Report with reference scenario and related offshore meshed HVDC grid topology

PROMOTioN – Progress on Meshed HVDC Offshore Transmission Networks
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This result is part of a project that has received funding form the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

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DOCUMENT HISTORY

Version	Date	Main modification	Author
1.0			
2.0			

WP Number	WP Title	Person months	Start month	End month

Deliverable Number	Deliverable Title	Type	Dissemination level	Due Date

DOCUMENT INFO SHEET

Document Name:	Report with reference scenario and related offshore meshed HVDC grid topology
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DOCUMENT HISTORY

Version	Date	Main modification	Author
1.0			
2.0			

WP Number	WP Title	Person months	Start month	End month
WP1	Requirements for meshed offshore grids	138	1	24

Deliverable Number	Deliverable Title	Type	Dissemination level	Due Date
D1.4	Report with reference scenario and related offshore meshed HVDC grid topology	Report	Public	15

LIST OF CONTRIBUTORS

Work Package and deliverable involve a large number of partners and contributors. The names of the partners, who contributed to the present deliverable, are presented in the following table.

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CONTENTS

ABBREVIATIONS

Term	Meaning
CCGTs	Combined-Cycle Gas Turbines
CCS	Carbon Capture and Storage
DSM	Demand Side Management
EC	European Commission
ENTSO-E	The European Network of Transmission System Operators for Electricity
ETS	Emissions Trading System
EV	Electric Vehicle
FSU	Former Soviet Union
GHG	Greenhouse gas
IEA WEO	International Energy Agency World Energy Outlook
IEM	Internal Energy Market
LNG	Liquefied Natural Gas
NREAPs	National Renewable Energy Action Plans
OWF	Offshore Wind Farm
RES	Renewable Energy Source
RIP	Regional Investment Plan
SOAF	Scenario Outlook and Adequacy Forecast
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan
WEE	Wind Energy Europe

1 INTRODUCTION

This document presents Deliverable 1.4 (D1.4) of Work Package 1 (WP1) of the PROMOTioN project. The purpose of this deliverable is to provide relevant scenarios for potential installed wind capacities in the Northern Seas and load/generation of surrounding countries based on available information. These scenarios will be used by other work packages as a basis for their activities and will inform the relevant metrics on future anticipated cases. Especially when meshed HVDC connections are used as an interconnector in non-windy situations, scenario assumptions are needed to value the interconnection capacity. The cost-benefit analyses from other Work Packages for various topology alternatives are based on the WP1 metrics.

In chapter 2 the content of the available made scenarios for the PROMOTioN project are summarized in order to explain the fundamental assumptions of the scenarios. Further, in chapter 3 the scenarios are discussed on their possible application in the PROMOTioN project and future updates of the scenarios are addressed. Finally the content of the available databases made available from these scenarios are listed.

Reconfiguration of the Deliverable

The PROMOTioN project plan describes the deliverable as such:

D1.4: Report with reference scenario and related offshore meshed HVDC grid topology

The scenarios for installed generation and demand development are described in this deliverable. This includes both on- and offshore figures which are an input for the business case study

The deliverable has been adjusted slightly to improve the usefulness for the PROMOTioN project. The fundamental topologies were already introduced in D1.1, describing the possible building blocks of a meshed offshore HVDC grid. Different needs were identified within the project for topologies. There is a need for a set of sufficiently simple topologies, so that the more technical Workpackages can create output that has been modelled on the same topologies. These topologies are already published and applied in Work Packages 2 and 4, which are further explained in respectively Deliverable 2.1 and 4.1. As the creation of these topologies is already covered within the project, these are not included in this deliverable.

2 SCENARIOS

2.1 SELECTED SCENARIOS

For the PROMOTioN project there is a need for scenarios with installed wind capacities for Northern Seas countries and load/generation of Northern Seas countries. This deliverable aims to make useful scenarios available to the project, explain choices for certain scenario's and explain the background of the scenarios. For the purpose of the PROMOTioN project there is a need for scenario's that show load and generation patterns of power flows, installed wind capacities and focus on the Northern Seas area with neighbouring countries. Further it will be useful if scenario's are updated regularly in order for PROMOTioN to make use of the scenarios based on the most recent data and developments.

The scenario's produced by The European Network of Transmission System Operators for Electricity (ENTSO-E) in the framework of the Ten Year Network Development Plan (TYNDP) are largely publicly available, which ensures a transparent and therefore accountable and reliable data set, and is developed on a bi-annual basis, which ensures a consistency in updated TYNDPs. The TYNDP with its focus on grid planning and grid development for Europe, and a guaranteed update of scenario's is fit for purpose for the PROMOTioN project. However the focus of the TYNDP2016 is limited to 2020 and 2030. To expand the timeline of scenarios a combination is made with the Modular Development Plan of the Pan-European Transmission System 2050 (e-Highway2050) from e-Highway2050, which builds further on the previous TYNDPs creating a certain consistency between both data sets. Further, currently ENTSO-E is developing their scenarios for TYNDP 2018 which will be scenarios for the year 2040 and will be built on the previous TYNDP and the developments in e-Highway2050.

Both TYNDP and e-Highway2050 have a detailed database for load/generation European countries as well as installed capacities for offshore and onshore wind and other generation units. The remainder of this chapter serves to introduce and explain the scenarios of the TYNDP (2.1) and e-Highway2050 (2.2).

Table 1 – Scenarios; overview of the scenario's developed in the TYNDP and e-Highway 2050 studies

Study	Scenarios	Projection time	Scope	Published
TYNDP 2016	• Expected progress • Slowest progress (V1) • Constrained progress (V2) • National green transition (V3) • European green revolution (V4)	2020 2030	EU	Bi-annually (latest instalment 2016)
e-Highway 2050	• Fossil & nuclear • Big & market • Large-scale RES • Small & local • 100% RES	2040 and 2050	EU	2015

Besides these two scenarios, a large range of scenario's are available globally, with different levels of detail, availability of data and geographical focus. Nevertheless, these International energy scenario's such as

International Energy Agency World Energy Outlook (IEA WEO) or Technology Perspectives, World Energy Council scenario's or Industry scenario's from BP, Exxon, and Shell, focus on global trends with large regions such as Europe, Africa and China, these scenario's lack load and generation profiles and are not as transparent as other scenarios. Therefore, for the purpose of the PROMOTioN project, these scenarios are not further considered.

2.2 TEN YEAR NETWORK DEVELOPMENT PLAN (TYNDP) 2016

This paragraph introduces and explains the TYNDP scenarios. The contents are based on TYNDP reports that are publicly available on **www.TYNDP.entsoe.eu** [1] [2] [3] [4]. Credits for this content therefore belong to ENTSO-E.

Timely and well-planned development of new network infrastructure is crucial in achieving the European internal energy market (IEM), as well as allowing for the integration of an ever increasing amount of renewable energy, and meeting the challenge of more dispersed on- and offshore energy sources which need be connected with major demand centres. This is why EU legislation has mandated ENTSO-E with the delivery of a biennial TYNDP the first pilot of which was released in 2010. [1]

The TYNDP identifies gaps in infrastructure from a European perspective and informs decision makers in Member States and other stakeholders about projects with a network-wide impact. [1]

The TYNDP builds on national and regional investment plans called RIPs. ENTSO-E has formed six regional groups (one of which is the north sea) to identify and address network investment and development challenges reflecting regional particularities and needs. [1]

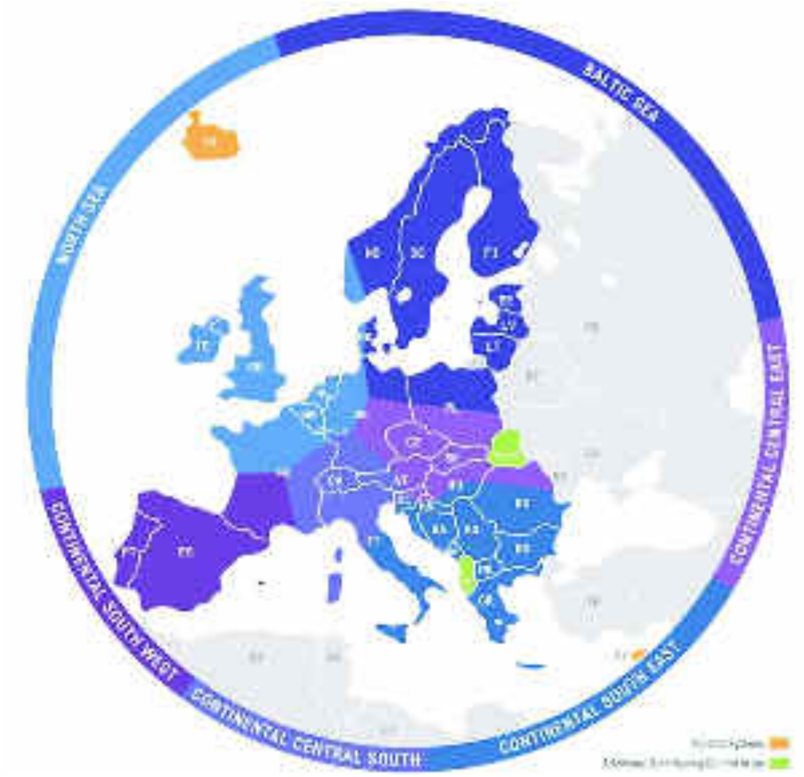

Figure 1 – Six regional groups ENTSO-E [1]

The TYNDP package also includes ENTSO-E's Scenario Outlook and Adequacy Forecast (SOAF) which assesses and forecasts long-term generation adequacy and provides the base scenarios for market and network studies developed within the TYNDP framework. [1]

2.2.1 SCENARIOS IN TYNDP [3]

For the long-term horizon 2030, four contrasting 'Visions' are presented which differ in terms of energy governance and Renewable Energy Source (RES) ambitions. In addition a mid-term 2020 'best estimate scenario' is covered to allow grid infrastructure candidates to be valued at a mid-term horizon as well.

The TYNDP 2030 Visions present contrasting scenarios that reflect similar boundary conditions and storylines for every country, and which differ enough from each other to capture a realistic range of possible future pathways. All result in different future challenges for the grids which a TYNDP grid endeavours to accommodate. The mid-term TYNDP 2020 scenario gives a best estimate for this time frame. The goal of the scenarios is to eventually allow TYNDP projects to be assessed across the same range of possible futures.

A key strength of the ENTSO-E scenarios is that they combine the views of national plans provided via Transmission System Operator (TSO) correspondents, the expertise and large variety of tools of dozens of market modelling experts, and the pan-European perspective via elaborate scenario development methodologies. Considering a close time horizon (max. 15 years) ENTSO-E scenarios are not developed as starting-from-scratch based on ideal optimizations, but are strongly linked with both national development plans and pan-European coordination. [3]

The consistency of the generation mix development strategy: Visions 1 and 3 are based upon each individual country's energy policies though still with a minimum harmonised approach across Europe; while Visions 2 and 4 assume a stronger top-down pan-European construction, based on new optimisation methods specifically developed for TYNDP 2016. [2]

To analyse the 2030 time-horizon, four visions are elaborated based on two axes. One axis is related to European ambitions and targets to reduce greenhouse gas emissions to 80-95% below 1990 levels by 2050. The axes provides a spectrum of progress, with the goal to assess the impact of progress/delay in decarbonisation of energy on grid development needs by 2030. The two selected outcomes are viewed to be extreme enough to result in very different flow patterns on the grid. The first selected outcome is a state where Europe is very well on track to realize the set objective of energy decarbonisation by 2050. The second selected outcome is a state where Europe progresses beyond 2020 targets to align with the recent 2030 targets set for renewables. It is assumed that the 27% target for renewables translates to about 40% of renewable share in electrical energy consumption.

The second axis relates to perspective of measures for decarbonisation of the energy system. This can be done firstly in a strong European framework in which national policies will be more effective, but not preventing Member States developing the options which are most appropriate to their circumstances, or secondly in a looser European framework effectively resulting in parallel national schemes. Figure 2 shows how the four Visions relate to the two axes.

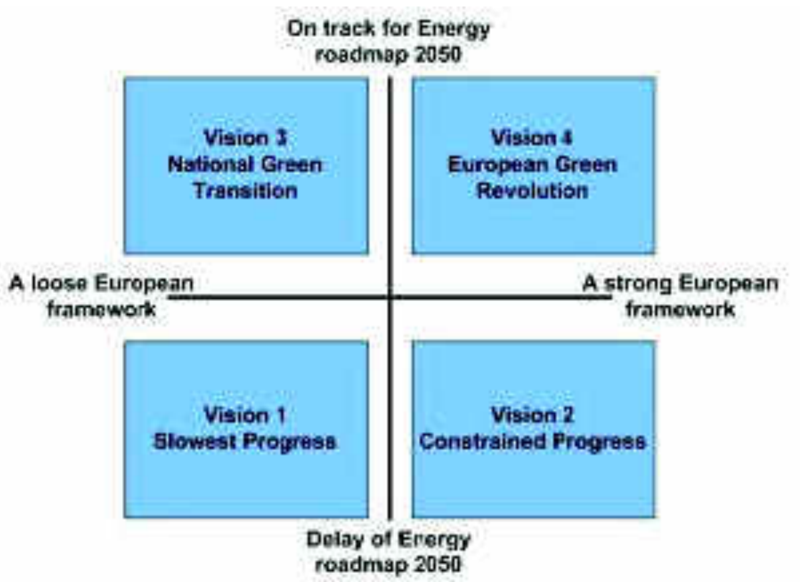

Figure 2 – Two-axis overview of the 4 Visions (general) [3]

2.2.2 STORYLINE 2020 SCENARIO AND 2030 SCENRIOS

The storylines of the TYNDP 2016 scenarios are described in the Table 2 – Table 6.

Table 2 – 2020 Best Estimate Scenario of "Expected Progress" **[3]**

Overall perspective	"Expected Progress" can be described as the best estimate of development until 2020, within the following boundaries.
Demand	Development of electricity demand is determined by diverging driving forces. On the one hand innovations lead to higher efficiencies of consumers and thus to a reduction of demand. On the other hand, innovation leads to a fuel switch of applications like electric vehicles, for example. A fuel switch towards electrification increases electric demand. Demand forecast in the "Expected Progress" scenario is the best national estimate available, under normal climatic conditions out to 2020. It is estimated according to technical and economic assumptions, especially on demography and economic growth.
Renewable Energy Sources	Binding EU driven national targets exist for the share of renewable energy sources in the energy mix by 2020. Renewable energy sources covered in this scenario report include electricity generation from solar, wind power, run-of-river, biomass and other supply depended renewable sources. The forecast of renewable energy sources in "Expected Progress" takes into account the current supporting mechanisms for renewable energy sources in each country and the expected development of support mechanisms, if changes are under discussion. Including the cost decrease, a realistic forecast for the year 2020 is derived, even if this means that the targets set by the National Renewable Energy Action Plans (NREAPs) will not be met.
Hydro Reservoir and Pumped Storage	In contrast to run-of-river power plants, hydro reservoir stations can regulate their electricity generation as long as their reservoir holds water. The creation of a new water reservoir is an expensive project which may cause high local environmental impact. Additional hydro generation capacity is only included in this scenario if the projects are confirmed and under construction. Pumped storage hydro stations are easier to build, if the required reservoir already exists and only the pumping machines have to be added. However, economic conditions for pumped energy storages are unfavourable, because of the absence of peak prices due to the high infeed of renewable energy sources. As such, also only confirmed pumped hydro projects are included.
Conventional Thermal Generation	The development of conventional thermal generation follows market mechanisms. As explained before this scenarios assumes the prices for emission certificates remain low. Due to coal-gas price spread the general economic conditions are more favourable for existing coal power stations. The estimated decommissioning of power stations is based on best available information and trends to TSOs. Regarding new units, only confirmed thermal power stations are taken into account. Carbon Capture and Storage (CCS) is assumed not to be an option yet for lignite and coal power stations by 2020.

	Generally, it is assumed that new nuclear power stations that are operational by 2020 need at least a final investment decision today, so that their construction will be finished by 2020. As a consequence, only confirmed new nuclear power projects are taken into account in this scenario. Power plants of the strategic reserve (as defined in some countries) are kept ready to start-up for emergency periods when secure operation of the system is at risk. They are not participating in the market. The capacity of power plants belonging to present strategic reserves have been included, but are in the market simulations distinguished from generation capacity that participates in the electricity markets. This scenario gives no specific assumptions about evolutions of strategic reserves or capacity mechanisms in the coming years.
Adequacy	"Expected Progress" should consider adequacy from a Pan-European perspective without explicitly addressing potential generation adequacy issues in some countries at present. This scenario does not assume autonomous adequacy of single countries. Still it is assumed that conventional thermal power stations do not face shortage in fuel supply, which might be different in a true generation adequacy analysis.
Emission and Fuel prices	Prices for CO2 emissions are currently low, which has an impact on the type of generation plant utilised in the electricity market. Under low CO2 prices, coal fired generation tends to be favoured over gas in the merit order. There is no indication of change in the short term of prices of emission certificates. Also natural gas prices in Europe have been relatively stable in recent years. In contrast, prices for import coal have decreased in previous years. As a consequence, based on primary fuel prices coal generation is favoured over gas generation. For the 2020 "Expected Progress" scenarios it is assumed that no major change happens in the boundary conditions for primary fuels and emission certificates.

Table 3 – 2030 Vision 1of "Slowest Progress" **[3]**

Economy and Market	The perspective of Vision 1 is a scenario where no common European decision regarding how to reach the CO2-emission reductions has been reached. Each country has its own policy and methodology for CO2, RES and system adequacy. Economic conditions are unfavourable, but there is still modest economic growth. This results in a limitation on willingness to invest in either high carbon or low carbon emitting sources due to investment risks, low CO2-prices and lack of aligned support measures. Consequently older power plants are kept online rather than being replaced if they are needed in order to maintain adequacy. The situation varies across countries. The absence of a strong European framework is a barrier to the introduction of fundamental new market designs that benefit from R&D developments resulting in parallel, loosely coordinated national R&D expenditure and cost inefficiencies. Carbon pricing remains at such a level that base-load electricity production based on hard coal is preferred to gas in the market.
Demand	In this Vision there are no major breakthroughs in energy efficiency developments such as large scale deployment of micro-cogeneration or heat pumps nor minimum

	requirements for new appliances and new buildings due to a lack of strong political and regulatory policy. There are also no major developments of the usage of electricity for transport such as large scale introduction of electric plug-in vehicles nor heating/cooling. A modest economic growth brings a modest electricity demand increase. Also demand response potential that would allow partial shifting of the daily load in response to the available supply remains largely untapped.
Generation	The future generation mix is determined by national policy schemes that are established without coordination at a European level. Due to a lack of joint framework and joint decision to reduce emissions, the generation mix in 2030, on a European level, fail to be on track for the realization of the energy roadmap 2050 and no additional policies are implemented after 2020 to stimulate the commissioning of additional RES except locally due to local subsidy schemes. Adequacy is handled on a National basis. Some countries may require complete adequacy while others may depend on neighbouring countries. Very little new thermal capacity will come online except in the case for subsidized production or adequacy required peak capacity. New CO2-emitters risk to be closed down after 2030 in order to reach the 2050 target; hence the financial risk is substantial and old units are kept online instead of replacing them. Nuclear power is a national issue. In some countries nuclear power is regarded as a clean and affordable source of electricity and new units are brought online before 2030.

Table 4 – 2030 Vision 2 of "Constrained Progress" **[3]**

Economy and Market	The perspective of Vision 2 is that the economic and financial conditions are more favourable compared to Vision 1 providing more room to reinforce/enhance existing energy policies. There is a strong European framework. The economic outlook facilitates new market implementations, and R&D expense focuses on cost cutting, increased energy efficiency and energy savings. On the other hand, there is a limitation on willingness to invest in either high carbon or low carbon emitting sources due to investment risks, low CO2-prices and lack of aligned support measures. Carbon pricing remains at such a level that base-load electricity production based on hard coal is preferred to gas in the market.
Demand	The breakthrough in energy efficiency developments (e.g. large scale deployment of micro-cogeneration or heat pumps as well as minimum requirements for new appliances and new buildings) and the development of the usage of electricity for transport (e.g. large scale introduction of electric plug-in vehicles) and heating/cooling is driven by innovation caused by R&D expenses focused on cost cutting and energy saving. As a consequence the electricity demand is lower compared to Vision 1. Furthermore, demand response potential is partially used to shift the daily load in response to the available supply, as it allows savings in backup capacity.
Generation	The future generation mix is driven by a strong European Vision which faces still financial challenges and construction delays due to permitting issues, combined with a halt in the implementation of additional policies needed for the realization of the energy

	roadmap 2050. As a consequence, lifetime extension of existing conventional thermal power plant is likely. Some additional policies are implemented after 2020 to stimulate the commissioning of additional RES, causing RES capacity to be higher than in Vision 1. Decarbonisation is only driven by carbon pricing (no additional policies are assumed if carbon prices are too low to ensure a lower usage of coal fired units). Adequacy is ensured on a European level in order to have the optimized cost for society. This results in less back-up capacity than for Vision 1.

Table 5 – 2030 Vision 3 of "National Green Transition" **[3]**

Economy and Market	Vision 3 shows economic conditions being more favourable than in Vision 1 and 2. It results in member states having more financial means to reinforce existing energy policies. Still a loose European energy governance is a barrier to the introduction of fundamental new market designs that fully benefit from R&D developments. Furthermore, opting for parallel national schemes regarding R&D expenses also results in a situation where major technological breakthroughs suffer from suboptimal R&D spending. Energy policies drive carbon pricing (e.g. the EU Emissions Trading System (ETS), carbon taxes or carbon price floors) to levels such that baseload electricity production based on gas is preferred to hard coal. On the balance gas is likely to push out hard coal for baseload electricity generation.
Demand	Developments in energy efficiency, as well as electrification of transport and heating/cooling minimize the ecological footprint. On the balance electricity demand is lower than in Vision 1 on European level. Demand response potential is partially used to shift the daily load in response to the available supply.
Generation	The future generation mix is determined by parallel national policy schemes that are aiming for the decarbonisation objectives for 2050. Large scale RES expansion drives the price of RES electricity production to a competitive level. The cost of the electricity system will be higher than it would be for the case with a strong European framework, since RES and adequacy is handled on a national basis without cooperation between the countries. Demand response potential is used, however, the majority of the additional back-up capacity in 2030 would come from gas units since additional central hydro storage is not developed due to the lack of a strong European framework. Only some extra national storage is developed (e.g., pump storage, decentralized batteries) Favourable economic conditions in combination with capacity mechanism (if needed) on a national basis result in conventional power plant investments and additional backup-capacity. Adequacy is handled on a national basis without cooperation

	between the countries. Old units are more likely to be decommissioned. New nuclear power plant projects become economically unattractive; only projects with a national acceptance for existing (or with final investment decision already made) are included in this vision. Carbon capture and storage are not (yet) economically attractive but are developed for pilot plants and for full-size demonstration plants.

Table 6 – 2030 Vision 4 of "European Green Revolution" **[3]**

Economy and Market	Vision 4 sees financial conditions that are more favourable than in any of the other Visions, allowing member states to reinforce existing energy policies. Significant investments in sustainable energy generation are undertaken. Furthermore, a strong European framework makes the introduction of fundamental new market designs that fully benefit from R&D developments more likely. This also allows R&D expenses to be optimized so that major technological breakthroughs are more likely. Energy policies drive carbon pricing (e.g. the EU Emissions Trading System, carbon taxes or carbon price floors) to reach levels such that baseload electricity production based on gas is preferred to hard coal. Gas is likely to push out hard coal for baseload electricity generation.
Demand	Efforts in energy efficiency developments (e.g. large scale deployment of micro cogeneration or heat pumps as well as minimum requirements for new appliances and new buildings) and further electrification of transport and heating/cooling are intensified. Furthermore market designs are adapted in such a way that the highest energy savings coincide with the highest energy substitution to electrical. Electrical usage still outweighs efficiency savings, giving a net energy increase. These new usages are intensified through additional national and/or European subsidies. Furthermore the demand response potential is fully used to shift the daily load in response to the available supply, because it allows a saving on back-up capacity.
Generation	The future generation mix is determined by a strong European Vision that is on clearly track to realize the decarbonisation objectives for 2050 at least cost. Thanks to a strong governance approach towards RES, RES is located in Europe in an optimal way lowering the cost for society. Likewise backup capacity to secure adequacy is handled on a European level. Large scale RES expansion drives the price of RES electricity production to a competitive level. Smart metering and smart grids are fully developed and thus demand response has a strong take-up. Additional hydro storage is built in centralized manner (focusing predominantly on Scandinavia, the Alps and the Pyrenees), with the remaining additional back-up capacity in 2030 coming predominantly from gas units. In this Vision no generating technology receives specific support and technologies compete with each other purely on a market basis. Furthermore decarbonisation is driven by carbon pricing.

	New nuclear power plant projects are not economically viable due competitiveness of RES production and no public acceptance for new projects. Older nuclear power plants are not considered flexible enough to balance the demand and RES and are consequently phasing out in areas with high RES production.

Figure 3 shows in more detail the differences between the four visions in relation to the key characteristics of the storyline behind the four visions.

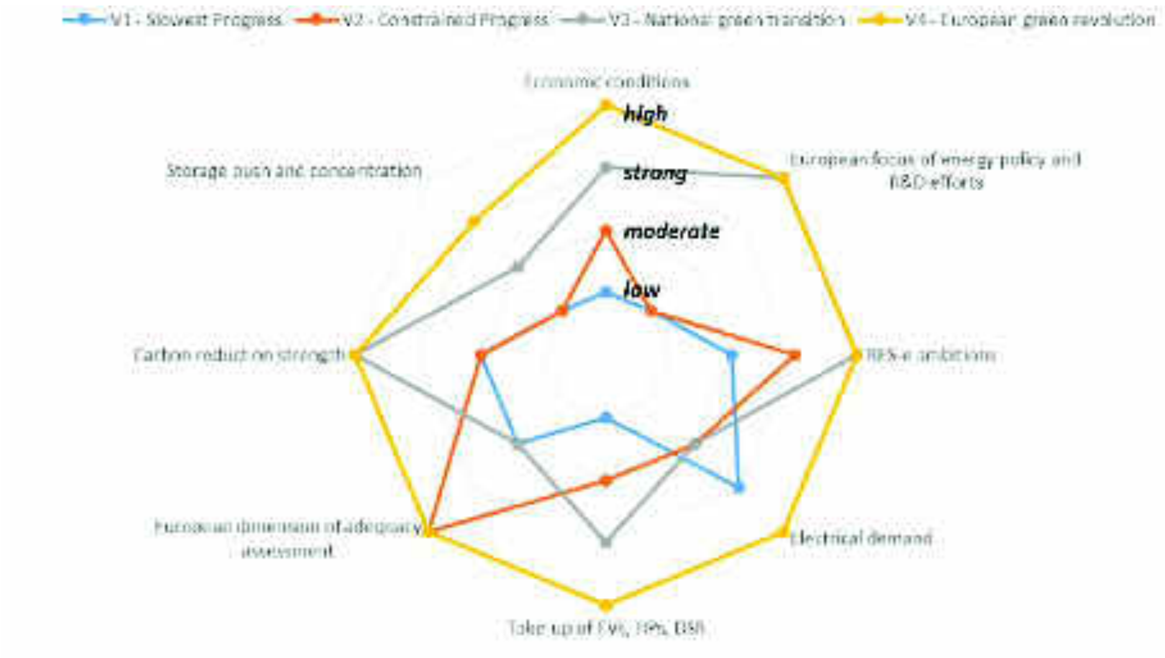

Figure 3 – Characteristics overview of the 4 Visions (more detailed) [3]

Table 7 shows a summary of the characteristics of the four visions.

Table 7 – Summary of characteristic elements of the 4 Visions [3]

	Slowest progress	Constrained progress	National green transition	European green revolution
	V1	V2	V3	V4
Economic and financial conditions	Least favourable	Less favourable	More favourable	Most favourable
Focus of energy policies	National	European	National	European
Focus of R&D	National	European	National	European
CO_2 and primary fuel prices	low CO_2 price, high fuel price	low CO_2 price, high fuel price	high CO_2 price, low fuel price	high CO_2 price, low fuel price
RES	Low national RES (>= 2020 target)	Between V1 and V3	High national RES	On track to 2050
Electricity demand	Increase (stagnation to small growth)	Decrease compared to 2020 (small growth but higher energy efficiency)	Stagnation compared to 2020)	Increase (growth demand)
Demand response (and smart grids)	As today	Partially used	Partially used	Fully used
	0%	5%	5%	20%
Electric vehicles	No commercial break through of electric plug-in vehicles	Electric plug-in vehicles (flexible charging)	Electric plug-in vehicles (flexible charging)	Electric plug-in vehicles (flexible charging and generating)
	0%	5%	5%	10%
Heat pumps	Minimum level	Intermediate level	Intermediate level	Maximum level
	1%	5%	5%	9%
Adequacy	National - not autonomous limited back-up capacity	European - less back up capacity than V1	National - autonomous high back-up capacity	European - less back up capacity than V3
Merit order	Coal before gas	Coal before gas	Gas before coal	Gas before coal
Storage	As planned today	As planned today	Decentralized	Centralized

2.2.3 OVERVIEW OF THE GENERAL AGGREGATED QUANTIFICATIONS [3]

The four 2030 Visions show a range of electrical demand from 3318 TWh (Vision 2) to 3680 TWh (Vision 4), in line with the scenario storyline. The 2020 Expected Progress shows a yearly change rate of electricity demand between 2014 and 2020 of around 1%/year at the level of the ENTSO-E perimeter. Note that the scenario building uses data collections of 2014; Figure 4 shows historical data up to 2014, and scenario interpolations beyond that year.

Figure 4 – Comparison of the annual demand among the five scenarios [3]

Figure 5 shows with which generation technology the demand in the four visions and the expected progress scenario is covered.

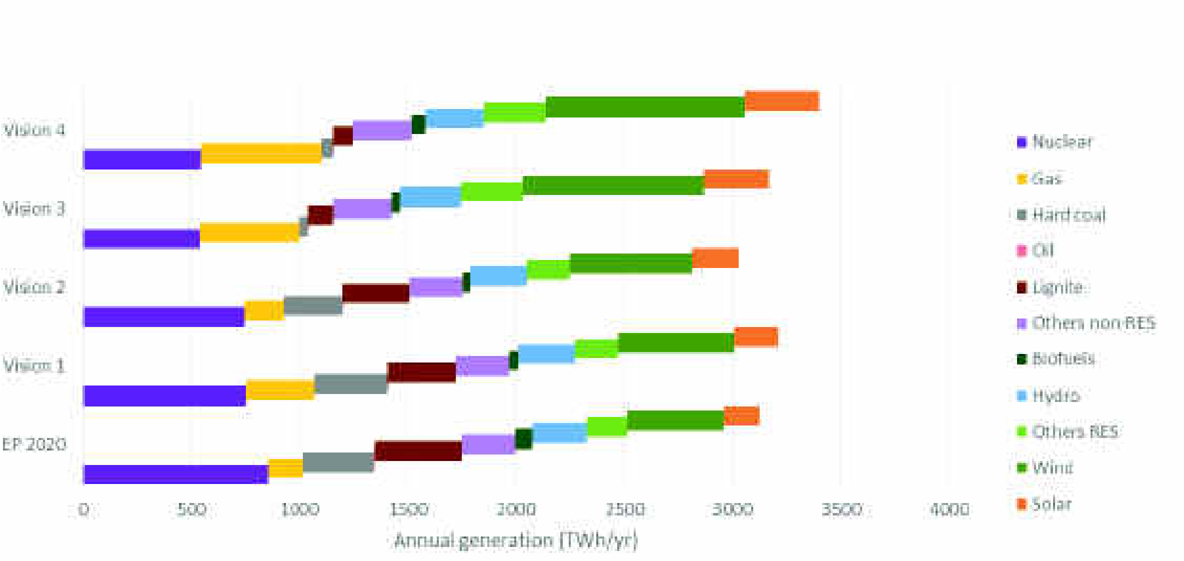

Figure 5 – Annual generation in each scenario – breakdown per technolgy class [3]

The installed capacity of wind and solar (Figure 6) increases from Vision 3 to Vision 4 in order to cover the increase of demand from Vision 3 to Vision 4. Thus, Visions 3 and 4 show the same share of the electricity demand being supplied by wind and solar sources.

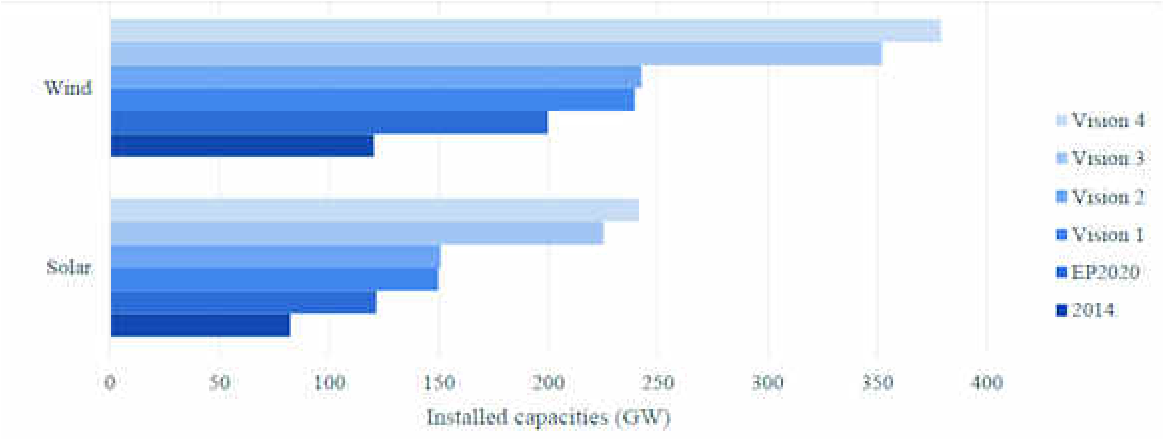

Figure 6 – Comparions of installed capaciteis [3]

The percentage of the demand covered by RES spreads from 44% in Vision 1 to close to 60% for Visions 3 and 4 as plotted in Figure 7. The total RES installed capacity in Vision 4 was increased compared to Vision 3 in order to keep the same percentage of electrical demand being covered by RES generation in both scenarios. All the 2030 Visions are expected to be in line with the recent 2030 targets set for renewables. Not that in case less energy efficiency savings are assumed (thus higher electrical demand), the %RES figure would drop.

To place it in perspective of the present situation, EUROSTAT's latest report (based on 2014 data) gives a 27.5% RES level in the EU-28 region [5].

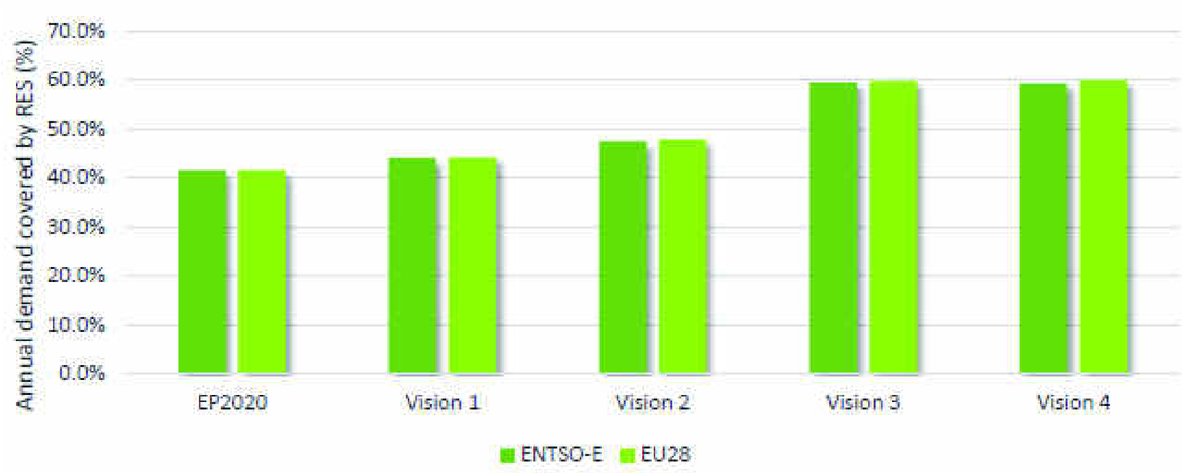

Figure 7 – Comparison of %RES [3]

2.2.4 TYNDP SCENARIOS COMPARED TO OTHER AVAILBALBE SCENARIOS

An issue in the use of scenarios for grid development, is the ever possible confusion when comparing different development plans (in particular national versus pan-European). ACER's opinion on consistency of ten-year network development plans highlights the different approaches in national plans (e.g. frequency of updates, time horizon) in which main directions are most often set in perspective of national policies. As plans and scenarios continuously evolve there is a challenge to any reader when comparing a pan-European plan for 2030 published in 2016 with for example a national plan published in 2015 looking at 2025.

A comparison of installed generation and electrical demand with the European Commission (EC) trends and IEA WEO may be valuable. It is worth noting the different strengths of each scenario report. On one hand pure energy-models (such as the PRIMES model used in the EC trends) allow to look forward based on an optimization of all energy components, not purely electricity but also gas and oil which all interact. On the other hand power-based models (such as the ones used by ENTSO-E in this report) are based on electricity market simulations which take into account full-year hourly based profiles of load and climate data, as well as grid constraints. Such power-based models allow to assess price zone differentials, RES spillage, country balances, etc. and are key in the methodologies which make the bridge from bottom-up scenarios to top-down scenarios.

Making an explicit comparison between the 2020 and 2030 scenarios in this report and 2050 outlooks (EC trends, IEA, electricity-Highways 2050 project) can be done on a qualitative level as it based on roadmap and progress assumptions. The four 2030 Visions are on track with the recent set targets for 2030, and as such are assumed to also all be on track to meet the ambitious 2050 goal of decarbonisation of the generation fleet, though at a different pace.

The comparison in Figure 8 has been performed by TYNDP 2016, scaling the ENTSO-E scenarios to the EU 28 perimeter to match with the EU trends to 2050 and the IEA WEO 2014 EU 28 perimeters. For the EU trends to 2050 and the WEO2014, the snapshot for the year 2030 was used as comparison. In the EU 28 perimeter, the ENTSO-E 2030 Visions annual demand ranges from 3062 (Vision 2) to 3397 TWh (Vision 4). The IEA scenarios from the WEO 2014 ranges from 3362 TWh (“450 Scenario”) to 3798 TWh (“Current policies”).

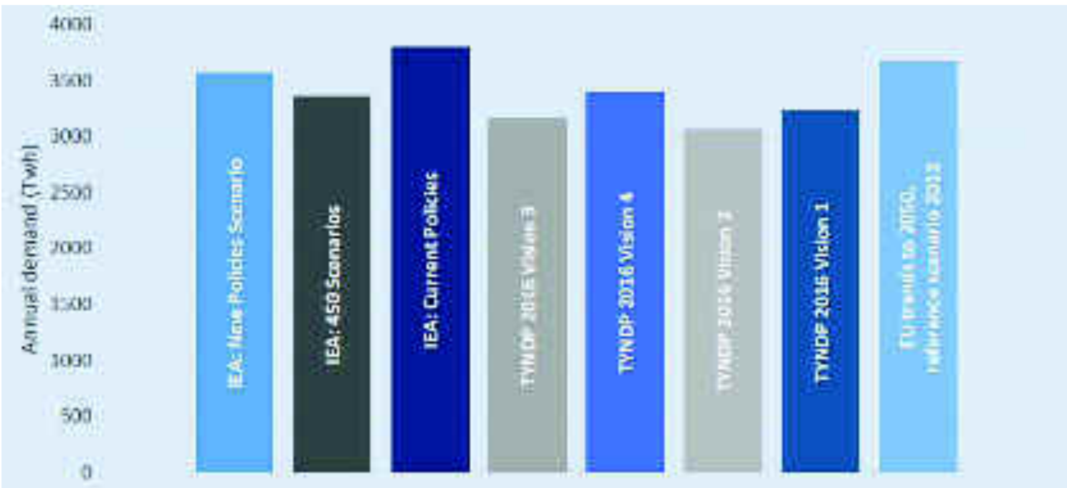

Figure 8 – Comparison of the annual demand for the year 2030 (EU 28 perimeter) [3]

Further, since one of the main objectives of meshed offshore grids is to evacuate large scale offshore wind energy to shore it is valuable toe zoom in into the different scenarios for installed capacities offshore. The publically available database of TYNDP makes no distinction between onshore and offshore wind. For the

PROMOTioN project this distinction is needed for the North Sea area and was therefore requested by ENTSO-E. This data shows the following installed offshore and onshore wind capacities for the North Sea area in Figure 9 and Figure 10 .

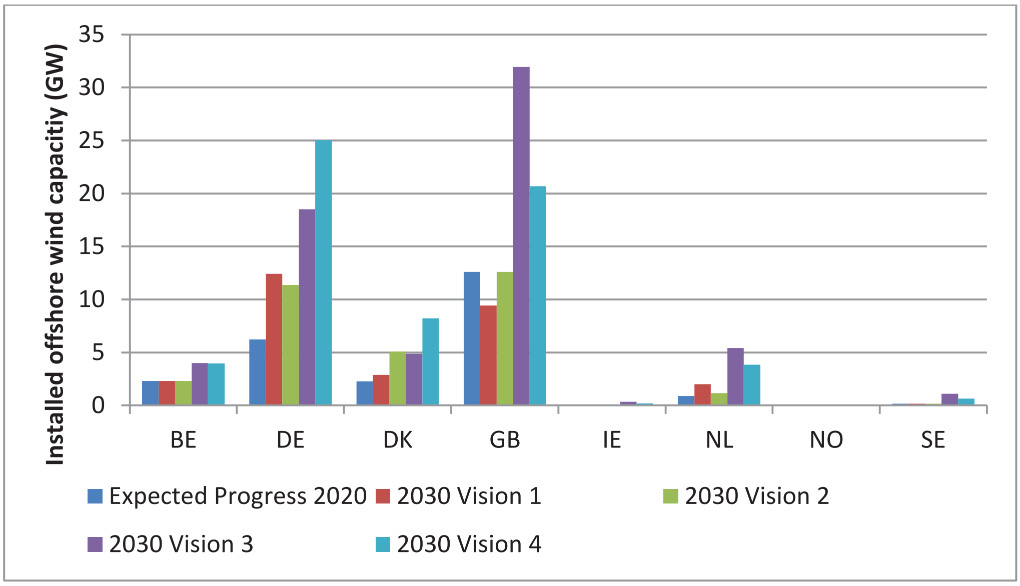

Figure 9 – Instaled offshore wind capacities for the North Sea area in the TYNDP scenarios

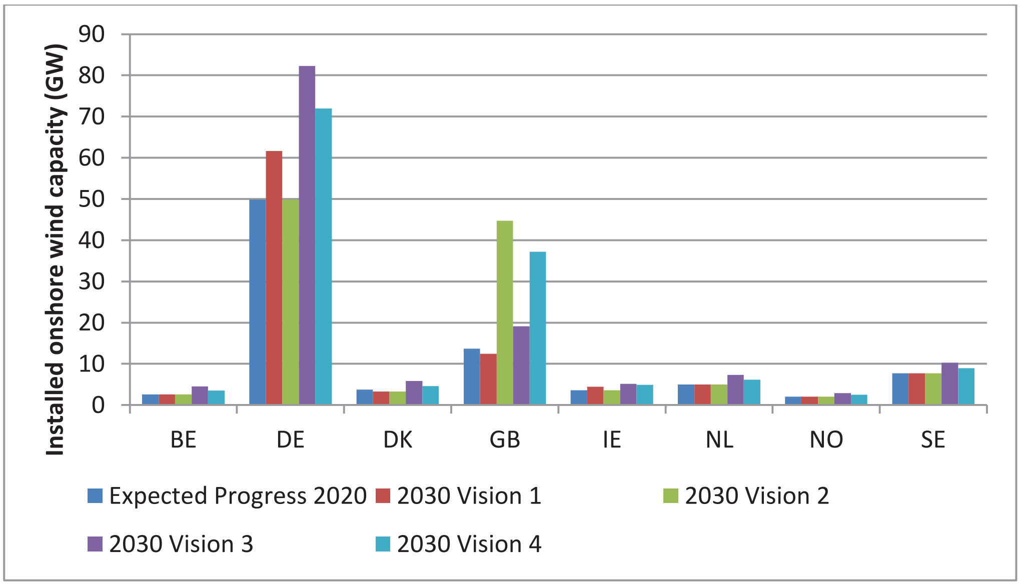

Figure 10 – Installed onshore wind capacities for the North Sea area in the TYNDP scenarios

To see if these scenarios are in line with the scenarios from the wind energy industry represented by Wind Energy Europe (WEE) a comparison is made (Figure 11) between the Expected Progress and the four Visions from TYNDP for the North Sea countries and the 2020 target scenario and the low, central and high scenarios for 2030 of WEE for the North Sea countries (excluding Norway due to no data mentioned by WEE). The TYNDP 2020 scenario is for both on- and offshore wind a bit more optimistic. For the onshore wind scenarios the TYNDP scenarios the 2020 scenario and the high renewable scenarios (Vison 3 and 4) are more optimistic than the expectations of WEE.

For the offshore wind 2030 scenarios the low WEE scenario is more optimistic than the low RES Visions 1 and 2 from TYNDP. The high WEE scenario shows a slightly higher installed capacity for wind compared to Vision 3 of TYNDP. Overall the scenarios of TYNDP are for offshore wind roughly in line with the scenarios of WEE.

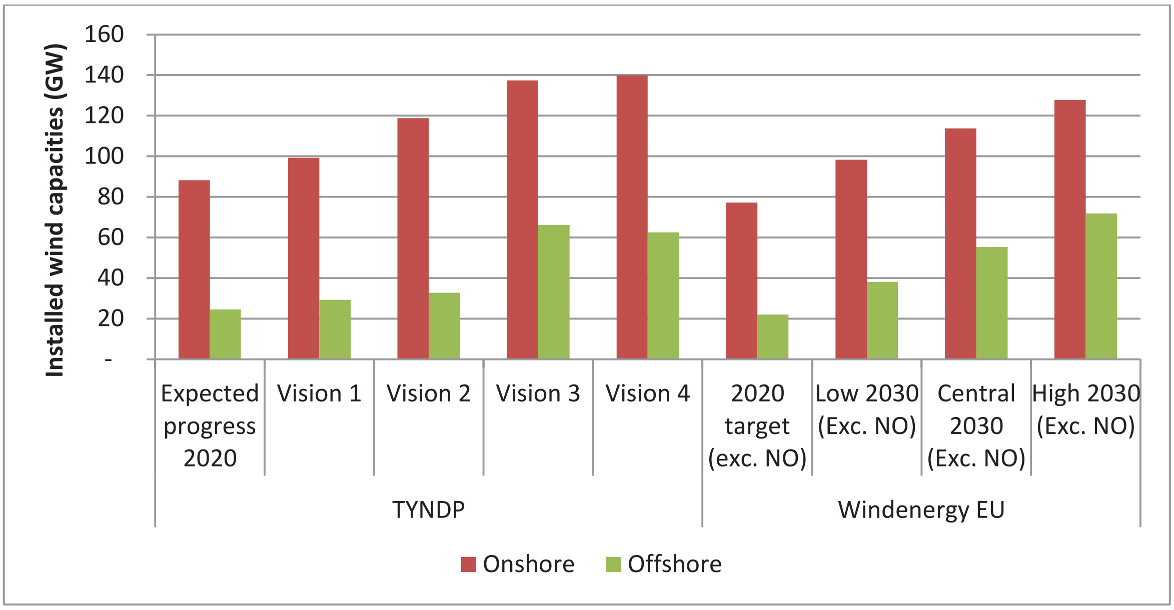

Figure 11 – Wind capacity scenario comparison between TYNDP and WEE

2.3 E-HIGHWAY2050

This paragraph introduces and explains the e-Highway2050 scenarios. The contents are based on e-Highway2050 reports that are publicly available on **www.e-Highway2050.eu** [6] [7] [8] [9]. Credits for this content therefore belong to e-Highway2050.

The ENTSO-E addresses the developments of the pan-European electricity transmission network until 2030 in the TYNDP. Starting with the same network configuration for 2030, the e-Highway2050 research and innovation project goes until 2050: it deals with the transition paths for the whole power system, with a focus on the transmission network, to support the European Union in reaching a low carbon economy by 2050. [9]

The overarching objective of e-Highway2050 is to develop a top-down planning methodology to provide a first version of a modular and robust expansion plan for the Pan-European Transmission Network from 2020 to 2050, in line with the pillars of European energy policy. The project is aimed at planning the Pan-European Transmission Network, including possible highways, capable of meeting European needs between 2020 and 2050. [6]

2.3.1 SCENARIOS IN E-HIGHWAY2050 [9]

The scenarios presented hereafter are the outcome of a sorting process implemented to select extreme scenarios regarding their impact on the transmission grid. They aim to explore a wide scope of plausible and predictable challenges to be faced by the power system. These challenges are driven by changes in generation, demand, energy storage and level of power exchanges. The e-Highway2050 scenarios are neither predictions nor forecasts about the future: the report does not consider any of them to represent the future, nor does it assume any to be more likely than the others.

2.3.2 STORYLINE SCENARIOS

2.3.2.1 LARGE SCALE RES AND LOW EMISSIONS [8]

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 Greenhouse gas (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 development of large solar resources in the south, including Africa (e.g. 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 Demand Side Management (DSM) and flexibility of electric vehicle (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 is 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.

Compared with others, this scenario envisages the highest electricity demand to be supplied by large scale centralized RES solutions.

2.3.2.2 100% RES [8]

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 CO_2 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' behaviours 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 Former Soviet Union (FSU) region etc.) are imported from outside EU.

Compared with others, this scenario provides the most challenging conditions for the 2050-time horizon. The European energy mix will be based on 100% RES.

2.3.2.3 BIG AND MARKET [8]

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 decentralized 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’ behaviours 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.

2.3.2.4 LARGE FOSSIL FUEL WITH CCS AND NUCLEAR [8]

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, CO_2 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' behaviours 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.

Europe is mainly relying on the non-RES technologies. Fossil fuel plants with CCS and nuclear play fundamental roles in the energy mix.

2.3.2.5 SMALL AND LOCAL [8]

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 decentralized RES technologies is positive in the EU.

A high degree of electrification of transport, heating and industry is considered to occur mainly at decentralized (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' behaviours 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 decentralized 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.

In this scenario, focus is on de-centralized RES. 60% of the demand is covered mostly by decentralized RES, while centralized RES fulfil 25% of the demand. Fossil fuel-fired power plants and nuclear power plants cover 5%, respectively 10% of the demand. X-16 is the scenario with the lowest annual demand (3.159 TWh per year) amongst the scenarios considered in the e-Highway 2050 project.

SUMMARY

The five challenging scenarios are summarized in Figure 12, going from a low to maximum RES generation contribution.

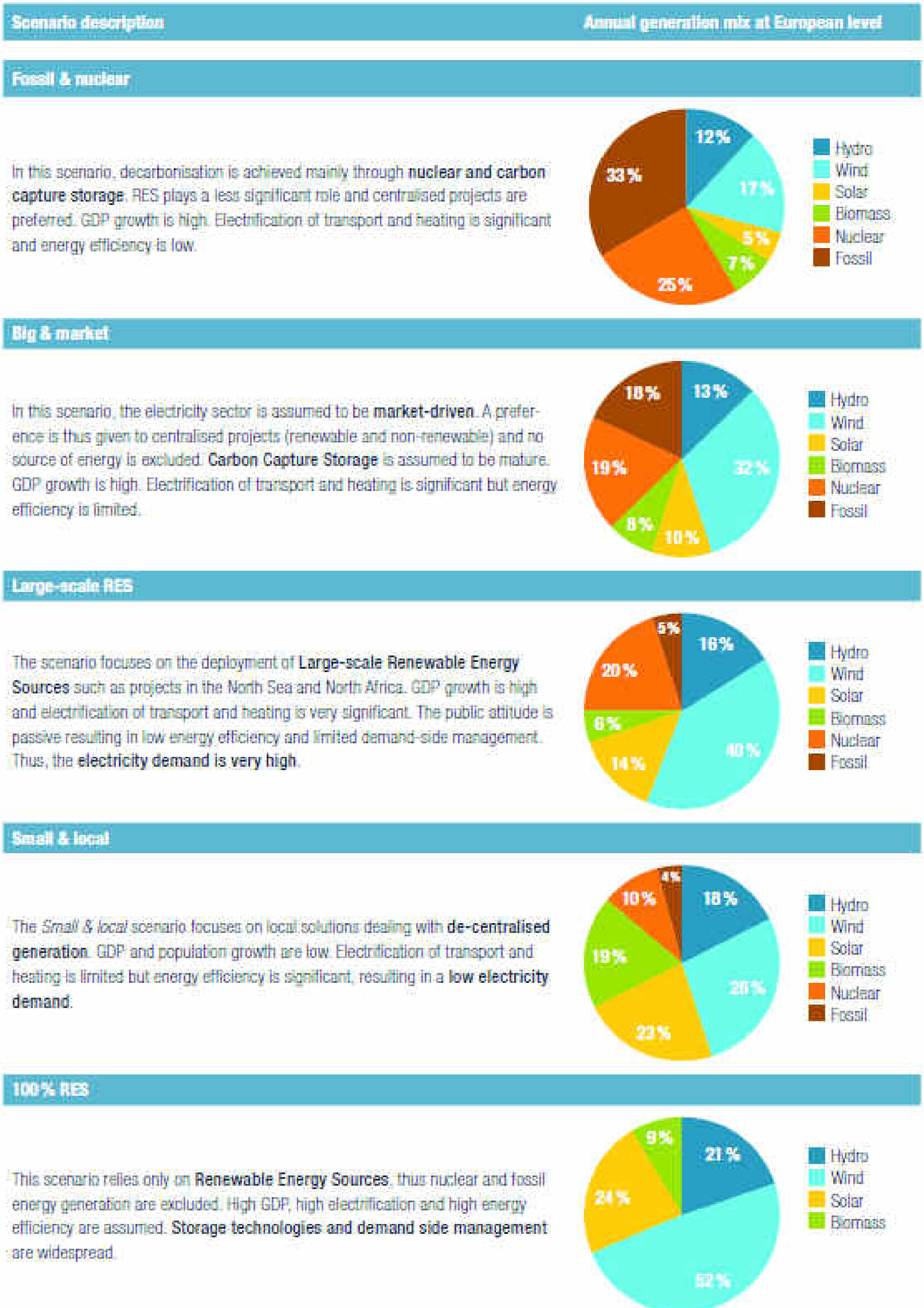

Figure 12– The five challenging scenarios: short scenario description (left) and corresponding European mix (right) [9]

Each scenario covers different backgrounds in terms of:

- Economy (GDP, population growth, fuel costs);
- Technology (maturity of CCS);
- Policies (incentives towards RES, energy efficiency, national / European energy independency);
- Social behaviour (nuclear acceptance, preference towards decentralised generation).

These various contexts result in significantly different assumptions for generation, electricity demand, storage, and power exchanges. The major differences between the five scenarios are presented qualitatively in Figure 13.

The share of RES in the annual European generation ranges from 40% to 100%. Wind generation is high in the scenarios Large-scale RES and 100% RES at levels of 40 – 50% of the generation mix. Solar generation plays a major role in the scenarios 100% RES and Small & local with about 25% of the total generation mix. Nuclear generation ranges from 19 to 25% of the generation mix in three of the five scenarios (Large-scale RES, Big & market and Fossil & nuclear). Indeed, nuclear helps achieving the 2050 EU decarbonisation orientations. The 100% RES scenario is nuclear generation free. Fossil energy sources remain high in the scenarios Big & market and Fossil & nuclear with 18% and 33% of the generation mix, respectively, since for these scenarios, the CCS technology is assumed to be mature. The share of fossil generation in the other scenarios stands below 5%.

Note: The generation mix refers to the proportion of each energy source in the annual generation. As seen in Figure 13, the yearly demand changes from one scenario to the other.

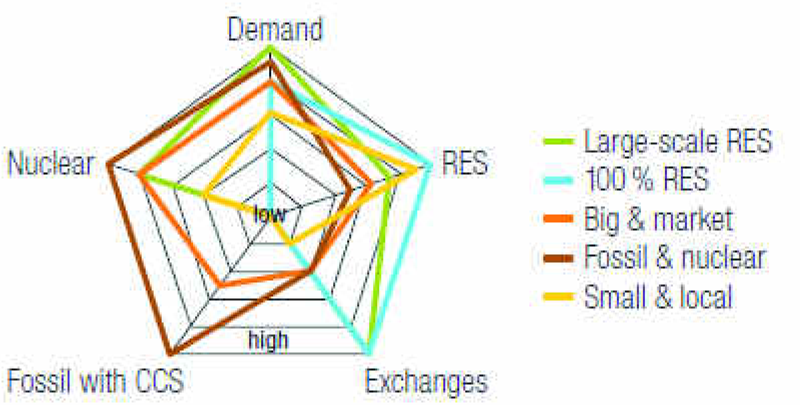

Figure 13 – Major differences between the scenarios [9]

2.3.3 GENERATION, DEMAND AND STORAGE ASSUMPTIONS IN THE SCENARIOS [9]

The annual electricity demand is depicted in Figure 14, for all of the 33 European countries considered and for each scenario. The assessment involves some of the scenario criteria, i.e. GDP and population growth, the use of electricity for heating, industry and transportation and energy efficiency measures. As a result, the European electricity demand varies significantly for each of the scenarios. The scenario *Small & local* has the smallest total volume (3.200 TWh), which is close to the 2013 levels (3.277 TWh). By contrast, the demand in the scenario *Large-scale RES* (5.200 TWh) is 60% more than the levels measured in 2013. The three other scenarios lie in-between such extreme values. The evolution of the minimal and maximal loads follow the same trends: the highest peak load – 926 GW – is encountered in the scenario Large Scale RES whereas the smallest – 532 GW – occurs in *Small & local* and is similar to 2013.

For each scenario, generation capacities are defined in Europe to meet the demand, consistent with each of the scenario backgrounds. The geographical dimensions retained for the study involved one hundred “clusters” covering the whole Europe and some neighbouring countries (see Figure 19). Indeed, due to the uncertainties of such a long-term horizon and the complexity of addressing the whole continent, more detailed descriptions are not attainable. The main goal of the approach is to ensure an overall consistency, meaning European targets translated into local generation portfolios, while taking into account parameters like:

- The 2020 national renewable action plans;
- Wind and solar potentials in the clusters (including a maximum acceptable land cover);
- Wind and solar average capacity factors in the clusters;
- Population development;
- National policies towards nuclear;
- The hydraulic potential.

The RES capacities are located preferably in the most profitable clusters. However, a criterion of national energy autonomy is also taken into account for each scenario. For instance, in the scenario *Small & local*, no country supplies more than 10% of its electricity demand using imports. By contrast, in the scenarios *Large-scale RES* and *100 % RES*, some countries import nearly 60% of their electricity needs.

Thermal generation is also defined with a European perspective. Simulations are performed to assess the appropriate number of power plants necessary to ensure adequacy (assuming infinite network capacities). Thus, over capacity for generation units in Europe is avoided.

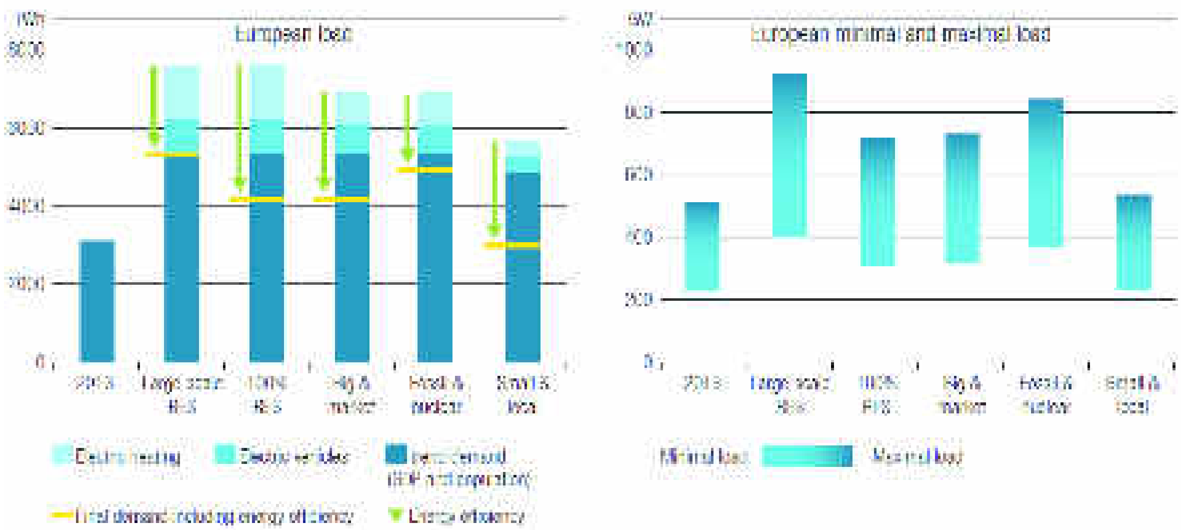

Figure 14 – European annual, minimal and maximal demands fo the five e-Highway2050 scenarios [9]

The realisation of such top-down scenarios would require a very high level of coordination within Europe, thus differing significantly from national independent plans. For each scenario, Figure 15 depicts the 2050 European installed capacities per technology with a reminder of the situation in 2012.

Wind generation capacity ranges from 260 GW to 760 GW plus from 15 GW to 115 GW in the North Sea. For solar generation, capacities range from 190 to 690 GW in Europe. Solar generation in North Africa is very high in the scenario Large-scale RES, covering up to 7% of the European demand with a solar installed capacity of 116 GW. In the 100% RES scenario, solar from the North African area covers 3% of the European demand and less than 1% for the other scenarios. The nuclear capacity increases compared to 2012 in the scenarios Fossil & nuclear and Large-scale RES – up to 169 GW and 157 GW, respectively. It decreases in the other scenarios. Biomass-based electricity generation, being a dispatchable RES source, reaches significant levels in the scenarios with high RES penetration. It reaches almost 200 GW in the scenario 100% RES. Noteworthy, in Figure 15, some fossils plants are displayed in the scenario 100% RES. It actually corresponds to plants that are necessary for adequacy; they are referred to here as “fossil” but other solutions, like more biomass / storage, or DSM measures, could also be imagined. However their profitability might be a critical issue as they serve only a few hours per year.

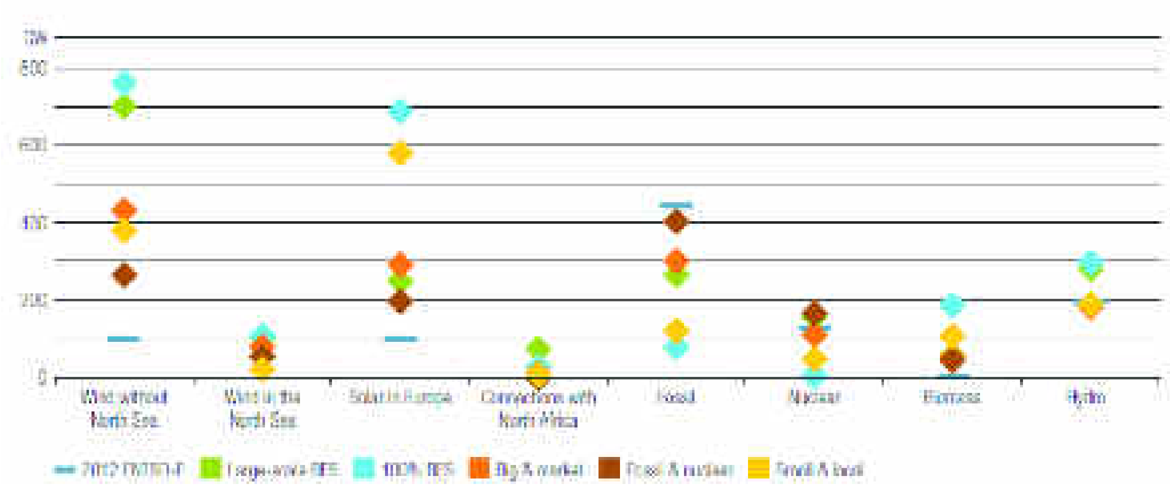

Figure 15 – European installed capacities per technology in the five scenarios at 2050 (compared to 2012) [9]

In Figure 16 a more detailed graph is presenting the installed wind capacities in the North Sea for the different scenarios.

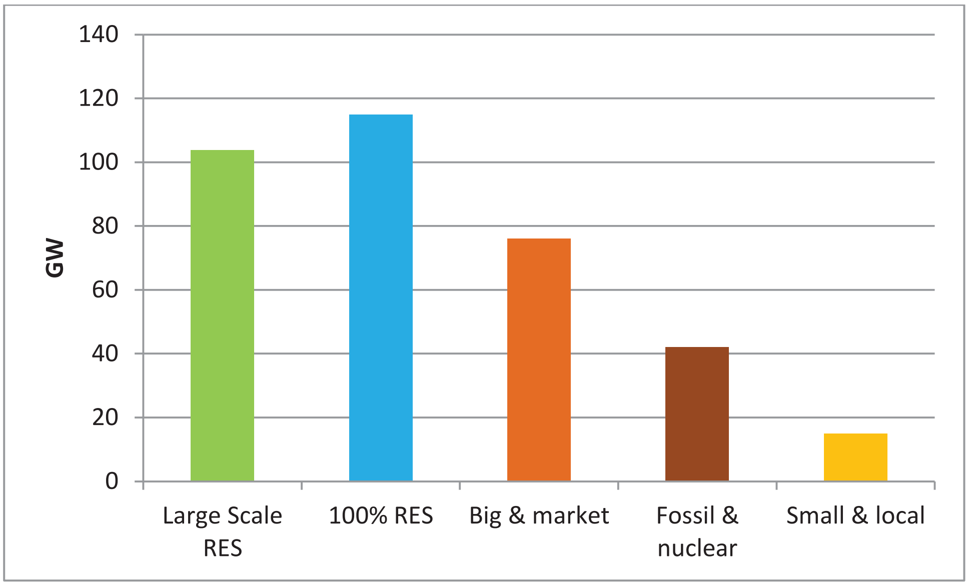

Figure 16 – Wind in the North Sea

With the high shares of renewable energy, the development of storage and demand side management is expected in the future. Ambitious assumptions are thus taken into account in the five scenarios as depicted in Figure 17, DSM is modelled as a shiftable load within the day. Electricity storage localisation and characteristics are based on typical Pumped Storage Plants.

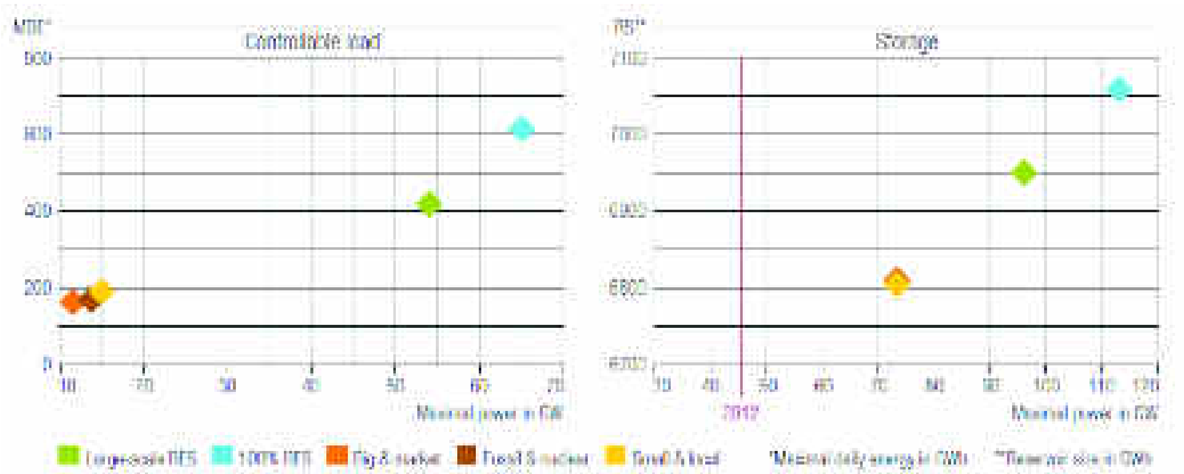

Figure 17 – European demand side management assumptions + European storage assumptions [9]

2.3.4 INTERMEDIATE 2040 SCENARIOS – LINK TO TYNDP

The 2040 scenarios of e-Highway2050 are constructed by linking the TYNDP 2016 Visions with the e-Highway2050 scenarios. The TYNDP 2016 has defined four “visions” to address the 2030 horizon. To assess the trajectory of the power system from 2030 to 2050, a corresponding 2030 vision is identified for each of the five 2050 scenarios consistent with the TYNDP2016 visions: it is considered as the most likely antecedent. Five 2040 scenarios are then defined by interpolating between the 2030 datasets of the TYNDP 2016 and the e-Highway2050 scenarios as presented in Figure 18. [7]

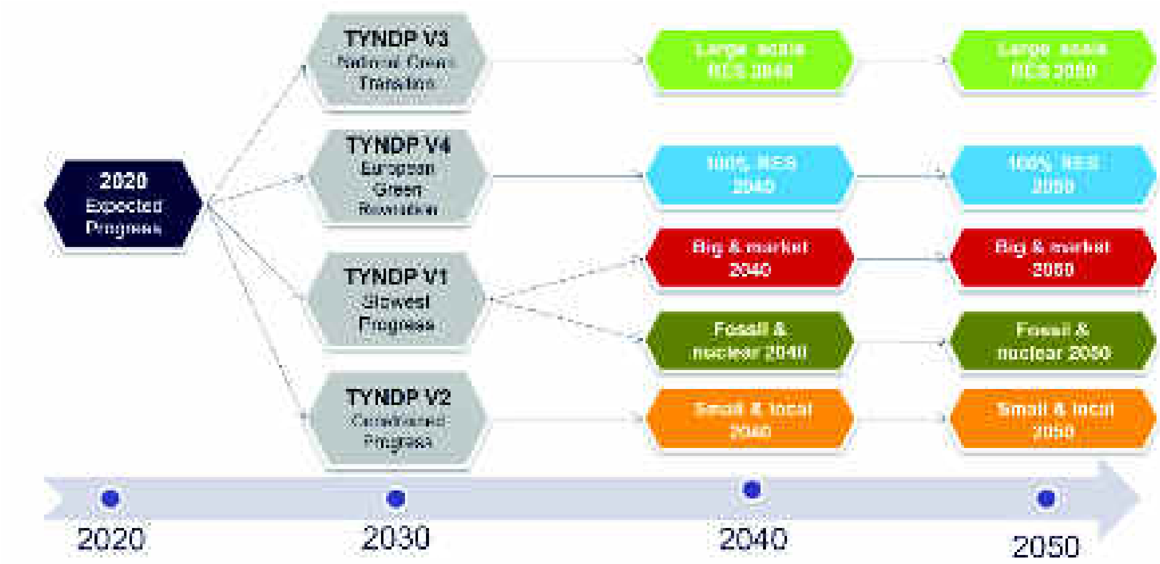

Figure 18 – Linking 2030 visions to 2050 scenarios [7]

For e-Highway2050 the countries are divided into clusters (Figure 19). Each cluster is considered as a copper plate in terms of grid, so only the transmission capacity and distance between cluster matters. Generation capacities and demand inputs are given per cluster, so the inputs for countries are an aggregation of the clusters of these countries. A comparison between the included countries of TYNDP 2016 and e-Highway2050 are listed in Table 10 in Annex II.

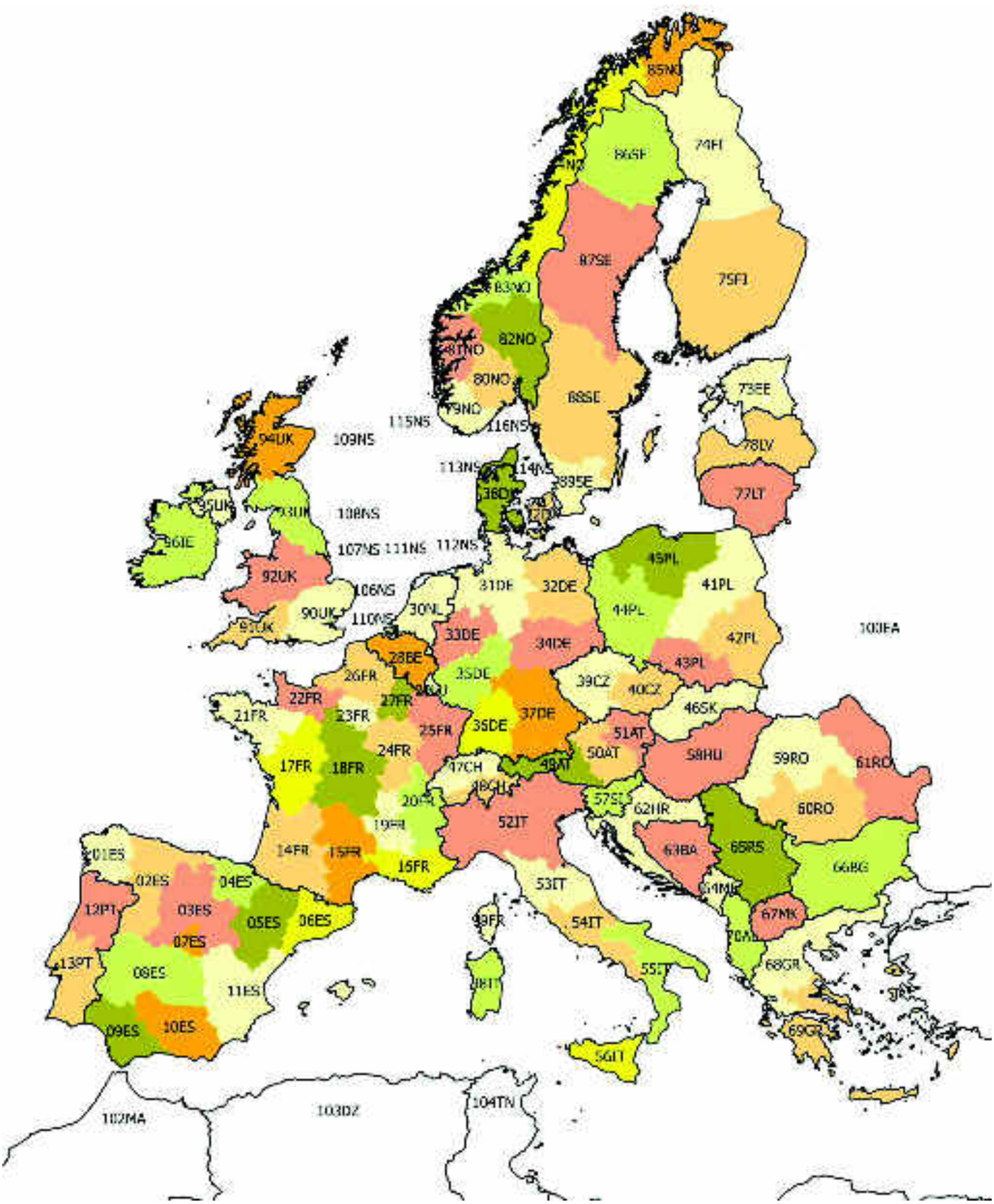

Figure 19 – Model with 100 clusters: For the study, the European power system is represented via a zonal model with 100 clusters. Demand and installed capacities for each generation technology have been defi ned per cluster, and for each scenario.

3 USE OF SELECTED SCENARIOS IN THE PROMOTION PROJECT

For the PROMOTioN project it is relevant to have the data used for these scenarios in order to use these scenarios for modelling purposes of the several work packages within PROMOTioN. It is therefore important to understand what data is available and at which aggregation level. A summary of the available data in TYNDP 2016 and e-Highway2050 is listed in respectively Table 8 and Table 9. Both databases are made available in project place:

- TYNDP 2016 | **https://service.projectplace.com/pp/pp.cgi/r1300948978**
- e-Highway2050 | **https://service.projectplace.com/pp/pp.cgi/r1211474342**

Table 8 – Available data in TYNDP 2016 database

Included	Description
Net generating capacities	Includes net generating capacities per country and per scenario. For the North Sea countries the wind capacities are split into onshore and offshore capacities
Generation basic model	Includes assumptions on the efficiency of thermal plants per technology.
Fuel and CO2 prices	Includes for each scenario the fuel price and CO2 price assumptions.
Basic Reference transmission capacities	The values represent a snapshot of transmission capacities across Europe used in the TYNDP 2016 assessments.
Demand - 2030 Expected Progress	Includes hourly demand (MW) per country for the scenario 2020 Expected Progress.
Demand - 2030 Vision 1	Includes hourly demand (MW) per country for the scenario 2030 Vision 1.
Demand - 2030 Vision 2	Includes hourly demand (MW) per country for the scenario 2030 Vision 2.
Demand - 2030 Vision 3	Includes hourly demand (MW) per country for the scenario 2030 Vision 3.
Demand - 2030 Vision 4	Includes hourly demand (MW) per country for the scenario 2030 Vision 4.

Table 9 – Available data in e-Highway2050 database

Included	Description
Large Scale RES (X5)	Includes net generating capacities (MW) per country or per Cluster, annual demand (GWh) per country or per cluster
100% RES (X7)	Includes net generating capacities (MW) per country or per Cluster, annual demand (GWh) per country or per cluster
Big and Market (X10)	Includes net generating capacities (MW) per country or per Cluster, annual demand (GWh) per country or per cluster
Fossil and nuclear (X13)	Includes net generating capacities (MW) per country or per Cluster, annual demand (GWh) per country or per cluster
Small and Local (X16)	Includes net generating capacities (MW) per country or per Cluster, annual demand (GWh) per country or per cluster

In addition, in Deliverable 1.6 of PROMOTioN an analysis is made for the location of future offshore wind farms (OWFs) in the North Seas countries for the purpose of input values for the initial/draft roadmap. In this analysis assumptions are made on the deployment of the capacity and the year of commissioning in order to be in line with the installed capacities per North Sea country as set in Vision 3 of TYND2016. These developments may deviate from most recent developments. Further, the timeline of commissioning are not based on any policy but rough assumptions. This databases is made available in project place:

- OWFs in D1.6 | **https://service.projectplace.com/pp/pp.cgi/r1328198768**

4 EXPECTED UPDATE OF TYNDP SCENARIOS

Further, it is worthwhile to note that TYNDP is updated biannually and will therefore be updated in 2018. ENTSO-E started the process for the development of scenarios for the TYNDP2018. Three scenarios are developed for 2030 and 2040 [10]. A summary of these scenarios is presented in Figure 20 followed by a summary of the three storylines behind these scenarios. In order to base the final results of PROMOTioN at the end of 2019 on the most recent available data it will be worthwhile to consider the outcomes and inputs from the TYNDP2018 which will be based on these three scenarios. As these scenarios are still in development it is not possible to make this data available yet. Therefore, this paragraph serves only as a preview of how these scenario's will be developed.

The project is aware that the use of different scenarios can lead to incomparable (sub) results. This is subject to consideration between consistency and use of recent data. Therefore we strongly recommend to all Work Packages to do the following when using the scenarios data:

1. Make explicit which data is used, including timestamps and source origin
2. Discuss if the use of a different scenario could have led to different insights.
3. In order to ensure comparable results at the end of the project, align within the project, in particular with WP12, which scenarios are included in the final results of every Work Package.

Scenario		Global climate action	Sustainable Transition	Distributed Generation
Category	**Criteria**	**Parameter**		
Macroeconomic Trends	Climate action driven by	Global ETS	EU ETS & direct RES subsidies	EU ETS
	EU on track to 2030 target?	Beyond	On track	Slightly beyond
	EU on track to 2050 target?	On track	Slightly behind	On track
	Economic conditions	High growth	Moderate growth	High growth
Transport	Electric and hybrid vehicles	High growth	Moderate growth	Very high growth
	Gas vehicles	High growth	Very high growth	Low growth
Residential / Commercial	Demand flexibility	High growth	Moderate growth	Very high growth
	Electricity demand	Moderate growth	Stable	Moderate growth
	Gas demand	Reduction	Slight reduction	Reduction
	Electric heat pump	High growth	Low growth	Moderate growth
	Energy efficiency	High growth	Moderate growth	High growth
	Hybrid heat pump	High growth	Moderate growth	Very high growth
Industry	Electricity demand	Stable	Stable	Moderate growth
	Gas demand	Stable	Stable	Reduction
	CCS	Low growth	Low growth	Not significant
	Demand flexibility	Moderate growth	Low growth	Very high growth
Power	Merit order	Gas before coal	Gas before coal	Gas before coal
	Nuclear	Depending on national policies	Reduction	Reduction
	Storage	Moderate growth	Low growth	Very high growth
	Wind	High growth	Moderate growth	High growth
	Solar	High growth	Moderate growth	Very high growth
	Other bio-energies	Moderate growth	Moderate growth	High growth
	CCS	Not significant	Not significant	Not significant
	Adequacy	Some surplus capacity	Some surplus capacity	High surplus capacity
Non-fossil gas sources	Power-to-gas	High growth	Not significant	High growth
	Bio Methane	High growth	High growth	High growth

Figure 20 – Overview of the draft storylines for TYNDP 2018 [10]

Scenario GLOBAL CLIMATE ACTION [10]

The "Global climate action" story line considers global climate efforts. Global methods regarding CO_2 reductions are in place, and the EU is on track towards its 2030 and 2050 decarbonisation targets. An efficient ETS trading scheme is a key enabler in the electricity sector's success in contributing to Global/EU decarbonisation policy objectives. In general renewables are located across Europe where the best wind, solar resources are found. As non-intermittent renewables bio methane is also developed. Due to the focus on environmental issues no significant investment in shale gas is expected.

A CO_2 market price provides the correct market signals that trigger investments in low-carbon power generation technologies and for flexibility services. A technology-neutral framework is established, which supports especially investments in renewables. Power-to-gas becomes a commercially viable technology for use as energy storage. The CO_2 price makes natural gas fired Combined-Cycle Gas Turbines (CCGTs) appear before coal in the merit order. Gas-fired units provide flexibility needed within the power market, helping facilitate intermittent renewable technologies within the market. Nuclear mostly depends on Country specific policies and there may be potential for some minimum new units in some countries. Carbon capture and storage is not an economically viable option in general, but it still represents a technically viable option for industries whose processes are characterized by high loads factors. System adequacy is driven by price signals, which allows market-based investments in peaking power plants to be made.

The efficient and widespread implementation of global climate schemes prevents carbon leakage between countries, therefore improving the relative competitiveness of energy intensive industries within Europe.
Electricity and natural gas are both key components for the transport sector in reaching emission reduction goals. The impact of electrification is that demand for electricity use in the private and small commercial transportation sector increases. There is an increase in the use of Liquefied Natural Gas (LNG) for the transportation especially where electricity does not represent an alternative fuel, such as heavy goods and shipping sectors. There is a limited penetration of hydrogen vehicles.

Electric and hybrid heat pumps are a significant technology in heating sector, helping to offset the use of fossil heating fuels. All electric heat pumps are installed in new high efficiency buildings, while hybrid heat pumps are installed in existing lower efficiency buildings with an existing gas connection. Together with electric and hybrid heat pumps, district heating plants represent an efficient solution.

Demand response in both industrial and residential sectors has increased - increased automation and internet of things gives consumers the option to move their demand to the lower-priced hours. The overall impact of energy efficiency is higher on the residential sector while offset by strong economic growth in the industrial sector. Demand flexibility is also a key factor ensuring system adequacy due to its ability to shift demand peaks.

Yearly electricity demand has increased in various sectors; overall electricity demand growth is limited by increasing energy efficiency. High GDP growth means that people invest in high efficiency produces such as, lighting, computers, and white goods all of which help to reduce the overall residential energy consumption.

Yearly final gas demand is increasing in the transport sector whilst decreasing in the residential sector, driven mainly from improvements in technology efficiencies and building insulation measures. Gas demand stable in the industrial sector where the impact of energy efficiency measures offsets the increase due to the strong economic growth. Gas is required for peak demand situation, such as, cold weather conditions. Industrial gas demand for heating is stable in this scenario.

Scenario SUSTAINABLE TRANSITION [10]

In "Sustainable Transition" story line, climate action is achieved with a mixture of national regulation, emission trading schemes and subsidies. National regulation takes the shape of legislation that imposes binding emission target. Overall, the EU is just on track with 2030 targets resulting slightly behind the 2050 decarbonisation goals. However targets are still achievable if rapid progress is made in decarbonising the power sector during 2040's.

The economic climate in the Sustainable Transition scenario is moderate growth, regulation and subsides are achievable since there is the capital available by national governments to fund RES projects (both intermittent and non-intermittent). There is a societal ambition to support and participate in climate action, as long as the climate action is seen to be managed in a cost effective way. As a result shale gas is not developed significantly.

Gas-fired power generation flourishes due to relatively cheap global gas prices and strong growth of bio methane. A regulatory framework in place decreases the use of coal-fired power stations. Gas-fired generation provides the necessary flexibility to balance renewables in the power system. There is a decrease in CO_2 emissions since much coal fired base load power generation retires or is out of merit due to a reasonably high ETS Carbon prices and governmental policies. Depending on national policies there could still be room for a minimum number of new units but overall number of nuclear plants in Europe is decreasing. Carbon capture and storage does represent a viable option in industries for those processes characterized by high loads factors. Efficient electricity market and strong price signals ensure necessary investment to peaking power generation, with gas being the preferred fuel. In this context there are increasing investments in Power-to-Gas as in order to optimise the use of available capacity either in gas or electricity network and taking benefit of huge gas storage capacity.

There are no significant changes in the heat generation; in most countries, gas will remain the most prominent source, however the use will decrease due to increasing energy efficiency. Hybrid heat pumps are considered an option in new buildings. Industrial gas and electricity demand is relatively stable. Development of energy efficiency is moderate. Driven by cheap gas prices natural gas is the preferred option for passenger cars to switch from oil in reaching emission reduction goals while electricity use for residential transport is growing moderately. Increase in the LNG use in heavy goods and shipping sectors. There is a limited penetration of hydrogen vehicles.

Overall electricity demand stagnates or grows moderately. Use of gaseous fuels increases for transport and power generation, but slightly decreases for heating.

Scenario DISTRIBUTED GENERATION [10]

In the "Distributed generation" story line, significant leaps in innovation of small-scale generation and residential /commercial storage technologies are a key driver in climate action. An increase in small-scale generation keeps EU on track to 2030 and 2050 targets. A “prosumer” rich society has bought into the energy markets, so society is engaged and empowered to help achieve a decarbonized place to live. As a result no significant investment in shale gas is expected.

Small-scale generation technologies costs have been rapidly declining. Technologies such as solar offer a non-subsidised option for “prosumers” in most parts of Europe. Major advances in batteries enable "prosumers" to balance their own electricity consumption within a day. Nuclear mostly depends on Country specific policies. Power-to-gas technologies become commercially viable for use as energy storage. Technological leaps in small-scale generation challenge large-scale power generation, pressurizing the profitability of traditional power plants. System adequacy is maintained through a centralised mechanism that retains enough peaking capacity, district heating CHP are suitable for both heating and electricity adequacy. The scenario has a strong ETS scheme which favours gas before coal in the power market, and an increasing share of bio fuels.

There is a strong EU climate policy in place, the decreasing cost of small-scale generation technologies drives down the cost of climate action. As solar yields are higher in Southern Europe, investments are likely to be higher in these regions, in comparison to Northern Europe.

Electricity demand flexibility has substantially increased, both in residential and industrial solutions, helping electric power adequacy. However, wintertime with high heating needs and low solar availability remains a challenge, since batteries cannot be used for seasonal storage.

Electricity and gaseous fuels are both key components for the transport sector in reaching emission reduction goals. Lower battery costs have significantly increase demand for electricity in transportation sector. There is an increase in the use of LNG for the transportation of heavy goods and also in the shipping sectors. There is a limited penetration of hydrogen vehicles.

Electric and hybrid heat pumps are a significant technology in heating sector, helping to offset the use of fossil heating fuels. With improved building efficiencies into both existing and new buildings hybrid heat pumps are the preferred option by the ‘prosumer’s’. Hybrid heat pumps allow the ‘prosumer’ to choose which source of energy to meet their heating needs. District heating CHP represent an alternative solution for residential districts.

Yearly electricity demand has increased in the heating and transport sectors, overall electricity demand growth reduced in the residential sector due to ‘prosumer’ behaviour, high efficiency goods and building efficiency measures. Demand responds well to market prices, the daily electricity demand profile is smoothened, the effect is that peak electricity demand is reduced in this scenario.

The yearly final gas demand is increasing in the transport sector. Annual gas demand is decreasing in the residential sector, driven mainly from all electric heating technologies, and building insulation measures. Gas is required for peak demand situation, such as, cold weather conditions. Natural gas for industrial use is decreasing in this scenario driven by electrification of industrial process heating, however gaseous fuels are still required to cover peak demands. The gas demand for other energy intensive industry processes is stable.

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ANNEX I – CONTENT DATABASES

CONTENT DATABASE TYNDP 2016

The following figures are snapshots of the excel databases and published with the intention to get a quick overview of the structure of the data. Since the figures are snapshots the data might nog always look complete, for the complete overview see the excel files.

Overview page excel TYNDP216data

Included	Link	Description
Net generating capacities	link	Includes net generating capacities per country and per scenario
Generation basic model	link	Includes assumptions on the efficiency of thermal plants per technology
Fuel and CO2 prices	link	Includes for each scenario the fuel price and CO2 price assumptions.
Basic Reference transmission capacities	link	The values represent a snapshot of the transmission capacities across Europe used in the TYNDP 2016 assessments.
Demand - 2030 Expected Progress	link	Includes hourly demand (MW) per country for the scenario 2030 Expected Progress.
Demand - 2030 Vision 1	link	Includes hourly demand (MW) per country for the scenario 2030 Vision 1.
Demand - 2030 Vision 2	link	Includes hourly demand (MW) per country for the scenario 2030 Vision 2.
Demand - 2030 Vision 3	link	Includes hourly demand (MW) per country for the scenario 2030 Vision 3.
Demand - 2030 Vision 4	link	Includes hourly demand (MW) per country for the scenario 2030 Vision 4.

Hourly demand patterns

Hour/Country	AL	AT	BA	BE	BG	CH	CY	CZ	DE
1	1293	7552	1425	10787	4847	6631	425	6570	49875
2	1006	7188	1346	10278	4664	6411	426	6424	46805
3	898	6895	1255	9842	4532	6301	387	6264	44925
4	802	6553	1197	9454	4363	6261	350	6158	44007
5	755	6459	1147	9276	4122	6242	323	6015	43938
6	756	6476	1141	9310	4079	6474	316	5880	42874
7	812	6361	1136	9470	3918	6545	316	5775	40894
8	962	6883	1154	9574	3845	6603	301	5826	40394
9	1154	7108	1241	9853	3940	6926	321	5751	41117
10	1262	7608	1369	10227	4069	7247	348	5970	43453
11	1328	8021	1458	10529	4142	7514	367	6510	46466
12	1348	8130	1518	10805	4178	7650	393	6724	50373
13	1364	7872	1532	10006	4185	7082	402	6665	51804
14	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Fuel & CO2 prices

	Expected Progress 2020 Fuel prices (€/ net GJ)	Vision 1 2030 Fuel prices (€/ net GJ)	Vision 2 2030 Fuel prices (€/ net GJ)	Vision 3 2030 Fuel prices (€/ net GJ)	Vision 4 2030 Fuel prices (€/ net GJ)
Nuclear	0,46	0,46	0,46	0,46	0,46
lignite	1,1	1,1	1,1	1,1	1,1
Hard coal	2,86	3,01	3,01	2,8	2,19
Gas	8,9	9,49	9,49	7,23	7,23
light oil	15,6	17,34	17,34	13,26	13,26
Heavy oil	12,32	13,7	13,7	9,88	9,88
Oil shale	2,3	2,3	2,3	2,3	2,3
CO_2 prices (€/ton)	11	17	17	71	76
Source[1]	IEA "Current Policies"	IEA "Current Policies"	IEA "Current Policies"	IEA "450" except coal price IEA "New Policies"	IEA "450" except CO2 price (UK FES High)

Efficiency assumption per generation type

Fuel	Type	Efficiency range in NCV terms %
Nuclear	-	30% - 35%
Hard Coal	-	30% - 46%
Lignite	-	30% - 46%
Gas	Conventional	25% - 42%
Gas	CCGT	33% - 60%
Gas	OCGT	35% - 44%
Light oil	-	32% - 38%
Heavy oil	-	25% - 43%
Oil shale	-	28% - 39%

Reference transmission capacities on all borders

Border/boundary	2020 Reference capacity (MW)	2030 Reference capacity (MW)
AL-GR	250	250
AL-ME	350	350
AL-MK	200	200
AL-RS	760	760
AT-CH	1700	1700
AT-CZ	1000	1000
AT-DE	5000	7500
AT-HU	1200	1200
AT-ITN	555	1655
AT-SI	1200	1200
BA-HR	1344	1844
BA-ME	500	500
BA-RS	1100	1100
BE-DE	1000	1000

Nominal Generation Capacities per country for all scenarios

Expected Progress 2020											
Country/Installi	Biofuels	Gas	Hard coal	Hydro	Lignite	Nuclear	Oil	Others non-RES	Others RES	Solar	Wind
AL	0	100	0	2446	0	0	0	0	0	0	0
AT	0	5119	598	14588	0	0	196	590	630	2000	3880
BA	0	0	0	2042	2158	0	0	0	0	0	350
BE	0	5400	0	1438	0	5060	0	3200	1700	4050	4900
BG	0	797	710	3050	4197	2000	0	0	0	1250	900
CH	0	0	0	18510	0	2845	0	520	380	1750	120
CY	0	925	0	0	0	0	470	0	20	280	200
CZ	0	3010	1500	2170	6000	4000	0	308	900	2560	580
DE	0	28166	26914	5349	21846	8107	3680	6390	7880	46860	56070
DK	1591	3772	1179	9	0	0	735	0	250	840	6040
EE	656	94	0	10	0	0	1291	150	180	0	400
ES	0	24948	9533	20890	0	7573	0	7390	1250	8090	27650
FI	580	0	565	3200	0	4350	1360	2310	3340	100	2500
FR	0	6951	2900	25200	0	63020	2905	5500	3400	8500	13900
GB	0	[illegible]	[illegible]	[illegible]	0	[illegible]	105	[illegible]	[illegible]	[illegible]	[illegible]

Additionally with offshore wind for north sea countries

Expected Progress 2020													
Countr	Biofuels	Gas	Hard coal	Hydro	Lignite	Nuclear	Oil	Others non RES	Others RES	Solar	Wind	Wind onsho	Wind offshore
BE	0	5400	0	1438	0	5060	0	3200	1700	4030	4900	2600	2300
DE	0	28165	26314	9145	21846	8107	3680	6390	7850	40800	30070	45840	5230
DK	1391	1771	1179	9	0	0	735	0	230	840	6040	3770	2270
GB	0	35152	7217	4754	0	8981	109	3670	3080	7430	26250	13670	12580
IE	0	3434	650	508	0	0	324	150	240	10	3600	3600	
NL	4010	11772	0	36	0	480	0	3230	420	1100	5900	5000	900
NO	0	421	0	38500	0	0	0	0	0	0	2080	2008	
SE	0	0	0	16203	0	7031	600	1020	4790	0	7640	7680	100
												88.168	24.440
													Total 112.608

CONTENT DATABES E-HIGHWAYS 2050

ClustersMap | Cluster_X-5 | Cluster_X-7 | Cluster_X-10 | Cluster_X-13 | Cluster_X-16

Country_X-5 | Country_X-7 | Country_X-10 | Country_X-13 | Country_X-16

Installed generation capacities renewables

A	B	C	D	E	F	G	H	I
COUNTRY	Clusters	Wind (MW)	PV (MW)	CSP (MW)	TOTAL SOLAR (MW)	Biomass I (MW)	Biomass II (MW)	Total biomass (MW)
X 5								
ALL	@ a-z areas							
ES	01_ES	7287	105	0	105	250	0	250
ES	02_ES	5087	4114	0	4114	500	0	500
ES	03_ES	12403	5099	937	6036	750	250	1000
ES	04_ES	5682	1563	0	1563	250	0	250
ES	05_ES	10426	2976	571	3548	500	250	750
ES	06_ES	3584	2863	376	3239	250	0	250
ES	07_ES	183	4561	282	4844	0	0	0

Wind in north seas = offshore wind:

COUNTRY	Clusters	Wind (MW)	PV (MW)	CSP (MW)	TOTAL SOLAR (MW)	Bio (I
LY	105_LY	0	7500	17600	25100	
NS	106_NS	24093	0	0	0	
NS	107_NS	12046	0	0	0	
NS	108_NS	2008	0	0	0	
NS	109_NS	2008	0	0	0	
NS	111_NS	8923	0	0	0	
NS	112_NS	20077	0	0	0	
NS	113_NS	23424	0	0	0	
NS	114_NS	7808	0	0	0	
NS	110_NS	2000	0	0	0	
NS	115_NS	669	0	0	0	
NS	116_NS	669	0	0	0	

Installed generation capacities conventional part I

COUNTRY	Clusters	Nuclear (MW)	OCGT (MW)	Gas without CCS (MW)	Gas with CCS (MW)	Coal without CCS (MW)	Coal with CCS (MW)	Lignite without CCS (MW)	Lignite with CCS (MW)
X-0									
ALL	@ a-z areas								
ES	01_ES	0	300	1500	0	0	0	0	0
ES	02_ES	0	300	3000	0	800	0	0	0
ES	03_ES	3200	0	300	0	0	0	0	0
ES	04_ES	0	300	4300	0	0	0	0	0
ES	05_ES	0	250	2000	0	0	0	0	0
ES	06_ES	1600	750	3500	0	0	0	0	0

Installed generation capacities conventional part II

COUNTRY	Clusters	Total Gas (MW)	Total har coal (MW)	Total Lignite (MW)	Total fossil (MW)
X-5					
ALL	@ a-z areas				
ES	01_ES	2000	0	0	2000
ES	02_ES	3500	800	0	4300
ES	03_ES	500	0	0	500
ES	04_ES	5000	0	0	5000
ES	05_ES	2250	0	0	2250
ES	06_ES	4250	0	0	4250
ES	07_ES	0	0	0	0

COUNTRY	Clusters	Demand (GWh)	Demand distribution per clusters (%)		RoR (GWh)	Hydro with reservoir (MW)	PSP (MW)
X-5							
ALL	@ a-z areas						
ES	01_ES	16515	2,7%		3833	4672	2737
ES	02_ES	48786	8,0%		10208	5171	3030
ES	03_ES	26834	4,4%		0	585	343
ES	04_ES	40576	6,7%		0	349	204
ES	05_ES	17901	2,9%		4003	1051	616
ES	06_ES	103381	17,0%		0	2752	1613
ES	07_ES	88039	14,4%		0	255	149

COUNTRY	Clusters	RoR (GWh)	Hydro with reservoir (MW)	PSP (MW)	PSP reservoir (GWh)	Hydro with reservoir distribution per clusters	RoR distribution per clusters
X 5							
ALL	@ a-z areas						
ES	01_ES	3833	4672	2737	415	24%	11%
ES	02_ES	10208	5171	3030	460	27%	28%
ES	03_ES	0	585	343	52	3%	0%
ES	04_ES	0	349	204	31	2%	0%
ES	05_ES	4003	1051	616	93	5%	11%
ES	06_ES	0	2752	1613	245	14%	0%
ES	07_ES	0	255	149	23	1%	0%
ES	08_ES	15030	914	536	81	5%	42%

ANNEX II – COMPARISON COUNTRIES TYNDP AND E-HIGHWAY2050

Comparison of the division of countries between TYNDP 2016 and e-Highway2050. There are a few distinctions between the two databases that are noteworthy mentioning. Cyprus is only a separate country in TYNDP, in e-Highway2050 it is not mentioned as a country. Further, Northern Ireland is modelled separately in TYNDP 2016 where it is part of the UK in e-Highway2050. Furthermore, in e-Highway2050 there are some additional regions, one of these is the North Sea, as a result all wind installed in the North Sea is part of this region. Therefore wind in the northern Seas countries is most likely onshore wind whereas the wind in the norths sea is offshore wind.

Table 10 – Country codes TYNDP 2016 and e-Highway2050

Country	TYNDP 2016 country code	e-Highway2050 country code
Albania	AL	AL
Austria	AT	AT
Bosnia and Herzegovina	BA	BA
Belgium	BE	BE
Bulgaria	BG	BG
Switzerland	CH	CH
Cyprus	CY	
Czech Republic	CZ	CZ
Germany	DE	DE
Denmark	DK	DK
Estonia	EE	EE
Spain	ES	ES
Finland	FI	FI
France	FR	FR
Great Britain	GB	UK
Greece	GR	GR
Croatia	HR	HR
Hungary	HU	HU
Ireland	IE	IE
Italy	IT	IT
Lithuania	LT	LT
Luxemburg	LU	LU
Latvia	LV	LV
Montenegro	ME	ME
Macedonia	MK	MK
Northern Ireland	NI	
the Netherlands	NL	NL
Norway	NO	NO

Poland	PL	PL
Portugal	PT	PT
Romania	RO	RO
Serbia	RS	RS
Sweden	SE	SE
Slovenia	SI	SI
Slovakia	SK	SK
Algeria		*DZ*
Libya		*LY*
Morocco		*MA*
Middle East		*MEA*
Tunisia		*TN*
North Sea		*NS*
East		*EA*