e-HIGHWAY 2050

Modular Development Plan of the Pan-European Transmission System 2050

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Addendum to D 4.2a	**Testing Aspects of the SESA Methodology to Grid Architectures of Large Scale RES and 100% RES Scenarios**		

		Date & Visa
Written by	Y.R.Bhavanam, G.A.Taylor, A.Alikhanzadeh (Brunel)	2015-12-24
Checked by	Rui Pestana (REN)	2015-12-29
Validated by	Gérald Sanchis, Nathalie Grisey (RTE)	2015-12-30

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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

This document constitutes the final version of 'Testing aspects of the SESA methodology to grid architectures of Large scales RES and 100% RES scenarios'. The SESA methodology is addressed in D4.2a – Methodology for strategic environmental and sustainability assessment. This document uses a two stage testing process for the grid reinforcements of 2050 based on the 3 strategies proposed in WP2. Grid Architectures of two scenarios- the Large Scale RES and 100% RES scenarios- have been examined.

Acknowledgements

BRUNEL drafted this document.

Change status

Revision	Date	Changes description	Authors
V1.0	2015-09-01	Application of SESA methodology to the Grid Architecture of Large Scale RES & No Emissions (x-5)	Brunel University London
V1.1.1	2015-09-17	Application of SESA methodology to the Grid Architecture of 100% RES (x-7)	Brunel University London
V1.1.2	2015-10-05	Comparison of SESA results the scenarios	Brunel University London
V1.1.3	2015-10-09	Executive Summary and Conclusions	Brunel University London
V1.2	2015-10-12	Final comments	Rui Pestana
V1.3	2015-10-14	Update conclusions	Brunel University London
V1.4	2015-10-15	Remarks from RTE	Nathalie Grisey
V1.5	2015-11-03	Update remarks	Brunel University London
V1.6	2015-12-01	Remarks from SINTEF and RTE	Rui Pestana
V1.7	2015-12-24	Remarks from the GA	Brunel University London
V1.8	2015-12-29	Remarks from IST Disclaimer	Rui Pestana

Disclaimer

The original purpose of Strategic Environmental and Sustainability Assessment (SESA) as part of the e-Highway2050 project was to advise on more sustainable options for grid design and reinforcement, and to provide guidelines for future environmental and sustainable integrated planning and development, as well as for monitoring and follow-up implementation. The SESA methodology was developed during task 4.2 at a time when no information on grid architectures was available. It was therefore an opportunity to identify possible courses of action that would enable opportunities for the environment and for sustainability, while avoiding risks, pursuing one, or a combination of various, strategic options for grid development. SESA could still deliver inputs to the design of grid reinforcements.

Setting environmental validation as the purpose of task 4.2 in this project was a highly ambitious objective. The scale and complexity involved in the e-Highway2050 project impede the achievement of this objective and a different, more strategic approaches was found to be more adequate to address environmental and sustainability aspects and contribute to a more integrated, sound and sustainable outcome, instead of providing yes or no answers that an environmental validation would entail.

Due to delays in processing and delivering the outcomes of WP2, it became impossible to apply the SESA to final grid layouts within the preparation of D4.2. The eHighway2050 project coordination then determined that D4.2 would be split in two separate reports: the first with the SESA methodology and results of the assessment of strategic options prepared by IST, with support from CEP; and a second report prepared by Brunel to apply the methodology to grid design layouts.

This document refers to this second report. It contains an engineering developed test to illustrate the application of aspects of the SESA methodology to two scenarios. It has not made use of the full SESA methodology and its contribution to the project needs to be viewed in this light.

Executive Summary

It is essential to adopt pan–European transmission network for the secure, reliable, affordable and clean power supply. The road map to achieve this aim will automatically include the impact of environment on it. Besides transition to a sustainable energy system, healthy ecosystems & environment are mandatory for the survival of humans, flora, fauna and fungi. E-Highway 2050 consortium finalised five scenarios which are neither predictions nor forecasts about the future power transmission. Each scenario is a possible alternative image of how the future European electricity highways might unfold. Scenarios contain individual grid architectures comprising of many transmission corridors within the countries or with other countries to contribute to energy security. The successful construction and commissioning of these transmission corridors requires European environmental objectives and standards to be met during the environmental impact assessment (EIA) at later stages. It is a challenge to balance the development of pan –European transmission network with sustainable energy systems on one side and protecting & restoring the biotic and abiotic components of nature on other side.

This report initially describes a two stage testing process that has been created to test some aspects of the strategic environmental and sustainability assessment methodology (SESA) to the grid architectures (GA) of a given e-Highway 2050 scenario. The strategic options introduced in deliverable 4.2a and validated by e-Highway 2050 consortium are a key feature of the SESA methodology that become useful when assessing GAs of the scenarios. A valid testing process also requires a dialogue with the deliverables of WP2. At Stage 1 of the two stage testing process the sequence algorithm illustrated in Figure A is followed to relate, verify and confirm strategic options (categorised under generation & regional balance, storage, transmission and international strategy) to individual transmission corridors. At stage 2, the three step process presented in Figure B is followed i.e. to identify further risks and opportunities and propose additional planning & management, monitoring and governance guidelines justified by the detail not yet covered in D4.2a to every individual risk that arose under the four critical decision factors (CDF).

Two stage testing process

Step 1 • Select the transmission link from the results of system simulations relevant to the scenario (excel file: Results T23)

Step 2 • Pick the relevant strategic options from G1 to G6 with the help of data related to installed capacities present in Annex L of D2.1

Step 3 • Check the location of transmission link at macro area level (Figure 6 of D2.1)

Step 4 • Choose the strategic options from G7 to G9 categorised under "energy flow" where relevant

Step 5 • Pick the relevant strategic options from S1 to S3 with the help of Table 3 of D4.2a & Table 2.1, 2.7 of D1.2

Step 6 • Choose the strategic option between T1 and T2 based on the three strategies that WP2 proposed in D2.3

Step 7 • Check if the selected transmission link is relevant to the imports from North Africa

Step 8 • Choose the relevant strategic option from IS1 and IS2

Step 9 • List all the strategic options that are relevant to the selected transmission link

Figure A: Nine Step Sequence Algorithm to Relate Strategic Options to Transmission Corridors in the Grid Architectures (stage1)

Step 1:

Identify all the Risks (-) and Opportunities (+) associated with the e-Highway2050 strategic options which are structured around four critical decision factors (CDFs) that are relevant to the grid architectures

Step 2:

Eliminate the Risks (-) & Opportunities (+) that are repetitive and verify whether risks are acceptable

Step 3:

For every individual risk, planning & management, monitoring and governance guidelines must be provided with the help of proposed guidelines in big picture (D4.2a) and verify their adequacy.

Figure B: Three steps to identify, eliminate and list/propose additional ROs& guidelines (stage2)

However, the transmission strategies play important role in applying the SESA methodology. The three transmission strategies to implement the grid reinforcements are as below :

Transmission						
Strategy	**Social Assumption**	**Technical Description**	**Cables**	**Up-Grade of OHL**	**New OHL**	**New OHL on non existing corridors**
1.New Grid Acceptance	Public acceptance for new OHL	Most efficient solution	✓	✓	✓	✓
2.Re –Use of corridors	Public acceptance for new lines in existing infrastructure corridors	Re-Use of existing infrastructure or construction of underground cable	✓	✓	✓	
3.Status Quo	No public acceptance for new OHL	Only upgrade of existing lines with same visual impact or construction of underground cables otherwise	✓	✓		

New grid acceptance is a very optimistic strategy where public acceptance of new OHL & infrastructure is expected. Even though majority of TCs in this strategy are OHLs, there are few links that are expected to be possible only through underground cables. Example: Links with North Sea. Re-use of corridors is a reasonable strategy where public acceptance of new OHL & infrastructure is not expected but upgrade of OHL on existing infrastructure is welcomed. Status Quo is a very pessimistic strategy where the upgrade of existing transmission lines with same visual impact to transmission infrastructure or else underground cable construction is expected to be acceptable by the public. However, these strategies are very extreme and in reality the combination of these strategies will provide a better solution depending on the circumstances that arise during the construction and commissioning of individual transmission corridors.

The grid architectures of all the five e-Highway2050 scenarios are realistic images of future Europe which includes incredible amount of opportunities and some risks. Some consideration of the scenarios is warranted before selecting two for testing. The 110 grid reinforcements of x-5 reflects the deployment of large scale offshore wind farms in North sea and a high priority to the pumped hydro centralised storage. Even though no new nuclear plants are expected the current ones contribution is expected to meet the demand. Demand side management concept seems to be of less interest. The agreements for power transmission across national boundaries requires more sophistication as 63 translational TCs exist.

Grid Architecture of x-7 requiring 74 grid reinforcements is going to supply the energy to entire Europe that is generated from renewables. In addition to the assumptions made in x-5, demand side management, electric vehicles and batteries are also considered to balance the inconsistencies in the renewable energy generation from wind and sun. These storage solutions also have positive impact in reducing the number of grid reinforcements when compared with x-5. The total transnational reinforcements are 42.

The grid architecture of x-10 comprises of 52 TCs including 32 transnational reinforcements. On an average €165 billion investments are required to transmit 255GW of power across Europe. It is complete market based strategy where renewable, fossil and nuclear generation sources are considered along with high importance to carbon capture and storage technology development. The importance is low towards imports from North Africa.

Grid Architecture of x-13 includes 72 TCs with the grid length of 20,647km to supply 253GW of power across Europe. The acceptability towards fossil and nuclear with carbon capture & storage is assumed to be positive throughout Europe. Renewable generation sources are of low priority. Only 40 transnational reinforcements are expected. Even though green initiatives are not focussed, an average investment of €153 billion is required to develop the pan–European transmission infrastructure.

Grid Architecture of x-16 consists of 51 TCs with a grid length of 16,376km to supply 190GW. Fossil, nuclear sources and CCS technology are not considered to reach the goal of reduced GHG emissions. Decentralised renewable energy generation is given high importance and is expected to be deployed locally. This assumption directly reflects on the number of transnational reinforcements i.e. only 27.

Every grid architecture has its pros and cons. The ultimate aim is to achieve secure, reliable and clean energy. Whichever the grid architecture and transmission strategy is adopted, it is difficult to go further without having a negative impact on the environment and vice versa. Every scenario will have a phase or a time period that will be experienced by Europe in its travel to year 2050. Denmark has already presented an Energy Strategy 2050 which declares their energy independence from fossil fuels by 2050 [1]. If Denmark sets an example to other European countries then the grid architectures of x-13 & x-10 are in question. The higher number of TCs in the GA will have to address various risks and the number of risks to be addressed depends on the combination of transmission strategies that will be adopted.

The GAs of x-5 and x-7 (Large Scale RES and 100% RES Scenarios) resembles similar characteristics and further evidence is provided in sections 8.2 and 8.3. Even though grid reinforcements in x-16 are less when compared to others, the increased local infrastructure development will have effect on the immediate surrounding environment of the public. By adopting the mitigation measures it could be beneficial to focus on x-5 and x-7 grid architectures. It is noted that the transmission strategies still play a crucial role in decision making, and should be considered appropriately with the help of WP2 deliverables. Although an initial testing of SESA methodology to grid architectures of x-5 and x-7 scenarios delivers a more structured understanding of risks, the decision to reject or prioritise scenarios at this stage remains a challenging task. It is nevertheless possible to identify and prepare for further evaluation those scenarios are promising.

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List of Acronyms

AAAC	All Aluminium Alloy Conductors
AC	Alternating Current
ACSS	Aluminium Conductor Steel Supported
CAES	Compressed Air Energy Storage
CCS	Carbon Capture and Storage
CDF	Critical Decision Factor
CE	Central Europe
CSP	Centralised Solar Power
DC	Direct Current
DG	Directorate General
DHC	District Heating and Cooling
DSM	Demand Side Management
DSO	Distribution System Operator
EC	European Commission
EEA	European Environment Agency
EIB	European Investment Bank
EIP	Energy Infrastructures Priorities
ENTOS-E	European Network of Transmission System Operators for Electricity
ERI	Electricity Regional Initiative
ERI	Electricity Regional Initiative
EU	European Union
EV	Electric Vehicle
FACTS	Flexible Alternating Current Transmission Systems
GA	Grid Architecture
GHG	Green House Gas
GTC	Grid Transfer Capacity
GWh	Giga Watt hours
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
IBA	Important Bird Area
IS	International Strategy
km	kilo meter
kV	kilo Volt
MS	Member-State
MW	Mega Watt

NE	North Europe
NGO	Non-Governmental Organisation
NIMBY	Not In My Back Yard
OECD	Organisation for Economic Co-operation and Development
OHL	Over Head Line
PHS	Pumped Hydroelectric Storage
PSP	Pumped Storage Power plant
PV	Photo-Voltaic
R& D	Research and Development
RES	Renewable Energy Sources
RoR	Run off River
ROs	Risks and Opportunities
RoW	Right of Way
SE	South Europe
SEA	Strategic Environmental Assessment
SESA	Strategic Environmental and Sustainability Assessment
SOs	Strategic Options
SWE	South West Europe
TC	Transmission Corridor
TD	Transmission Distance
TL	Transmission Link
TRL	Technology Readiness Level
XLPE	Cross Linked Poly Ethylene

1. Introduction

In this report some aspects of the Strategic Environmental and Sustainability Assessment (SESA) methodology that were tested to two scenarios of the e-Highway 2050 - the Grid Architectures of Large scale RES & no emissions (x-5) and 100% RES (x-5) - are presented. Initially the sixteen strategic options which are classified under four strategic themes that are relevant to the scenarios are extracted from Table 3 of [2] and are checked with Table 2 of [2] to confirm if all the strategic issues are covered. Then the essence of x-5 Grid architecture is explained.

The process of testing the SESA methodology using the proposed sequence algorithm is described. This further analysis enabled detailing risks and opportunities (ROs) associated with the selected e-Highway 2050 strategic options which are checked for relevance with individual TCs. The repetitive ROs are identified and highlighted in red colour. The highlighted are eliminated and the remaining risks and opportunities are presented in section 5. Finally, Table 14 in Section 6 is designed to present additional planning & management, governance and monitoring guidelines of [2] in the process of reducing the risks and enhancing the opportunities.

Table 1: Strategic options relevant to e-Highway 2050 scenario, Large Scale RES & No Emissions (x-5) **[2]**

Strategic Theme		**Strategic Option**	**2050 Scenario**
			Large Scale RES & No Emissions (x-5)
Generation and regional balance	RES Scale and Location	G1-Centralised and large scale RES	✓
		G2-Decentralised and small scale RES	
	Energy Mix	G3-Dominant RES	✓
		G4- RES non-dominant	
	Nuclear and Fossil	G5-Nuclear and Fossil without CCS near existing capacity	✓
		G6- Nuclear and Fossil with CCS close to demand	
	Energy Flow	G7-High to very high flows from SE and NE to CE	✓

		G8 – High to medium flows from NE to CE	
		G9 – Low Energy Flows	
Storage		S1 – Centralised Hydro Storage	✓
		S2 – Centralised Hydro and CAES	✓
		S3 – Mixed Scale storage	
Transmission		T1 – Overhead Transmission	✓
		T2 – Underground HVDC and Overhead HVAC	✓
International Strategy		IS1 – Irrelevant import from North Africa	
		IS2 – Relevant import from North Africa	✓

2. Grid Architecture of x-5 Scenario

Here, the scenario details of x-5 along with the grid reinforcements required are presented. An example of a TC between Spain and France is discussed to introduce the three transmission strategies.

According to [3], Scenario X-5 is characterized with high demand that reaches 5364 TWh, the highest demand among analysed scenarios. This level of demand without any grid constraints is supplied by:

- Centralized RES (Wind +Hydro) – 56 %
- Decentralized RES (Solar + Biomass) – 19%
- Nuclear – 20%
- Fossil fuel – 5%

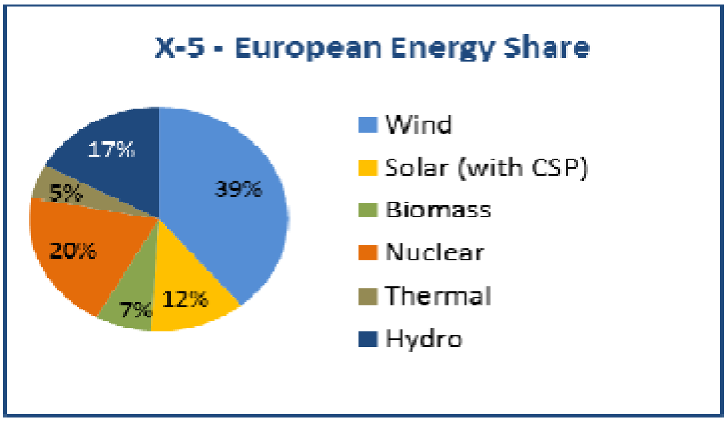

Figure 1: x-5 European energy share

The Grid Transfer Capacity (GTC) and the additional transmission requirements within and across the member states in the grid architecture of x-5 are presented in Table 2

Table 2: GTCs in the starting grid and identified transmission requirements

Links	*Reference distance (km)*	GTCs in the starting Grid- MW		Transmission requirements identified-MW	
		Type in the starting grid (AC/DC/RoW)	Large scale RES (X5)	Reinforcements (Reinforced/not reinforced/new)	Large scale RES (X5)
01_es - 02_es	186	AC	7200	reinforced	0
01_es - 03_es	372	non existing	0	new	0
01_es - 12_pt	204	AC	1200	reinforced	1000
02_es - 03_es	186	AC	19100	not reinforced	0
02_es - 04_es	302	AC	2400	not reinforced	0
02_es - 07_es	260	non existing	0	new	0
02_es - 08_es	335	AC	2400	reinforced	1000
02_es - 12_pt	215	AC	950	reinforced	1000
03_es - 04_es	181	AC	7100	reinforced	2000
03_es - 05_es	257	AC	3900	not reinforced	0
03_es - 07_es	118	AC	10200	reinforced	2000
03_es - 11_es	344	AC	2700	not reinforced	0
04_es - 05_es	181	AC	900	not reinforced	0
04_es - 07_es	276	non existing	0	new	0
04_es - 14_fr	238	AC + DC	2000	reinforced	5000
05_es - 06_es	185	AC	7000	not reinforced	0
05_es - 07_es	280	non existing	0	new	0
05_es - 11_es	259	AC	5700	not reinforced	0
…	…	…	…	…	…
95_uk - 96_ie	188	AC	1100	reinforced	1000
98_it - 99_fr	229	DC	400	reinforced	800

The full table is listed in annex 1.

The starting grid comprises of both AC and DC transmission liks within and across the member states. There is also combination of AC+DC transmission infrastructure that is used to supply power. The transmission requirements identified for x-5 can be satisfied with the help of overhead and underground HVAC/HVDC transmission. The transmission links throughout Table 2 that has no additional transmission requirements are therefore not reinforced.

The severity of the risks and opportunities depends on the following three reinforcement strategies, i.e.

- A strategy with no public opposition, i.e. new overhead lines (OHL) are built when needed with no constraints,
- A strategy with moderate public opposition where existing corridors are refurbished (i.e. mainly OHL with some partial undergrounding)
- A strategy with high public opposition where only buried cables are used.

Example: Transmission link between Spain and France (04_es - 14_fr)

The grid transfer capacity (GTC) in the starting grid is 2000 MW (AC+ DC) and the transmission requirement identified is 5000 MW. The reinforcement is expected to take place to satisfy the requirement. One of the above three reinforcement strategies has to be followed during which risks and opportunities are addressed depending on the transmission infrastructure i.e. overhead and underground HVAC/HVDC transmission. Using the example of critical decision factor (CDF) 1 the risks and opportunities associated with transmission could be:

Table 3: SOs related to transmission **[2]**

Strategic Option	**(+) Opportunities/ (-) Risks - CDF 1 Social acceptance and acceptability**
T1	(-) Poor public acceptance and acceptability of transmission infrastructure due to visual impacts and perceived/actual health impacts of overhead HVAC lines (identified in D4.2a) (+) Overhead transmission infrastructure located in Southern Europe is not vulnerable to key climate change impacts
T2	(+) Underground transmission infrastructure is likely to enjoy high levels of public acceptance and acceptability (identified in D4.2a)

	(+) Small land take associated with underground HVDC transmission infrastructure reduces pressure on landscapes, ecosystems and ecosystem services (-) Underground cable systems may constrain land use options to a degree due to buffer distance that can't be developed (-) Land take within pan-European electricity highway corridors may constrain land use/management options including biodiversity/habitat (-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associated ground movements

Various risks and opportunities that are associated with the generation, transmission and where possible storage structured around four critical decision factors (CDFs) from [2] are presented in section 5 and 6 of the report. In the process of reducing risks and enhancing the opportunities the planning & management, governance and monitoring guidelines are provided in section 6 in addition to the guidelines presented in [2] to help achieve the requirements of x-5 2050 scenario in meeting the future demand.

3. Strategic Options Related to Large Scale RES & No Emissions (x-5)

Relevant strategic options that are mentioned in Table 1 are extracted and presented in Table 4. In the testing process the strategic options related to TCs in stage1 will lead to the identification of risks and opportunities structured around the four critical decision factors (CDFs) in stage2.

Table 4: Strategic options (SOs) related to Large Scale RES & No Emissions (x-5)

Strategic options : Large Scale RES & No Emissions (x-5)	
G1	Centralised and large scale RES
G3	Dominant RES
G5	Nuclear and Fossil without CCS near existing capacity
G7	High to very high flows from SE and NE to CE
S1	Centralised Hydro Storage
S2	Centralised Hydro and CAES
T1	Overhead Transmission
T2	Underground HVDC and Overhead HVAC
IS2	Relevant import from North Africa

4. Testing aspects of SESA Methodology to Grid Architectures

The strategic options that were discussed and validated by e-Highway 2050 consortium play crucial role in the process of applying SESA methodology to the grid architectures (GA) based on different scenarios. The application of SESA to e-Highway 2050 requires a dialogue with the deliverables of WP2. The complete testing process is performed in two stages.

At Stage 1 the sequence algorithm illustrated with the help of smart art in Figure 2 is followed to verify and confirm the strategic options that relate to individual identified transmission links in the GAs. At Stage 2, the three steps described in Figure 3 are implemented with the aim to present guidelines in addition to the ones presented in [2] (planning & management, monitoring and governance) for every risk that helps the development of pan European grid architecture.

Stage 1:

The nine step sequence algorithm followed during the testing to the GA's is as below:

- Step 1 • Select the transmission link from the results of system simulations relevant to the scenario (excel file: Results T23)
- Step 2 • Pick the relevant strategic options from G1 to G6 with the help of data related to installed capacities present in Annex L of D2.1
- Step 3 • Check the location of transmission link at macro area level (Figure 6 of D2.1)
- Step 4 • Choose the strategic options from G7 to G9 categorised under "energy flow" where relevant
- Step 5 • Pick the relevant strategic options from S1 to S3 with the help of Table 3 of D4.2a & Table 2.1, 2.7 of D1.2
- Step 6 • Choose the strategic option between T1 and T2 based on the three strategies that WP2 proposed in D2.3
- Step 7 • Check if the selected transmission link is relevant to the imports from North Africa
- Step 8 • Choose the relevant strategic option from IS1 and IS2
- Step 9 • List all the strategic options that are relevant to the selected transmission link

Figure 2: Sequence algorithm to identify the relevant SOs

The above eight sequence of steps requires detailed analysis of individual transmission links in the grid architectures to reach Step 9.

<u>Stage 2:</u>

Further testing comprises of the following steps:

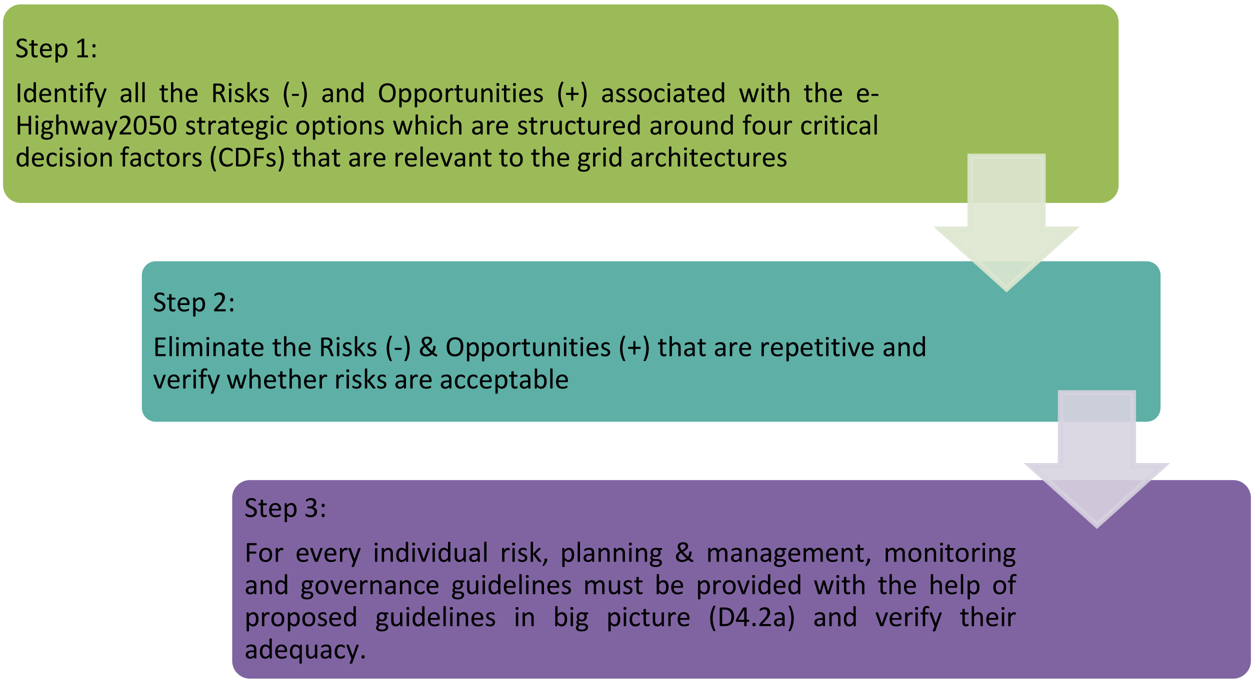

Figure 3: Three steps to identify, eliminate and list/propose additional ROs & guidelines (stage2)

4.1 List of Transmission Corridors Identified for GA Based on x-5

The results of system simulations performed with Antares provided only the corridors that are required and beneficial even under difficult circumstances. Therefore the given corridors in Figure 4 present the minimum required grid reinforcements in x-5

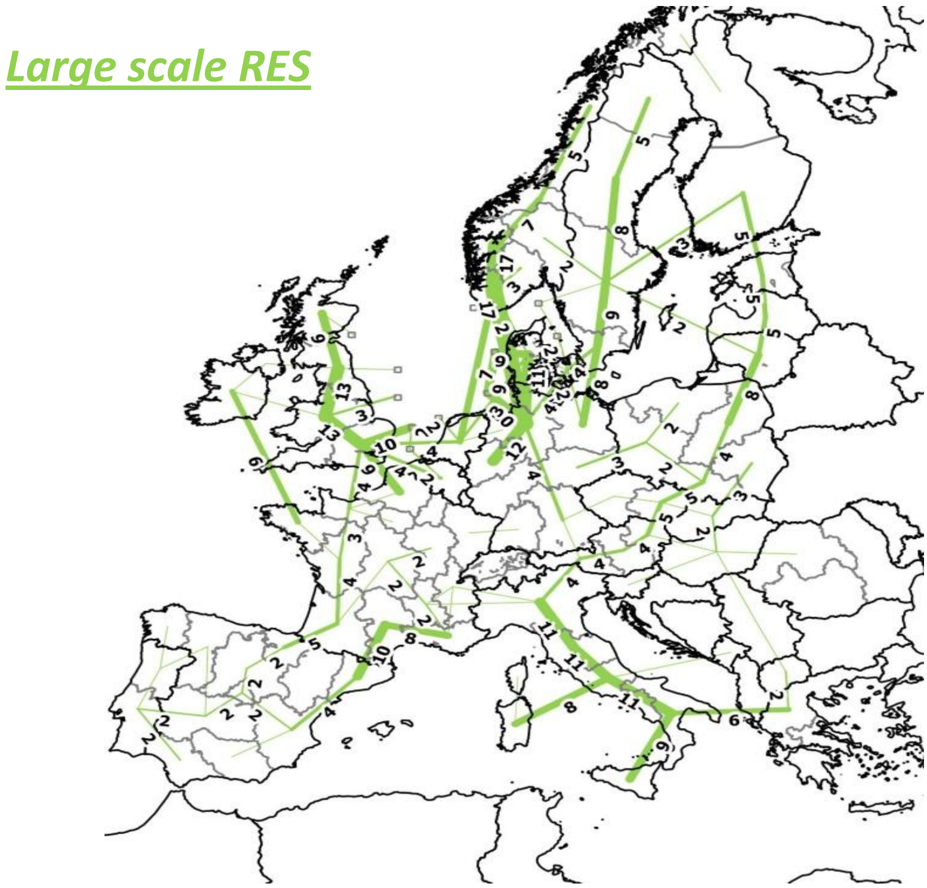

Figure 4: Required Transmission Corridors in x-5

4.2 Stage1: Application of Sequence Algorithm to Transmission Corridors

<u>Step 1</u>:

Transmission Link: 01_es – 12_pt

<u>Step 2</u>:

Installed capacities by technology relevant to both countries are as below:

Table 5: Installed capacities

Technology	**Spain**	**Portugal**
Wind (MW)	67450	11450
Solar (PV + CSP)(MW)	50800	5550
Biomass(MW)	6000	1000
Nuclear(MW)	8000	0
Thermal(MW)	31800	4750
Hydro Power [(RoR (GWh)), (Reservoir + PSP(MW))]	35895, 30556	14539, 7675

Even though distribution keys are used to further allocate the installed capacities at cluster level in percentages, the data available at country level is sufficient to pick the relevant SOs from G1 to G6. The relevant SOs are presented in Table 6.

Table 6: SOs (G1 – G6) relevant to 01_es – 12_pt

G1-Centralised and large scale RES	✓
G2-Decentralised and small scale RES	
G3-Dominant RES	✓
G4- RES non-dominant	
G5-Nuclear and Fossil without CCS near existing capacity	✓
G6- Nuclear and Fossil with CCS close to demand	

<u>Step 3:</u>

The location of transmission link at macro area level can be identified with the help of the following Figure 5. Both the clusters 01es and 12pt are located in South West Europe (SWE).

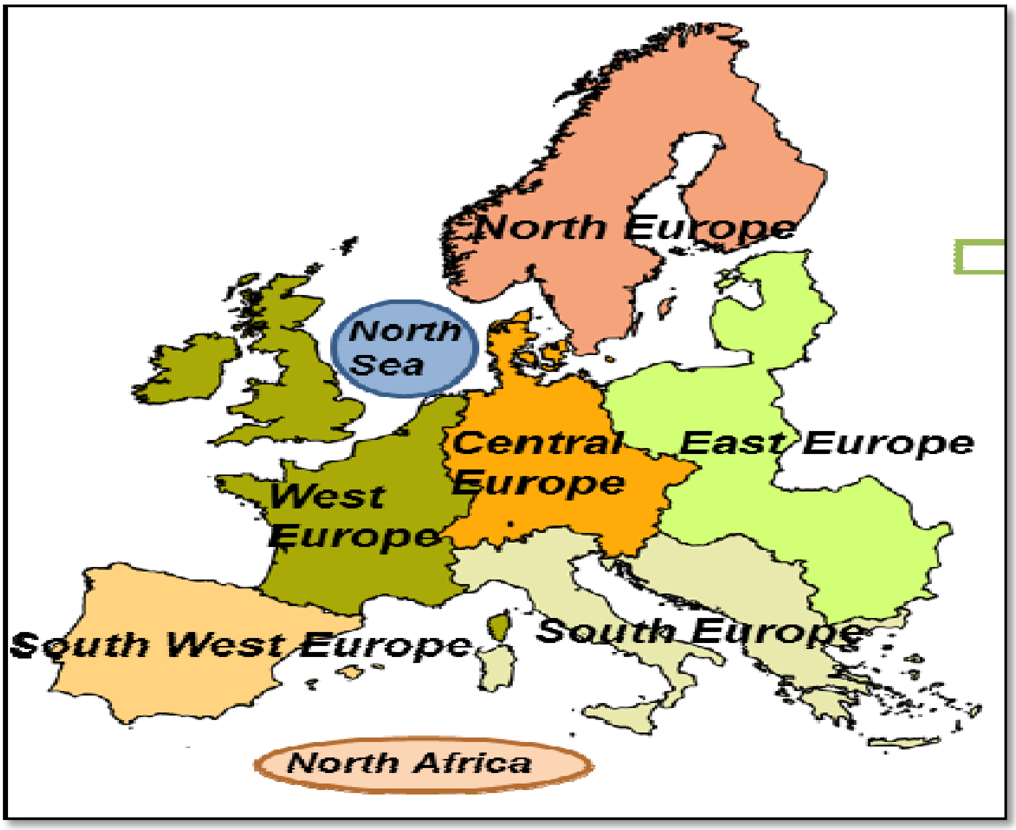

Figure 5: Europe at macro area level

Step 4:

Both the clusters are present in SWE and the energy flow does not have direct relevance with the SOs G7 – G9. For this particular transmission link, G7 – G9 is not required to be taken into consideration.

Step 5:

According to D1.2 Table 8.5, the level of centralised storage is high in x-5. Data present in Table 2.7 of D1.2 also confirms the existing storage facilities in both the countries. S1 and S3 are highly relevant and S2 is also considerable due to the advancements of storage facilities. Storage data at cluster level is not available at this stage.

Step 6:

Transmission is a crucial stage in energy trading across and within the countries. It has significant impact in terms of public acceptance, cost, technology and energy security. Additionally, e-Highway 2050 gives serious consideration to curb the contribution of energy related activity to global warming and emissions to the atmosphere.

In [4] researchers proposed three strategies to encompass wide range of possibilities for the development of transmission infrastructure. Each strategy will imply different length (km) of transmission network in the GA's. The inputs from [4] give an indication of the total length of the transmission network based on the type of technology that can be used to develop pan European GA. The x-5 transmission technical data classification is presented in Table 7.

Table 7: Length (km) classification based on technology in three strategies (x-5)

Strategy	Total Distance (km)	AC OHL AAAC-	AC OHL AAAC- 4 conductor	AC OHL AAAC- 2 conductor	AC OHL ACSS-	DC OHL-	DC Cable XLPE-V1	DC CABLE XLPE-V2	Refurbish Upgrade
1	85729	8182	11951	14302	1280	975	34599	14440	0
2	86427	8182	10905	13139	1280	975	36343	15603	0
3	107779	0	0	0	0	0	70167	32719	4893

For this particular transmission link (TL) 01_es – 12_pt, the technology, number of circuits along with the length of transmission link and transmission requirement (MW) is presented in Table 8.

Table 8: Technical data regarding the transmission link: 01_es – 12_pt

TL = 01_es – 12_pt; Length = 204km; TR = 1000MW				
Strategy	**Social Assumption**	**Technical Description**	**Technology**	
1.New Grid Acceptance	Public acceptance for new OHL	Most efficient solution	AC OHL AAAC- 2 Conductors	
2.Re –Use of corridors	Public acceptance for new lines in existing infrastructure corridors	Re-Use of existing infrastructure or construction of underground cable	AC OHL AAAC- -2 Conductors	
3.Status Quo	No public acceptance for new OHL	Only upgrade of existing lines with same visual impact or construction of underground cables otherwise	DC Cable XLPE-	

Both SOs T1 and T2 are adequate to the transmission corridor between Spain and Portugal which links the clusters 01 and 12. Further evidence of public opinion is required to confine and finalise the technology. However, in this report the guidelines are proposed to overcome the risks during the infrastructure development considering either of the technology or in combination at stage 2.

Step 7:

In D2.3 it is said that connections with North Africa to Europe are considered to be already in place and their development is out of the scope of e-Highway 2050. Even though the import of energy from North Africa to Europe has relevant share in meeting the overall demand in x-5, the SO’s IS1 and IS2 are not adequate for 01_es – 12_pt.

Step 8:

The SO’s under the international strategy theme are not adequate for 01_es – 12_pt.

Step 9:

On conducting detailed analysis in the above eight steps, the SOs that are relevant to the transmission link 01_es – 12_pt are presented in Table 10.

Table 9: SOs relevant to 01_es – 12_pt

Strategic Option	Transmission Link: 01-es – 12-pt
G1-Centralised and large scale RES	✓
G2-Decentralised and small scale RES	
G3-Dominant RES	✓
G4-RES non-dominant	
G5-Nuclear and Fossil without CCS near existing capacity	✓
G6-Nuclear and Fossil with CCS close to demand	
G7-High to very high flows from SE and NE to CE	
G8–High to medium flows from NE to CE	
G9–Low Energy Flows	
S1–Centralised Hydro Storage	✓
S2–Centralised Hydro and CAES	✓
S3–Mixed Scale storage	✓
T1–Overhead Transmission	✓
T2–Underground HVDC and Overhead HVAC	✓
IS1–Irrelevant import from North Africa	
IS2–Relevant import from North Africa	

Similar process is followed for all other transmission links identified in grid architecture based on scenario x-5. The results of relevant SOs to the transmission links are presented in Table 10.

Table 10: Related SOs to identified Transmission corridors/links (x-5)

Transmission link	G1	G2	G3	G4	G5	G6	G7	G8	G9	S1	S2	S3	T1	T2	IS1	IS2
01_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
02_es - 08_es	✓		✓		✓					✓	✓	✓	✓			
02_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
03_es - 04_es	✓		✓		✓					✓	✓	✓	✓			
03_es - 07_es	✓		✓		✓					✓	✓	✓	✓			
04_es - 14_fr	✓		✓		✓					✓	✓	✓	✓	✓		
…																
114_ns - 72_dk	✓		✓		✓		✓			✓	✓	✓		✓		
116_ns - 88_se	✓		✓		✓					✓	✓	✓		✓		

The full table is listed in annex 2.

5. Risks and Opportunities after Elimination

In this test risks and opportunities were selected for individual TC and presented in the following table.

Table 11: (-) Risks and opportunities (+) after elimination

Grid X-5 Characteristics	CDF 1- Social acceptance and acceptability	CDF 2- Energy security and technologies	CDF 3- Geo-Political Economy and Regional Equity	CDF 4 – European Regional Governance
G1-Large Scale RES	(-)less equitable distribution of energy system benefits due to the inherent risks associated with an energy system based on regional imbalances (-) public acceptance and acceptability could be in flux – support for this type of generation system may change in the future (-) Centralised permitting frameworks may reduce participation opportunities at local level, reducing social equity (-) Uneven distribution of some energy system costs and benefits (+) Forest biomass production may	(+) More efficient generation units and more competitive RES vs. fossil fuels in electricity generation, promoting low-carbon energy; (+) Promotion of a low-carbon economy and contribution to RES incorporation goals. (-) May not be the most cost-efficient solution to provide for all European regions, namely for current	(+) Viability of EU energy export and import potential and development of energy trade agreements with 3rd countries; (+) Contribution to EU international energy and technology trade; (+) Support the expansion of the Energy Community. (-) May affect equitable distribution of energy system costs and benefits; (-) Poor access to finance	(+) May increase MS level interest and adherence to RES policies; (+) Increase the dynamics of market functioning may contribute to EU strategic objective of security of supply based on RES. (-) Fragmentation of market may reduce predictability among policy-makers. (-) May determine regional imbalances and provoke unsustainability and non-

	help deliver multiple benefits for landscapes, ecosystems and ecosystem services (-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations (-) Infrastructure related land take altering the type and distribution of ecosystem services across the EU (+) Reduced exposure to perceived or actual health vulnerabilities if generation happens where the resource is best/away from population centre (-) Infrastructure vulnerability to extreme climatic events, depending on location and specific local climate change impacts	energy islands, due to high investment in storage and transmission. (+) Promotes technological development of large-scale and centralized technologies which may drive down RES costs. (-) Inhibits investment in decentralised generation technologies. (+) Promote Europe's RES potential, reducing energy dependence from abroad. (-) Depends on the realisation of large-scale storage; (-) Centralized generation as single option against EU macro-policies; (-) Increased vulnerability to energy outages of regions that depend on pan-	may constrain energy system development resulting in electricity price differentials and regional equity impacts; (-) Real estate values may diminish within areas affected by new infrastructure.	competitive internal market of electricity. (-) Potential policy conflicts between EU macro-policies may be more evident under this option. (+) Encourages the application of cross-border cooperation mechanisms (trades and subsidies rates). (-) Discourage small producers to be engaged in energy initiatives; (-) Overrule MS level planning processes due to current administration procedures.

		European grid, hence, energy islands might remain.		

The full table is listed in annex 5.

6. Test Results of Stage 2

In [2] majority of the guidelines to address the risks are proposed. In this step of the testing process the specific guidelines to address individual risk are chosen from the general list of guidelines provided in [2]. Where required additional guidelines are proposed and the overall list of guidelines to address risks is presented in Table 13.

Table 12: Guidelines for x-5 **[2]**

CDF	Grid x-5 Characteristics	(+) Opportunities / (-) Risks	Planning and Management Guidelines	Monitoring Guidelines	Governance Guidelines
1	G1-Large Scale RES	(-)less equitable distribution of energy system benefits due to the inherent risks associated with an energy system based on regional imbalances.	Design electricity grids and markets to assure equitable distribution of energy system benefits, especially where fuel poverty is critical.	Monitor the distribution of energy system costs and benefits.	DG Energy: Impose a requirement for further harmonisation of energy policy, price coupling initiatives etc. (this should aim to protect MS that are net energy importers in particular)
		(-) public acceptance and acceptability could be in flux – support for this type of generation system may change in the future.	Ensure continued engagement with the public and affected communities during energy system implementation. This should be designed in order to: 1) promote increased awareness of climate change and sustainability issues; 2) promote green behaviours;	Monitor the public acceptance and acceptability of different aspects of the EU energy system.	DG Energy: Undertake further research and consultation with stakeholders, the public and affected communities to gauge current support for different generation

			and 3) to capture data on changing community needs, thereby ensuring continued service delivery improvements		technologies

The full table is listed in annex 6.

7. Length of TCs Based on Three Strategies for 100% RES X-7

Transmission is a crucial stage in energy trading across and within the countries. It has significant impact in terms of public acceptance, cost, technology and energy security. Additionally, e-Highway 2050 gives serious consideration to curb the contribution of energy related activity to global warming and emissions to the atmosphere.

In [4] researchers proposed three strategies to encompass wide range of possibilities for the development of transmission infrastructure. Each strategy will imply different length (km) of transmission network in the GA's. The inputs from WP2 give an indication of the total length of the transmission network based on the type of technology that can be used to develop pan European GA. The GA of x-7 transmission technical data classification is presented in Table 14.

Table 13: Length (km) classification based on technology in three strategies for GA of x-7

Strategy	Total Distance (km)	AC OHL AAAC	AC OHL AAAC4 conductor	AC OHL AAAC- 2 conductor	AC OHL ACSS-	DC OHL-	DC Cable XLPE-V1	DC CABLE XLPE-V2	Refurbish Upgrade
1	84251	9022	10141	6193	972	0	35648	22275	0
2	102217	9981	7531	4661	852	0	7767	71425	0
3	103182	0	0	0	0	0	59556	41210	2416

8. Critical Comparison of GAs

8.1 Relation between Strategic Options and GAs

The generalised SOs presented in Table 3 of [2] gives an overview of the scenarios. The relevant number of strategic options to individual transmission corridors either increase or decrease in the GAs. This can be clearly observed in Table 10 for Large scale RES (x-5) and Table 21 for 100% RES (x-7).

S3-mixed scale storage is an extra SO that is applicable to TCs in the GA of x-7 arising from Spain, France, Netherlands, Germany, Denmark, Czech Republic, Austria, Italy, Belgium, Macedonia, Finland, Norway, Sweden, UK and countries linked with North Sea clusters. This SO has been considered where one of the two linked clusters has existing operational measures & desirable political policies that are adopted at national level for storage. In the GA of x-7, there are no additional SO's that are considered. On performing the two stage SESA application process to GAs of x-10, x-13 and x-16 the consideration of extra SOs can be determined.

8.2 Transmission Strategies within the GA

T1- Overhead transmission and T2- Underground HVDC & Overhead HVAC are applicable to both Large scale RES and 100% RES scenarios. This applicability can be narrowed in the GAs and can even be more specific with the individual TCs. The technology that can be used to construct the TCs has been classified based on three strategies. The three strategies adopted are:

Table 14: Transmission Strategies for Reinforcements

Transmission						
Strategy	**Social Assumption**	**Technical Description**	**Cables**	**Up-Grade of OHL**	**New OHL**	**New OHL on non-existing corridors**
1.New Grid Acceptance	Public acceptance for new OHL	Most efficient solution	✓	✓	✓	✓
2.Re –Use of corridors	Public acceptance for new lines in existing infrastructure corridors	Re-Use of existing infrastructure or construction of underground cable	✓	✓	✓	
3.Status Quo	No public acceptance for new OHL	Only upgrade of existing lines with same visual impact or construction of underground cables otherwise	✓	✓		

New grid acceptance is a very optimistic strategy where public acceptance of new OHL & infrastructure is expected. Even though majority of TCs in this strategy are OHLs, there are few links that are expected to be possible only through underground cables. Example: Links with North Sea. Re-use of corridors is a reasonable strategy where public acceptance of new OHL & infrastructure is not expected but upgrade of OHL on existing infrastructure is welcomed. Status Quo is a very pessimistic strategy where the upgrade of existing transmission lines with same visual impact to transmission infrastructure else underground cable construction is expected to be acceptable by the public.

The GA of Large scale RES (x-5) is aimed to satisfy the requirement of 451,800MW. This amount of power transmission is possible through 110 TCs with a total GA running 31,545km across Europe. The total transmission lines distance is different to that of total GA length because the earlier is multiplied with number of conductors to obtain the final value. The total TD varies with transmission strategies in all GAs. 100% RES (x-7) is aimed to meet the demand of 378,000MW with the help of 74 TCs running 22,795km.

The estimated transmission distances (TD) in strategy 1 for both the GAs of x-5 & x-7 are very close with 1478km difference i.e. higher in x-5. In strategy 2 the TD is higher in x-7 when compared to x-5 by 15,790km and TD in strategy 3 is again very close estimation with 4,597km higher in x-5.

During the process of assigning transmission SOs (T1,T2) to TCs it is observed that 975km of DC OHL-500kV is used in strategies 1 & 2 of Large scale RES GA whereas this technology is not used in other GAs of scenarios. Refurbishment is accounted for upgrading OHLs which are AC.

Table 15: Example: Transmission corridor 02_es – 08_es in the GA of x-5

TC	Strategy 1	Strategy 2	Strategy 3
02_es – 08_es	AC OHL AAAC--2conductor	AC OHL AAAC--2conductor	Refurbishment

For the above TC the applicable SO among T1 and T2 is considered to be T1.

8.3 Impact of Risks on Grid Reinforcements

The transmission SOs that are relevant to TCs in different transmission strategies pose risks under any of the four CDFs. These risks are to be addressed in order to proceed with the establishment of pan-European GA. In this testing process the total numbers of risks that comply with T1, T2 are 8 and 9 respectively. As it is difficult to differentiate the major and minor risks at this stage, it is recommended to be prepared to apply the guidelines in order to address risks of every TC that connects the clusters either within the country or with other country.

Some of the TCs in x-5 & x-7 are possible only using DC underground cable technology in all transmission strategies. The list of TCs and the corresponding risks to be addressed are presented in Table 17.

Table 16: List of TCs possible only with DC Underground Cable Technology and the corresponding Risks

TCs with common technology in all transmission strategies for the GA of x-5 (12,487km)	21_fr - 96_ie, 22_fr - 90_uk, 26_fr - 90_uk, 28_be - 90_uk, 30_nl - 38_dk, 30_nl - 79_no, 30_nl - 90_uk, 31_de - 72_dk, 31_de - 79_no, 32_de - 72_dk, 32_de - 89_se, 38_dk - 72_dk, 38_dk - 79_no, 54_it - 64_me, 54_it - 98_it, 55_it - 56_it, 55_it - 68_gr, 72_dk - 89_se, 73_ee - 75_fi, 75_fi - 88_se, 77_lt - 88_se, 92_uk - 96_ie, 93_uk - 95_uk, 98_it - 99_fr, 106_ns - 110_ns, 106_ns - 90_uk, 107_ns - 92_uk, 108_ns - 93_uk, 109_ns - 94_uk, 110_ns - 28_be, 111_ns - 30_nl, 112_ns - 113_ns, 112_ns - 31_de, 113_ns - 38_dk, 114_ns - 116_ns, 114_ns - 72_dk, 116_ns - 88_se	
TCs with common technology in all transmission strategies for the GA of x-7 (10,842km)	21_fr - 96_ie, 22_fr - 90_uk, 26_fr - 90_uk, 28_be - 90_uk, 30_nl - 79_no, 31_de - 79_no, 31_de - 89_se, 32_de - 89_se, 37_de - 49_at, 49_at - 52_it, 54_it - 64_me, 54_it - 98_it, 55_it - 68_gr, 59_ro - 61_ro, 66_bg - 68_gr, 73_ee - 75_fi, 73_ee - 78_lv, 77_lt - 78_lv, 79_no - 92_uk, 92_uk - 96_ie, 106_ns - 90_uk, 107_ns - 92_uk, 109_ns - 94_uk, 110_ns - 28_be, 111_ns - 30_nl, 112_ns - 113_ns, 112_ns - 31_de, 112_ns - 33_de, 113_ns - 30_nl, 115_ns - 79_no	
Risks to be addressed under CDFs	CDF1- Social Acceptance and Acceptability	(-) Underground cable systems may constrain land use options to a degree due to buffer distance that can't be developed (-) Land take within pan-European electricity highway corridors may constrain land use/management options including biodiversity/habitat

		(-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associated ground movements
	CDF2- Energy Security and Technologies	(-) Infrastructure costs may risk overall monetary efficiency of energy system. (-) Repair times to underground cables are usually longer; (-) Depends on the TRL for HVDC components; (-) Higher costs of underground and submarine cables may restrict their use in most remote areas, possibly resulting in the maintenance of exiting energy islands.
	CDF3- Geo-Political Economy and Regional Equity	(-) HVDC grid connections may not be compatible with North African infrastructure. (-) High start-up and maintenance costs of underground and submarine HVDC may contribute to high energy costs and less consistent energy pricing across Europe.
	CDF4- European Regional Governance	None

Same risks apply to TCs in other GAs using DC Underground Cable technology (x-10, x-13, and x-16).

8.4 Mitigation of Impacts

The applicability of risks to TCs have been narrowed in this report based on the three transmission strategies to implement the grid reinforcements .The guidelines to address the risks (T1 and T2) are provided in Table 13 and those can be followed or applied to all reinforcements in the GAs.

8.5 Discussion

The grid architectures of all the five e-Highway2050 scenarios are realistic images of future Europe which includes incredible amount of opportunities and some risks. The 110 grid reinforcements of x-5 reflects the deployment of large scale offshore wind farms in North sea and a high priority to the pumped hydro centralised storage. Even though nuclear plants and fossil fuels are expected as the centralized technology to meet the 2050 demand, advancements in the carbon capture and storage technologies are immature here.. Demand side management concept seems to be of less interest. The agreements for power transmission across national boundaries require more sophistication as 63 translational TCs exist.

Grid Architecture of x-7 comprising 74 grid reinforcements constitutes to satisfy the demand by supplying the energy to entire Europe that is generated from renewables. In addition to the assumptions made in x-5, mixed scale storage solutions such as demand side management, electric vehicles and batteries are also considered to balance the inconsistencies in the renewable energy generation from wind and sun. The total transnational reinforcements are 42.

The grid architecture of x-10 comprises of 52 TCs including 32 transnational reinforcements. On an average €165 billion investments represent a transmission capacity of 255GW across Europe. It is complete market based strategy where renewable, fossil and nuclear generation sources are considered along with high importance to carbon capture and storage technology development. The importance is low towards mixed scale storage options and imports from North Africa.

Grid Architecture of x-13 includes 72 TCs with the grid length of 20,647km to supply 253GW of power across Europe. The acceptability towards fossil and nuclear with carbon capture & storage is assumed to be positive throughout Europe. The mixed scale storage options are not considered and renewable generation sources are of low priority. Only 40 transnational reinforcements are expected. Even though green initiatives are not focussed, the development of pan-European transmission infrastructure amounts to an average investment of €153 billion.

Grid Architecture of x-16 consists of 51 TCs with a grid length of 16,376km to supply 190GW. Fossil fuels and nuclear plants are also part of the energy mix to meet the 2050 demand but the CCS technology is not considered as an option to reach the goal of reduced GHG emissions. Decentralised renewable energy generation is given high importance and is deployed locally. As the demand (190GW) is the lowest compared to other scenarios, it directly reflects on the number of transnational reinforcements required i.e. only 27.

Table 17: Number of TCs, Grid Length and Power Requirement

Scenario	Number of Required Transmission Corridors/Links	Total Distance of the GA (km)	Transmission Requirement (MW)
x-5	110	31 545	451 800
x-7	74	22 795	378 000
x-10	52	16 228	255 000
x-13	72	20 647	253 000
x-16	51	16 376	190 000

Table 18: Investments based on Transmission Strategies

Scenario	Total Investment Required for Transmission in Different Strategies (€ billion)		
	New Grid Acceptance (1)	Re-Use of Corridors (2)	Status Quo (3)
x-5	255	269	384
x-7	245	247	345
x-10	138	142	216
x-13	121	127	211
x-16	116	135	192

The development of grid architectures based on the energy mix, storage options and international strategy has its pros and cons. The ultimate aim is to achieve secure, reliable and clean energy. Which ever the grid architecture and transmission strategy is adopted, it is difficult to go further without having a negative impact on the environment and vice versa and challenging to reject or prioritise at this stage. Denmark has already presented an Energy Strategy 2050 which declares their energy independence from fossil fuels by 2050 [1]. If Denmark sets an example to other European countries then the grid architectures of x-13 & x-10 are in question. The higher number of TCs in the GA with Status Quo transmission strategy will have to address various risks. The GAs of x-5 and x-7 resembles similar characteristics and further evidence is provided in sections 8.2 and 8.3. Even though grid reinforcements in x-16 are less when compared to others, the increased local infrastructure development will have effect on the immediate surrounding environment of the public. By adopting the mitigation measures it could be beneficial to focus on x-5 and x-7 grid architectures. However, it is again the energy mix and the transmission strategies adopted based on the public acceptance that play crucial role in decision making.

Regarding the other scenarios, they follow the x-7 layout since the DC OHL is not used.

Table 19: Length of TCs based on three strategies for x-10, x-13 and x-16

Scenario	Strategy	Total Distance (km)	AC OHL AAAC-	AC OHL AAAC- 4 conductor	AC OHL AAAC- 2 conductor	AC OHL ACSS-	DC OHL-	DC Cable XLPE-V1	DC CABLE XLPE-V2	Refurbish Upgrade
x-10	1	46718	2020	4902	5588	4768	0	14818	14622	0
	2	46718	2020	4902	5588	4768	0	14818	14622	0
	3	58355	0	0	0	0	0	37731	19720	904
x-13	1	47977	2426	8055	11144	1773	0	8579	16000	0

	2	47977	2426	8055	11144	1773	0	8579	16000	0
	3	60699	0	0	0	0	0	34961	23426	2312
x-16	1	48153	5240	4870	8173	1663	0	10169	18038	0
	2	50245	5240	2921	8173	602	0	17290	16019	0
	3	55512	0	0	0	0	0	43204	10535	1773

9. Conclusion

This report has tested aspects of Strategic Environmental and Sustainability Assessment (SESA) methodology for the cases of two Grid Architectures of e-Highway 2050: the "Large scale RES & no emissions" (x-5) and "100% RES" (x-7) scenarios. For this purpose, a two stage testing method is introduced and described. A nine step sequence algorithm is explained in section 4 that relates the strategic options (SOs) for transmission development introduced in WP2 to a given transmission corridor/link. The identified 110 transmission corridors/links in x-5 and 74 TCs in x-7 are individually assessed to relate the SOs categorised under generation & regional balance, storage, transmission and international strategy. In Stage 1, data available at macro-area level, county level and cluster level is considered where relevant during the application process. The applicability of additional SOs to the individual TCs is also studied based on the existing operational measures & desirable political policies that are adopted at national level in member states. For the scenario "Large Scale RES & no emissions" (x-5), strategic option 'S3' is considered in addition to the relevant SOs proposed in [2] to acknowledge the stance and data contained within existing national policies of member states for storage. Even though grid design choices are made, influenced by desirable scenarios to have alternative images of future transmission, it is also important to accept or consider the best that is required and available to reach the goal of reduced GHG emissions at every stage. The installed capacities of generating sources classified based on technology at country level are considered to relate the SOs of generation & regional balance. The additional storage facilities available in the member states are also considered when assessing the TCs of grid architectures. The SOs related to transmission are more specific and are narrowed based on the transmission technology and strategies that are applicable to TCs. The boxes of international strategy options are left blank as there is no direct link between the identified TCs and North Africa. The connections between European member states and North Africa are considered as already in service in WP2.

Stage 2 comprises of detailing ROs, and proposing additional guidelines for relevant risks. A careful consideration has been given to various risks in all strategic themes with special interest in transmission area. Stage 2 of testing process is completed successfully by listing/proposing additional planning & management, monitoring and governance guidelines. The idea behind the two stage testing process is to make it convenient for the decision makers to initially consider the SOs that are relevant to TCs in stage 1 and later refer to the guidelines presented in stage 2 to address the risks.

Critical comparison of GAs has been made analysing the critical areas such as relation between SOs and GAs, transmission strategies within the GAs, the impact of risks on grid reinforcements and finally the mitigation of impacts. Though it is very challenging to reject or prioritise the GAs at this stage, an indication can be drawn from the analysis and discussion. The Danish parliament's decision that the entire economy of Denmark must be powered by 100% renewables energy sources (RES) by the year 2050 seems to be the most ambitious energy goal. If this slogan is adopted strictly by politicians of other member states in Europe in addition to the existing GHG reduction targets by 2050 then the opportunities and consideration of RES at pan-European level will be fuelled. The usage of conventional sources of energy will become standby. The percentage of fossil in the European energy mix might get diminished in the long run. This will have consequences on carbon capture & storage technology and also the grid architectures that will be designed based on the scenarios x-10 and x-13. The concept of decentralisation and small scale RES which is predominant in x-16 might help in achieving the GHG reduction targets but will increase several local establishments which directly develops serious impacts on the immediate surrounding environment of the public. The abundance in local infrastructure will also become threat to security, health and safety. The GAs of x-5 and x-7 subjected to the transmission strategies are promising for the development of pan-European transmission system 2050.

Contribution to e-Highway 2050 Project

1. A two stage testing process is created to check the applicability of SESA methodology to the GAs of e-Highway 2050 scenarios although only in relation to some aspects, since the complete outcomes of the assessment presented in D4.2a have not been tested.
2. A critical link is made between WP2 and WP4 (D4.2a) by providing decision makers with a streamlined process to relate strategic options to particular transmission corridors, this way enabling a project-based interpretation of potential physical environmental impacts.

3. For the scenario "Large Scale RES & no emissions" (x-5), strategic option 'S3' is considered in addition to the relevant SOs proposed in [2] to acknowledge the stance and data contained within existing national policies of member states for storage.
4. Additional guidelines have been identified and suggested to address some risks.

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Annex 1 - GTCs in the starting grid and identified transmission requirements (x-5)

Links	*Reference distance (km)*	GTCs in the starting Grid- MW		Transmission requirements identified-MW	
		Type in the starting grid (AC/DC/Rest Of the World)	Large scale RES (X5)	Reinforcements (Reinforced/not reinforced/new)	Large scale RES (X5)
01_es - 02_es	186	AC	7200	reinforced	0
01_es - 03_es	372	non existing	0	new	0
01_es - 12_pt	204	AC	1200	reinforced	1000
02_es - 03_es	186	AC	19100	not reinforced	0
02_es - 04_es	302	AC	2400	not reinforced	0
02_es - 07_es	260	non existing	0	new	0
02_es - 08_es	335	AC	2400	reinforced	1000
02_es - 12_pt	215	AC	950	reinforced	1000
03_es - 04_es	181	AC	7100	reinforced	2000
03_es - 05_es	257	AC	3900	not reinforced	0
03_es - 07_es	118	AC	10200	reinforced	2000
03_es - 11_es	344	AC	2700	not reinforced	0
04_es - 05_es	181	AC	900	not reinforced	0
04_es - 07_es	276	non existing	0	new	0
04_es - 14_fr	238	AC + DC	2000	reinforced	5000
05_es - 06_es	185	AC	7000	not reinforced	0
05_es - 07_es	280	non existing	0	new	0
05_es - 11_es	259	AC	5700	not reinforced	0
05_es - 14_fr	283	AC	100	not reinforced	0
06_es - 07_es	463	non existing	0	new	0
06_es - 11_es	365	AC	1100	reinforced	4000
06_es - 15_fr	272	AC + DC	1800	reinforced	10000

07_es - 08_es	183	AC	8700	reinforced	2000
07_es - 11_es	265	AC	2100	reinforced	2000
07_es - 12_pt	343	non existing	0	new	0
08_es - 09_es	234	AC	6100	reinforced	0
08_es - 10_es	223	AC	4000	reinforced	0
08_es - 13_pt	269	AC	900	reinforced	2000
09_es - 10_es	205	AC	8100	not reinforced	0
09_es - 102_ma	317	RoW	12000	not reinforced	0
09_es - 13_pt	299	AC	500	reinforced	2000
10_es - 11_es	269	AC	3200	reinforced	1000
100_ru - 73_ee	502	RoW	1000	not reinforced	0
100_ru - 74_fi	809	RoW	70	not reinforced	0
100_ru - 75_fi	485	RoW	1400	not reinforced	0
100_ru - 77_lt	803	RoW	1900	not reinforced	0
100_ru - 78_lv	639	RoW	400	not reinforced	0
100_ua - 42_pl	217	RoW	1000	not reinforced	0
100_ua - 58_hu	511	RoW	700	not reinforced	0
100_ua - 59_ro	386	RoW	700	not reinforced	0
101_mi - 66_bg	573	RoW	1500	not reinforced	0
101_mi - 68_gr	785	RoW	2000	not reinforced	0
101_mi - 69_gr	784	RoW	2000	not reinforced	0
102_ma - 13_pt	590	RoW	5000	not reinforced	0
103_dz - 10_es	654	RoW	6000	not reinforced	0
103_dz - 16_fr	929	RoW	12000	not reinforced	0
103_dz - 98_it	710	RoW	11000	not reinforced	0
104_tn - 56_it	458	RoW	8500	not reinforced	0
105_ly - 56_it	788	RoW	8500	not reinforced	0
105_ly - 69_gr	918	RoW	6000	not reinforced	0
106_ns - 110_ns	105	non existing	0	new	2000

106_ns - 90_uk	217	DC	8000	reinforced	10000
107_ns - 92_uk	295	DC	6023	reinforced	3000
108_ns - 93_uk	231	DC	1004	reinforced	1000
109_ns - 94_uk	162	DC	1004	reinforced	1000
110_ns - 28_be	188	DC	1000	reinforced	2000
111_ns - 30_nl	140	DC	4462	reinforced	2000
112_ns - 113_ns	198	non existing	0	new	9000
112_ns - 30_nl	261	non existing	0	new	0
112_ns - 31_de	210	DC	8000	reinforced	10000
112_ns - 33_de	331	non existing	0	new	0
113_ns - 30_nl	455	non existing	0	new	0
113_ns - 38_dk	128	DC	8000	reinforced	9000
114_ns - 116_ns	173	non existing	0	new	1000
114_ns - 72_dk	171	DC	3904	reinforced	2000
115_ns - 79_no	114	DC	335	reinforced	0
116_ns - 88_se	286	DC	335	reinforced	1000
12_pt - 13_pt	214	AC	4000	reinforced	1000
14_fr - 15_fr	189	AC	2000	reinforced	0
14_fr - 17_fr	308	AC	3000	reinforced	4000
14_fr - 18_fr	360	AC	1100	reinforced	1000
15_fr - 16_fr	254	AC	3500	reinforced	8000
15_fr - 18_fr	306	AC	4500	not reinforced	0
16_fr - 19_fr	173	AC	5200	reinforced	2000
16_fr - 20_fr	237	AC	450	reinforced	1000
17_fr - 18_fr	190	AC	4200	not reinforced	0
17_fr - 21_fr	244	AC	5400	reinforced	1000
17_fr - 22_fr	248	AC	250	reinforced	3000
18_fr - 19_fr	257	AC	2200	reinforced	2000
18_fr - 23_fr	191	AC	10000	not reinforced	0

18_fr - 24_fr	181	AC	125	reinforced	2000
19_fr - 20_fr	136	AC	6000	reinforced	1000
19_fr - 24_fr	272	AC	2500	not reinforced	0
19_fr - 52_it	450	DC	1000	reinforced	1000
20_fr - 24_fr	205	AC	3000	not reinforced	0
20_fr - 25_fr	266	AC	1150	reinforced	0
20_fr - 47_ch	211	AC	4300	not reinforced	0
20_fr - 48_ch	261	AC	1300	not reinforced	0
20_fr - 52_it	353	AC	4800	reinforced	1000
21_fr - 22_fr	211	AC	7000	not reinforced	0
21_fr - 96_ie	682	DC	700	reinforced	6000
22_fr - 23_fr	184	AC	2400	reinforced	1000
22_fr - 26_fr	216	AC	3200	reinforced	1000
22_fr - 90_uk	313	DC	1000	reinforced	4000
23_fr - 24_fr	196	AC	3500	not reinforced	0
23_fr - 25_fr	306	AC	4000	not reinforced	0
23_fr - 26_fr	147	AC	17900	not reinforced	0
23_fr - 27_fr	167	AC	1100	not reinforced	0
24_fr - 25_fr	169	AC	4200	reinforced	0
25_fr - 27_fr	179	AC	3500	not reinforced	0
25_fr - 28_be	287	AC	400	reinforced	0
25_fr - 35_de	246	AC	2100	reinforced	0
25_fr - 36_de	195	AC + DC	1800	reinforced	1000
25_fr - 47_ch	170	AC	3900	not reinforced	0
26_fr - 27_fr	159	AC	4900	not reinforced	0
26_fr - 28_be	175	AC	2900	not reinforced	0
26_fr - 90_uk	275	DC	2000	reinforced	9000
27_fr - 28_be	160	AC	1300	not reinforced	0
28_be - 29_lu	152	AC	700	not reinforced	0

28_be - 30_nl	191	AC	3500	reinforced	0
28_be - 33_de	223	DC	1000	reinforced	0
28_be - 90_uk	353	DC	1000	reinforced	4000
29_lu - 35_de	162	AC	2900	not reinforced	0
30_nl - 31_de	271	AC	1400	reinforced	1000
30_nl - 33_de	162	AC	7100	not reinforced	0
30_nl - 38_dk	499	DC	700	reinforced	3000
30_nl - 79_no	739	DC	700	reinforced	7000
30_nl - 90_uk	390	DC	1000	reinforced	4000
31_de - 32_de	228	AC	5400	not reinforced	0
31_de - 33_de	219	AC + DC	17330	reinforced	12000
31_de - 35_de	333	AC + DC	6300	not reinforced	0
31_de - 36_de	510	DC	2000	not reinforced	0
31_de - 37_de	488	DC	4000	reinforced	4000
31_de - 38_dk	333	AC	3000	reinforced	11000
31_de - 72_dk	308	non existing	0	new	4000
31_de - 79_no	652	DC	1400	reinforced	17000
31_de - 89_se	474	DC	1200	reinforced	0
32_de - 34_de	208	AC	9300	not reinforced	0
32_DE - 38_DK	400	non existing	0	new	0
32_de - 44_pl	264	AC	3400	not reinforced	0
32_de - 72_dk	270	DC	600	reinforced	2000
32_DE - 89_SE	386	non existing	0	new	8000
33_de - 35_de	147	AC	19050	not reinforced	0
33_de - 36_de	344	DC	2000	not reinforced	0
34_de - 35_de	312	AC	2600	reinforced	0
34_de - 37_de	260	AC + DC	14840	reinforced	0
34_de - 39_cz	200	AC	1700	not reinforced	0
34_de - 44_pl	296	AC	1700	reinforced	3000

35_de - 36_de	197	AC	7700	not reinforced	0
35_de - 37_de	274	AC	6130	not reinforced	0
36_de - 37_de	181	AC	7500	reinforced	0
36_de - 47_ch	175	AC	6000	not reinforced	0
36_de - 49_at	281	AC	2800	not reinforced	0
37_de - 39_cz	231	AC	2000	reinforced	1000
37_de - 49_at	198	AC	2500	reinforced	1000
37_de - 50_at	280	AC	5500	not reinforced	0
38_dk - 72_dk	172	DC	600	reinforced	1000
38_dk - 79_no	335	DC	1700	reinforced	2000
38_dk - 88_se	465	DC	740	reinforced	0
39_cz - 40_cz	190	AC	7600	reinforced	1000
39_cz - 44_pl	289	non existing	0	new	0
40_cz - 43_pl	191	AC	2100	reinforced	5000
40_cz - 46_sk	213	AC	2700	reinforced	1000
40_cz - 51_at	166	AC	2100	reinforced	5000
41_pl - 42_pl	215	AC	4700	not reinforced	0
41_pl - 43_pl	302	AC	4900	reinforced	4000
41_pl - 44_pl	338	AC	3400	reinforced	0
41_pl - 45_pl	219	AC	4400	not reinforced	0
41_pl - 77_lt	349	AC	1000	reinforced	8000
42_pl - 43_pl	212	AC	4300	not reinforced	0
42_pl - 46_sk	298	AC	600	reinforced	3000
43_pl - 44_pl	296	AC	4000	reinforced	2000
44_pl - 45_pl	227	AC	8900	reinforced	2000
45_pl - 89_se	423	DC	600	reinforced	0
46_sk - 58_hu	172	AC	5400	reinforced	2000
47_ch - 48_ch	110	AC	19800	not reinforced	0
47_ch - 49_at	332	AC	900	not reinforced	0

48_ch - 49_at	259	AC	1500	not reinforced	0
48_ch - 52_it	158	AC + DC	8500	not reinforced	0
49_at - 50_at	177	AC	6300	reinforced	4000
49_at - 52_it	262	AC	2300	reinforced	4000
50_at - 51_at	119	AC	6100	reinforced	4000
50_at - 57_si	168	AC	1600	not reinforced	0
51_at - 58_hu	284	AC	1600	reinforced	1000
52_it - 53_it	264	AC	2200	reinforced	11000
52_it - 57_si	356	AC + DC	3600	not reinforced	0
53_it - 54_it	192	AC	2000	reinforced	11000
53_it - 62_hr	457	DC	1000	not reinforced	0
53_it - 99_fr	263	DC	300	reinforced	0
54_it - 55_it	301	AC	10000	reinforced	11000
54_it - 64_me	499	DC	1000	reinforced	1000
54_it - 98_it	429	DC	700	reinforced	8000
55_it - 56_it	357	AC	1100	reinforced	9000
55_it - 68_gr	463	DC	1000	reinforced	6000
55_it - 70_al	335	DC	1000	not reinforced	0
57_si - 58_hu	384	AC	900	reinforced	1000
57_si - 62_hr	161	AC	3400	not reinforced	0
58_hu - 59_ro	315	AC	1400	reinforced	1000
58_hu - 62_hr	274	AC	2300	not reinforced	0
58_hu - 65_rs	367	AC	700	reinforced	1000
59_ro - 60_ro	203	AC	3500	not reinforced	0
59_ro - 61_ro	300	AC	900	reinforced	0
60_ro - 61_ro	270	AC	4700	not reinforced	0
60_ro - 65_rs	285	AC	2500	not reinforced	0
60_ro - 66_bg	249	AC	800	not reinforced	0
61_ro - 66_bg	390	AC	900	not reinforced	0

62_hr - 63_ba	182	AC	4000	not reinforced	0
62_hr - 65_rs	372	AC	700	not reinforced	0
63_ba - 64_me	200	AC	1400	not reinforced	0
63_ba - 65_rs	242	AC	3100	not reinforced	0
64_me - 65_rs	180	AC	2900	not reinforced	0
64_me - 70_al	190	AC	900	not reinforced	0
65_rs - 66_bg	383	AC	900	reinforced	0
65_rs - 67_mk	272	AC	1900	reinforced	1000
65_rs - 70_al	325	AC	900	not reinforced	0
66_bg - 67_mk	308	AC	700	not reinforced	0
66_bg - 68_gr	430	AC	500	reinforced	0
67_mk - 68_gr	183	AC	600	reinforced	2000
67_mk - 70_al	160	AC	700	not reinforced	0
68_gr - 69_gr	254	AC	11600	not reinforced	0
68_gr - 70_al	181	AC	800	not reinforced	0
72_dk - 89_se	168	AC	1700	reinforced	4000
73_ee - 75_fi	404	DC	1000	reinforced	5000
73_ee - 78_lv	204	AC	950	reinforced	5000
74_fi - 75_fi	498	AC	3500	reinforced	0
74_fi - 85_no	315	AC	50	reinforced	1000
74_fi - 86_se	286	AC	1800	not reinforced	0
75_fi - 88_se	690	AC	1350	reinforced	3000
77_lt - 78_lv	182	AC	1500	reinforced	5000
77_lt - 88_se	698	DC	700	reinforced	2000
79_no - 80_no	152	AC	1500	reinforced	3000
79_no - 81_no	216	AC	1700	reinforced	17000
79_no - 92_uk	902	non existing	0	new	0
79_no - 93_uk	719	DC	1400	not reinforced	0
80_no - 81_no	143	AC	1500	not reinforced	0

80_no - 82_no	172	AC	5300	reinforced	0
81_no - 83_no	283	AC	800	reinforced	7000
81_no - 92_uk	1066	non existing	0	new	0
82_no - 83_no	188	AC	400	reinforced	0
82_no - 88_se	323	AC	2148	reinforced	2000
83_no - 84_no	488	AC	200	reinforced	5000
83_no - 87_se	316	AC	1000	not reinforced	0
84_no - 85_no	497	AC	700	reinforced	0
84_no - 86_se	234	AC	700	not reinforced	0
84_no - 87_se	363	AC	250	not reinforced	0
86_se - 87_se	407	AC	4200	reinforced	5000
87_se - 88_se	499	AC	7300	reinforced	8000
88_se - 89_se	307	AC	6500	reinforced	9000
90_uk - 91_uk	232	AC	7600	not reinforced	0
90_uk - 92_uk	196	AC	8000	reinforced	13000
91_uk - 92_uk	204	AC	5000	not reinforced	0
92_uk - 93_uk	239	AC	7900	reinforced	13000
92_uk - 96_ie	385	DC	500	reinforced	1000
93_uk - 94_uk	273	AC	4500	reinforced	9000
93_uk - 95_uk	287	DC	500	reinforced	1000
95_uk - 96_ie	188	AC	1100	reinforced	1000
98_it - 99_fr	229	DC	400	reinforced	800

Annex 2 - SOs Related to Transmission Links/Corridors (x-5)

Transmission link	G1	G2	G3	G4	G5	G6	G7	G8	G9	S1	S2	S3	T1	T2	IS1	IS2
01_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
02_es - 08_es	✓		✓		✓					✓	✓	✓	✓			
02_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
03_es - 04_es	✓		✓		✓					✓	✓	✓	✓			
03_es - 07_es	✓		✓		✓					✓	✓	✓	✓			
04_es - 14_fr	✓		✓		✓					✓	✓	✓	✓	✓		
06_es - 11_es	✓		✓		✓					✓	✓	✓	✓	✓		
06_es - 15_fr	✓		✓		✓					✓	✓	✓	✓	✓		
07_es - 08_es	✓		✓		✓					✓	✓	✓	✓			
07_es - 11_es	✓		✓		✓					✓	✓	✓	✓	✓		
08_es - 13_pt	✓		✓		✓					✓	✓	✓	✓	✓		
09_es - 13_pt	✓		✓		✓					✓	✓	✓	✓	✓		
10_es - 11_es	✓		✓		✓					✓	✓	✓	✓			

12_pt - 13_pt	✓		✓		✓					✓	✓		✓			
14_fr - 17_fr	✓		✓		✓					✓	✓	✓	✓	✓		
14_fr - 18_fr	✓		✓		✓					✓	✓	✓	✓	✓		
15_fr - 16_fr	✓		✓		✓					✓	✓	✓	✓	✓		
16_fr - 19_fr	✓		✓		✓					✓	✓	✓	✓			
16_fr - 20_fr	✓		✓		✓					✓	✓	✓	✓	✓		
17_fr - 21_fr	✓		✓		✓					✓	✓	✓	✓			
17_fr - 22_fr	✓		✓		✓					✓	✓	✓	✓	✓		
18_fr - 19_fr	✓		✓		✓					✓	✓	✓	✓	✓		
18_fr - 24_fr	✓		✓		✓					✓	✓	✓	✓	✓		
19_fr - 20_fr	✓		✓		✓					✓	✓	✓	✓			
19_fr - 52_it	✓		✓		✓					✓	✓	✓	✓	✓		
20_fr - 52_it	✓		✓		✓					✓	✓	✓	✓	✓		
21_fr - 96_ie	✓		✓		✓					✓	✓	✓		✓		
22_fr - 23_fr	✓		✓		✓					✓	✓	✓	✓			
22_fr - 26_fr	✓		✓		✓					✓	✓	✓	✓			

22_fr - 90_uk	✓		✓		✓					✓	✓	✓		✓		
25_fr - 36_de	✓		✓		✓					✓	✓	✓	✓	✓		
26_fr - 90_uk	✓		✓		✓					✓	✓	✓		✓		
28_be - 90_uk	✓		✓		✓					✓	✓	✓		✓		
30_nl - 31_de	✓		✓		✓					✓	✓	✓	✓	✓		
30_nl - 38_dk	✓		✓		✓						✓	✓		✓		
30_nl - 79_no	✓		✓		✓					✓	✓	✓		✓		
30_nl - 90_uk	✓		✓		✓					✓	✓	✓		✓		
31_de - 33_de	✓		✓		✓					✓	✓	✓	✓	✓		
31_de - 37_de	✓		✓		✓					✓	✓	✓		✓		
31_de - 38_dk	✓		✓		✓					✓	✓	✓	✓	✓		
31_de - 72_dk	✓		✓		✓					✓	✓	✓		✓		
31_de - 79_no	✓		✓		✓		✓			✓	✓	✓		✓		
32_de - 72_dk	✓		✓		✓					✓	✓	✓		✓		
32_de - 89_se	✓		✓		✓		✓			✓	✓	✓		✓		
34_de - 44_pl	✓		✓		✓					✓	✓	✓	✓	✓		

37_de - 39_cz	✓		✓		✓					✓	✓	✓	✓			
37_de - 49_at	✓		✓		✓					✓	✓	✓	✓			
38_dk - 72_dk	✓		✓		✓						✓	✓		✓		
38_dk - 79_no	✓		✓		✓		✓			✓	✓	✓		✓		
39_cz - 40_cz	✓		✓		✓					✓	✓	✓	✓			
40_cz - 43_pl	✓		✓		✓					✓	✓	✓	✓	✓		
40_cz - 46_sk	✓		✓		✓					✓	✓	✓	✓			
40_cz - 51_at	✓		✓		✓					✓	✓	✓	✓	✓		
41_pl - 43_pl	✓		✓		✓					✓	✓		✓	✓		
41_pl - 77_lt	✓		✓		✓					✓	✓		✓	✓		
42_pl - 46_sk	✓		✓		✓					✓	✓		✓	✓		
43_pl - 44_pl	✓		✓		✓					✓	✓		✓	✓		
44_pl - 45_pl	✓		✓		✓					✓	✓		✓			
46_sk - 58_hu	✓		✓		✓					✓	✓		✓			
49_at - 50_at	✓		✓		✓					✓	✓	✓	✓	✓		
49_at - 52_it	✓		✓		✓		✓			✓	✓	✓	✓	✓		

50_at - 51_at	✓		✓		✓					✓	✓	✓	✓	✓		
51_at - 58_hu	✓		✓		✓					✓	✓	✓	✓	✓		
52_it - 53_it	✓		✓		✓					✓	✓	✓	✓	✓		
53_it - 54_it	✓		✓		✓					✓	✓	✓	✓	✓		
54_it - 55_it	✓		✓		✓					✓	✓	✓	✓	✓		
54_it - 64_me	✓		✓		✓					✓	✓	✓		✓		
54_it - 98_it	✓		✓		✓					✓	✓	✓		✓		
55_it - 56_it	✓		✓		✓					✓	✓	✓		✓		
55_it - 68_gr	✓		✓		✓					✓	✓	✓		✓		
57_si - 58_hu	✓		✓		✓					✓	✓		✓	✓		
58_hu - 59_ro	✓		✓		✓					✓	✓	✓	✓	✓		
58_hu - 65_rs	✓		✓		✓					✓	✓		✓	✓		
65_rs - 67_mk	✓		✓		✓					✓	✓		✓	✓		
67_mk - 68_gr	✓		✓		✓					✓	✓	✓	✓	✓		
72_dk - 89_se	✓		✓		✓		✓			✓	✓	✓		✓		
73_ee - 75_fi	✓		✓		✓					✓	✓			✓		

73_ee - 78_lv	✓		✓		✓					✓	✓		✓	✓		
74_fi - 85_no	✓		✓		✓					✓	✓	✓	✓	✓		
75_fi - 88_se	✓		✓		✓					✓	✓	✓		✓		
77_lt - 78_lv	✓		✓		✓					✓	✓		✓	✓		
77_lt - 88_se	✓		✓		✓					✓	✓	✓		✓		
79_no - 80_no	✓		✓		✓					✓	✓	✓	✓	✓		
79_no - 81_no	✓		✓		✓					✓	✓	✓	✓	✓		
81_no - 83_no	✓		✓		✓					✓	✓	✓	✓	✓		
82_no - 88_se	✓		✓		✓					✓	✓	✓	✓	✓		
83_no - 84_no	✓		✓		✓					✓	✓	✓	✓	✓		
86_se - 87_se	✓		✓		✓					✓	✓	✓	✓	✓		
87_se - 88_se	✓		✓		✓					✓	✓	✓	✓	✓		
88_se - 89_se	✓		✓		✓					✓	✓	✓	✓	✓		
90_uk - 92_uk	✓		✓		✓					✓	✓	✓	✓	✓		
92_uk - 93_uk	✓		✓		✓					✓	✓	✓	✓	✓		
92_uk - 96_ie	✓		✓		✓					✓	✓	✓		✓		

93_uk - 94_uk	✓		✓		✓					✓	✓	✓	✓	✓		
93_uk - 95_uk	✓		✓		✓					✓	✓	✓		✓		
95_uk - 96_ie	✓		✓		✓					✓	✓	✓	✓	✓		
98_it - 99_fr	✓		✓		✓					✓	✓	✓		✓		
106_ns - 110_ns	✓		✓		✓					✓	✓			✓		
106_ns - 90_uk	✓		✓		✓					✓	✓	✓		✓		
107_ns - 92_uk	✓		✓		✓					✓	✓	✓		✓		
108_ns - 93_uk	✓		✓		✓					✓	✓	✓		✓		
109_ns - 94_uk	✓		✓		✓					✓	✓	✓		✓		
110_ns - 28_be	✓		✓		✓					✓	✓	✓		✓		
111_ns - 30_nl	✓		✓		✓					✓	✓			✓		
112_ns - 113_ns	✓		✓		✓					✓	✓			✓		
112_ns - 31_de	✓		✓		✓		✓			✓	✓	✓		✓		
113_ns - 38_dk	✓		✓		✓		✓			✓	✓	✓		✓		
114_ns - 116_ns	✓		✓		✓					✓	✓			✓		
114_ns - 72_dk	✓		✓		✓		✓			✓	✓	✓		✓		

116_ns - 88_se	✓		✓		✓					✓	✓	✓		✓		

Annex 3 - SOs Related to Transmission Links/Corridors (x-7)

By following the nine step sequence algorithm, SOs that are relevant to 74 transmission corridors are identified and presented in **Table 20:** Related SOs to identified Transmission Corridors/links (x-7). The technology, length and strategy that can be adopted at cluster level will have major impact in the development of pan-European transmission network. The significant changes that can be observed in the following **Table 20:** Related SOs to identified Transmission Corridors/links (x-7) when compared with the SOs presented in general in Table 3 of D4.2a are in terms of Transmission and Storage. Further evidence of public opinion is required to confine and finalise the technology for transmission where NIMBY attitude plays important role. Transmission can be clearly differentiated at the cluster level with the help of inputs from WP2. Only S3 under storage has variation with regards to the applicability depending on the existing operational measures & desirable political policies that are adopted at national level for storage.

Table 20: Related SOs to identified Transmission Corridors/links (x-7)

Transmission link/corridor	G1	G2	G3	G4	G5	G6	G7	G8	G9	S1	S2	S3	T1	T2	IS1	IS2
01_es - 02_es	✓		✓		✓					✓	✓	✓	✓			
01_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
02_es - 12_pt	✓		✓		✓					✓	✓	✓	✓	✓		
03_es - 04_es	✓		✓		✓					✓	✓	✓	✓			
03_es - 07_es	✓		✓		✓					✓	✓	✓	✓			

04_es - 14_fr	✓		✓		✓					✓	✓	✓	✓	✓		
06_es - 11_es	✓		✓		✓					✓	✓	✓	✓	✓		
06_es - 15_fr	✓		✓		✓					✓	✓	✓	✓	✓		
09_es - 13_pt	✓		✓		✓					✓	✓	✓	✓	✓		
14_fr - 15_fr	✓		✓		✓					✓	✓	✓	✓	✓		
14_fr - 17_fr	✓		✓		✓					✓	✓	✓	✓	✓		
15_fr - 16_fr	✓		✓		✓					✓	✓	✓	✓	✓		
17_fr - 21_fr	✓		✓		✓					✓	✓	✓	✓	✓		
17_fr - 22_fr	✓		✓		✓					✓	✓	✓	✓	✓		
20_fr - 25_fr	✓		✓		✓					✓	✓	✓	✓	✓		
21_fr - 96_ie	✓		✓		✓					✓	✓	✓		✓		
22_fr - 90_uk	✓		✓		✓					✓	✓	✓		✓		
25_fr - 28_be	✓		✓		✓					✓	✓	✓	✓	✓		
25_fr - 35_de	✓		✓		✓					✓	✓	✓	✓	✓		
26_fr - 90_uk	✓		✓		✓					✓	✓	✓		✓		
28_be - 30_nl	✓		✓		✓					✓	✓	✓	✓	✓		

28_be - 33_de	✓		✓		✓					✓	✓	✓	✓	✓		
28_be - 90_uk	✓		✓		✓					✓	✓	✓		✓		
30_nl - 79_no	✓		✓		✓					✓	✓			✓		
31_de - 32_de	✓		✓		✓					✓	✓	✓	✓	✓		
31_de - 79_no	✓		✓		✓		✓			✓	✓	✓		✓		
31_de - 89_se	✓		✓		✓		✓			✓	✓	✓		✓		
32_de - 89_se	✓		✓		✓		✓			✓	✓	✓		✓		
34_de - 35_de	✓		✓		✓					✓	✓	✓	✓	✓		
34_de - 37_de	✓		✓		✓					✓	✓	✓	✓			
34_de - 44_pl	✓		✓		✓					✓	✓	✓	✓	✓		
37_de - 49_at	✓		✓		✓					✓	✓	✓		✓		
39_cz - 44_pl	✓		✓		✓					✓	✓	✓	✓	✓		
41_pl - 44_pl	✓		✓		✓					✓	✓		✓	✓		
41_pl - 77_lt	✓		✓		✓					✓	✓		✓	✓		
49_at - 52_it	✓		✓		✓		✓			✓	✓	✓		✓		
52_it - 53_it	✓		✓		✓					✓	✓	✓	✓	✓		

53_it - 54_it	✓		✓		✓					✓	✓	✓	✓	✓		
54_it - 55_it	✓		✓		✓					✓	✓	✓	✓	✓		
54_it - 64_me	✓		✓		✓					✓	✓	✓		✓		
54_it - 98_it	✓		✓		✓					✓	✓	✓		✓		
55_it - 56_it	✓		✓		✓					✓	✓	✓	✓	✓		
55_it - 68_gr	✓		✓		✓					✓	✓	✓		✓		
58_hu - 59_ro	✓		✓		✓					✓	✓	✓	✓	✓		
59_ro - 61_ro	✓		✓		✓					✓	✓	✓		✓		
66_bg - 68_gr	✓		✓		✓					✓	✓	✓		✓		
73_ee - 75_fi	✓		✓		✓					✓	✓			✓		
73_ee - 78_lv	✓		✓		✓					✓	✓			✓		
77_lt - 78_lv	✓		✓		✓					✓	✓			✓		
79_no - 80_no	✓		✓		✓					✓	✓	✓	✓	✓		
79_no - 81_no	✓		✓		✓					✓	✓	✓	✓	✓		
79_no - 92_uk	✓		✓		✓					✓	✓	✓		✓		
80_no - 82_no	✓		✓		✓					✓	✓	✓	✓			

81_no - 83_no	✓		✓		✓					✓	✓	✓	✓	✓		
83_no - 84_no	✓		✓		✓					✓	✓	✓	✓	✓		
84_no - 85_no	✓		✓		✓					✓	✓	✓	✓	✓		
86_se - 87_se	✓		✓		✓					✓	✓	✓	✓	✓		
87_se - 88_se	✓		✓		✓					✓	✓	✓	✓	✓		
88_se - 89_se	✓		✓		✓					✓	✓	✓	✓	✓		
90_uk - 92_uk	✓		✓		✓					✓	✓	✓	✓	✓		
92_uk - 93_uk	✓		✓		✓					✓	✓	✓	✓	✓		
92_uk - 96_ie	✓		✓		✓					✓	✓	✓		✓		
93_uk - 94_uk	✓		✓		✓					✓	✓	✓	✓	✓		
95_uk - 96_ie	✓		✓		✓					✓	✓	✓	✓	✓		
106_ns - 90_uk	✓		✓		✓					✓	✓	✓		✓		
107_ns - 92_uk	✓		✓		✓					✓	✓	✓		✓		
109_ns - 94_uk	✓		✓		✓					✓	✓	✓		✓		
110_ns - 28_be	✓		✓		✓					✓	✓	✓		✓		
111_ns - 30_nl	✓		✓		✓					✓	✓			✓		

112_ns - 113_ns	✓		✓		✓					✓	✓			✓		
112_ns - 31_de	✓		✓		✓		✓			✓	✓	✓		✓		
112_ns - 33_de	✓		✓		✓		✓			✓	✓	✓		✓		
113_ns - 30_nl	✓		✓		✓					✓	✓			✓		
115_ns - 79_no	✓		✓		✓					✓	✓	✓		✓		

Annex 4: Stage2: ROs of x-5

Grid X-5 Characteristics	**CDF 1- Social acceptance and acceptability**	**CDF 2- Energy security and technologies**	**CDF 3- Geo-Political Economy and Regional Equity**	**CDF 4 – European Regional Governance**
G1-Large Scale RES	(-)less equitable distribution of energy system benefits due to the inherent risks associated with an energy system based on regional imbalances (-) public acceptance and acceptability could be in flux – support for this type of generation system may change in the future (-) Centralised permitting frameworks may reduce participation opportunities at local level, reducing social equity (-) Uneven distribution of some energy system costs and benefits (+) Forest biomass production may help deliver multiple benefits for landscapes, ecosystems and ecosystem services (-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations (-) Infrastructure related land take altering the type and distribution of ecosystem services across the EU (+) Reduced exposure to perceived or actual health vulnerabilities if	(+) More efficient generation units and more competitive RES vs. fossil fuels in electricity generation, promoting low-carbon energy; (+) Promotion of a low-carbon economy and contribution to RES incorporation goals. (-) May not be the most cost-efficient solution to provide for all European regions, namely for current energy islands, due to high investment in storage and transmission. (+) Promotes technological development of large-scale and centralized technologies which may drive down RES costs. (-) Inhibits investment in decentralised generation technologies. (+) Promote Europe's RES	(+) Viability of EU energy export and import potential and development of energy trade agreements with 3rd countries; (+) Contribution to EU international energy and technology trade; (+) Support the expansion of the Energy Community. (-) May affect equitable distribution of energy system costs and benefits; (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (-) Real estate values may diminish within areas affected by new infrastructure.	(+) May increase MS level interest and adherence to RES policies; (+) Increase the dynamics of market functioning may contribute to EU strategic objective of security of supply based on RES. (-) Fragmentation of market may reduce predictability among policy-makers. (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (-) Potential policy conflicts between EU macro-policies may be more evident under this option. (+) Encourages the application of cross-border cooperation mechanisms (trades and subsidies rates). (-) Discourage small producers to be engaged in energy initiatives;

	generation happens where the resource is best/away from population centre (-) Infrastructure vulnerability to extreme climatic events, depending on location and specific local climate change impacts	potential, reducing energy dependence from abroad. (-) Depends on the realisation of large-scale storage; (-) Centralized generation as single option against EU macro-policies; (-) Increased vulnerability to energy outages of regions that depend on pan-European grid, hence, energy islands might remain.		(-) Overrule MS level planning processes due to current administration procedures.
G3 – Res Dominance	(+) Even access to energy system benefits – RES-based EU internal energy system less vulnerable to external volatility (-) Reliance on storage infrastructure may expose the energy system to key climate change risks	(+) More efficient generation units and more competitive RES vs. fossil fuels in electricity generation, promoting (G1) low-carbon energy; (+) Promotion of a low-carbon economy and contribution to RES incorporation goals. (G1) (+) Promotes more efficient waste and biomass management; (+) Promotes DHC from RES might also result in additional CO2 reduction. (-) Existing fossil fuel plants making become less efficient working in under-optimal conditions.	(+) Contribution to EU international energy and technology trade. (-) May affect equitable distribution of energy system costs and benefits; (G1) (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (G1) (-) Real estate values may diminish within areas affected by new infrastructure. (G1) (-) Withdrawal of MS RES support schemes may delay or threaten implementation.	(+) Contribute to the converging of MS decarbonisation policy objectives. (-) Fragmentation of market may reduce predictability among policy-makers. (G1) (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (G1) (-) Potential policy conflicts between EU macro-policies may be more evident under this option. (G1) (+) Encourages the application of cross-border cooperation mechanisms (trades and subsidies rates).

		(+) Promotes investment in RES-related technologies, both large and small scale, such as storage, smart grids, next generation biofuels, electric-vehicles, CSP, ocean and wind energy, DHC, etc.; (+) In line with increasing R&D investment in sustainable energies. (-) Inhibit the development of innovative tech. not related to RES, which may have advantages for specific highly concentrated urban and industrial settings. (+) Promote Europe's RES potential, reducing energy dependence from abroad. (G1) (-) Increased vulnerability to power outages.		(G1) (+) Promotes national strategies for European coordination in energy issues; (-) Risk of opposition from countries with solid strategies for RES and non-RES (opposite strategies for energy mix).
G5- No new nuclear & Fossil	(+) Thermal and nuclear generation technologies can be sited close to demand with no loss of efficiency producing a constant supply of electricity, helping to maintain fair access to energy system benefits (-) Uneven distribution of some energy system costs and Benefits (G1) (-) Could face problems of public acceptance and acceptability as nuclear and thermal generation technologies are not favoured by EU	(-) Fossil fuels as a dominant energy source against macro-policy unless CCS is in place; (-) Inhibit more efficient use of RES capacities within Europe; (-) Need to transport primary fuels demanding additional resource consumption.	(-) Vulnerable to external market and political volatility; (-) Dependence on external fossil and nuclear fuel leaves Europe in a fragile negotiating position. (-) May affect equitable distribution of energy system costs and benefits; (G1)	(-) Risk of maintenance or increase of current support schemes for fossils, contradicting EU macro-objectives. (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (G1) (-) Success depends on regional security

	citizens (-) Increased risk of climate change (due to sustained GHG emissions) and associated social equity concerns (-) Continued resource depletion (fossil and nuclear), compromising the ability of future generations to meet their needs, making for a less equitable energy system (+) May have a smaller land take footprint per unit of energy produced, reducing energy development related pressure on land resources and ecosystem services (+) Limited requirement for grid reinforcements and therefore limited additional pressure on landscape, ecosystem and species population integrity (-) Increased volume of nuclear waste and concerns over its storage/management and implications of any accidents for biodiversity, landscapes and ecosystem services (-) Increased risk of climate change and concerns for the resilience of ecosystems, landscapes, habitats and species populations (-) Thermal and nuclear generation infrastructure located in southern Europe may become increasingly vulnerable to extreme climatic events.	(-) Inhibit CCS and nuclear energy related technological development. (-) Threaten overall reliability of supply, especially in regions where RES is not productive.	(-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts;(G1) (-) Real estate values may diminish within areas affected by new infrastructure. (G1)	coordination among stakeholders (risk of increasing political tension).
G7 – High to very high flows from SE and NE to CE	(-) Less equitable distribution of energy system benefits due to the inherent	(+) In line with macro-policy objectives of strengthening	(+) Support greater electricity market	(+) Opportunity to MS alignment strategies to

	risks associated with an energy system based on regional imbalances (G1) (-) Uneven distribution of some energy system costs and Benefits (G1) (-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations (G1) (-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associated ground movements.	the regional network in North-South flow directions (EIP 2020). (-) Likely to create major imbalances, and possible tensions, in terms of energy provision, capacity and demand within regions in Europe; (-) Central Europe is left dependent on regional energy imports, although it may access cheaper energy.	integration. (-) Less market integration and regional equity; (-) Central Europe exposed to EU internal energy market fluctuations.	promote regional cooperation and co-ordination (under ERI). (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (G1) (+) Opportunity to create cross-border institutional mechanisms (like engagement and cooperative mechanisms) to support the most vulnerable regions.
S1 – PHS Storage	(+) Can reduce the need for thermal and nuclear peaking units, potentially improving the overall public acceptance and acceptability of the energy system (-) Uneven distribution of some energy system costs and Benefits (G1) (-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations(G1) (-) Loss of efficacy during droughts – likely to affect centralised hydro storage in Southern Europe and South Central Europe in particular	(+) PHS has very high electrical efficiency (80%) and CAES has medium to very high (50% - 70%), thus reducing storage energy losses. (-) Limits future options by inhibiting technological development of other large-scale storage technologies. (-) Demotes the development of decentralized storage technologies and its massive deployment (e.g. EV) as of smart and microgrids, as well as breakthroughs in battery technology, which still has environmental impact issues.	(-) May affect equitable distribution of energy system costs and benefits; (G1) (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (G1) (-) Real estate values may diminish within areas affected by new infrastructure. (G1) (-) Difficulty of finding sites where additional capacity can be installed threatening the whole energy system. (-) Reliance on Central	(+) Opportunity for future institutional reforms to match different RES sources; (-) Limits political advances (regulatory mechanisms or governance approaches) due to the expected phase out of supporting schemes for mature technology. (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (G1) (-) Risk of divergent opinions (causing political tension and instability) from different territorial contexts (capacity vs. non-capacity to high scale hydro systems).

		(+) PHS is a readily available storage technology; (+) Large-scale storage allows efficient management of the energy system increasing its reliability. (-) Threatened by limited availability of adequate PHS (S1) and CAES (S2) locations, high investment costs and long lead times reducing the capacity of EU to create additional storage capacity; (-) Discourage small producers and local generation; (-) Energy system dependent on MS that provide high levels of storage - energy islands might remain.	Europe and Northern Europe affecting regional/distributional equity.	
S2- Centralised Hydro and CAES	(+) More socially acceptable due to the lesser environmental impacts of CAES technology (-) Diabatic CAES requires thermal energy (gas) and will therefore contribute to continued resource depletion (fossil fuels) and associated social equity issues (+) Combined strategy may reduce the need for additional centralised hydro storage, maintaining pressure on landscape, biodiversity and aquatic ecosystems at current levels (no net increase)	(+) PHS has very high electrical efficiency (80%) and CAES has medium to very high (50% - 70%), thus reducing storage energy losses. (S1) (-) May be less viable as part of a mixed generation portfolio based energy system, where CCS is used in conjunction with thermal generation. (+) Promotes technological	(+) Contribution to EU international trade, exporting CAES technology (S2) and other demand driven storage technologies (S3). (-) Difficulty of finding sites where additional capacity can be installed threatening the whole energy system.(S1)	(+) Opportunity for future institutional reforms to match different RES sources; (S1) (-) Limits political advances (regulatory mechanisms or governance approaches) due to the expected phase out of supporting schemes for mature technology. (S1) (-) May determine regional imbalances and provoke unsustainability and non-

	(-) Loss of efficacy during droughts – likely to affect centralised hydro storage in Southern Europe and South Central Europe in particular (S1)	development of more efficient adiabatic CAES. (-) Demotes the development of decentralized storage technologies and its massive deployment (e.g. EV) as of smart and microgrids, as well as breakthroughs in battery technology, which still has environmental impact issues. (S1) (+) PHS is a readily available storage technology; (S1) (+) Large-scale storage allows efficient management of the energy system increasing its reliability.(S1) (+) Using CAES (in addition to PHS) increases Europe's large-scale storage capacity. (-) Threatened by limited availability of adequate PHS (S1) and CAES (S2) locations, high investment costs and long lead times reducing the capacity of EU to create additional storage capacity; (S1) (-) Discourage small producers and local generation;(S1) (-) Energy system dependent		competitive internal market of electricity.(G1) (-) Risk of divergent opinions (causing political tension and instability) from different territorial contexts(capacity vs. non-capacity to high scale hydro systems).(S1)

		on MS that provide high levels of storage - energy islands might remain.(S1)		
T1 – Overhead HVAC/HVDC transmission	(-) Poor public acceptance and acceptability of transmission infrastructure due to visual impacts and perceived/actual health impacts of overhead HVAC lines (+) Overhead transmission infrastructure located in Southern Europe is not vulnerable to key climate change impacts.	(+) HVDC allows efficient long-distance bulk power delivery enhancing transmission capacity; (+) Using FACTS increases the efficiency of the electric system possibly reducing the need for new AC lines/cabling. (-) HVAC has higher energy losses and limits line length when compared to HVDC; (-) Overhead lines constrain HVDC's potential due to physical limits (weight, materials, and line's exposure to natural elements). (+) Promotes the technological development of HVDC components. (-) NIMBY effect might threaten transmission expansion; (-) Repair times to underground cables are usually longer; (-) Depends on the TRL for HVDC components; (-) Higher costs of	(-) HVDC grid connections may not be compatible with North African infrastructure. (-) May affect equitable distribution of energy system costs and benefits; (G1) (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (G1) (-) Real estate values may diminish within areas affected by new infrastructure. (G1)	(+) Engage state-level administrations and regulators for collaborative efforts in de development of context related public policy goals.

		underground and submarine cables may restrict their use in most remote areas, possibly resulting in the maintenance of exiting energy islands.		
T2- Underground HVDC and Overhead HVAC	(+) Underground transmission infrastructure is likely to enjoy high levels of public acceptance and acceptability (+) Small land take associated with underground HVDC transmission infrastructure reduces pressure on landscapes, ecosystems and ecosystem services (-) Underground cable systems may constrain land use options to a degree due to buffer distance that can't be developed (-) Land take within pan-European electricity highway corridors may constrain land use/management options including biodiversity/habitat (-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associated ground movements (G7)	(+) HVDC allows efficient long-distance bulk power delivery enhancing transmission capacity;(T1) (+) Using FACTS increases the efficiency of the electric system possibly reducing the need for new AC lines/cabling.(T1) (+) Conductor size in underground cables is larger than corresponding overhead line, thus reducing transmission losses even further. (-) HVAC has higher energy losses and limits line length when compared to HVDC;(T1) (-) Overhead lines constrain HVDC's potential due to physical limits (weight, materials, and line's exposure to natural elements). (T1) (-) Infrastructure costs may risk overall monetary efficiency of energy system.	(-) HVDC grid connections may not be compatible with North African infrastructure.(T1) (+) Efficient pan-European transmission via underground HVDC may contribute to low energy costs and consistent energy pricing across EU. (+) Minimal impacts on real estate values within areas affected by new strategic transmission infrastructure projects. (+) Ability to transmit high flows, including cross-border capacity and ability to manage regional imbalances, may support greater electricity market integration. (-) High start-up and maintenance costs of underground and submarine HVDC may contribute to high energy costs and less consistent energy pricing across Europe.	(+) Engage state-level administrations and regulators for collaborative efforts in de development of context related public policy goals.(T1)

		(+) Promotes the technological development of HVDC components.(T1) (+) Supply disruptions are less frequent than in overhead lines and the reliability of submarine cables is very high. (-) NIMBY effect might threaten transmission expansion;(T1) (-) Repair times to underground cables are usually longer;(T1) (-) Depends on the TRL for HVDC components;(T1) (-) Higher costs of underground and submarine cables may restrict their use in most remote areas, possibly resulting in the maintenance of exiting energy islands.(T1)		

IS2 – Relevant import from North Africa	(-) Increased pressure on marine ecosystems, habitats, species and ecosystem services (including commercial fisheries) in the Mediterranean sea as a result of submarine cable systems linking North Africa to continental Europe (-) Risks also associated with pressure caused as a result of cable landing station infrastructure	(-) Maintenance of energy dependency from the East and vulnerability to geopolitical tensions in neighbouring countries. (-) Strategy threatened by Desertec Industrial Initiative's low interest in exporting solar power from North Africa to Europe.	(+) Expansion of EU energy markets and greater opportunities for international energy trade. (-) May affect equitable distribution of energy system costs and benefits; (G1) (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (G1) (-) Real estate values may diminish within areas affected by new infrastructure. (G1) (-) Dependence on external fossil and nuclear fuel leaves Europe in a fragile negotiating position. (G5)	(-) Potential policy conflicts between EU macro-policies may be more evident under this option. (G1)

Annex 5: (-) Risks and opportunities (+) after elimination for x-5

Grid X-5 Characteristics	CDF 1- Social acceptance and acceptability	CDF 2- Energy security and technologies	CDF 3- Geo-Political Economy and Regional Equity	CDF 4 – European Regional Governance
G1-Large Scale RES	(-)less equitable distribution of energy system benefits due to the inherent risks associated with an energy system based on regional imbalances (-) public acceptance and acceptability could be in flux – support for this type of generation system may change in the future (-) Centralised permitting frameworks may reduce participation opportunities at local level, reducing social equity (-) Uneven distribution of some energy system costs and benefits (+) Forest biomass production may help deliver multiple benefits for landscapes, ecosystems and ecosystem services (-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations (-) Infrastructure related land take altering the type and distribution of ecosystem services across the EU (+) Reduced exposure to perceived or actual health vulnerabilities if	(+) More efficient generation units and more competitive RES vs. fossil fuels in electricity generation, promoting low-carbon energy; (+) Promotion of a low-carbon economy and contribution to RES incorporation goals. (-) May not be the most cost-efficient solution to provide for all European regions, namely for current energy islands, due to high investment in storage and transmission. (+) Promotes technological development of large-scale and centralized technologies which may drive down RES costs. (-) Inhibits investment in decentralised generation technologies. (+) Promote Europe's RES potential, reducing energy	(+) Viability of EU energy export and import potential and development of energy trade agreements with 3rd countries; (+) Contribution to EU international energy and technology trade; (+) Support the expansion of the Energy Community. (-) May affect equitable distribution of energy system costs and benefits; (-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts; (-) Real estate values may diminish within areas affected by new infrastructure.	(+) May increase MS level interest and adherence to RES policies; (+) Increase the dynamics of market functioning may contribute to EU strategic objective of security of supply based on RES. (-) Fragmentation of market may reduce predictability among policy-makers. (-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity. (-) Potential policy conflicts between EU macro-policies may be more evident under this option. (+) Encourages the application of cross-border cooperation mechanisms (trades and subsidies rates). (-) Discourage small producers to be engaged in energy initiatives;

	generation happens where the resource is best/away from population centre (-) Infrastructure vulnerability to extreme climatic events, depending on location and specific local climate change impacts	dependence from abroad. (-) Depends on the realisation of large-scale storage; (-) Centralized generation as single option against EU macro-policies; (-) Increased vulnerability to energy outages of regions that depend on pan-European grid, hence, energy islands might remain.		(-) Overrule MS level planning processes due to current administration procedures.
G3 – Res Dominance	(+) Even access to energy system benefits – RES-based EU internal energy system less vulnerable to external volatility (-) Reliance on storage infrastructure may expose the energy system to key climate change risks	(+) Promotes more efficient waste and biomass management; (+) Promotes DHC from RES might also result in additional CO2 reduction. (-) Existing fossil fuel plants making become less efficient working in under-optimal conditions. (+) Promotes investment in RES-related technologies, both large and small scale, such as storage, smart grids, next generation biofuels, electric-vehicles, CSP, ocean and wind energy, DHC, etc.; (+) In line with increasing R&D investment in sustainable energies.	(+) Contribution to EU international energy and technology trade. (-) Withdrawal of MS RES support schemes may delay or threaten implementation.	(+) Contribute to the converging of MS decarbonisation policy objectives. (+) Promotes national strategies for European coordination in energy issues; (-) Risk of opposition from countries with solid strategies for RES and non-RES (opposite strategies for energy mix).

		(-) Inhibit the development of innovative tech. not related to RES, which may have advantages for specific highly concentrated urban and industrial settings. (-) Increased vulnerability to power outages.		
G5- No new nuclear & Fossil	(+) Thermal and nuclear generation technologies can be sited close to demand with no loss of efficiency producing a constant supply of electricity, helping to maintain fair access to energy system benefits (-) Could face problems of public acceptance and acceptability as nuclear and thermal generation technologies are not favoured by EU citizens (-) Increased risk of climate change (due to sustained GHG emissions) and associated social equity concerns (-) Continued resource depletion (fossil and nuclear), compromising the ability of future generations to meet their needs, making for a less equitable energy system (+) May have a smaller land take footprint per unit of energy produced, reducing energy development related pressure on land resources and ecosystem services (+) Limited requirement for grid reinforcements and therefore limited	(-) Fossil fuels as a dominant energy source against macro-policy unless CCS is in place; (-) Inhibit more efficient use of RES capacities within Europe; (-) Need to transport primary fuels demanding additional resource consumption. (-) Inhibit CCS and nuclear energy related technological development. (-) Threaten overall reliability of supply, especially in regions where RES is not productive.	(-) Vulnerable to external market and political volatility; (-) Dependence on external fossil and nuclear fuel leaves Europe in a fragile negotiating position.	(-) Risk of maintenance or increase of current support schemes for fossils, contradicting EU macro-objectives. (-) Success depends on regional security coordination among stakeholders (risk of increasing political tension).

	additional pressure on landscape, ecosystem and species population integrity (-) Increased volume of nuclear waste and concerns over its storage/management and implications of any accidents for biodiversity, landscapes and ecosystem services (-) Increased risk of climate change and concerns for the resilience of ecosystems, landscapes, habitats and species populations (-) Thermal and nuclear generation infrastructure located in southern Europe may become increasingly vulnerable to extreme climatic events			
G7 – High to very high flows from SE and NE to CE	(-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associate ground movements	(+) In line with macro-policy objectives of strengthening the regional network in North-South flow directions (EIP 2020). (-) Likely to create major imbalances, and possible tensions, in terms of energy provision, capacity and demand within regions in Europe; (-) Central Europe is left dependent on regional energy imports, although it may access cheaper energy.	(+) Support greater electricity market integration. (-) Less market integration and regional equity; (-) Central Europe exposed to EU internal energy market fluctuations.	(+) Opportunity to MS alignment strategies to promote regional cooperation and co-ordination (under ERI). (+) Opportunity to create cross-border institutional mechanisms (like engagement and cooperative mechanisms) to support the most vulnerable regions.
S1 – PHS Storage	(+) Can reduce the need for thermal and nuclear peaking units, potentially improving the overall public	(+) PHS has very high electrical efficiency (80%) and CAES has medium to	(-) Difficulty of finding sites where additional capacity can be installed threatening	(+) Opportunity for future institutional reforms to match different RES sources;

	acceptance and acceptability of the energy system (-) Loss of efficacy during droughts – likely to affect centralised hydro storage in Southern Europe and South Central Europe in particular	very high (50% - 70%), thus reducing storage energy losses. (-) Limits future options by inhibiting technological development of other large-scale storage technologies. (-) Demotes the development of decentralized storage technologies and its massive deployment (e.g. EV) as of smart and microgrids, as well as breakthroughs in battery technology, which still has environmental impact issues. (+) PHS is a readily available storage technology; (+) Large-scale storage allows efficient management of the energy system increasing its reliability. (-) Threatened by limited availability of adequate PHS (S1) and CAES (S2) locations, high investment costs and long lead times reducing the capacity of EU to create additional storage capacity; (-) Discourage small producers and local generation;	the whole energy system. (-) Reliance on Central Europe and Northern Europe affecting regional/distributional equity.	(-) Limits political advances (regulatory mechanisms or governance approaches) due to the expected phase out of supporting schemes for mature technology. (-) Risk of divergent opinions (causing political tension and instability) from different territorial contexts (capacity vs. non-capacity to high scale hydro systems).

		(-) Energy system dependent on MS that provide high levels of storage - energy islands might remain.		
S2-- Centralised Hydro and CAES	(+) More socially acceptable due to the lesser environmental impacts of CAES technology (-) Diabatic CAES requires thermal energy (gas) and will therefore contribute to continued resource depletion (fossil fuels) and associated social equity issues (+) Combined strategy may reduce the need for additional centralised hydro storage, maintaining pressure on landscape, biodiversity and aquatic ecosystems at current levels (no net increase).	(-) May be less viable as part of a mixed generation portfolio based energy system, where CCS is used in conjunction with thermal generation. (+) Promotes technological development of more efficient adiabatic CAES. (+) Using CAES (in addition to PHS) increases Europe's large-scale storage capacity.	(+) Contribution to EU international trade, exporting CAES technology (S2) and other demand driven storage technologies (S3).	
T1 – Overhead HVAC/HVDC transmission	(-) Poor public acceptance and acceptability of transmission infrastructure due to visual impacts and perceived/actual health impacts of overhead HVAC lines (+) Overhead transmission infrastructure located in Southern Europe is not vulnerable to key climate change impacts.	(+) HVDC allows efficient long-distance bulk power delivery enhancing transmission capacity; (+) Using FACTS increases the efficiency of the electric system possibly reducing the need for new AC lines/cabling. (-) HVAC has higher energy losses and limits line length when compared to HVDC; (-) Overhead lines constrain HVDC's potential due to physical limits (weight, materials, and line's	(-) HVDC grid connections may not be compatible with North African infrastructure.	(+) Engage state-level administrations and regulators for collaborative efforts in de development of context related public policy goals.

		exposure to natural elements). (+) Promotes the technological development of HVDC components. (-) NIMBY effect might threaten transmission expansion; (-) Repair times to underground cables are usually longer; (-) Depends on the TRL for HVDC components; (-) Higher costs of underground and submarine cables may restrict their use in most remote areas, possibly resulting in the maintenance of exiting energy islands.		
T2- Underground HVDC and Overhead HVAC	(+) Underground transmission infrastructure is likely to enjoy high levels of public acceptance and acceptability (+) Small land take associated with underground HVDC transmission infrastructure reduces pressure on landscapes, ecosystems and ecosystem services (-) Underground cable systems may constrain land use option to a degree due to buffer distance that can't be developed.	(+) Conductor size in underground cables is larger than corresponding overhead line, thus reducing transmission losses even further. (-) Infrastructure costs may risk overall monetary efficiency of energy system. (+) Supply disruptions are less frequent than in overhead lines and the reliability of submarine cables is very high.	(+) Efficient pan-European transmission via underground HVDC may contribute to low energy costs and consistent energy pricing across EU. (+) Minimal impacts on real estate values within areas affected by new strategic transmission infrastructure projects. (+) Ability to transmit high flows, including cross-border capacity and ability to	

	(-) Land take within pan-European electricity highway corridors may constrain land use/management options including biodiversity/habitat		manage regional imbalances, may support greater electricity market integration. (-) High start-up and maintenance costs of underground and submarine HVDC may contribute to high energy costs and less consistent energy pricing across Europe.	
IS2 – Relevant import from North Africa	(-) Increased pressure on marine ecosystems, habitats, species and ecosystem services (including commercial fisheries) in the Mediterranean sea as a result of submarine cable systems linking North Africa to continental Europe (-) Risks also associated with pressure caused as a result of cable landing station infrastructure	(-) Maintenance of energy dependency from the East and vulnerability to geopolitical tensions in neighbouring countries. (-) Strategy threatened by Desertec Industrial Initiative's low interest in exporting solar power from North Africa to Europe.	(+) Expansion of EU energy markets and greater opportunities for international energy trade.	

Annex 6: Guidelines for x-5

CDF	Grid x-5 Characteristics	(+) Opportunities / (-) Risks	Planning and Management Guidelines	Monitoring Guidelines	Governance Guidelines
1	G1-Large Scale RES	(-)less equitable distribution of energy system benefits due to the inherent risks associated with an energy system based on regional imbalances.	Design electricity grids and markets to assure equitable distribution of energy system benefits, especially where fuel poverty is critical.	Monitor the distribution of energy system costs and benefits.	<u>DG Energy:</u> Impose a requirement for further harmonisation of energy policy, price coupling initiatives etc. (this should aim to protect MS that are net energy importers in particular)
		(-) public acceptance and acceptability could be in flux – support for this type of generation system may change in the future.	Ensure continued engagement with the public and affected communities during energy system implementation. This should be designed in order to: 1) promote increased awareness of climate change and sustainability issues; 2) promote green behaviours; and 3) to capture data on changing community needs, thereby ensuring continued service delivery improvements	Monitor the public acceptance and acceptability of different aspects of the EU energy system.	<u>DG Energy:</u> Undertake further research and consultation with stakeholders, the public and affected communities to gauge current support for different generation technologies
		(-) Centralised permitting frameworks may reduce participation opportunities at local level, reducing social equity	Ensure that multiple scale, robust governance arrangements are in place, to provide a framework for multiple energy system stakeholders engagement in delivery and management	Monitor the distribution of energy system costs and benefits.	<u>DG Energy:</u> Robust governance arrangements should be put in place, at a range of scales, to provide the necessary framework whereby multiple energy system stakeholders (including affected communities) can engage in delivery and

					management;
		(-) Uneven distribution of some energy system costs and benefits	Design electricity grids and markets to ensure more deprived/less affluent communities do not bear the greatest burden of energy system costs	Monitor the distribution of energy system costs and benefits**.**	DG Energy: Impose a requirement for further harmonisation of energy policy, price coupling initiatives etc. (this should aim to protect MS that are net energy importers in particular)
		(+) Forest biomass production may help deliver multiple benefits for landscapes, ecosystems and ecosystem services			
		(-) Infrastructure pressure affecting the integrity of landscapes, ecosystems, communities (of species), habitats and individual species populations	Seek to avoid first, then reduce (mitigate) and only as a last resort compensate for loss of biodiversity and other ecosystem services	Monitor energy system infrastructure pressure on biodiversity, landscapes and ecosystem services.	MS: Effective integrated land use planning and sensitive landscape design to 'fit' RES development within the landscape, protecting ecosystem function and biodiversity
		(-) Infrastructure related land take altering the type and distribution of ecosystem services across the EU	Ensure that any essential grid reinforcements are planned and designed to minimise pressure on biodiversity, landscape and ecosystem services	Monitor energy system infrastructure pressure on biodiversity, landscapes and ecosystem services.	MS: Effective integrated land use planning and sensitive landscape design to 'fit' RES development within the landscape, protecting ecosystem function and biodiversity

		(+) Reduced exposure to perceived or actual health vulnerabilities if generation happens where the resource is best/away from population centre			
		(-) Infrastructure vulnerability to extreme climatic events, depending on location and specific local climate change impacts	Consider how appropriate use of transmission technology can minimise health vulnerabilities associated with transmitting flows from energy generation to energy demand regions (e.g. use underground cables in vulnerable locations)	Monitor energy system infrastructure vulnerability to extreme climatic events.	<u>MS:</u> Consider key climatic vulnerabilities in the planning and design of large scale, centralised RES.
	G3 – Res Dominance	(+) Even access to energy system benefits – RES-based EU internal energy system less vulnerable to external volatility			
		(-) Reliance on storage infrastructure may expose the energy system to key climate change risks	Develop a portfolio of storage options to minimise exposure to climate change risks (i.e. avoid reliance on pumped hydro storage).	Monitor energy storage infrastructure vulnerability to extreme climatic change risks	<u>Regulators:</u> Use capacity market design and management to reduce regional energy system climate change vulnerability.
	G5- No new nuclear & Fossil	(+) Thermal and nuclear generation technologies can be sited close to demand with no loss of efficiency producing a constant supply of electricity, helping to maintain fair access to energy system benefits			
		(-) Could face problems of public acceptance and acceptability as nuclear and thermal generation technologies are not favoured by EU citizens	Use upfront public engagement as early as possible to help deliver these types of mitigation strategies most effectively.	Monitor the public acceptance and acceptability of different aspects of the EU energy system.	<u>DG Energy:</u> Undertake further research and consultation with stakeholders, the public and affected communities to gauge current support

					for different generation technologies;
		(-) Increased risk of climate change (due to sustained GHG emissions) and associated social equity concerns	Use environmental planning and spatial planning effectively	Monitor EU GHG emissions	MS: Consider full range of land take related life cycle impacts (e.g. resource extraction, GHG emissions and waste management) during options appraisal and planning/design of energy generation development;
		(-) Continued resource depletion (fossil and nuclear), compromising the ability of future generations to meet their needs, making for a less equitable energy system	Identify opportunities for energy development (e.g. through the planning and construction of new transmission infrastructure) to enhance structural and functional landscape connectivity (e.g. development of wildlife corridors and stepping stones).	Monitor EU domestic fossil fuel exploitation	DG Energy: Promote R&D to maximise the efficiency of nuclear and thermal generation technologies.
		(+) May have a smaller land take footprint per unit of energy produced, reducing energy development related pressure on land resources and ecosystem services			
		(+) Limited requirement for grid reinforcements and therefore limited additional pressure on landscape, ecosystem and species population integrity			

		(-) Increased volume of nuclear waste and concerns over its storage/management and implications of any accidents for biodiversity, landscapes and ecosystem services	Seek to avoid first, then reduce (mitigate) and only as a last resort compensate for loss of biodiversity and other ecosystem services	Monitor energy sector (nuclear) related waste and waste management.	MS: Consider full range of land take related life cycle impacts (e.g. resource extraction, GHG emissions and waste management) during options appraisal and planning/design of energy generation development;
		(-) Increased risk of climate change and concerns for the resilience of ecosystems, landscapes, habitats and species populations	Use environmental planning and spatial planning effectively	Monitor forest biomass production. Monitor uptake of greener environment. Monitor status of habitats and species of European interest within affected areas	MS: Put in place wider resilience measures to protect the most vulnerable during heat waves; Ensure effective use of spatial planning and constraints analysis to guide large scale RES deployment away from the most ecologically sensitive terrestrial and marine areas (e.g. areas of land with a distinct primary use such as national parks, Natura 2000 sites, Important Bird Areas (IBAs), prime agricultural land, carbon rich soils);
		(-) Thermal and nuclear generation infrastructure located in southern Europe may become increasingly vulnerable to extreme climatic events.	Effective use of spatial planning and constraints analysis to guide generation infrastructure deployment to the most suitable locations	Monitor energy system infrastructure vulnerability to extreme climatic events.	DG Energy: Promote R&D in climate resilient generation technologies;

	G7 – High to very high flows from SE and NE to CE	(-) Underground lines transmitting high flows from Southern Europe will be particularly vulnerable to prolonged periods of drought causing changes in soil conditions and associated ground movements	Use spatial planning and constraints analysis to guide underground lines away from particularly vulnerable locations (e.g. in terms of soils, hydrology, hydrogeology etc.).	Monitor energy system infrastructure vulnerability to extreme climatic events	MS: Put in place wider resilience measures to protect the most vulnerable during heat waves; Regulators: Use capacity market design and management to reduce regional energy system climate change vulnerability.
	S1 – PHS Storage	(+) Can reduce the need for thermal and nuclear peaking units, potentially improving the overall public acceptance and acceptability of the energy system			
		(-) Loss of efficacy during droughts – likely to affect centralised hydro storage in Southern Europe and South Central Europe in particular	Develop a portfolio of storage options to minimise exposure to climate change risks (i.e. avoid reliance on pumped hydro storage).	Monitor energy system infrastructure vulnerability to extreme climatic events.	Regulators: Use capacity market design and management to reduce regional energy system climate change vulnerability.
	S2-- Centralised Hydro and CAES	(+) More socially acceptable due to the lesser environmental impacts of CAES technology			
		(-) Diabatic CAES requires thermal energy (gas) and will therefore contribute to continued resource depletion (fossil fuels) and associated social equity issues	Only use CAES technology where geophysical conditions allow (e.g. watercourses with high recreational or biodiversity value)	Monitor EU domestic fossil fuel exploitation and GHG emissions.	DG Energy: Promote R&D that speeds up the market readiness of adiabatic CAES storage technologies (eliminates the need for gas inputs).

		(+) Combined strategy may reduce the need for additional centralised hydro storage, maintaining pressure on landscape, biodiversity and aquatic ecosystems at current levels (no net increase)			
	T1 – Overhead HVAC/HVDC transmission	(-) Poor public acceptance and acceptability of transmission infrastructure due to visual impacts and perceived/actual health impacts of overhead HVAC lines	Effectively use spatial planning and constraints analysis to guide transmission infrastructure deployment to the most suitable locations/routes. Engage the public and promote increased awareness and understanding of energy system costs and benefits	Monitor public participation in energy system planning and delivery.	<u>DG Energy:</u> Undertake further research and consultation with stakeholders, the public and affected communities to gauge current support for different transmission technologies
		(+) Overhead transmission infrastructure located in Southern Europe is not vulnerable to key climate change impacts			
	T2-Underground HVDC and Overhead HVAC	(+) Underground transmission infrastructure is likely to enjoy high levels of public acceptance and acceptability			
		(+) Small land take associated with underground HVDC transmission infrastructure reduces pressure on landscapes, ecosystems and ecosystem services			
		(-) Underground cable systems may constrain land use options to a degree due to buffer distance that can't be developed	Effectively use spatial planning and constraints analysis to guide transmission infrastructure deployment to the most suitable locations/routes	Monitor energy system infrastructure pressure on biodiversity, landscapes and ecosystem services.	<u>MS:</u> Ensure effective use of spatial planning and constraints analysis to guide transmission infrastructure deployment
		(-) Land take within pan-European	Work with landowners/managers to	Monitor energy system	<u>MS:</u> Effective integrated

		electricity highway corridors may constrain land use/management options including biodiversity/habitat	find suitable land use/management options (e.g. agriculture, forestry, semi-natural habitat, wildlife corridor etc.) within electricity highway corridors to ensure that land delivers multiple benefits	infrastructure pressure on biodiversity, landscapes and ecosystem services.	land use planning and sensitive landscape design to 'fit' transmission deployment within the landscape, protecting ecosystem function and biodiversity;
	IS2 – Relevant import from North Africa	(-) Increased pressure on marine ecosystems, habitats, species and ecosystem services (including commercial fisheries) in the Mediterranean sea as a result of submarine cable systems linking North Africa to continental Europe	Effectively use integrated marine/land spatial planning and constraints analysis to guide transmission infrastructure deployment to the most suitable locations/routes (e.g. less vulnerable areas in terms of marine habitats, fisheries, recreational areas)	Monitor energy system infrastructure pressure on biodiversity, landscapes and ecosystem services (including commercial fisheries)	<u>MS:</u> Ensure effective use of spatial planning and constraints analysis to guide transmission infrastructure deployment away from the most ecologically sensitive terrestrial and marine areas.
		(-) Risks also associated with pressure caused as a result of cable landing station infrastructure	Cable landing stations can be constructed far away from the coast where necessary. Marine/land spatial planning and constraints analysis must be effectively utilised.	Monitor energy system infrastructure pressure on landscapes	<u>MS:</u> Ensure that all aspects of infrastructure development are considered within integrated/cross-sector land use plans to avoid conflicts and maximise the delivery of multiple benefits
2	G1-Large Scale RES	(+) More efficient generation units and more competitive RES vs. fossil fuels in electricity generation, promoting low-carbon energy;			
		(+) Promotion of a low-carbon economy and contribution to RES incorporation goals.			

		(-) May not be the most cost-efficient solution to provide for all European regions, namely for current energy islands, due to high investment in storage and transmission.	Combine large-scale and decentralised, smaller-scale generation and storage solutions to reduce vulnerabilities.	Monitor the resource-efficiency per energy source, namely in the industrial and residential sectors.	DG Energy, DG Consumers National and Regional Consumer's Associations, EEA & NGOs Civil Society: Increase consumer awareness regarding DSM, load management and energy efficiency;
		(+) Promotes technological development of large-scale and centralized technologies which may drive down RES costs.			
		(-) Inhibits investment in decentralised generation technologies.	Develop decentralised, smaller-scale generation and storage solutions where these might have higher economic rational	Monitor resource efficiency and then manage the investments. Monitor the return of investment and needs for further investment	**DSO:** Develop collective approaches to contracting and managing decentralized energy facilities that may enable SMEs as well as larger companies to benefit from decentralized energy systems.
		(+) Promote Europe's RES potential, reducing energy dependence from abroad			
		(-) Depends on the realisation of large-scale storage;	Combine large-scale and decentralised, smaller-scale generation and storage solutions to reduce vulnerabilities.	Monitor the economic and social efficiency of energy, storage.	Regulators, Research institutions and companies carrying out R&D Banks and Funds: Target research and development to storage technologies with a potential for low raw material cost and low-

					cost mass production techniques
		(-) Centralized generation as single option against EU macro-policies;	Combine large-scale and decentralised, smaller-scale generation and storage solutions to reduce vulnerabilities.	Monitor the resource-efficiency per energy source	**DSO:** Develop collective approaches to contracting and managing decentralized energy facilities that may enable SMEs as well as larger companies to benefit from decentralized energy systems.
		(-) Increased vulnerability to energy outages of regions that depend on pan-European grid, hence, energy islands might remain.	Combine large-scale and decentralised, smaller-scale generation and storage solutions to reduce vulnerabilities.	Monitor energy import dependence and vulnerability, at country and regional level.	**DG Energy & DG Competition European Competition** **Authorities:** Market functioning and governance arrangements must insure that those countries that depend on neighbours' capacity are not left in a vulnerable position in terms of energy security.
	G3 – Res Dominance	(+) Promotes more efficient waste and biomass management;			
		(+) Promotes DHC from RES might also result in additional CO2 reduction.			
		(-) Existing fossil fuel plants making become less efficient working in under-optimal conditions.	Develop assertive decommissioning plans and compare risk/benefit profiles of options in terms of private and public services' total economic value.	Monitor the resource-efficiency per energy source	**NGOs Civil Society:** Use resource-efficiency as a benchmark for economic productivity. Ensure CCS deployment

					takes place for carbon efficient fossil fuel plant.
		(+) Promotes investment in RES-related technologies, both large and small scale, such as storage, smart grids, next generation biofuels, electric-vehicles, CSP, ocean and wind energy, DHC, etc.;			
		(+) In line with increasing R&D investment in sustainable energies.			
		(-) Inhibit the development of innovative tech. not related to RES, which may have advantages for specific highly concentrated urban and industrial settings.	Develop innovative technologies not related to RES where these might have higher economic rational and public acceptance.	Monitor the downfall of innovation in technology not related to RES	**OECD & NGOs Civil Society**: Use resource-efficiency as a benchmark for economic productivity
		(-) Increased vulnerability to power outages.	Adequately distributed and connected storage is necessary to cope with RES intermittence; Engage local stakeholders to develop innovative generation solutions, especially where RES are not very productive.	Monitor energy import dependence and monitor storage technology.	**DG Energy, DG Competition European Competition** **Authorities, ENTSO-E, Regulators:** Market functioning and governance arrangements must insure that those countries that depend on neighbours' capacity are not left in a vulnerable position in terms of energy security.

	G5- No new nuclear & Fossil	(-) Fossil fuels as a dominant energy source against macro-policy unless CCS is in place;	Ensure this strategy is accompanied by the development and deployment of CCS technologies	Monitor the impact of CCS technology.	**DG Energy, DG Climate Action:** Ensure CCS deployment does not inhibit technological development towards a more carbon-efficient energy sector.
		(-) Inhibit more efficient use of RES capacities within Europe;	Significant levels of RES must be in the energy mix to reduce GHG emissions;	Monitor the resource-efficiency per energy source	DG Energy: Increase consumer awareness regarding energy efficiency
		(-) Need to transport primary fuels demanding additional resource consumption.	Resources used in the transportation of raw fuels also must be accounted as additional capacity requirement for consumption	Monitor energy import dependence and vulnerability, at country and regional level.	**OECD & NGOs Civil Society**: Use resource-efficiency as a benchmark for economic productivity
		(-) Inhibit CCS and nuclear energy related technological development.	Promote CCS as a production factor opposed to being an imposed technological cost for CO2 mitigation (e.g. Biomass with CCS or production of synthetic gas).	Monitor the impact of CCS technology.	**OECD & NGOs Civil Society**: Use resource-efficiency as a benchmark for economic productivity
		(-) Threaten overall reliability of supply, especially in regions where RES is not productive.	Consider a stress test scenario of zero fossil and nuclear fuel import and analyse the viability and sustainability (including financial and political indicators) of maintaining this grid profile without inbound RES.	Monitor the economic and social efficiency of energy generation, storage and transmission.	**DG Energy:** Develop cooperation and energy treaties with multiple neighbouring countries avoiding over-concentrated energy import origins and vulnerability in terms of energy dependence from abroad.

	G7 – High to very high flows from SE and NE to CE	(+) In line with macro-policy objectives of strengthening the regional network in North-South flow directions (EIP 2020).			
		(-) Likely to create major imbalances, and possible tensions, in terms of energy provision, capacity and demand within regions in Europe;	Keep a share of backup / reserve capacity in the regions where high levels of imbalance are expected;	Monitor the grid's efficiency, security and stability.	**DG Energy**: Promote cooperation among all European TSOs in order to coordinate the construction of the pan-European grid; Market functioning and governance arrangements must insure that those countries that depend on neighbours' capacity are not left in a vulnerable position in terms of energy security.
		(-) Central Europe is left dependent on regional energy imports, although it may access cheaper energy.	Develop and implement smart grids as a way of mitigating regional imbalances;	Monitor energy import dependence and vulnerability	**NGOs Civil Society:** Use resource-efficiency as a benchmark for economic productivity
	S1 – PHS Storage	(+) PHS has very high electrical efficiency (80%) and CAES has medium to very high (50% - 70%), thus reducing storage energy losses.			
		(-) Limits future options by inhibiting technological development of other large-scale storage technologies.	Consider and enable alternative, multi-scale storage technologies depending on its adequacy to local conditions and storage needs, considering the economic rational of investment;	Monitor the economic efficiency of storage and investments on storage technology development	**DG Energy:** Achieve the conditions for all necessary cooperation between the energy markets in electricity and gas, including use of infrastructure for the

					development of alternative storage technologies
		(-) Demotes the development of decentralized storage technologies and its massive deployment (e.g. EV) as of smart and microgrids, as well as breakthroughs in battery technology, which still has environmental impact issues.	Anticipate phase-out and recycling costs of battery energy storage systems considering social and environmental costs and benefits; Invest in the development of less environmentally harmful battery technologies.	Monitor the breakthroughs in battery technology and associated recycling measures	Develop collective approaches to managing decentralized storage technologies that may enable consumer awareness regarding DSM through smart and microgrids.
		(+) PHS is a readily available storage technology;			
		(+) Large-scale storage allows efficient management of the energy system increasing its reliability.			
		(-) Threatened by limited availability of adequate PHS (S1) and CAES (S2) locations, high investment costs and long lead times reducing the capacity of EU to create additional storage capacity;	Implement SEA to identify areas/sites that are sufficiently robust to accommodate PHS/CAES and those where the environment is sensitive and should be avoided, before the project level;	Monitor energy import dependence and vulnerability	**DG Energy:** Achieve the conditions for all necessary cooperation between the energy markets in electricity and gas, including use of infrastructure for the development of alternative storage technologies
		(-) Discourage small producers and	Mix centralised and decentralised	Monitor the grid's efficiency,	**DG Energy:** Develop

		local generation;	storage and enable load management (including DSM) technologies to reduce overall energy consumption and enable decentralise generation.	security and stability.	collective approaches to contracting and managing decentralized energy facilities that may enable small and medium enterprises (SMEs) as well as larger companies to benefit from decentralized energy systems
		(-) Energy system dependent on MS that provide high levels of storage - energy islands might remain.	Increase storage options at all MS through investments and develop DSM technologies	Monitor energy import dependence	**DG Energy:** Develop cooperation and energy treaties with multiple neighbouring countries avoiding over-concentrated energy import origins and vulnerability in terms of energy dependence from abroad
	S2-- Centralised Hydro and CAES	(-) May be less viable as part of a mixed generation portfolio based energy system, where CCS is used in conjunction with thermal generation.	Consider multiple uses for these sites, considering the different life times, TRL, overall improvement of the energy system and benefits for local communities of the different solutions (CAES/CCS). This way the necessary investment may be optimized.	Monitor the impact of CCS technology	**DG Energy:** Achieve the conditions for all necessary cooperation between the energy markets in electricity and gas, including use of infrastructure for the development of alternative storage technologies
		(+) Promotes technological development of more efficient adiabatic CAES.			
		(+) Using CAES (in addition to PHS) increases Europe's large-scale storage capacity.			

	T1 – Overhead HVAC/HVDC transmission	(+) HVDC allows efficient long-distance bulk power delivery enhancing transmission capacity;			
		(+) Using FACTS increases the efficiency of the electric system possibly reducing the need for new AC lines/cabling.			
		(-) HVAC has higher energy losses and limits line length when compared to HVDC;	Promote R&D to develop superconductive conductors' technology to drastically reduce AC losses.	Monitor the energy savings regarding the relation between primary and final energy consumption.	Research institutions and companies carrying out R&D: Target research and development to overcome the constraints
		(-) Overhead lines constrain HVDC's potential due to physical limits (weight, materials, and line's exposure to natural elements).	Perform an extensive analysis and promote R&D to overcome the constraints.	Monitor investments on R&D to overcome the constraints.	Research institutions and companies carrying out R&D: Target research and development to overcome the constraints
		(+) Promotes the technological development of HVDC components.			
		(-) NIMBY effect might threaten transmission expansion;	Engage MS and relevant stakeholders at regional and national levels to raise awareness to the advantages of a pan-European grid, reducing possible NIMBY effect;	Monitor public participation in transmission expansion	Increase consumer awareness regarding the benefits of pan European grid. Promote the collaboration between business and government and include the public opinion.
		(-) Repair times to underground cables are usually longer;	Perform an extensive analysis to improve R&D to reduce cable repair times	Monitor the grid's reliability depending on the repair times	Research institutions and companies carrying out R&D: Target research and development to overcome the constraints

		(-) Depends on the TRL for HVDC components;	Assess if HVDC components' TRL and investment return rate is compatible with the strategy's implementation.	Monitor TRL for HVDC components	Research institutions and companies carrying out R&D: Target research and development to overcome the constraints
		(-) Higher costs of underground and submarine cables may restrict their use in most remote areas, possibly resulting in the maintenance of existing energy islands.	Perform an extensive cost-benefit analysis, accounting for public, environmental and social risks and benefits, to assess the trade-offs between energy losses, the cost of new lines / cabling, wellbeing and the access to cheaper energy for consumers	Monitor the return of investment and needs for further investment	Grid investors (including TSOs): Account for the public goods and services not properly captured by financial statements in order to estimate the opportunity cost of R&D in the development of promising technological breakthroughs – as a way of gathering public acceptance and also support to R&D.
	T2- Underground HVDC and Overhead HVAC	(+) Conductor size in underground cables is larger than corresponding overhead line, thus reducing transmission losses even further.			
		(-) Infrastructure costs may risk overall monetary efficiency of energy system.	Perform an extensive cost-benefit analysis, accounting for public, environmental and social risks and benefits, to assess the trade-offs between energy losses, the cost of new lines /cabling, wellbeing and the access to cheaper energy for consumers	Monitor the return of investment and needs for further investment	Grid investors (including TSOs): Account for the public goods and services not properly captured by financial statements in order to estimate the opportunity cost of R&D in the development of promising technological breakthroughs – as a way of gathering public acceptance and also support to R&D.

		(+) Supply disruptions are less frequent than in overhead lines and the reliability of submarine cables is very high.			
	IS2 – Relevant import from North Africa	(-) Maintenance of energy dependency from the East and vulnerability to geopolitical tensions in neighbouring countries.	Identify and develop alternative origins for energy import – namely the Baltic states.	Monitor energy import dependence and vulnerability, at country and regional level.	**<u>DG Energy:</u>** Develop cooperation and energy treaties with multiple neighbouring countries avoiding over-concentrated energy import origins and vulnerability in terms of energy dependence from abroad
		(-) Strategy threatened by Desertec Industrial Initiative's low interest in exporting solar power from North Africa to Europe.	Identify and develop alternative origins for energy import – namely the Baltic states.	Monitor energy import dependence and vulnerability, at country and regional level.	**<u>DG Energy:</u>** Develop cooperation and energy treaties with multiple neighbouring countries avoiding over-concentrated energy import origins and vulnerability in terms of energy dependence from abroad
3	G1-Large Scale RES	(+) Viability of EU energy export and import potential and development of energy trade agreements with 3rd countries;			
		(+) Contribution to EU international energy and technology trade;			
		(+) Support the expansion of the Energy Community.			

		(-) May affect equitable distribution of energy system costs and Benefits	Ensure electricity grids and markets are designed to assure equitable distribution of energy system costs and benefits.	Monitor regional equity of the energy system.	European Parliament: Consider introduction of additional energy market tax and incentive mechanisms to protect and promote market integration and regional equity.
		(-) Poor access to finance may constrain energy system development resulting in electricity price differentials and regional equity impacts;	Consider introduction of additional energy market tax and incentive mechanisms to protect and promote market integration and regional equity.	Monitor uptake of finance for energy infrastructure development.	Finance, funds and banks: Promote the EU-EIB Project Bond Initiative, particularly to MS with poor credit ratings.
		(-) Real estate values may diminish within areas affected by new infrastructure.	Engage with stakeholders, the public and affected communities early-on to ensure that strategic energy infrastructure projects are located away from areas where real estate values are particularly influenced by landscape quality; Use spatial planning and constraints analysis to steer strategic energy infrastructure projects away from areas where real estate values are particularly influenced by landscape quality.	Monitor the effect of strategic energy infrastructure development on real estate values.	MS: Engage with stakeholders, the public and affected communities early-on to ensure that strategic energy infrastructure projects are located away from areas where real estate values are influenced by landscape quality; Effective use of spatial planning and constraints analysis to steer strategic energy infrastructure projects (including new thermal and nuclear generation capacity) away from areas where real estate values are particularly influenced by landscape quality. Put in place energy system

					preparedness and resilience measures at the MS level; Assess the economic impact of residual risks of strategic energy infrastructure development on businesses reliant on landscape quality and provide adequate compensation where alternative routes, locations and technologies are not viable
	G3 – Res Dominance	(+) Contribution to EU international energy and technology trade.			
		(-) Withdrawal of MS RES support schemes may delay or threaten implementation.	Ensure long term benefits of pan European grid are discussed and explained. Ensure the MS support towards RES is checked and agreed through MOUs	Monitor MS support for RES generation	**<u>DG Energy:</u>** Promote the appropriate sustainment and greater harmonisation of MS RES support schemes.
	G5- No new nuclear & Fossil	(-) Vulnerable to external market and political volatility	Develop long term bilateral and multilateral agreements to develop pan-European energy security	Monitor EU vulnerability to external energy supply chain shocks.	**<u>International Associations (Energy Community) and third party countries:</u>** Keep the regional and global geopolitical situation under review to pre-empt supply chain stresses and volatility.

		(-) Dependence on external fossil and nuclear fuel leaves Europe in a fragile negotiating position.	Improved interconnection capacity and wider exploitation of RES will create better position.	Monitor EU vulnerability to external energy supply chain shocks.	**<u>DG Energy and MS:</u>** Engage with stakeholders and affected communities to gauge the desirability and acceptability of further exploitation of EU internal fossil fuel resources to reduce the vulnerability of the energy system to external volatility;
	G7 – High to very high flows from SE and NE to CE	(+) Support greater electricity market integration.			
		(-) Less market integration and regional equity;	Ensure that grid reinforcements and storage enhancements are designed to support greater market integration and regional equity.	Monitor EU internal market dynamics	<u>European Parliament:</u> Consider introduction of additional energy market tax and incentive mechanisms to protect and promote market integration and regional equity.
		(-) Central Europe exposed to EU internal energy market fluctuations.	Ensure that grid reinforcements and storage enhancements are designed to support greater market integration and regional equity.	Monitor EU internal market Dynamics Monitor levels of EU and MS level energy independence	**<u>MS:</u>** Ensure sufficient fuel reserves to accommodate periods of supply chain stress and volatility
	S1 – PHS Storage	(-) Difficulty of finding sites where additional capacity can be installed threatening the whole energy system.	Consider and enable alternative, multi-scale storage technologies depending on its adequacy to local conditions and storage needs, considering the economic rational of investment.	Monitor regional equity of the energy system.	Ensure alternative or secondary storage technologies e.g.: EV batteries
		(-) Reliance on Central Europe and Northern Europe affecting regional/distributional equity.	Ensure that grid reinforcements and storage enhancements are designed to support greater market integration and regional equity.	Monitor levels of EU and MS level energy independence	**<u>International Associations (Energy Community) and third party countries:</u>** Encourage and facilitate

					bilateral and multilateral agreements between MS with significant generation capacity and third countries; **<u>MS:</u>** Consider introduction of additional energy market tax and incentive mechanisms to protect and promote market integration and regional equity;
	S2-- Centralised Hydro and CAES	(+) Contribution to EU international trade, exporting CAES technology (S2) and other demand driven storage technologies (S3).			
	T1 – Overhead HVAC/HVDC transmission	(-) HVDC grid connections may not be compatible with North African infrastructure.	Work with North African partners to ensure that grid connections are compatible.	Monitor international energy trade	**<u>European Parliament:</u>** Explore synergies between energy related trade links and initiatives and other relevant sectors (e.g. finance and technology);
	T2- Underground HVDC and Overhead HVAC	(+) Efficient pan-European transmission via underground HVDC may contribute to low energy costs and consistent energy pricing across EU.			
		(+) Minimal impacts on real estate values within areas affected by new strategic transmission infrastructure projects.			

		(+) Ability to transmit high flows, including cross-border capacity and ability to manage regional imbalances, may support greater electricity market integration.			
		(-) High start-up and maintenance costs of underground and submarine HVDC may contribute to high energy costs and less consistent energy pricing across Europe.	A separate expert committee involving all MS must be formed and a road map should be designed to discuss and finalise energy pricing.	Monitor EU internal market Dynamics. Electricity prices (by MS)	**DG Energy:** Promote and support energy sector R&D across all key technologies to accelerate market readiness; **Finance, funds and banks**: Promote the EU-EIB Project Bond Initiative, particularly to MS with poor credit ratings.
	IS2 – Relevant import from North Africa	(+) Expansion of EU energy markets and greater opportunities for international energy trade.			
4	G1-Large Scale RES	(+) May increase MS level interest and adherence to RES policies;			
		(+) Increase the dynamics of market functioning may contribute to EU strategic objective of security of supply based on RES.			
		(-) Fragmentation of market may reduce predictability among policy-makers.	Encourage and promote future development of the harmonisation of energy markets for an EU-level unified market.	Monitor the harmonisation of regulations to ensure an equitable burden sharing affordable for all MS (in relation to the 2030 European	**EC:** Create targeted regulatory instruments and initiatives to deal and possibly overcome effects of market distortion.

				Framework).	
		(-) May determine regional imbalances and provoke unsustainability and non-competitive internal market of electricity.	Encourage healthy competition between MS framed by harmonized institutional regulations, without disregarding MS specificities; Encourage the development of "best practices" rather than (only) regulatory compliance; Encourage the development and definition of a set of regulatory rules to improve resilience and stability of markets; Contribute to discussion of new (or improved) public policy goals.	Monitor the harmonisation of regulations to ensure an equitable burden sharing affordable for all MS (in relation to the 2030 European Framework).	**EC:** Promote coordination and co-operation between EU administrations to build cooperative approaches;
		(-) Potential policy conflicts between EU macro-policies may be more evident under this option.	Clarify policy macro-objectives (centralized vs. decentralized energy generation; share of RES vs. fossils in energy mix; internal market vs. international position of EU);	Monitor potential policy conflicts between EU macro objectives.	**EC:** Promote the complementarity and integration between macro-objectives of energy policies and other sectorial EU policies
		(+) Encourages the application of cross-border cooperation mechanisms (trades and subsidies rates).			
		(-) Discourage small producers to be engaged in energy initiatives;	Ensure early and effective engagement of affected communities in areas where centralized RES may be deployed in relation to grid planning and management.	Monitor the level of engagement of relevant stakeholders in energy initiatives.	**EC:** Contribute to set up an energy market providing citizens and business with affordable energy, competitive prices and

					technologically advanced energy services;
		(-) Overrule MS level planning processes due to current administration procedures.	Consider inputs at MS level planning process for better administration procedures	Monitor collaborative initiatives between MS administrations and regulators;	**EC:** Promote the prosecution of the European Energy Dialogue for flexible interaction and conversations between MS administrations, regulators and citizens; **MS Public Authorities:** Promote dialogue between state, regional and local stakeholder's organisations.
	G3 – Res Dominance	(+) Contribute to the converging of MS decarbonisation policy objectives.			
		(+) Promotes national strategies for European coordination in energy issues;			
		(-) Risk of opposition from countries with solid strategies for RES and non-RES (opposite strategies for energy mix).	Engage in dialogues and negotiations with countries with opposite visions for their energy mix; Promote the engagement of all relevant stakeholders' initiatives and dialogues for future planning and development strategies.	Monitor the development of future investment policies that regulates supporting schemes for renewables and fossils.	**NGOs:** Contribute to a democratic development of the European energy strategy together with decision-makers, regulators, market entities and civil society; **Civil Society:** Act as knowledge brokerages in the share of public knowledge, views and

					values (cultural, historical, environmental priorities and perceptions) to adjust and tailored energy agenda to context-situations.
	G5- No new nuclear & Fossil	(-) Risk of maintenance or increase of current support schemes for fossils, contradicting EU macro-objectives.	Explain clearly the benefits of RES and pan-European grid. Should also demonstrate long term benefits.	Monitor the development of future investment policies that regulates supporting schemes for renewables and fossils.	**EC:** Promote the complementarity and integration between macro-objectives of energy policies and other sectorial EU policies
		(-) Success depends on regional security coordination among stakeholders (risk of increasing political tension).	Encourage the development of national institutional arrangements to promote regional security coordination activities among stakeholders;	Monitor the harmonisation of regulations to ensure an equitable burden sharing affordable for all MS (in relation to the 2030 European Framework).	**Regulators:** Ensure the transparency of obligations and the availability of data to all interested stakeholders
	G7 – High to very high flows from SE and NE to CE	(+) Opportunity to MS alignment strategies to promote regional cooperation and co-ordination (under ERI).			
		(+) Opportunity to create cross-border institutional mechanisms (like engagement and cooperative mechanisms) to support the most vulnerable regions.			
	S1 – PHS Storage	(+) Opportunity for future institutional reforms to match different RES sources;			

		(-) Limits political advances (regulatory mechanisms or governance approaches) due to the expected phase out of supporting schemes for mature technology.	Encourage decision-makers to set up new (or renewed) investment policies to overcome the phase-out of mature technologies;	Monitor the areas of regulatory mechanism or governance approach which hinders the development of mature technology	**<u>EC:</u>** Maintain awareness of strategic risks identified by current (and future) policies and interventions
		(-) Risk of divergent opinions (causing political tension and instability) from different territorial contexts (capacity vs. non-capacity to high scale hydro systems).	Promote dialogue and joint initiatives to reach consensus on multilateral opportunities of centralized PHS.	Monitor different opinions between MS administrations and regulators and if possible harmonise them	**<u>EC:</u>** Promote coordination and co-operation between EU administrations to build cooperative approaches; **<u>MS Public Authorities:</u>** Promote dialogue between state, regional and local stakeholder's organisations
	S2-- Centralised Hydro and CAES				
	T1 – Overhead HVAC/HVDC transmission	(+) Engage state-level administrations and regulators for collaborative efforts in de development of context related public policy goals.			
	T2- Underground HVDC and Overhead HVAC				
	IS2 – Relevant import from North Africa				