***x-10:*** *Big and market, out of group 2, i.e. {x8, x10},*
- ***x-13:*** *Large fossil fuel with CCS and nuclear, out of group 3, i.e. {x13},*
- ***x-16:*** *Small and local, out of group 5, i.e. {x2, x6, x9, x16}.*

8.4 Detailed description of the five scenarios selected for the e-Highway2050 project

8.4.1 Big and market (x-10):

In this Scenario, a global agreement for climate mitigation is achieved. Thus, CO_2 costs are high due to the existence of a global carbon market. Europe is fully committed to meet its 80-95% GHG reduction orientation by 2050 but it relies mainly on a market based strategy.

Moreover, in this scenario, there is a special interest on large scale centralized solutions, especially for RES deployment and storage. Public attitude towards deployment of RES technologies is indifferent in the EU, while acceptance of nuclear and shale gas, as energy sources, is positive since being preferred to decentralize local solutions. CCS technology is also assumed mature in this scenario.



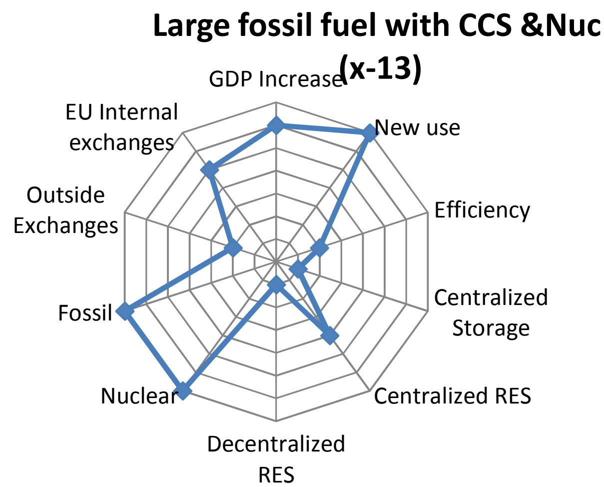
Electrification of transport, heating and industry is considered to occur mainly at centralized (large scale) level. Only a minor shift towards ‘greener’ behaviors is experienced in this scenario compared to present practices. Therefore, the efficiency level is low. In general, the public is somehow passive, and the players are active in a market-driven energy system.

8.4.2 Large fossil fuel with CCS and nuclear (x-13)

In this Scenario, a global agreement for climate mitigation is achieved and Europe is fully committed to its target of 80-95% GHG reduction. Thus, CO2 costs are high due to the existence of a global carbon market.

Europe is mainly following a non-RES strategy to reach this target. Acceptance of nuclear and shale gas as energy sources is positive. Nuclear and fossil fuel plants with CSS play pivotal roles in achieving the 80-95% GHG targets without large scale RES deployment. Public attitude towards deployment of RES technologies is indifferent in the EU. There is a low focus on development of RES and storage solutions.

Electrification of transport, heating and industry is considered to occur mainly at centralized (large scale) level. Energy efficient options (including DSM and flexibility of EV use) are deployed only at medium level, mainly aiming at reducing energy demand. Indeed a minor shift towards 'greener' behaviors is experienced in this Future compared to present practices.



No further flexibility is needed since variable generation from PV and wind is low.

The energy strategy is deployed from a top-down approach at EU level with coordinated trans-national approaches based on a strong framework for policy and incentives, supporting market operation. In general, the public is somehow passive and everything has to be coordinated at high level, following a top-down vision.

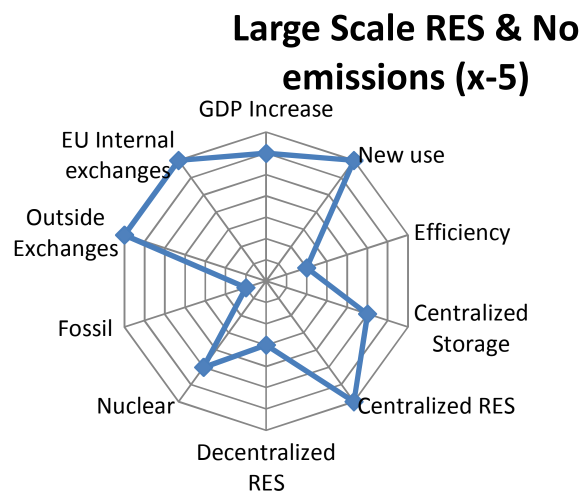
In this case, Electricity exchanges with outside Europe are low.

8.4.3 Large scale RES & no emission (x-5):

In this Scenario, a European agreement for climate mitigation is achieved and fossil fuel consumption is generally low worldwide. Therefore, fuel costs are relatively low. On the other hand, the CO_2 costs are high due to the existence of a global carbon market. The EU's ambition for GHG emission reductions is achieved: 80-95% GHG reduction.

The strategy focuses on the deployment of large-scale RES technologies, e.g. large scale offshore wind parks in the North Sea and Baltic Seas as well as the Desertec project in North Africa. A lower priority is given to the deployment of decentralized RES (including CHP and Biomass) solutions.

Similarly, a high priority is given to the development of centralized storage solutions (pumped hydro storage, compressed air, etc…) which accompanies the large-scale RES deployment. Decentralized storage solutions are considered to be insufficient to support the large-scale RES deployment: they are not given priority.



Nuclear technology as a centralized technology is included in this Scenario. Yet, no development in new nuclear technologies is assumed: the current level of deployment is maintained according to standard decommissioning rates for present nuclear plants up to 2050. Since only Europe has a strong policy for the reduction of GHG emissions, CCS technologies are not mature enough (high cost): they are not among the options to reach GHG reduction targets.

Electrification of Transport, Heating and Industry is considered to occur both at centralized (large scale) and decentralized (domestic) level. However, the political focus is mainly on the supply side: large amount of fossil-free generation will make investments in energy efficiency solutions less attractive. A low increase in energy efficient solutions is foreseen (including DSM and flexibility of EV use). Moreover, a clear shift towards 'greener' behaviours is experienced compared to e.g. present practices (focused and active involvement towards more energy efficiency, focused and active involvement towards more use of sustainable energy by the European citizen).

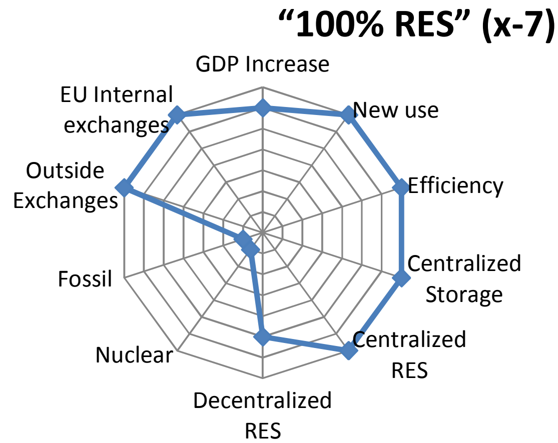
A convergent and strong policy framework for the whole European Member States is in place: the deployment of the available RES potential is possible everywhere. Common agreements/rules for transnational initiatives regarding the functioning of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges exist.

Little attention paid to large-scale solutions which lowers the priority for imports of fossil fuels at EU level. As a consequence, Europe's energy dependence is low. However, a high import of RES from North Africa – Desertec project is included.

8.4.4 100%RES (x-7)

In this Scenario, the global community has not succeeded in reaching a global agreement for climate mitigation. Yet, Europe is fully committed to its target of 80-95% GHG reduction and the CO2 costs in EU are high due to these strict climate mitigation targets.

The strategy to achieve this target has a higher ambition than the other scenarios: it bases Europe's energy system entirely (100%) on renewable energy. To reach this target, both large scale and small-scale options are used: offshore wind parks in the North Sea and Baltic Seas and the Desertec project in North Africa, combined with EU-wide deployment of de-centralized RES (including CHP and Biomass) solutions.



Public attitude towards the deployment of RES technologies is very positive in the whole Europe, while attitude towards nuclear and shale gas is negative.

Neither nuclear nor fossil fuels with CCS are used in this Scenario. Thus, both centralized storage solutions (pumped hydro storage, compressed air, etc…) and de-centralized solutions are needed to balance the variability in terms of renewable energy generation

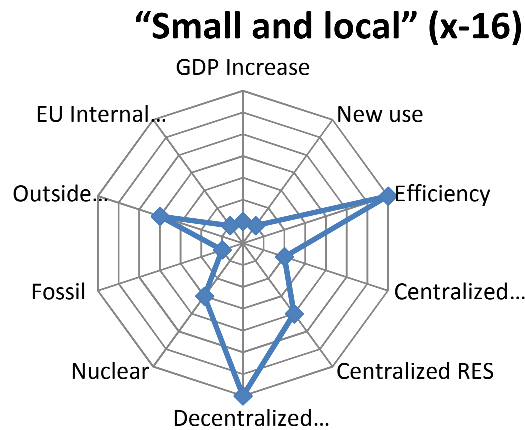
On the consumer side, a marked increase in energy efficiency (including DSM and flexibility of EV use) is also needed. Electrification of transport, heating and industry is considered to occur both at centralized (large scale) and de-centralized (domestic) level and these solutions will reduce resulting energy demand as well as provide complementary flexibility and storage to account for variability of RES production from PV and wind. There is a strong drive towards 'greener' behaviors in the population with active involvement towards more energy efficiency, more use of sustainable energy and clean transport etc.

As part of the 100% RES strategy, no import of fossil fuels occurs. Only renewable sources (solar energy from Africa, biomass from FSU region etc) are imported from outside EU.

8.4.5 Small and local (x-16)

In this Scenario, the global community has not succeeded in reaching an agreement for climate mitigation. Yet, Europe is fully committed to meet its target of 80-95% GHG reduction. Compared to the other scenarios, the European member states have chosen a bottom-up strategy mainly based on small-scale/local solutions to reach this target.

Common agreements/rules for transnational initiatives regarding the operation of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges do not exist. The focus is rather on local solutions dealing with de-centralized generation and storage and smart grid solutions at transmission and mainly on a distribution level.



In this Scenario, there is a high focus on deployment of de-centralized storage and RES solutions (including CHP and Biomass), while nuclear and CCS are not considered as options to reach the GHG emission reduction target. The public attitude towards the deployment of local de-centralized RES technologies is positive in the EU.

A high degree of electrification of transport, heating and industry is considered to occur mainly at de-centralized (small scale) level; there is a corresponding high focus on the deployment of energy efficient solutions (including DSM and flexibility of EV use).

GDP growth in EU is assumed low, mainly due an inhomogeneous economic activity landscape among Member States. Demographic change towards 2050 is assumed to be migration only at EU level.

A major shift towards 'greener' behaviors is experienced in this scenario compared to present practices. In general, the public is very active and most of the development occurs at a local de-centralized level.

The European permitting framework (including nature legislation) is also inhomogeneous/de-centralized at member state level. Some countries will still require energy imports from outside the EU.

8.5 Consistency of the chosen challenging scenarios with similar energy scenario building studies

A large number of past or on-going scenario studies have been reviewed before beginning to develop this methodology. Two main types of studies have addressed the challenges of decarbonization of the energy system in Europe:

- *Studies analysing how the European energy or electricity system should develop to obtain low carbon emissions, e.g. "EU Energy Road Map 2050", "Power Perspectives 2030" and "Power Choices".*
- *Studies focusing on a specific issue related to the decarbonisation of the energy or power system, e.g. IRENE-40 (what kind of a pan-European grid is preferred in a long term perspective in Europe).*

Several of the reviewed studies have the same time perspective as e-Highway2050: they analyse alternatives for a European power system with very low CO_2 emissions. The "EU Energy Road Map 2050" is specifically reflecting the EU's aims about a low carbon energy system in 2050 and with reduction of GHG emissions by 80-95% by 2050 compared to 1990 levels. The Road Map has five scenarios about how the low carbon future may be achieved: it provides consistent and quantitative information related to the alternatives. Moreover, the two European Climate Foundation's (ECF) studies "Roadmap 2050" and "Power perspectives 2030" and Eurelectric's "Power choices" provide alternative scenario analysis compared to "EU Energy Road Map 2050".

The present e-Highway2050 work provides European electricity stakeholders with an innovative methodology to infer the "extreme" energy scenarios which will be used by the project to identify, for each one, the most robust and sustainable grid architectures by 2050.

9 Summary

Work Package 1 (WP1) has established a comprehensive set of Boundary Conditions (BC) for the e-Highway2050 project. A detailed bottom-up approach has been used to ensure transparency and efficient communication of Boundaries to the other WP's, distinguishing between *uncontrollable Uncertainties* which are important for the development of an Electricity Highways System (EHS) but which the decision maker(s) cannot control, and *controllable Options* which can be chosen by the decision maker(s).

The following Boundary Conditions have been assessed in separate tasks in WP1: Technological BC, Economic and financial BC, Political, socio-political and environmental BC and Research, development and deployment BC. Furthermore, two questionnaires have been answered by European TSO's; the first about expected developments of load, generation and transmission, the second about national policies and codes. Through careful review by the project partners and feedback from stakeholders, the most relevant uncertainties and options have been identified in each category. These were used to establish possible e-Highway2050 Scenarios.

In the scenario building process, first qualitative definitions of relevant Futures and Strategies where established by assigning possible ranges to each of the most relevant Uncertainties and Options. Second, the list of possible Scenarios was reduced through elimination to a final list of *5 relevant e-Highway2050 Scenarios*. This is a feasible number of scenarios to perform detailed analyses in the following work packages, but may be further reduced during the numerical quantification in WP2. The tentative descriptive names for these scenarios are:

- Big & Market
- Large fossil fuel with CCS and nuclear
- Large scale RES and no emission
- 100% RES
- Small and local

We emphasize that the e-Highway2050 scenarios are neither predictions nor forecasts about the future. We do not conclude that one scenario will be more likely to happen than another, nor that one scenario is more preferred or "better" than another. Rather, each e-Highway2050 scenario is one alternative image of how the future of European Electricity Highways (EHS) could unfold.

10 References

[1] e-Highway2050 Deliverable D1.1.a "Review of useful studies, policies and codes". Open version, 20 March 2013

[2] "BP Energy Outlook 2030". Booklet. www.bp.com/sectiongenericarticle800.do?categoryId=9037134&contentId=7068677. Accessed Nov 2012.

[3] "Energy [R] evolution. Report 4th edition 2012 world energy scenarios" GWEC.EREC.Greenpeace. ISBN 978-90-73361-92-8.

[4] "Energy Technology Perspectives 2012. Pathways to a Clean Energy System" IEA. ISBN 978-92-64.17488-7.

[5] "World Energy Outlook 2012". IEA.

[6] "Shell Energy Scenarios to 2050" Shell International BU. 2008.

[7] European Commission "Energy Roadmap 2050", COM (2011) 885/2, SEC (2011) 1565

[8] Mittelstaedt Moritz et. al. "Scenario Benchmark" D3.2 IRENE-40 Draft version 2012,

[9] Eurelectric. "Power Choices. Pathways to Carbon-Neutral Electricity in Europe by 2050".

[10] "Roadmap 2050. A practical guide to a prosperous low-carbon Europe. Technical analysis" European Climate Foundation. April 2010 http://www.roadmap2050.eu/

[11] "Power Perspectives 2030. On the road to a decarbonized power sector". European Climate Foundation. http://www.roadmap2050.eu/project/power-perspective-2030. Accessed Nov 2012.

[12] Vafeas A et al. "Realisegrid D1.4.2 Final WP1 report on cost/benefit analysis of innovative technologies and grid technologies roadmap report validated by external partners". May 2011

[13] Loulou R et al. "Realisegrid D2.3.2 Final report of WP2 on results of long term scenario analysis for European power systems". June 2011

[14] Bakken Bjørn et al. "Final Report" SUSPLAN Deliverable D7.2, Dec 2011. www.susplan.eu

[15] Graabak Ingeborg et al. "Profitable increases in cross border transmission capacities in a European power system with large shares of renewables", SINTEF TR A7216 June 2012

[16] "Getting in the right Lane for 2050", Netherlands Environmental Assessment Agency/ Stockholm Resilience Centre, 27-10-2009. http://www.pbl.nl/en/publications/2009/Getting-into-the-Right-Lane-for-2050

[17] "The challenges of intermittency in North West European power markets", Pöyry, March 2011

[18] "Energy Corridors", European Commission. Directorate-General for Research. Directorate Energy. EUR 22581.2007

[19] http://www.fenix-project.org/. Accessed Nov 2012

[20] http://icoeur.eu/index.php/structure.html?showall=1. Accessed Nov 2012.

[21] "Medgrid. Opening new lines for sustainable electricity" www.medgrid-psm.com/en. Accessed Nov 2012.

[22] http://ec.europa.eu/energy/international/studies/external_dimension_en.htm Accessed Nov. 2012

[23] http://ec.europa.eu/energy/infrastructure/tent_e/doc/off_shore_wind/2011_annual_report_Annex2_en.pdf Accessed Nov. 2012

[24] Decker J. D. et al "OffshoreGrid Electricity Grid Infrastructure in Europe. Final report". October 2011

[25] "Feasibility Study. Synchronous Interconnections of the IPS/UPS with the UCTE. Summary of Investigations and Conclusions" Dec 2008, www.ucteipsups,org

[26] Veum K et al. "Roadmap to the deployment of offshore wind energy in the Central and Southern North Sea 2020-2030" Windspeed, August 2011.

[27] "RE-thinking 2050: A 100% Renewable Energy Vision for the European Union", European Renewable Energy Council, April 2010. http://www.rethinking2050.eu/fileadmin/documents/ReThinking2050_full_version_final.pdf

[28] "100% renewable electricity: A Roadmap to 2050 for Europe and North Africa", PriceWaterhouseCoopers, March 2010, http://uk.sitestat.com/pwc/uk/s?ukws.eng_publications.pdf.sustainability.the_climate_principles_progress_review&ns_type=pdf&ns_url=http://www.pwc.co.uk/pdf/100_percent_renewable_electricity.pdf

[29] "Moving towards 100% renewable electricity in Europe & North Africa by 2050", PriceWaterhouseCoopers, May 2011, http://www.pwc.com/en_GX/gx/sustainability/research-insights/assets/renewable-electricity-2050.pdf

[30] http://www.twenties-project.eu/node/1. Accessed March 2013

[31] European Wind Integration Study (EWIS), Final report March 2010, http://www.wind-integration.eu/downloads/

[32] Wagner F. "Feature of an electricity supply system based on variable input", IPP Report 18/1, September 2012. http://edoc.mpg.de/get.epl?fid=100920&did=618631&ver=0

[33] "Roadmap 2050. A practical guide to a prosperous low-carbon Europe. Volume 2: Policy recommendations." European Climate Foundation, April 2010. http://www.roadmap2050.eu/

[34] Klobasa M and Boie I. "Synthesis on implementation strategies for decision makers" SUSPLAN Deliverable D5.4, December 2011. www.susplan.eu

[35] e-Highway2050 Milestone M1.1 "Summary of Technology boundary conditions". March 2013

[36] "Renewable Electricity Futures Study", National Renewable Energy Laboratory (NREL), 2012 http://www.nrel.gov/analysis/re_futures/

[37] Schroeder et al. "Draft paper on current and prospective production costs of electricity generation", TU Berlin 2012

[38] "Cost and performance data for power generation technologies" prepared for the National Renewable Energy Laboratory, Black and Veatch, February 2012 http://bv.com/docs/reports-studies/nrel-cost-report.pdf

[39] e-Highway2050 Milestone M1.2 "General conditions for e-Highway2050 Scenarios". March 2013

[40] e-Highway2050 Milestone M1.3 "Economic and financial boundary conditions". March 2013

[41] United Nations (2011): World Population Prospects, the 2010 Revision [WWW Document]. URL http://esa.un.org/unpd/wpp/excel-data/population.htm

[42] Eurostat (2011): Regional yearbook (No. KS-HA-11-001). European Union, Luxemburg.

[43] Eurostat (2012): NUTS classification [WWW Document]. URL http://epp.eurostat.ec.europa.eu/portal/page/portal/nuts_nomenclature/introduction

[44] e-Highway2050 Milestone M1.4 "Political, Socio-Political and Environmental Boundary Conditions", March 2013

[45] Johansson, Å, Guillemette, Y, Murtin, F, Turner, D, Nicoletti, G, Maisonneuve, C de la, Bagnoli, P, Bousquet, G, Spinelli, F (2012): Looking to 2060: Long-Term Global Growth Prospects. OECD Economic Policy Papers.

[46] Fouré, J, Bénassy-Quéré, A, Fontagné, L (2012): The Great Shift: Macroeconomic projections for the world economy at the 2050 horizon. CEPII: Centre d'Études Prospective et d'Informations Internationales, France.

[47] U.S. Energy Information Administration (2011): International Energy Outlook 2011. Washington DC.

[48] "Discussion paper on Boundary Conditions towards an Electricity Highways System 2050", ENTSO-E, 8 March 2012

[49] e-Highway2050 Milestone M1.4 "Political, Socio-Political and Environmental Boundary Conditions", March 2013

[50] e-Highway2050 Task 1.5: "Research, development and grid deployment conditions", March 2013.

[51] European Commission, "Green paper A 2030 framework for climate and energy policies" COM(2013) 169 final, March 27-th 2013

[52] European Commission "A Roadmap for moving to a competitive low carbon economy in 2050", COM(2011) 112 final, Brussels, 8.3.2011

[53] European Commission, "White Paper: Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" COM(2011) 144 final, Brussels, 28.3.2011

[54] European Parliament Resolution on a Roadmap for moving to a competitive low carbon economy in 2050: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P7-TA-2012 0086&language=EN&ring=A7-2012-0033

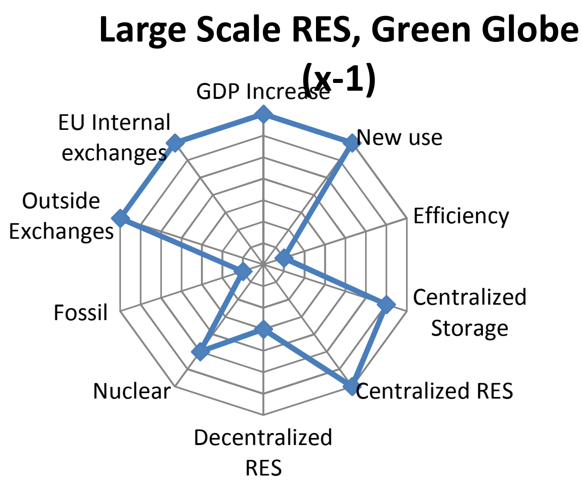
[55] European Parliament Resolution on the White Paper on a Single European Transport Area: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P7-TA-2011-0584&language=EN&ring=A7-2011-0425

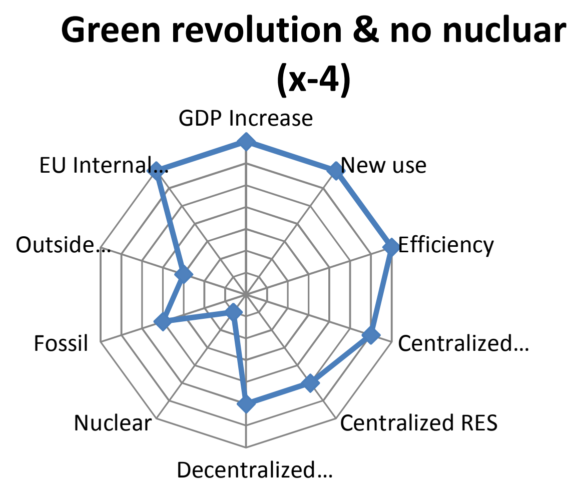
[56] European Parliament Resolution on the Energy Roadmap 2050: http://www.europarl.europa.eu/sides/getDoc.do?type=TA&reference=P7-TA-2013-0088&language=EN&ring=A7-2013-0035

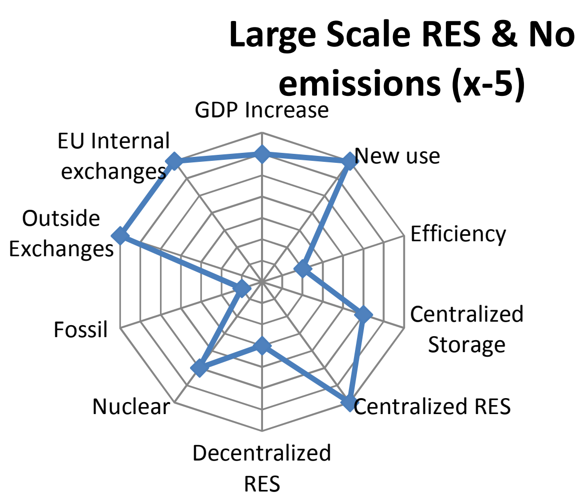
Annex 1

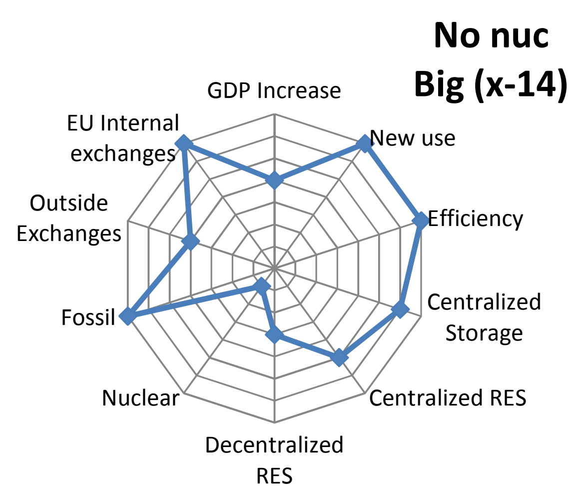
This Annex summarizes the 15 scenarios which have been studied in details before leading to the five selected scenarios for Transmission System by 2050.

Group 1



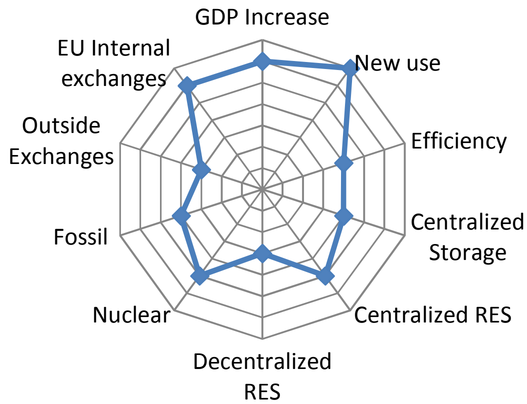




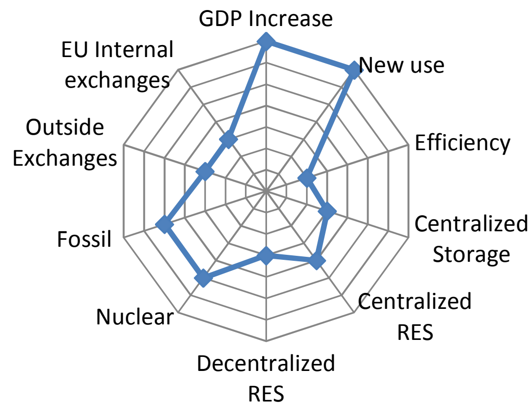


Group 2

Big & Market (x-10)

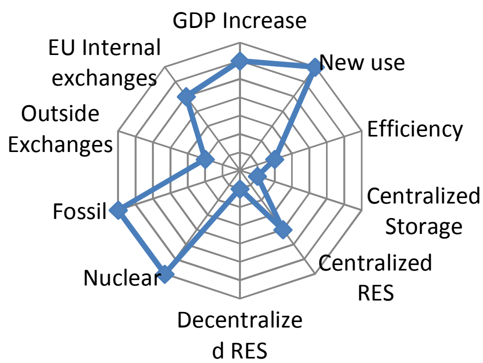


Pure Market (x-8)



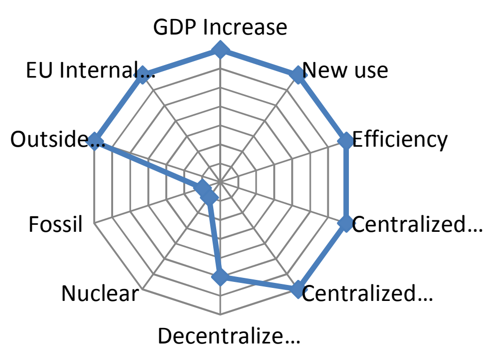
Group 3

Big, Nuc & CCS (x-13)

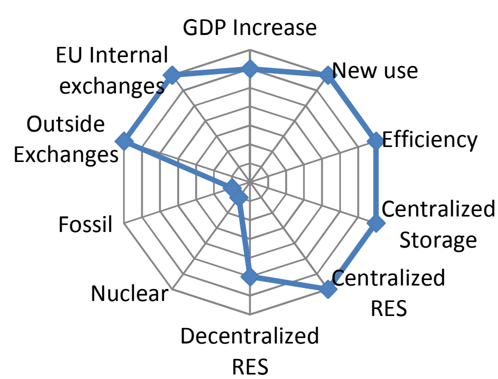


Group 4

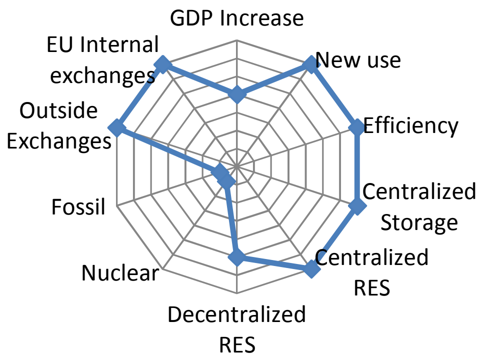
100% RES, Green Globe (x-3)



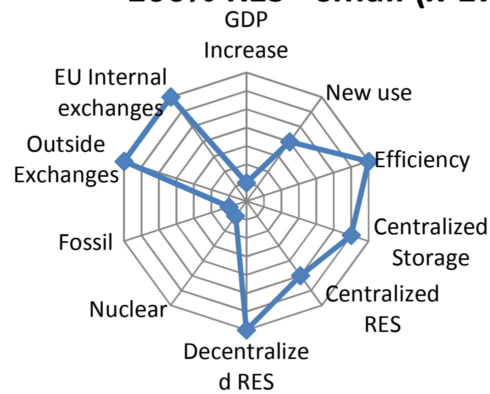
"100% RES" (x-7)



100% RES Big EU (x-12)

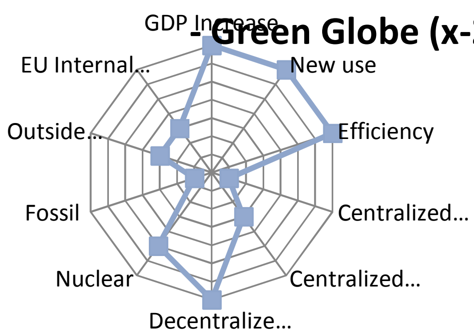


100% RES - small (x-17)

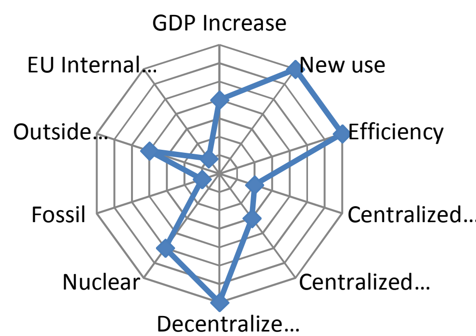


Group 5

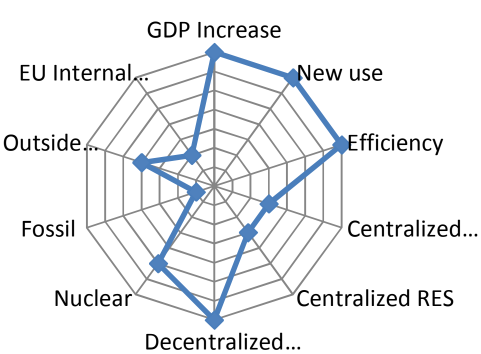
Local solutions - Green Globe (x-2)



Local solutions (x-6)



local solutions & market (x-9)



"Small and local" (x-16)