Annex A : Abbreviations

Country and region abbreviations:

Code	Country
AL	Albania
AT	Austria
BA	Bosnia-Herzegovina
BE	Belgium
BG	Bulgaria
CH	Switzerland
CZ	Czech Republic
DE	Germany
DK	Denmark
EE	Estonia
ES	Spain
FI	Finland
FR	France
GR	Greece
HR	Croatia
HU	Hungary
IE	Ireland
IT	Italy
LT	Lithuania
LU	Luxembourg
LV	Latvia
ME	Montenegro
MK	FYROM
NL	Netherlands
NO	Norway
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
SE	Sweden
SI	Slovenia
SK	Slovak Republic
UK	United Kingdom
NS	North Sea
NA	North Africa

DZ	Algeria
MA	Morocco
MI	Middle East
TN	Tunisia
LY	Libya

Other abbreviations:

ENS	Energy Not Supplied (unsupplied energy or unsupplied demand)
LOLD	Loss Of Load Duration (adequacy indicator-length of shortfalls)
Spilled energy	Potential generation from RES (non-dispatchable generation) that is not utilized to supply the demand
MCV	Marginal Cost Variation = Decrease of the system's overall cost that would be brought by the optimal use of an additional MW to the transmission capacity (in both directions).
MC	Monte-Carlo
GTC	Grid Transfer Capacity
PSP	Pumped storage power plant
RES	Renewable Energy Sources
Res Hydro	Hydro power plants with Reservoirs
RoR Hydro	Run-Of-River hydro power plants
TYNDP	Ten Years Network Development Plan; published by ENTSO-e on a bi-annual basis

Annex B : Assignment to TYNDP '14 and its projects

The project e-Highway 2050 aimed at performing the analyses and grid development planning for the year 2050 as close to the real transmission system as possible. Given the fact that not only ENTSO-e as the Head-Association but also 15 TSOs are partner of the project and Working Package two, it was decided to use the most recent grid data available within ENTSO-e. The simplified grid model used has been developed staring at the beginning of 2013. For the purpose of task 2.2, where it was build, it was necessary to freeze the most current grid data, which was identical with the dataset used in the TYNDP 2014 – Status April 2013.

Since April 2014 the TYNDP 2014 and the e-Highway 2050 project progressed in parallel. During the TYNDP the grid development revealed new projects that are included in the final report and removed other projects from the common dataset. This is why a discrepancy exists between the projects considered in the starting grid of e-Highway 2050 and the final TYNDP 2014. The following table gives some projects that differ between the two processes (this list is not exhaustive):

Project	From <-> To Cluster	Capacity in e-Highway Starting Grid	Capacity in final TYNDP ´14	Comment/ Effect on e-Highway results
FAB	22FR<->91UK	---	1.400MW – DC	The e-Highway 2050 analyses reveleaed an need for increased interconnection capacity between Great Britain and France. This Capacity is already partly considered in the final TYNDP '14projects.
Eleclink	26FR<->90UK	---	1.000MW –DC	
BRITIB	17FR<->91UK	---	1.000MW –DC	
INELFE	15FR<->06FR	1.000MW –DC	2.000MW –DC	This link is a necessary reinforcement throughout all scenarios in e-Highway 2050. An increase in capacity, as has foreseen already by the TYNDP '14 can be supported.
Biscay Gulf	14FR<->04ES	1.000MW –DC	2.000MW –DC	The analyses reveleaed an need for increased interconnection

BRITIB	17FR<->04ES	---	1.000MW –DC	capacity between Spain and France. This Capacity is already partly considered in the final TYNDP '14 projects.
principle project FR-DE	25FR<->36DE	1.000MW –DC	0 MW (discarded)	Though the project was eventually discarded in the final version of the TYNDP '14, e-Highway 2050 has determined a need for increased capacity in 3 out of 5 scenarios (beyond these 1.000GW). If It is not included the required capacity in analyses of e-Highway2050 between France and Germany is likely to increase even further and it will proves necessary in most scenarios.
HVDC connection Italy to Croatia	53IT<->62HR	1.000MW –DC	0 MW (discarded)	This link has been discarded in the TYNDP '14. Yet during the analyses in this project it turned out to be highly profitable to have a connection between Balkan region and Italy.
HVDC connection Italy to Greece	55it <->68GR	1.000MW –DC	500MW	An increaseof this link by 500 MW was analyzed in the TYNDP '14, but discarded at the end. Yet additional exchange capacity between Greece and Italy has been beneficial throughout all e-Highway 2050 scenarios. A realization of an capacity increase can be supported.

Annex C : Transmission requirements in all the scenarios (MW)

Links	Rein-forced/new	Large scale RES (X5)	100% RES (X7)	Big & market (X10)	Fossil & nuclear (X13)	Small & local (X16)
01_es - 02_es	reinforced	0	2000	0	0	1000
01_es - 03_es	new	0	0	0	2000	0
01_es - 12_pt	reinforced	1000	1000	1000	1000	0
02_es - 07_es	new	0	0	0	0	1000
02_es - 08_es	reinforced	1000	0	0	0	0
02_es - 12_pt	reinforced	1000	1000	0	0	0
03_es - 04_es	reinforced	2000	2000	0	0	0
03_es - 07_es	reinforced	2000	1000	0	0	1000
04_es - 07_es	new	0	0	0	0	7000
04_es - 14_fr	reinforced	5000	5000	6000	7000	8000
05_es - 07_es	new	0	0	0	0	1000
06_es - 07_es	new	0	0	0	0	2000
06_es - 11_es	reinforced	4000	2000	6000	9000	0
06_es - 15_fr	reinforced	10000	8000	14000	13000	0
07_es - 08_es	reinforced	2000	0	0	0	3000
07_es - 11_es	reinforced	2000	0	1000	5000	1000
07_es - 12_pt	new	0	0	0	0	2000
08_es - 09_es	reinforced	0	0	0	0	1000
08_es - 10_es	reinforced	0	0	0	0	1000
08_es - 13_pt	reinforced	2000	0	0	0	1000
09_es - 13_pt	reinforced	2000	2000	2000	2000	0
10_es - 11_es	reinforced	1000	0	0	0	0
106_ns - 110_ns	new	2000	0	6000	5000	0
106_ns - 90_uk	reinforced	10000	14000	11000	7000	1000
107_ns - 92_uk	reinforced	3000	8000	4000	2000	1000
108_ns - 93_uk	reinforced	1000	0	0	1000	0
109_ns - 94_uk	reinforced	1000	2000	0	1000	0
110_ns - 28_be	reinforced	2000	7000	6000	6000	1000
111_ns - 30_nl	reinforced	2000	1000	4000	2000	0
112_ns - 113_ns	new	9000	12000	0	1000	0
112_ns - 30_nl	new	0	0	0	2000	0
112_ns - 31_de	reinforced	10000	5000	7000	3000	3000
112_ns - 33_de	new	0	6000	0	0	0
113_ns - 30_nl	new	0	5000	0	0	0
113_ns - 38_dk	reinforced	9000	0	4000	1000	1000
114_ns - 116_ns	new	1000	0	0	0	0
114_ns - 72_dk	reinforced	2000	0	0	1000	0
115_ns - 79_no	reinforced	0	5000	0	0	0
116_ns - 88_se	reinforced	1000	0	0	1000	0
12_pt - 13_pt	reinforced	1000	0	0	0	0
14_fr - 15_fr	reinforced	0	3000	8000	10000	0
14_fr - 17_fr	reinforced	4000	6000	14000	15000	7000

14_fr - 18_fr	reinforced	1000	0	0	0	0
15_fr - 16_fr	reinforced	8000	4000	2000	1000	0
16_fr - 19_fr	reinforced	2000	0	0	0	0
16_fr - 20_fr	reinforced	1000	0	0	2000	0
17_fr - 21_fr	reinforced	1000	3000	0	0	0
17_fr - 22_fr	reinforced	3000	6000	14000	17000	7000
18_fr - 19_fr	reinforced	2000	0	0	0	0
18_fr - 24_fr	reinforced	2000	0	0	1000	0
19_fr - 20_fr	reinforced	1000	0	0	0	0
19_fr - 52_it	reinforced	1000	0	0	0	0
20_fr - 25_fr	reinforced	0	3000	0	0	0
20_fr - 52_it	reinforced	1000	0	0	0	0
21_fr - 96_ie	reinforced	6000	5000	1000	2000	2000
22_fr - 23_fr	reinforced	1000	0	0	0	0
22_fr - 26_fr	reinforced	1000	0	0	0	0
22_fr - 90_uk	reinforced	4000	4000	14000	15000	3000
24_fr - 25_fr	reinforced	0	0	0	1000	0
25_fr - 28_be	reinforced	0	3000	3000	0	2000
25_fr - 35_de	reinforced	0	5000	0	0	0
25_fr - 36_de	reinforced	1000	0	0	2000	1000
26_fr - 90_uk	reinforced	9000	8000	12000	7000	1000
28_be - 30_nl	reinforced	0	10000	0	0	0
28_be - 33_de	reinforced	0	5000	0	0	0
28_be - 90_uk	reinforced	4000	4000	2000	2000	0
30_nl - 31_de	reinforced	1000	0	0	0	0
30_nl - 38_dk	reinforced	3000	0	0	0	0
30_nl - 79_no	reinforced	7000	14000	4000	3000	0
30_nl - 90_uk	reinforced	4000	0	3000	0	0
31_de - 32_de	reinforced	0	1000	0	0	0
31_de - 33_de	reinforced	12000	0	0	0	0
31_de - 37_de	reinforced	4000	0	0	0	0
31_de - 38_dk	reinforced	11000	0	6000	1000	0
31_de - 72_dk	new	4000	0	0	0	0
31_de - 79_no	reinforced	17000	9000	2000	0	0
31_de - 89_se	reinforced	0	4000	0	4000	0
32_DE - 38_DK	new	0	0	2000	0	0
32_de - 72_dk	reinforced	2000	0	0	0	0
32_DE - 89_SE	new	8000	11000	3000	2000	6000
34_de - 35_de	reinforced	0	5000	0	0	0
34_de - 37_de	reinforced	0	4000	0	0	0
34_de - 44_pl	reinforced	3000	10000	2000	0	0
36_de - 37_de	reinforced	0	0	0	2000	0
37_de - 39_cz	reinforced	1000	0	0	2000	0
37_de - 49_at	reinforced	1000	8000	0	2000	1000
38_dk - 72_dk	reinforced	1000	0	0	0	0
38_dk - 79_no	reinforced	2000	0	0	1000	0

38_dk - 88_se	reinforced	0	0	0	0	4000
39_cz - 40_cz	reinforced	1000	0	0	0	0
39_cz - 44_pl	new	0	2000	0	0	0
40_cz - 43_pl	reinforced	5000	0	2000	0	0
40_cz - 46_sk	reinforced	1000	0	0	0	0
40_cz - 51_at	reinforced	5000	0	0	0	0
41_pl - 43_pl	reinforced	4000	0	2000	0	0
41_pl - 44_pl	reinforced	0	6000	0	0	0
41_pl - 77_lt	reinforced	8000	8000	7000	2000	6000
42_pl - 46_sk	reinforced	3000	0	0	1000	0
43_pl - 44_pl	reinforced	2000	0	0	0	0
44_pl - 45_pl	reinforced	2000	0	0	0	0
45_pl - 89_se	reinforced	0	0	3000	2000	0
46_sk - 58_hu	reinforced	2000	0	0	0	0
49_at - 50_at	reinforced	4000	0	0	2000	0
49_at - 52_it	reinforced	4000	8000	0	2000	2000
50_at - 51_at	reinforced	4000	0	0	2000	0
51_at - 58_hu	reinforced	1000	0	0	2000	1000
52_it - 53_it	reinforced	11000	8000	0	2000	11000
53_it - 54_it	reinforced	11000	8000	0	2000	11000
53_it - 99_fr	reinforced	0	0	2000	1000	0
54_it - 55_it	reinforced	11000	8000	0	2000	8000
54_it - 64_me	reinforced	1000	2000	0	0	0
54_it - 98_it	reinforced	8000	3000	2000	1000	3000
55_it - 56_it	reinforced	9000	2000	2000	1000	4000
55_it - 68_gr	reinforced	6000	9000	2000	2000	6000
57_si - 58_hu	reinforced	1000	0	0	0	1000
58_hu - 59_ro	reinforced	1000	2000	0	2000	0
58_hu - 65_rs	reinforced	1000	0	0	0	1000
59_ro - 61_ro	reinforced	0	2000	0	0	0
65_rs - 66_bg	reinforced	0	0	0	2000	0
65_rs - 67_mk	reinforced	1000	0	0	0	0
66_bg - 68_gr	reinforced	0	1000	0	0	1000
67_mk - 68_gr	reinforced	2000	0	0	0	0
72_dk - 89_se	reinforced	4000	0	0	0	0
73_ee - 75_fi	reinforced	5000	4000	3000	2000	5000
73_ee - 78_lv	reinforced	5000	4000	3000	2000	5000
74_fi - 75_fi	reinforced	0	0	1000	2000	2000
74_fi - 85_no	reinforced	1000	0	0	0	0
75_fi - 88_se	reinforced	3000	0	0	0	0
77_lt - 78_lv	reinforced	5000	3000	4000	2000	5000
77_lt - 88_se	reinforced	2000	0	0	0	0
79_no - 80_no	reinforced	3000	4000	2000	5000	0
79_no - 81_no	reinforced	17000	12000	2000	0	0
79_no - 92_uk	new	0	5000	0	0	0
80_no - 82_no	reinforced	0	1000	2000	4000	0

81_no - 83_no	reinforced	7000	7000	0	0	9000
81_no - 90_uk	new	0	0	0	0	12000
82_no - 83_no	reinforced	0	0	0	3000	0
82_no - 88_se	reinforced	2000	0	0	0	0
83_no - 84_no	reinforced	5000	5000	0	3000	2000
84_no - 85_no	reinforced	0	1000	0	0	0
86_se - 87_se	reinforced	5000	4000	1000	3000	5000
87_se - 88_se	reinforced	8000	9000	4000	4000	8000
88_se - 89_se	reinforced	9000	7000	4000	5000	5000
90_uk - 92_uk	reinforced	13000	5000	19000	10000	6000
92_uk - 93_uk	reinforced	13000	4000	13000	9000	0
92_uk - 96_ie	reinforced	1000	2000	4000	1000	0
93_uk - 94_uk	reinforced	9000	6000	6000	5000	0
93_uk - 95_uk	reinforced	1000	0	1000	1000	0
95_uk - 96_ie	reinforced	1000	2000	0	0	0
98_it - 99_fr	reinforced	800	0	0	0	0
TOTAL		451800	378000	255000	253000	190000

Annex D : Constraints analysis on critical weeks

In this section of the report, maps with main indicators of the system's operation and flow patterns in the starting grid for the selected weeks are presented for each scenario. They were used to suggest first transmission requirements.

Values and colors used to present main indicators on the maps are the following:

1. ENS – Average power (annual or weekly) in average MW per year or week
   ENS is presented only if > selected threshold
2. deltaSpillage – Average power (annual or weekly) in average MW per year or week
   deltaSpillage is presented only if > selected threshold
3. Positive thermal redispatching**+** - Average power (annual or weekly) in average MW per year or week
   Thermal redispatching**+** is presented only if > selected threshold
4. Negative thermal redispatching**-** - Average power (annual or weekly) in average MW per year or week
   Thermal redispatching**-** is presented only if > selected threshold
5. MCV – Average value (annual or weekly) in Euro/MW
   MCV is presented only if > selected threshold

Large Scale RES

WEEK 48

WEEK 48 - Average

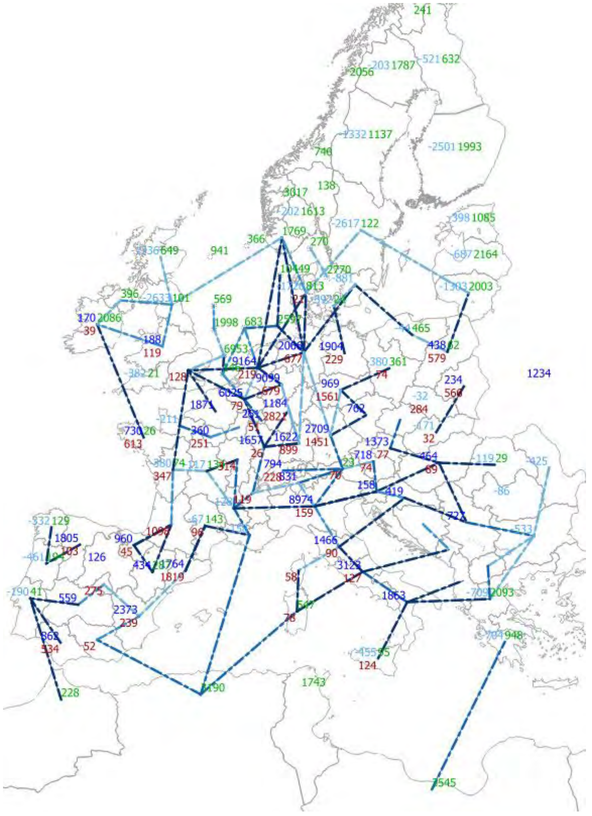

Fig. 193: Map with ENS, spillage variation, thermal redispatching in week 48 (average MW per week) – X-5

LEGEND:
ENS > 20 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 20 MWh/h
Link: MCV>200Euro/MWh

WEEK 48 – Worst year

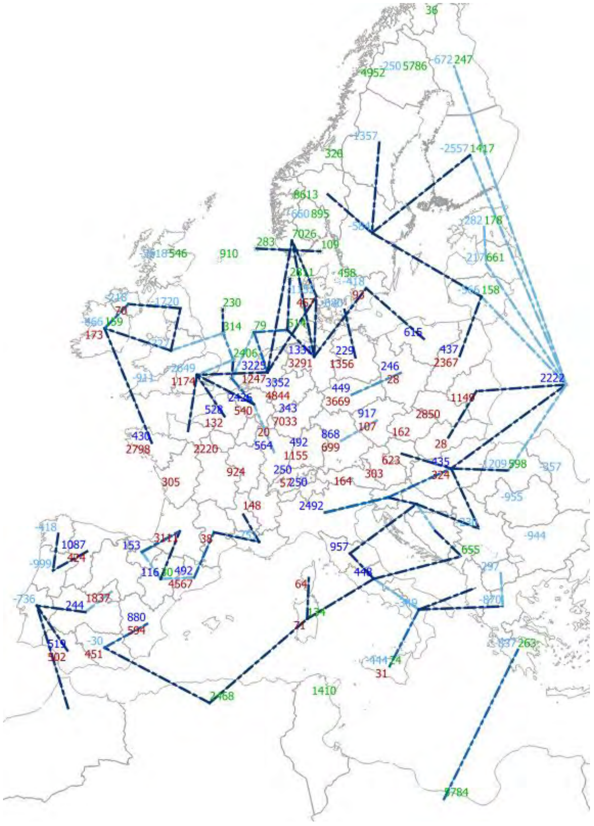

Fig. 194: Map with ENS, spillage variation, thermal redispatching and MCV in week 48 & "worst" year (average MW per week) – X-5

LEGEND:
ENS > 20 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 20 MWh/h
Link: MCV>200Euro/MWh

Clusters with highest ENS are clusters in Germany, eastern part of Poland, western part of France, Spain (southern part and Catalonia). Excess of energy that is spilled or limited can be seen in Nordic countries, Baltic countries, UK, IE, Greece, and North Sea and North Africa.

Bulgaria and Romania can be also recognized as surplus areas of competitive thermal generation.

Indicators on the map points to links with MCV > 200 Euro/MWh:

a) Links between Nordic countries and continental Europe
b) Links between Baltic countries and Poland
c) Links between Greece& Balkan countries and Italy
d) Links between Portugal and Spain
e) Links between Spain and France
f) Links between UK & Ireland and continental Europe

Fig. 195: Map with corridors recognized as a 1st set of reinforcements, based on week 48 – X-5

- Reinforcements of the corridors from North of Nordic countries towards Germany and Poland, as seen in this week (week 48) are mainly used to solve ENS, by utilization of spilled energy and available competitive thermal generation.
- Similar is the role of reinforcements from UK&IE to France and Portugal to Spain, although in this case, surplus of energy are mostly competitive thermal power plants.
- Reinforcements from south France to Spain are considered as a corridor for transfer of power from North Africa (Algeria).
- Similar is with reinforcements in Italy, that enable transfer of power from the south (Greece and North Africa) to Central Europe, but also enable reduction of expensive thermal generation in Italy and reduction of costs.

As it can be seen, there is a significant excess of thermal generation in South-Eastern Europe for which suitable reinforcements will be analyzed and assessed in next steps.

WEEK 47

WEEK 47 - Average

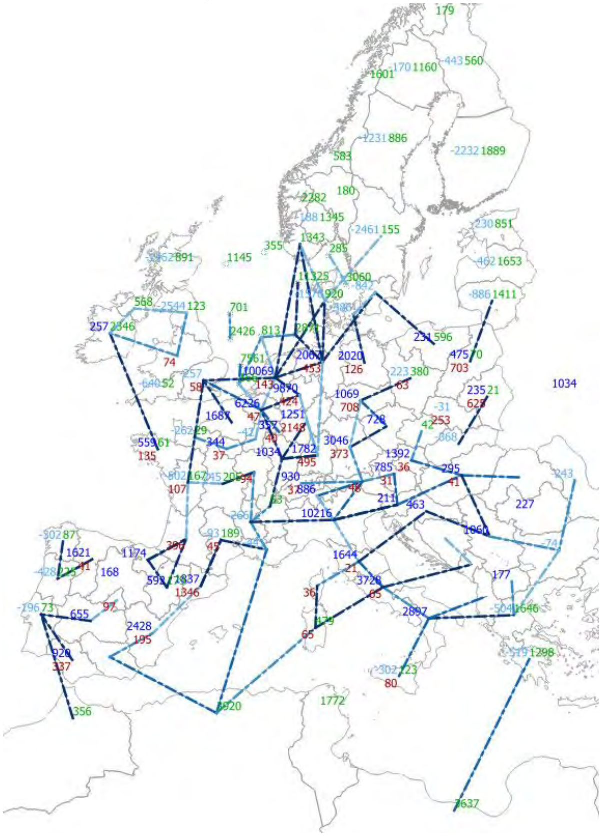

Fig. 196: Map with ENS, spillage variation, thermal redispatching in week 47 (average MW per week) – X-5

LEGEND:

ENS > 20 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 20 MWh/h

Link: MCV>200Euro/MWh

WEEK 47 – Worst year

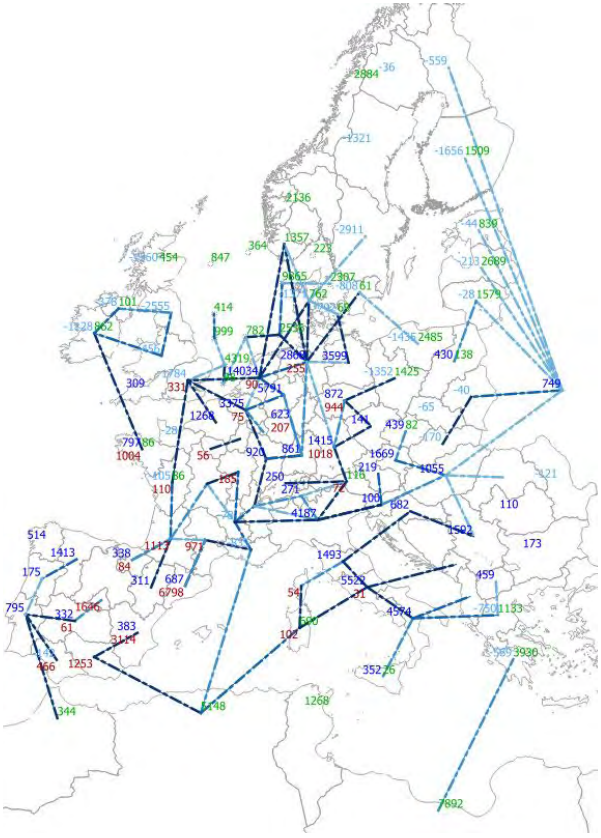

Fig. 197: Map with ENS, spillage variation, thermal redispatching and MCV in week 47 & "worst" year (average MW per week) – X-5

LEGEND:

ENS > 20 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 20 MWh/h

Link: MCV>200Euro/MWh

Week 47 seems to be more critical than week 10, with ENS and spillages of higher magnitude, so week 47 has been used as a representative of weeks with high ENS in Spain. This week can be considered as characteristic also for Italy, where high thermal redispatching can be observed.

Fig. 198: Map with corridors recognized as a 1st set of reinforcements, based on week 47 – X-5

WEEK 10

Week 10 has been used as a representative of weeks with high ENS in Italy, but is also very similar to week 47.

WEEK 10 - Average	**WEEK 10 – Worst year**
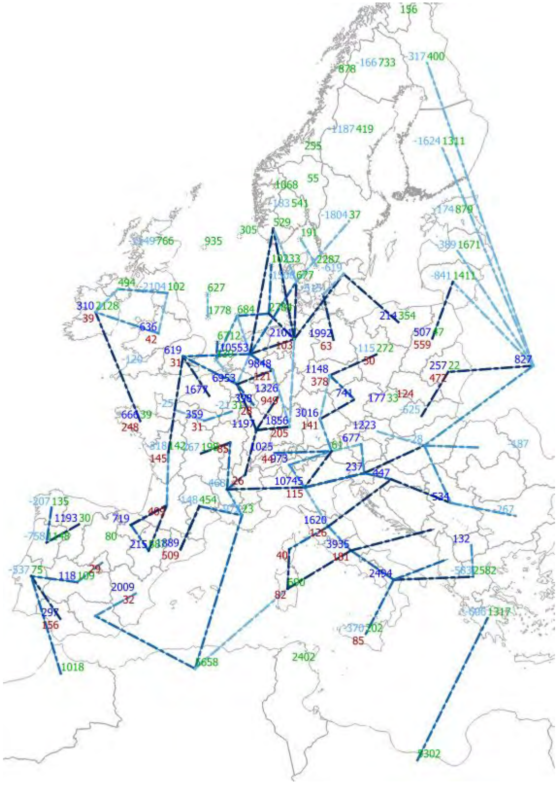	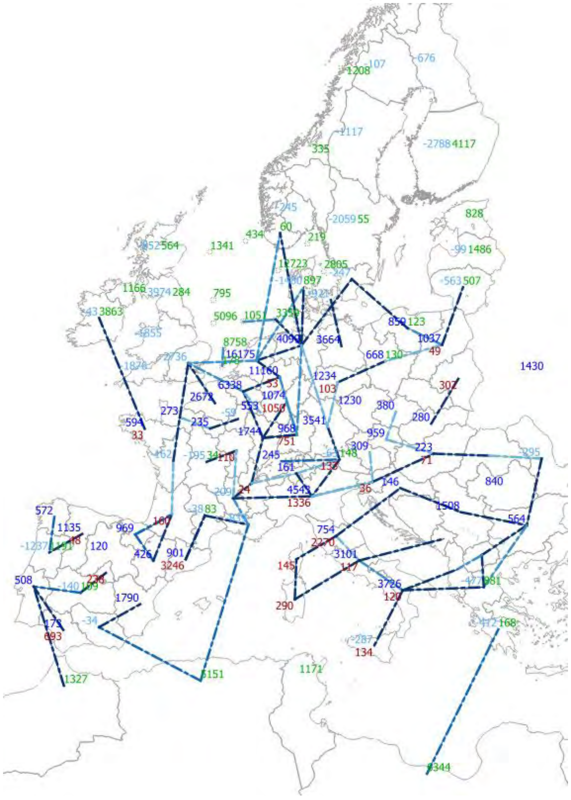
Fig. 199: Map with ENS, spillage variation, thermal redispatching in week 10 (average MW per week) – X-5	**Fig. 200: Map with ENS, spillage variation, thermal redispatching in week 10 & "worst year" (average MW per week) – X-5.**

LEGEND: ENS > 20 MW Thermal re-dispatch > 100 MWh/h Thermal re-dispatch < -20 MWh/h Increase spillage > 20 MWh/h Link: MCV>200Euro/MWh	LEGEND: ENS > 20 MW Thermal re-dispatch > 100 MWh/h Thermal re-dispatch < -20 MWh/h Increase spillage > 20 MWh/h Link: MCV>200Euro/MWh

The analysis of week 10 suggests similar reinforcements to those identified for week 47 but with smaller sizes for some of them :

Fig. 201: Map with corridors recognized as a 1st set of reinforcements, based on week 10 – X-5

WEEK 25

Week 25 is recognized as the week with highest spillage and negative thermal redispatching. Maps with specific indicators for week 25 are presented in sequel.

WEEK 25 - Average

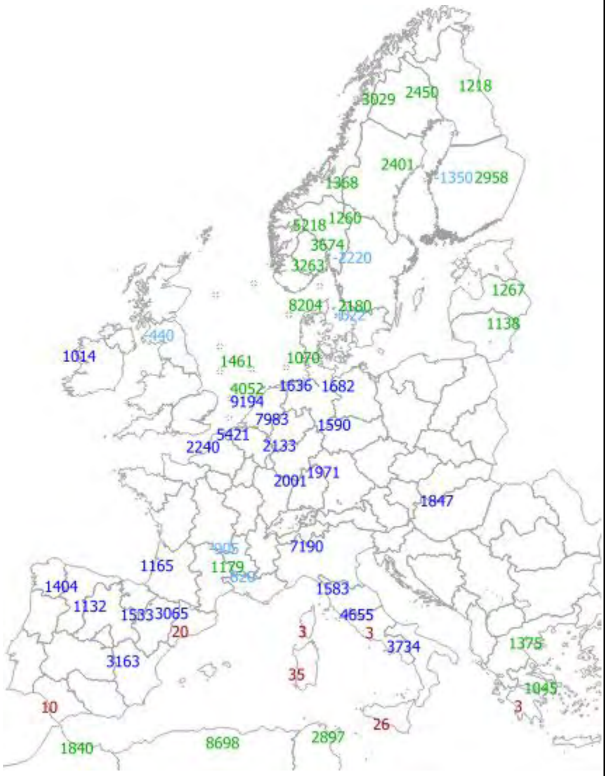

Fig. 202: Map with ENS, spillage variation, thermal redispatching in week 25 (average MW per week) – X-5

LEGEND:
ENS > 0 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -300 MWh/h
Increase spillage > 1000 MWh/h
Link: MCV>200Euro/MWh

WEEK 25 – Worst year

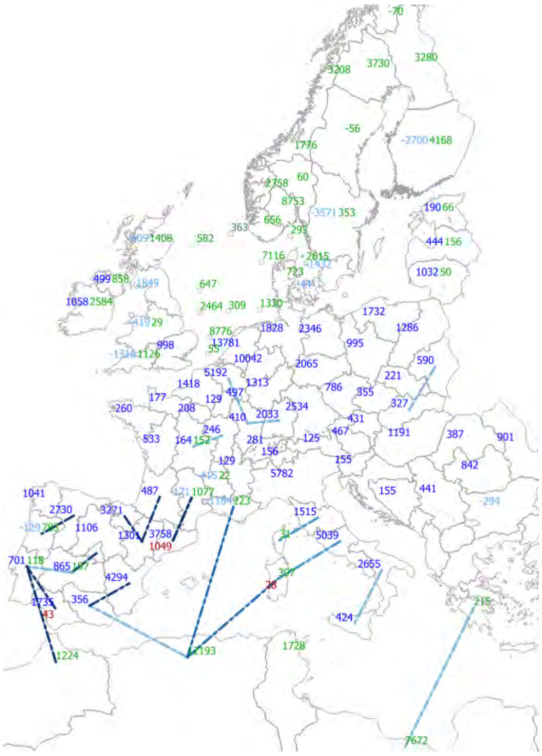

Fig. 203: Map with ENS, spillage variation, thermal redispatching and MCV in week 25 & "worst" year (average MW per week) – X-5

LEGEND:
ENS > 0 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 20 MWh/h
Link: MCV>200Euro/MWh

Week 25 is different in comparison to week 48, but still clusters that can be recognized as the main surplus areas are the same, pointing to high excess of energy in Nordic countries, Baltic countries, UK, Greece, and North Sea and North Africa. In this week, there is ENS only in few clusters in Sardinia, Corsica, Italy and Spain, with average ENS reaching 35MW, while maximum delta spillage is 8 GW.

Several clusters have high positive thermal redispatching. These clusters are the same clusters recognized as deficit areas in week 48.

Fig. 204: Map with corridors recognized as a 1st set of reinforcements, based on week 25 – X-5

Week 40: average 99 MC years

Week 40 is a week with high ENS outside winter.

Week 40 - Average

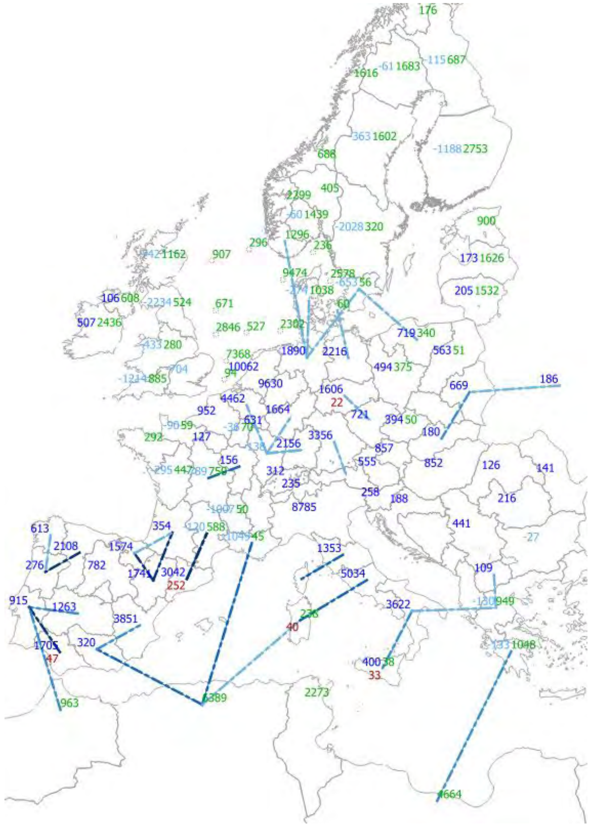

Fig. 205: Map with ENS, spillage variation, thermal redispatching in week 40 (average MW per week) – X-5

LEGEND:

ENS > 20 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 20 MWh/h

Link: MCV>200Euro/MWh

Week 40 – Worst year

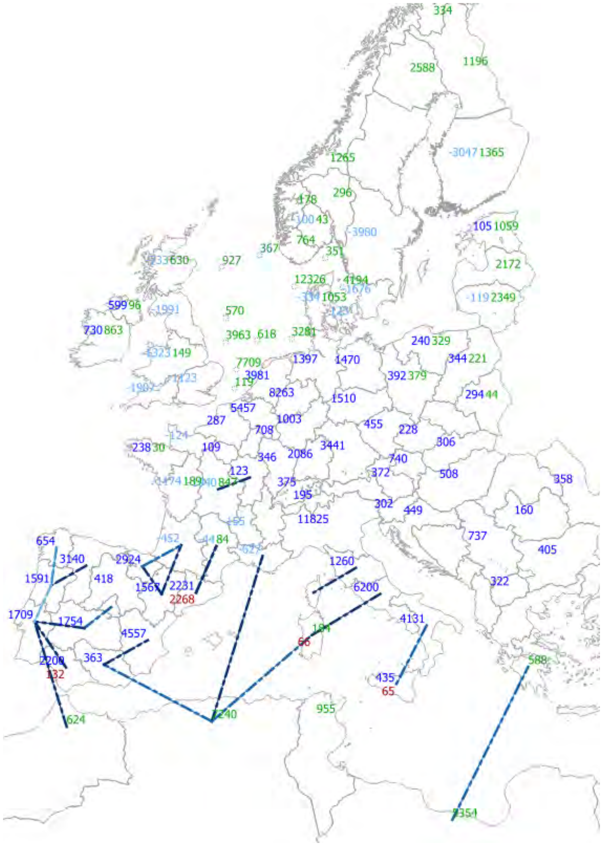

Fig. 206: Map with ENS, spillage variation, thermal redispatching and MCV in week 40&worst year (average MW per week) – X-5

LEGEND:

ENS > 20 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 20 MWh/h

Link: MCV>200Euro/MWh

Similar to week 25, there is ENS in Spain and in Italy, but at higher level. Beside this, in comparison to week 25, in the regions near Spain, there is lower negative thermal redispatching in south of France (although it is higher in western coast of France and UK, which is far away from Spain) and no spillages in Portugal. Similar situation is in Italy. Thus, week 40 is more critical than week 25. Transmission requirements recognized in week 40 are presented in Fig. 205.

Fig. 207: Map with corridors recognized as a 1st set of reinforcements, based on week 40 – X-5

Conclusions

Based mainly on the results for week 48 and "worst" year, but also all other weeks, sizes of the transmission requirements recognized in the first step are assessed and presented in Fig. 208.

Reinforcements in red box are used in this first step to :

- solve ENS in Germany from Norway and Sweden (where high spillage and excess of thermal capacity exist) and
- further help in continental Europe (BE, NL, FR, IT…)

Reinforcements in light blue box are used to:

- solve ENS in Poland from Finland and Baltic states (where high spillage and excess of thermal capacity exist)

Reinforcements in dark blue box are used to:

- solve ENS in France from UK & IE (where high spillage and excess of thermal capacity exist)

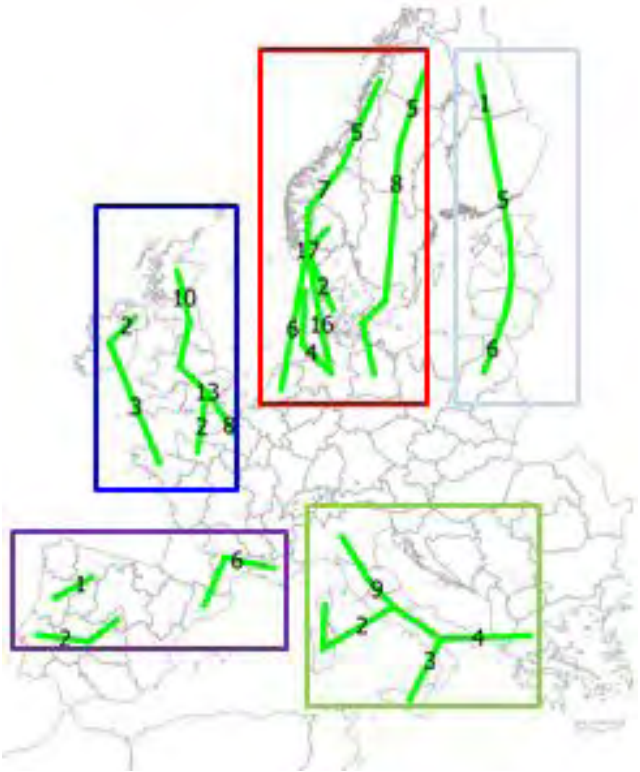

Fig. 208: Assessed 1st set of transmission requirements – X-5

Reinforcements in violet box are used to:

- solve ENS in Spain from Portugal (where excess of thermal capacity exist)
- solve ENS in Spain from France (where excess of thermal capacity exist)

Reinforcements in green box are used to:

- solve ENS and to enable more economic dispatch in Italy from Greece (where high spillage and excess of thermal capacity exist) and excess of solar generation from North Africa

100% RES

WEEK 2

It can be noticed that situation in week 2 is really critical: clusters that in the annual balance present characteristics of net importer or net exporter are in this week more “radicals” with more extreme situations. In the following images similar reasoning of the ones related to the annual analysis can be draw.

WEEK 2 - Average

Fig. 209 -week 2 – results for 99 average MC years – X7

LEGEND:
ENS > 1000 MW
Thermal re-dispatch > 500 MWh/h
Thermal re-dispatch < -500 MWh/h
Increase spillage > 1000 MWh/h
Link: MCV>100Euro/MWh

WEEK 2 – Worst year

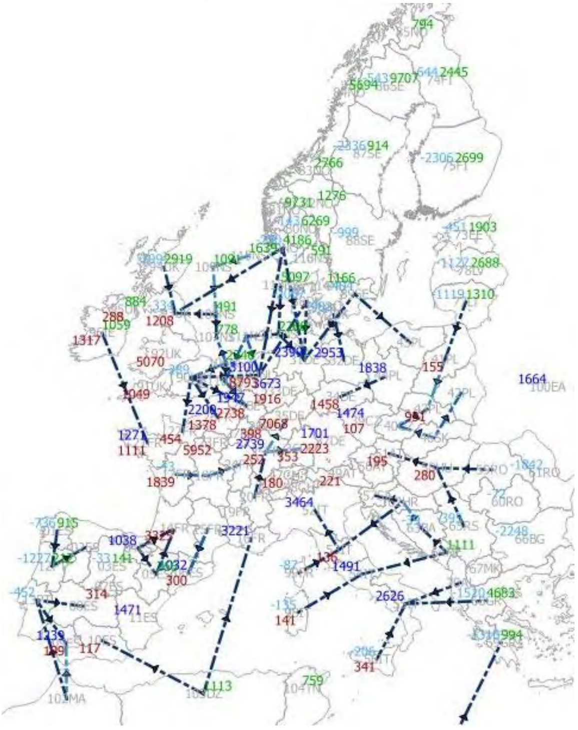

Fig. 210 - week 2 – results for worst MC year (67) – X7

LEGEND:
ENS > 100 MW
Thermal re-dispatch > 1000 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 10 MWh/h
Link: MCV>500Euro/MWh

Analyzing the results, it can be seen that:

- links on corridors from Norway to continental Europe should collect excess of energy along the way;
- Baltic countries and Poland should collect energy to bring towards Germany;
- the link between Greece and Italy seems really interesting for a possible expansion;
- The connection of United Kingdom from North to South, and then to Europe is relevant.

On the basis of the results shown, potentially interesting corridors to develop are shown in Fig. 211.

Fig. 211 – definition of new interconnection on the basis of the results of week 2

WEEK 50

The analysis carried out brings us to see the behavior of the system in week 50. As it can be seen in the following Figures, the situation is less critical with respect to week 2, but in any case energy not provided is still really high, and at the same time spillage is present in North Europe.

WEEK 50 - Average	**WEEK 50 – Worst year**
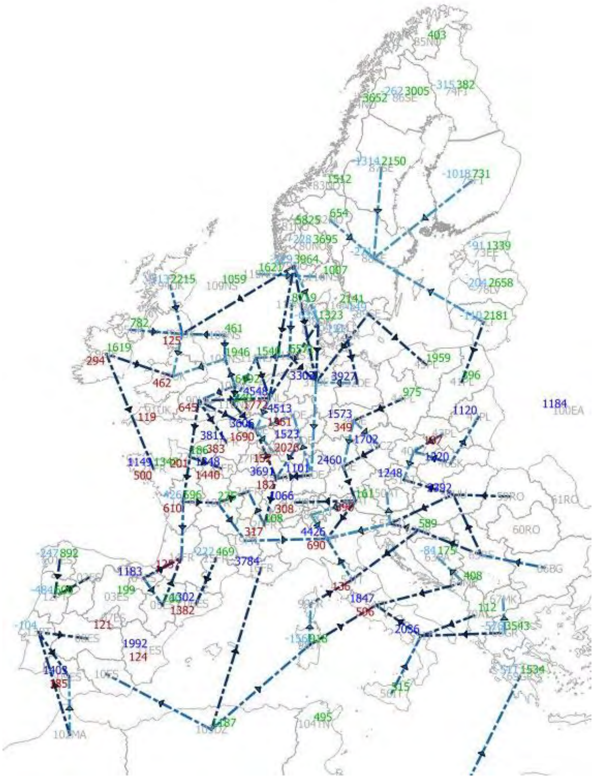	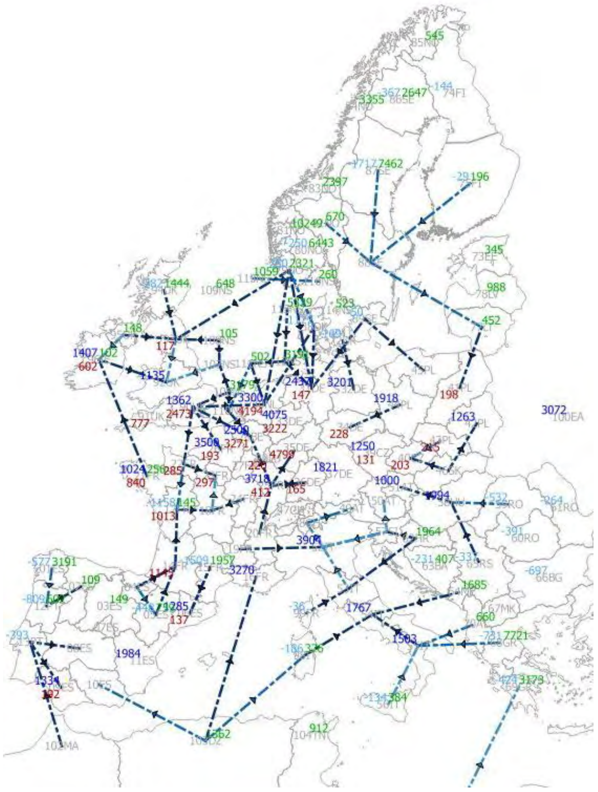
Fig. 212- week 50 – results for 99 average MC years	**Fig. 213 week 50 – results for worst MC year (74)**
LEGEND: ENS > 100 MW Thermal re-dispatch > 1000 MWh/h Thermal re-dispatch < -20 MWh/h Increase spillage > 10 MWh/h Link: MCV>500Euro/MWh	LEGEND: ENS > 100 MW Thermal re-dispatch > 1000 MWh/h Thermal re-dispatch < -20 MWh/h Increase spillage > 10 MWh/h Link: MCV>500Euro/MWh

Analyzing the results, it can be seen that:

- Similar to week 2, links on corridors from Norway to continental Europe should collect excess of energy along the way;
- Baltic countries and Poland should collect energy to bring towards Germany;
- the link between Greece and Italy seems really interesting for a possible expansion;
- The connection of United Kingdom from North to South should enable reduction of ENS in UK first. Interconnection with continental Europe is also promising.

Fig. 214 - definition of new interconnection on the basis of the results of week 50

WEEK 25

The analysis of the most interesting weeks lead us to see in detail the characteristics of week 25 for summer, because in this week occurs a lot of spillage.

WEEK 25 - Average

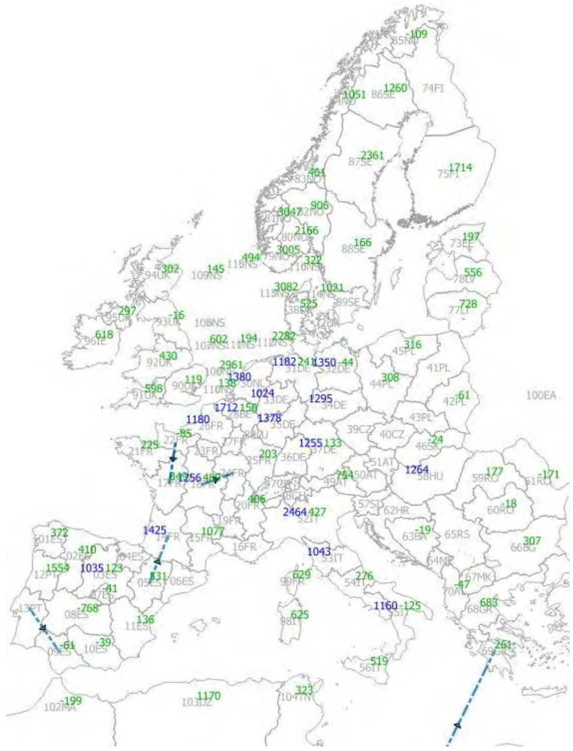

Fig. 215 – week 25 – results for 99 average MC years

LEGEND:

ENS > 100 MW

Thermal re-dispatch > 1000 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Link: MCV>500Euro/MWh

WEEK 25 – Worst year

Fig. 216 - week 25 – results for worst MC year (31)

LEGEND:

ENS > 100 MW

Thermal re-dispatch > 1000 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Link: MCV>500Euro/MWh

With respect to the situation in the winter period, it has been chosen to start the reinforcement on the basis of the winter solutions, and analyze in further steps, if necessary, the reinforcement needs for the summer period.

Conclusions

Based mainly on the results for week 2 and “worst” year, but also all other weeks, sizes of the reinforcements proposed for the first step are assessed and presented in Fig. 217.

In this first step reinforcements are used to :
- solve ENS in Germany and Central Europe from Norway and Sweden (where high spillage exist)
- further help in continental Europe (BE, NL, FR, IT…)

- bring spilled energy from Baltic states to continental & East Europe
- solve ENS in France from IE
- utilize spillage in NS and North UK to reduce ENS in south UK
- solve ENS and to enable more economic dispatch in Italy from Greece and North Africa (where high spillage exist)

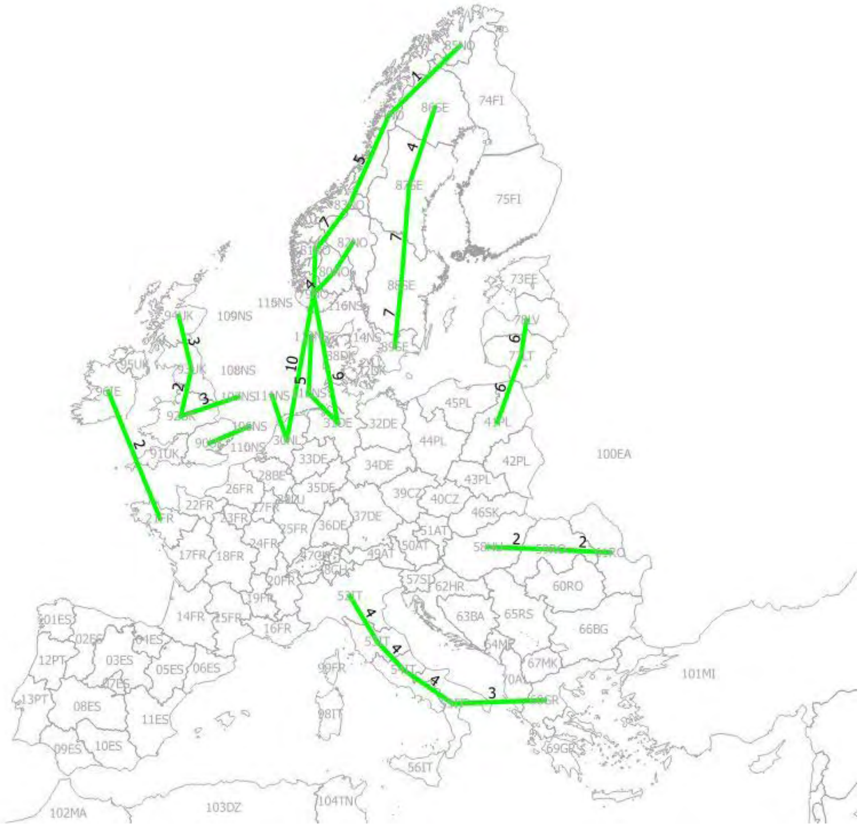

Fig. 217: Assessed 1st set of transmission requirements – X-7

Big & market

In this section of the report, maps with main indicators of the system's operation and flow patterns on the European transmission grid in the selected weeks are presented.

Results of the constraints analyses show that there are several corridors which should be reinforced with the aim to enable exchange of energy, primarily reduction of ENS, but also reduction of overall operating costs. With the aim to define links that should be reinforced but also to assess the size of each reinforcement, week 48 is further analyzed on the 99 years average results and also on the MC-year (Monte Carlo Year) in which ENS is the highest ("worst" year).

In addition to this week, more detailed analyses are also carried out for weeks 6, 25, 43.

Values and colors used to present main indicators on the maps are explained in Section 2.4 (Scenario X-5)

WEEK 48

WEEK 48 – Average	**WEEK 48 – Worst year**
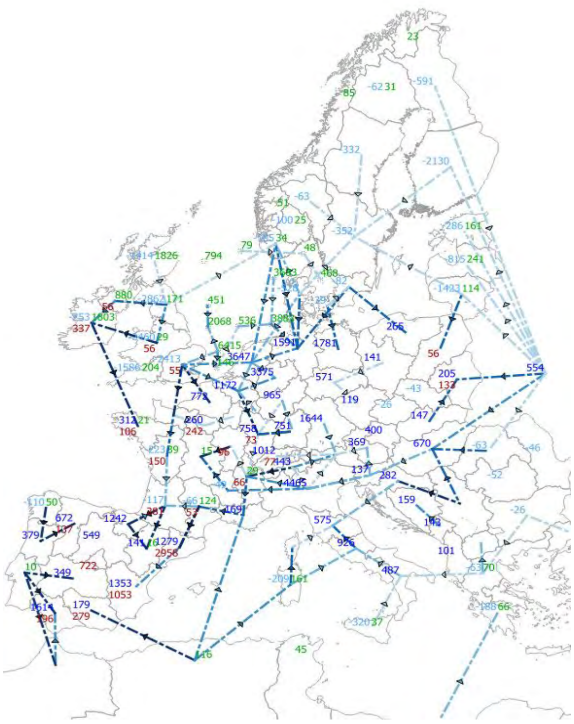	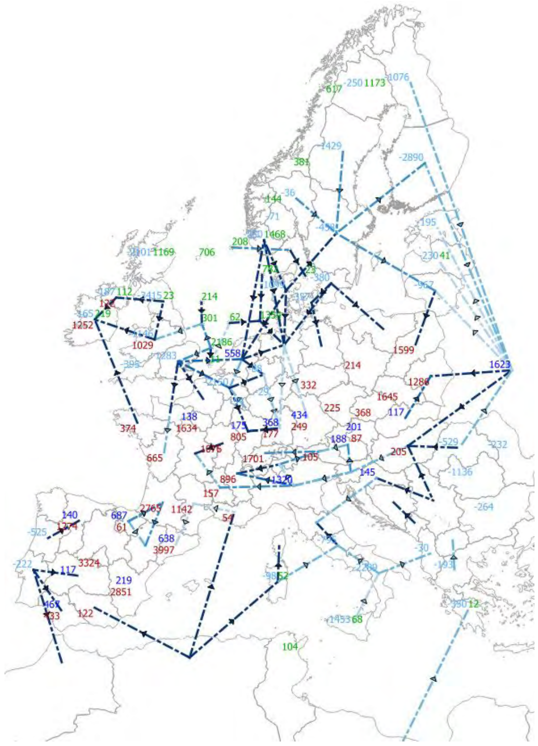
Fig. 218: Map with average hourly values on the 99 Monte Carlo years in week 48 for ENS, spillage variation, thermal redispatching and MCV – X-10	**Fig. 219: Map with ENS, spillage variation, thermal redispatching and MCV in week 48 & "worst" year – X-10**
LEGEND :	LEGEND : ENS > 50 MW

ENS > 50 MW Thermal re-dispatch > 100 MWh Thermal re-dispatch < -20 MWh Increase spillage > 10 MWh MCV [€/MWh]: → 100-200 → 200-500 → 500-1000 → 1000-2000 → 2000-100000	Thermal re-dispatch > 100 MWh Thermal re-dispatch < -20 MWh Increase spillage > 10 MWh MCV[€/MWh]: → 100-200 → 200-500 → 500-1000 → 1000-2000 → 2000-100000

Huge amounts of unsupplied energy are located across Spain, in France (mainly in West part), in Ireland, south UK and East Poland.

Positive thermal redispatching of expensive generation is located in Spain and north, central and south continental Europe.

Huge amounts of excess of spilled energy or of thermal negative redispatching are located :

- In NS clusters close to south UK clusters (wind spillage),
- In Northern UK (Spillage, nuclear and biomass),
- In all Sweden (nuclear),
- In Finland and Baltic (spillage, biomass, cheaper gas)
- In Denmark (biomass).

Based on these elements, first transmission requirements are suggested :

Reinforcement of links between 2 NS clusters close to south UK clusters will bring energy from NS to UK (and then continental Europe).

Reinforcement of the corridor from north UK to North of France will collect energy from North UK and NS clusters to help solve problems in West continental Europe (ENS in France and Spain, expensive thermal redispatching in continental Europe). A reinforcement between UK and Ireland will help to solve ENS in Ireland.

Reinforcement of the corridor going from north Finland to North Poland will collect energy all along the path (in Finland clusters and Baltic countries) to solve ENS in Poland and reduce expensive thermal generation in continental Europe.

Reinforcement of the corridor going from north Sweden to North East Germany and North Poland will collect energy all along Sweden clusters to solve ENS in Poland and thermal positive redispatching in Germany and more generally continental Europe.

The link between western Denmark and North Germany will allow bringing excess of biomass generation in Denmark to Germany.

These reinforcements are summarized in the figure below :

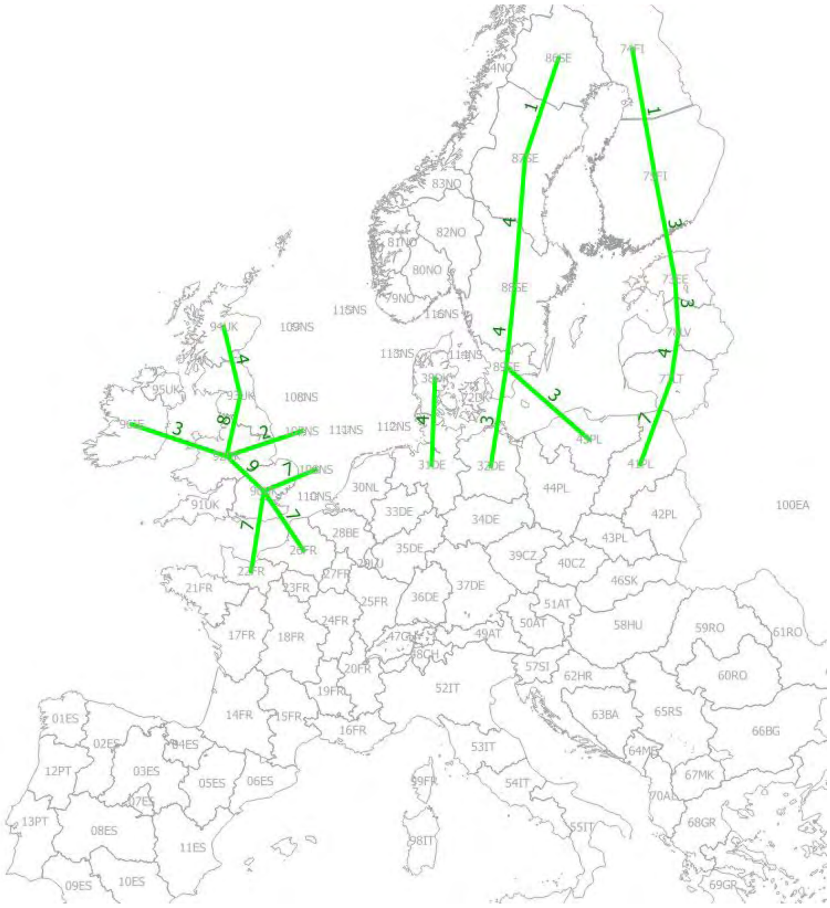

Fig. 220 : Map with corridors recognized as a 1st set of reinforcements, based on week 48 – X10

These corridors mainly present connections between distant areas and continental Europe and because of that, reinforcement of these corridors can be applied in one first step assuming that there is no mutual impact between applied reinforcements. Reinforcements inside continental Europe will be considered in further steps, depending on the effect of the first step.

WEEKS 6, 25 and 43

Week 6 – average	**Week 43 - average**
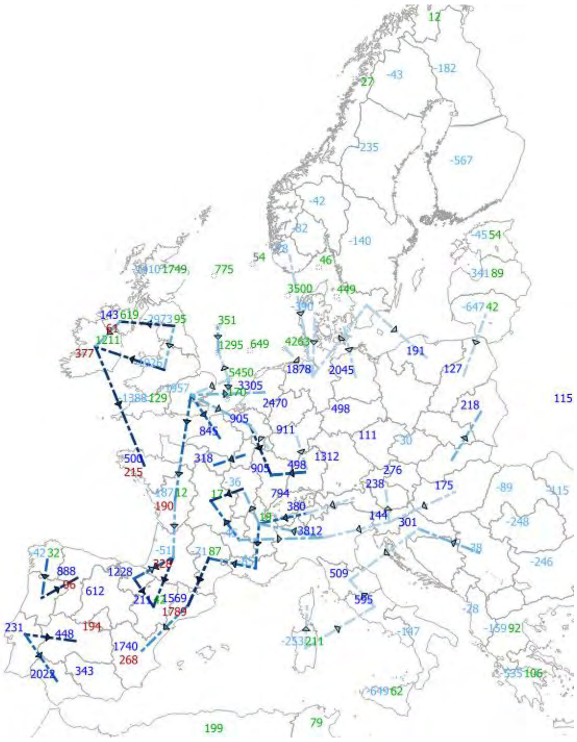	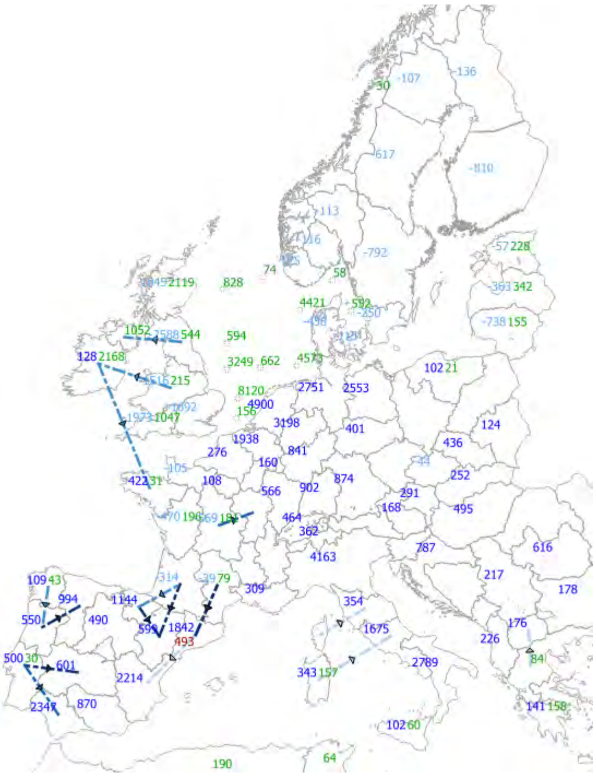
Fig. 221 : Map with average hourly values on the 99 Monte Carlo years in week 6 for ENS, spillage variation, thermal redispatching, MCV – X-10	**Fig. 222 : Map with average hourly values on the 99 Monte Carlo years in week 43 for ENS, spillage variation, thermal redispatching, MCV – X-10**
LEGEND : ENS > 50 MW Thermal re-dispatch > 100 MWh Thermal re-dispatch < -20 MWh Increase spillage > 10 MWh MCV[€/MWh]: → 100-200 → 200-500 → 500-1000 → 1000-2000 → 2000-100000	LEGEND : ENS > 50 MW Thermal re-dispatch > 100 MWh Thermal re-dispatch < -20 MWh Increase spillage > 10 MWh MCV[€/MWh]: → 100-200 → 200-500 → 500-1000 → 1000-2000 → 2000-100000

Week 25 - average

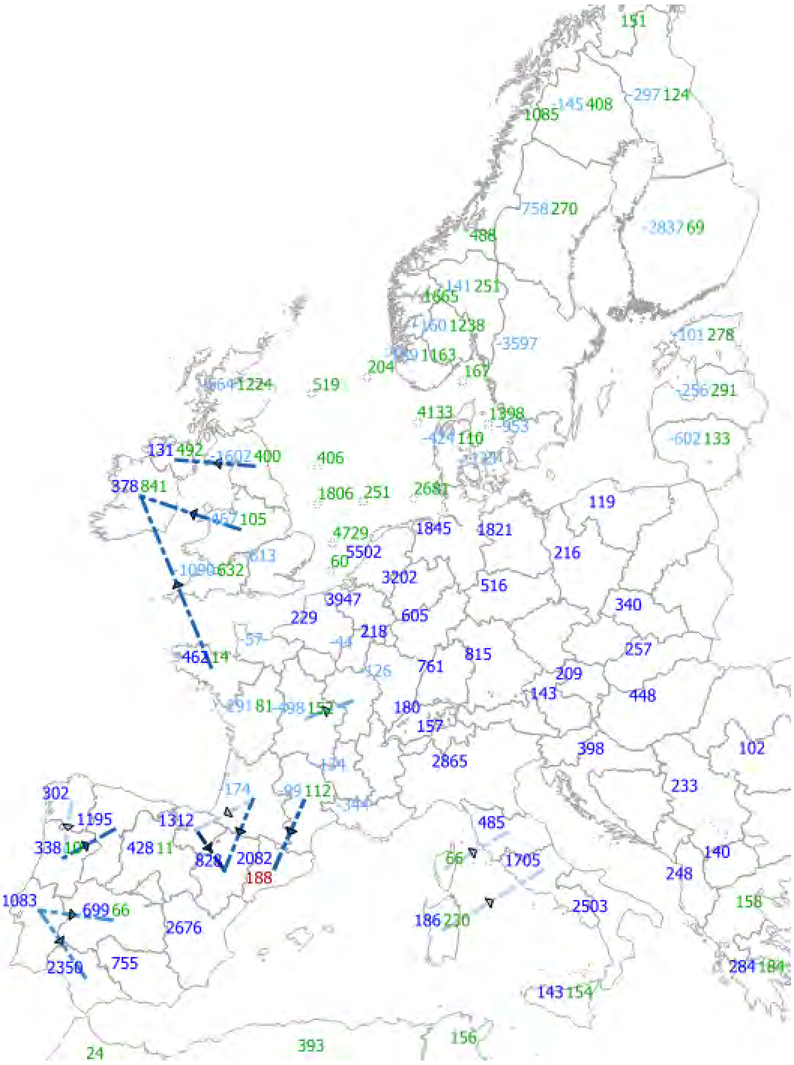

Fig. 223 : Map with average hourly values on the 99 Monte Carlo years in week 25 or ENS, spillage variation, thermal redispatching, MCV – X-10

LEGEND :

ENS > 50 MW

Thermal re-dispatch > 100 MWh

Thermal re-dispatch < -20 MWh

Increase spillage > 10 MWh

MCV[€/MWh]:

➝ 100-200
➝ 200-500
➝ 500-1000
➝ 1000-2000
➝ 2000-100000

Week 6 is close to week 48 in terms of location of ENS, spillage and thermal redispatching, with smaller volumes.

In week 43 there is on average only ENS in one eastern cluster in Spain. Areas in excess of energy are located mainly in North Sea, UK, Scandinavia, Baltic countries and western France (except Britain) while areas with lack of energy are located in Spain, central and east continental Europe and Italy. First reinforcements for this week 43 would aim at bring energy from northern countries (North Sea, UK, Scandinavia, Baltic countries) towards north continental Europe to reduce expensive thermal generation. These reinforcements already belong to the list proposed for week 48.

Week 25 presents the same locations of areas with excess of energy and areas with lack of energy as week 43, with higher level of spillage in Scandinavia. So the first reinforcements for week 25 would be the same as for week 43, which already belong to the list proposed for week 48.

Conclusions

Based mainly on the results for week 48 (average on the 99 Monte Carlo years and "worst" year), and confirmed also by other characteristic weeks, transmission requirements are presented in Fig.2245.

Fig. 225 : The first set of transmission requirements – X10

Reinforcements on the UK corridor proposed in the first step are aimed to :

- solve ENS in south continental Europe and France from North Sea and UK (where high spillage and excess of thermal capacity exist) and

- further help in Spain

Reinforcements on the corridor from Sweden and Finland proposed in the first step are aimed to:

- solve ENS in East Poland
- further help to reduce expensive thermal generation in continental Europe

Reinforcements on the corridor from Denmark proposed in the first step are aimed to:

- help to reduce expensive thermal generation in continental Europe

Fossil & nuclear

WEEK 48

For this period the focus is on Spain, Italy, France and Portugal which are facing high energy not served.

Week 48 – Average

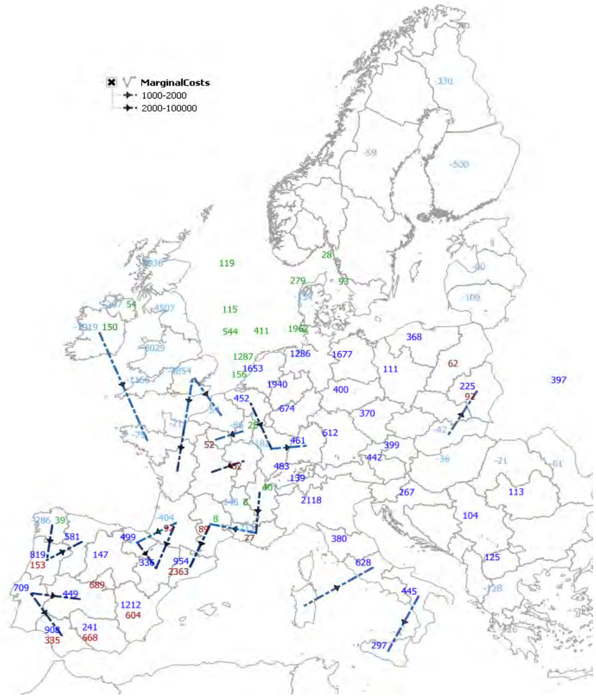

Fig. 226: Map with ENS, spillage variation, positive and negative thermal redispatching (average MW for week 48) and MCVs – X-13

LEGEND:
ENS > 50 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -10 MWh/h
Increase spillage > 5 MWh/h
Thermal margin > 100MW
Link: MCV>1000Euro/MWh

Week 48 – Worst year

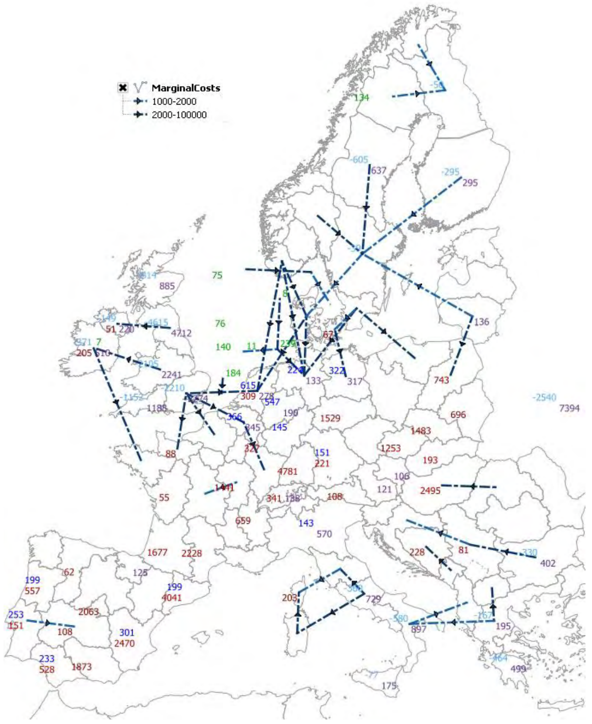

Fig. 227: Map with ENS, spillage variation, positive and negative thermal redispatching, margin on thermal (average MW for week 48 worst MC) and MCVs – X-13

LEGEND:
ENS > 50 MW
Thermal re-dispatch > 100 MWh/h
Thermal re-dispatch < -10 MWh/h
Increase spillage > 5 MWh/h
Thermal margin > 100MW
Link: MCV>1000Euro/MWh

Week 48 - Average over the 99 MC years

While there is energy not served in Spain, France and Portugal during this period, there is spillage of wind energy in North Sea. To a lesser extent there is also some spillage in Portugal, South of France and Ireland. It can be noticed that the total amount of spillage will not be sufficient to cover the total amount of ENS, even if they happen at the same time. North Sea can be a source of energy for the deficit areas in Southern Europe but this also will not be enough. The light blue negative thermal redispatching Figures show that there is a huge potential of the thermal generation in the United Kingdom. More interconnection with the UK will help to solve the ENS in Spain and Portugal. It can be noticed that the MCVs (Marginal cost variation) are particularly higher for the France-Spain border and interconnection from UK and Ireland to continental Europe. This confirms the prior analysis, competitive and available generation could be shipped from UK to continental Europe and down to Spain.

Week 48 - Worst year

For this moment of analysis the most extreme year of all Monte Carlo years was also chosen. The total energy not served amounts 14 TWh, the double of the average of all Monte Carlo years. In this most extreme year there is energy not served spread over whole Europe except for Scandinavia and the UK. Spillage energy in North Sea can only contribute very little to solve the ENS. Therefore the negative thermal redispatching energy should again be used. The margin on thermal, the thermal capacity that is not used is indicated in purple. This should also be taken into account to solve the ENS. It is doubtful that all energy not served will be solved when using the available capacity and spillage. However, it should be stressed that this is the most extreme Monte Carlo year with the double of total energy not served than the average over all Monte Carlo years.

Week 48 - Suggested corridors

Depending on the time stamp, Ireland is both a deficit and a surplus area. The UK is the nearest source for Ireland. To evacuate the spilled energy from North Sea a link to continental Europe is suggested. To use the thermal potential in the UK, a link is suggested from the North to the South of UK, crossing North Sea and reaching continental Europe in France. Because the spilled energy in North Sea will not always be enough to solve the ENS in continental Europe, connection with the UK and its thermal potential can serve as backup solution. This energy from North Sea and UK should go through France down to Spain. Between Spain and Portugal, another reinforcement is suggested

Recognized links to be reinforced are presented in the figure below.

Fig. 228: Map with suggested corridors for week 48– X-13

WEEK 26

For this period the focus is on Italy. As conclusions are similar to week 48, analysis for this week will be described less detailed.

Week 26 – Average	**Week 26 – Worst year**

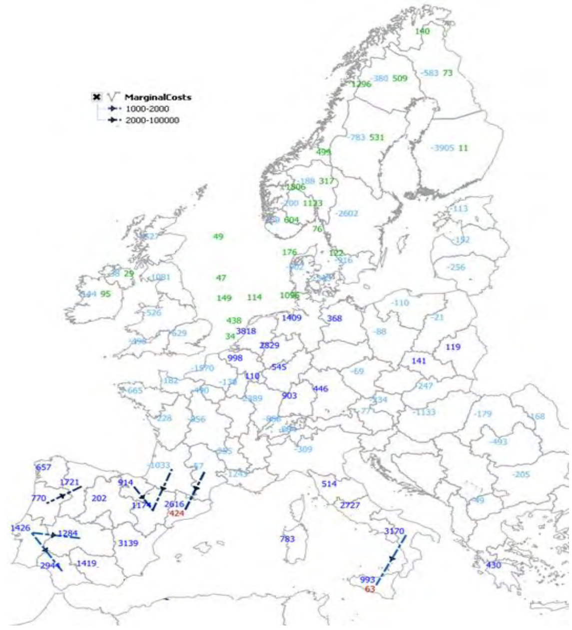

Fig. 229: Map with ENS, spillage variation, positive and negative thermal redispatching (average MW for week 26) and MCVs – X-13

LEGEND:

ENS > 50 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -10 MWh/h

Increase spillage > 5 MWh/h

Link: MCV>1000Euro/MWh

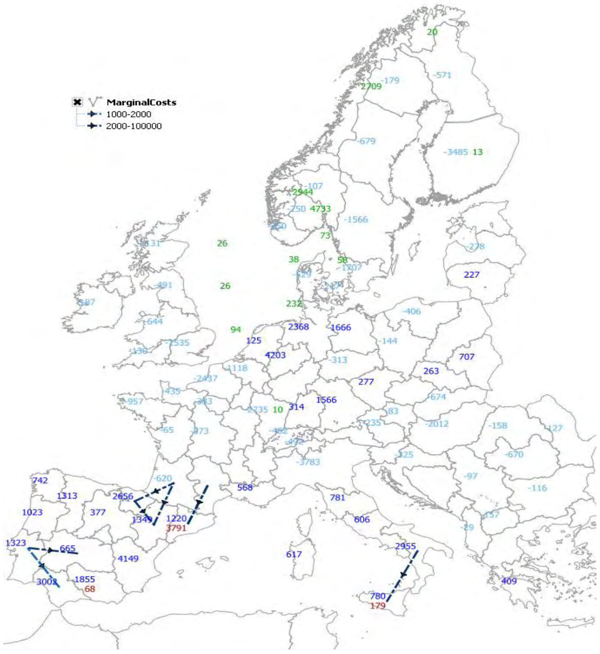

Fig. 230 : Map with ENS, spillage variation, positive and negative thermal redispatching (average MW for week 26 worst MC) and MCVs – X-13

LEGEND:

ENS > 50 MW

Thermal re-dispatch > 100 MWh/h

Thermal re-dispatch < -10 MWh/h

Increase spillage > 5 MWh/h

Link: MCV>1000Euro/MWh

While there is some energy not served in Spain and Sicilia during this period there is spillage of energy in North Sea and Scandinavia, and large volumes of thermal (biomass, nuclear) generation that are limited by network constraints in UK, France and Scandinavia. This energy should be used to solve the ENS and the positive thermal redispatch in the area Belgium, The Netherlands and Germany on one hand and Italy and the Iberian peninsula on the other hand.

It can be noticed that the cost are particularly higher for the France-Spain border and for internal lines of Spain, Portugal and Italy.

The in-depth analysis on this week has shown that competitive thermal margins and renewable generations should be shipped from Scandinavia, UK, France and Eastern Europe to Central North Europe (Germany, Netherlands, and Belgium) and down to Italy, Spain and Portugal. Therefore, on the map below, a first set of corridors is suggested to solve the problems of week 26.

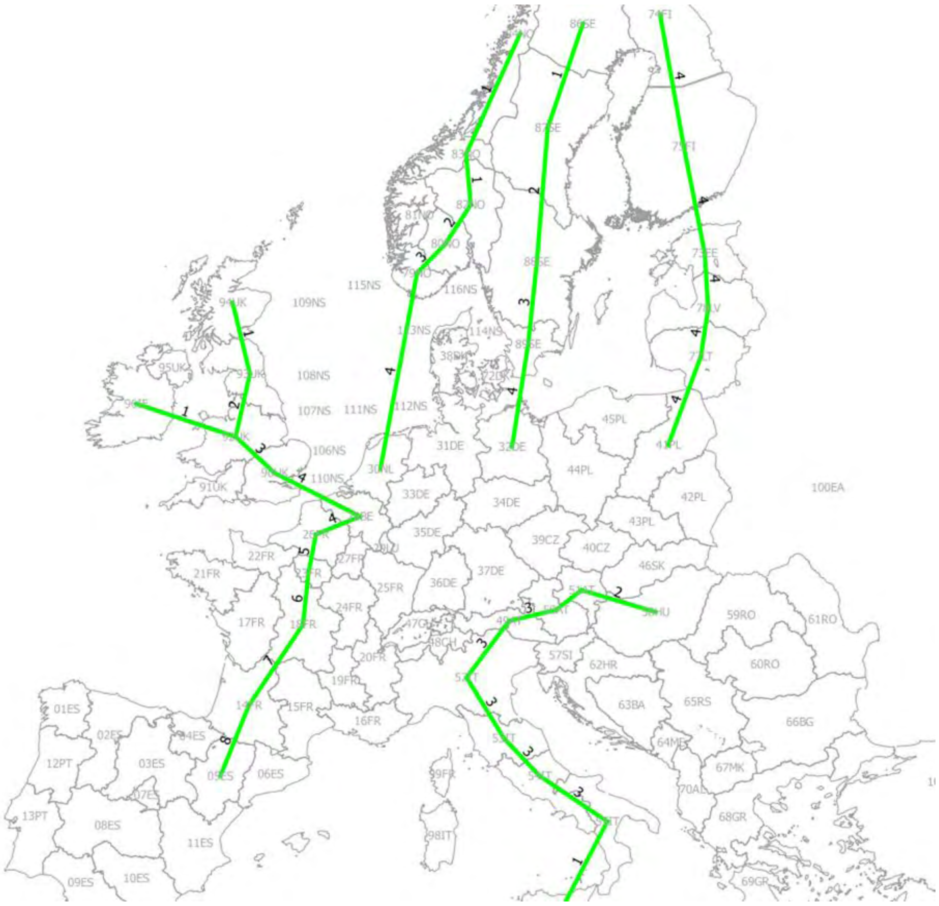

Fig. 231: Map with suggested corridors for week 26 (GW) – X-13

WEEK 22-28

This period is chosen to focus on spillage energy in Sweden and Norway during summer. Due to grid constraints this energy cannot be exported and gas and coal production elsewhere in Europe increases. Similar to the analysis for week 26, there is also cheaper thermal potential in UK, France, Eastern Europe and Scandinavia.

Map for week 22-28 is presented below (whole day, ENS >50 MW in red, Spillage > 10 MW in green, MCV >50 Euro/MW)

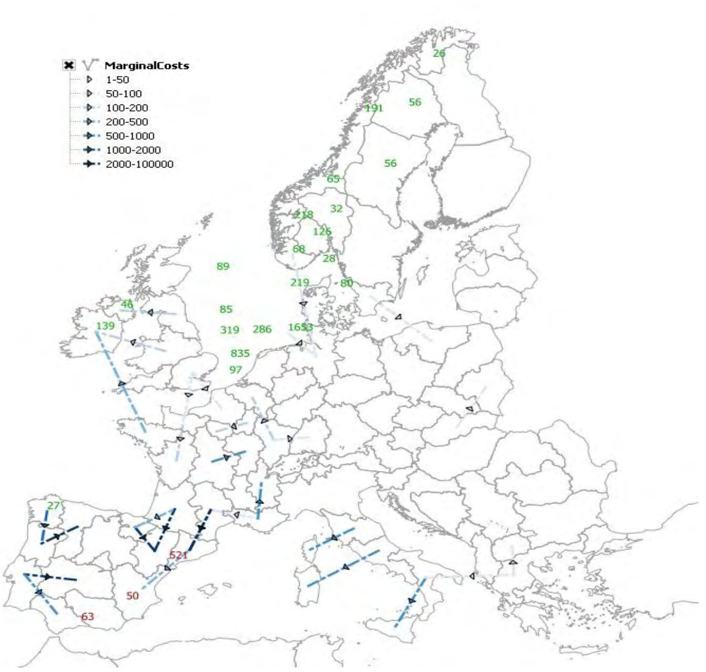

Fig. 232: Map with ENS, spillage variation (average MW for week 22-28) and MCVs – X-13

The in-depth analysis on this week has shown that competitive thermal margins and renewable generations should be shipped from Scandinavia, UK, France and Eastern Europe to Central North Europe (Germany, Netherlands, and Belgium) and down to Italy, Spain and Portugal. Therefore, on the map below, a first set of corridors is suggested to solve the problems for this week. The suggested corridors follow a similar way as suggested from the analysis of week 26. The difference is that some capacities should be higher. From this analysis there seems to be more potential in the UK. Compared to week 26, there is less potential in Scandinavia. The link from Norway to the Netherlands can even be replaced with a link from North Sea to the Netherlands and Germany.

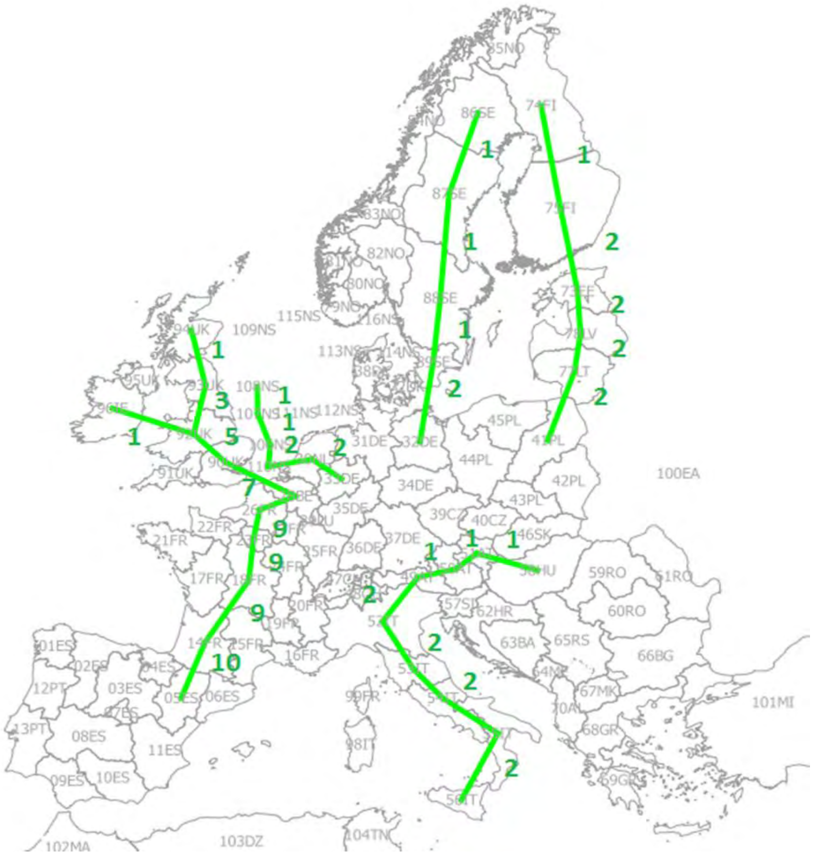

Fig. 233: Map with suggested corridors for week 22-28 (GW) – X-13

Conclusions

Combining the outcomes from the analyses above results in a first set of candidate corridors. These are shown in **Fig. 234**.

Assessment of the size of reinforcement is based on minimum of:

- Maximal hourly value of ENS in cluster which connection is to be reinforced
- Corresponding hourly value of spillage + negative thermal redispatching in cluster which provides energy to be transferred to the clusters with ENS

The size of the corridors also takes into account possibility to collect excess of energy along the corridor.

Proposed links should be considered as 1st proposals that are checked in further steps.

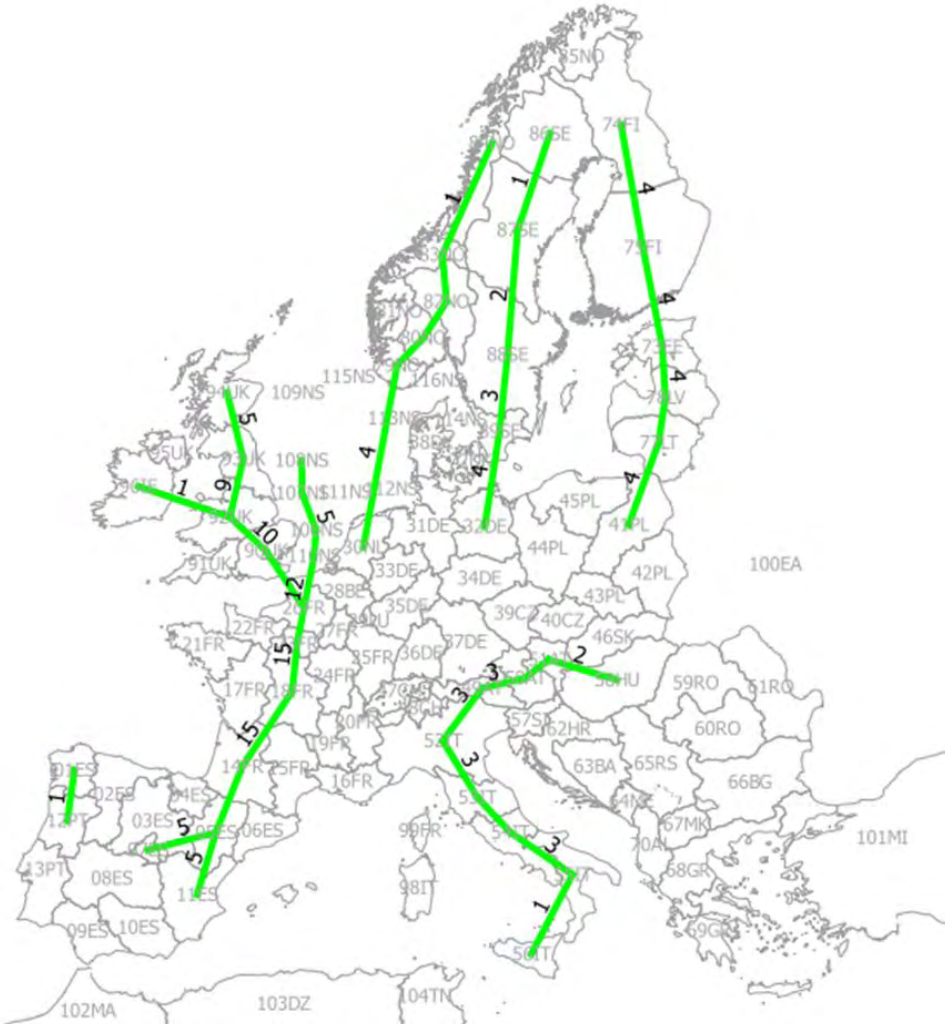

Fig. 234: Map with suggested corridors (GW) – X-13

Small & local

WEEK 48 – ENS in whole Europe

Week 48 – Average

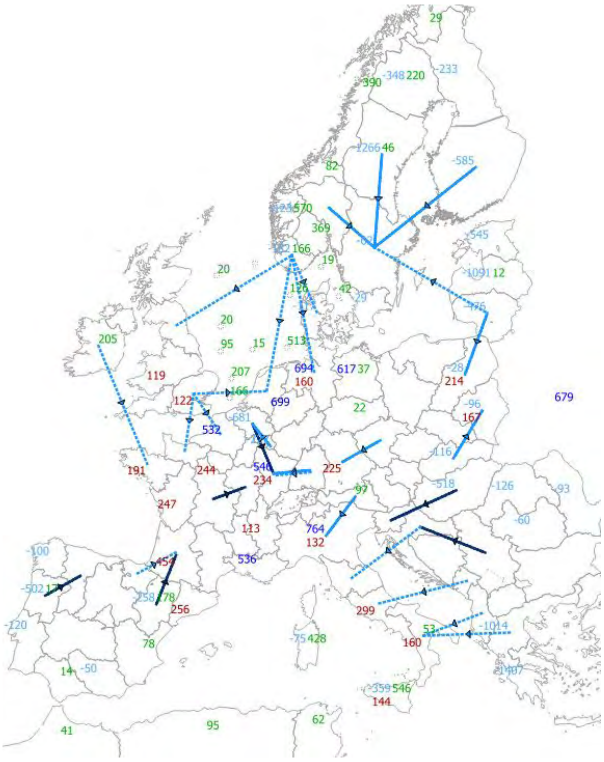

Fig. 235: Expected, average hourly values on the 99 Monte Carlo years in week 48.

LEGEND:

ENS > 100 MW

Thermal re-dispatch > 500 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Arrows:

1500 €/MWh < MCV < 5000 €/MWh

5000€/MWh < MCV < 10000 €/MWh

Week 48 – Worst year

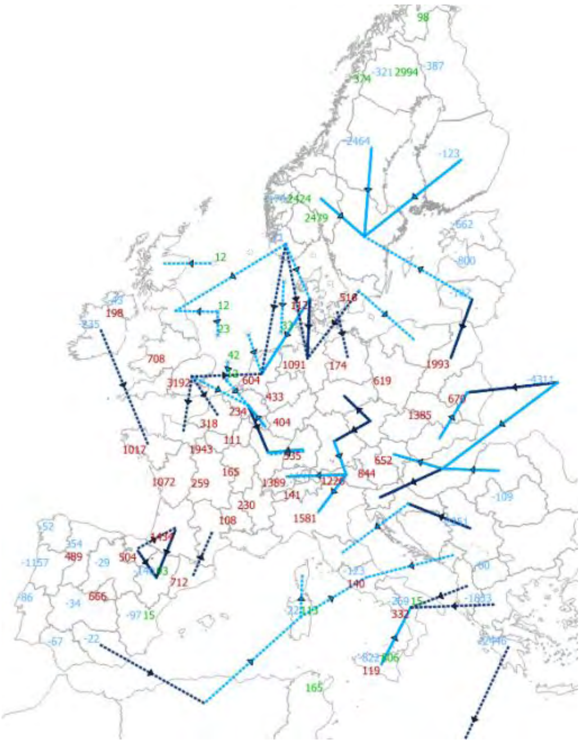

Fig. 236: Average hourly values in worst Monte Carlo year in week 48

LEGEND:

ENS > 100 MW

Thermal re-dispatch > 500 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Arrows:

1500 €/MWh < MCV < 5000 €/MWh

5000€/MWh < MCV < 10000 €/MWh

Week 48 – Average over the 99 MC years (Fig. 235)

As highlighted above, week 48 concentrated 17% of the total ENS volume. This number increases to 44% if we assume that week 48 is representative for the 12 winter weeks (December – February). During week 48, the western France and Italy account for more than 50% of the total ENS. The remainder of ENS-issues is concentrated around the major cities in Italy, Spain, Germany, Poland and the UK. Fig. 235 shows the average, hourly expected variation of spillages, ENS and thermal redispatching in week 48. Furthermore, it shows the MCV (marginal cost variation) of the transmission corridors. From Fig. 235, one can see that the system tries to minimize the amount of ENS with positive thermal re-dispatching in France and Germany (near or in the clusters with ENS) compared to the copperplate simulation. This shows that transmission grid reinforcements might not only solve ENS-issues in these clusters, but also would allow for an increase in operational efficiency in the dispatch.

Week 48 – Worst year (**Fig. 236*****)***

To get information on the magnitude and the synchronicity of ENS, spillages and re-dispatching, the Monte Carlo year with the highest ENS volume in week 48 is analyzed. The flow patterns are visualized in this Monte Carlo year in Fig. 236. The ENS issues, as well as potential surplus areas as identified in the average year are confirmed. Based on the worst-case analysis presented above, one could identify a first set of transmission requirements that could alleviate ENS-issues in Europe during week 48. The first set of transmission requirements entails (solid lines in Fig. 237)

- Greece to Italy (5 GW);
- Finland to Poland, collection power in the Baltic states (5 GW);
- Sweden to northern Germany and Denmark (8 GW);
- Portugal to Spain, where Madrid and Barcelona are connected (2 GW);
- Norway to the UK (9 GW).

A first estimate of the size of these transmission corridors is presented in Fig. 237 (and between brackets above). This value is merely a first estimate and should be regarded as an upper bound for the transmission requirement between those clusters. Furthermore, note that these transmission requirements or corridors may represent multiple or equivalent solutions. Multiple grid architectures may correspond to these transmission corridors. On the other hand, various transmission requirements may address the same issues, making them equivalent solutions.

Additional reinforcements shall be needed, especially to solve ENS issues in France and Germany. However, ENS issues in Central Europe will be affected by the reinforcement of the transmission corridors listed above. Therefore, the effect of the increased transmission capacity on these corridors must be first investigated before sizing or testing the reinforcement on other transmission corridors, such as, but not limited to (see dotted lines in Fig. 237.):

- Ireland to France;
- Spain to France;
- The UK to France;
- Serbia to Poland and Southern Germany.

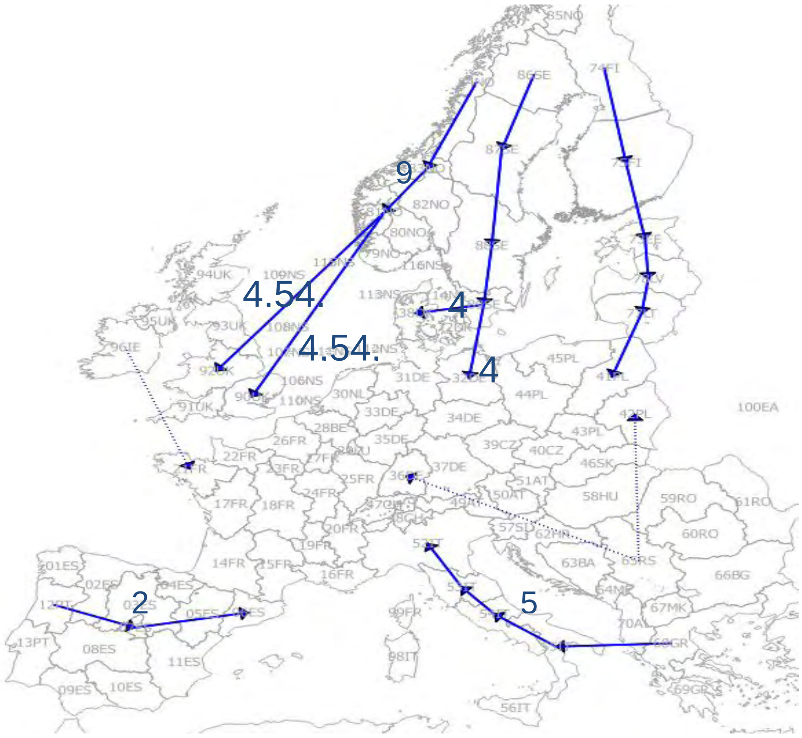

Fig. 237: A first set of transmission requirements that might solve the ENS issues during week 48.

WEEK 6 – ENS in France & Italy

Week 6 - Average

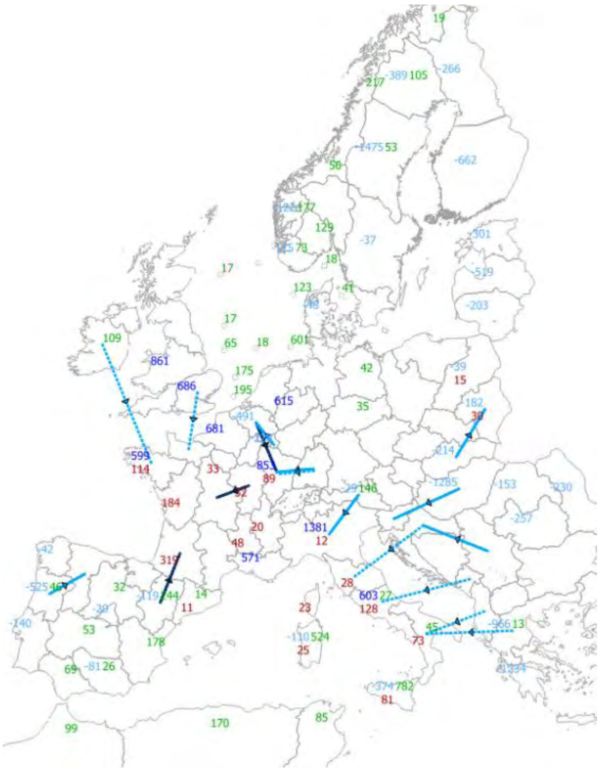

Fig. 238: Expected, average hourly values over all Monte Carlo years in week 6.

LEGEND:

ENS > 10 MW

Thermal re-dispatch > 500 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Arrows:

1500 €/MWh < MCV < 5000 €/MWh

5000€/MWh < MCV < 10000 €/MWh

Week 6- Worst year

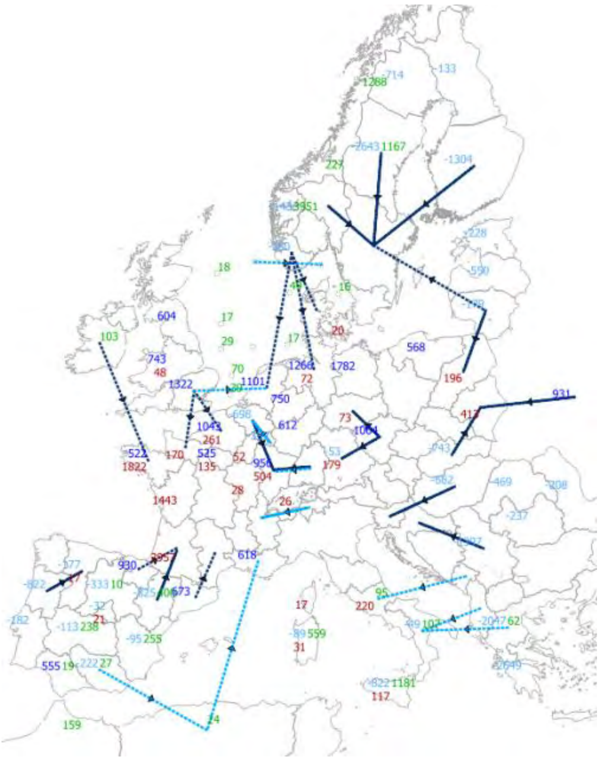

Fig. 239: Average hourly values in the Monte Carlo year with the highest ENS volume in week 6.

LEGEND:

ENS > 10 MW

Thermal re-dispatch > 500 MWh/h

Thermal re-dispatch < -20 MWh/h

Increase spillage > 10 MWh/h

Arrows:

1500 €/MWh < MCV < 5000 €/MWh

5000€/MWh < MCV < 10000 €/MWh

Week 6 and the weeks with a similar pattern concentrate around 20% of the annual ENS. During these weeks, major ENS issues occur in France (especially the south-west), Italy and (to a lesser extent) Poland. During week 6, there is some positive thermal re-dispatching in the UK, Germany and France. Reinforcements might help not only to solve ENS issues, but also to increase the operational dispatch efficiency.

Note that the congestion patterns and MCVs from week 48 are partly ‘confirmed’ in week 6. Especially between Italy and the Balkan and Greece, congestion patterns are very similar.

The worst-case analysis confirms the patters drawn from the average hourly results, although the effects are more pronounced. Especially thermal re-dispatching in the UK, Northern Germany, Belgium and France is prominently present. MCVs and congestion patterns increase, also in Northern Europe, highlighting the importance of adequate grid reinforcements during ‘worst-case’ situations.

Based on this analysis, a first set of transmission requirements is proposed to alleviate ENS issues during week 6 (solid lines in Fig. 240):

- Greece to Italy (6 GW);
- Finland to Poland, collecting power from the Baltic States (4 GW).

In a second step, possible transmission requirements to solve ENS problems in France and Germany could be (dotted lines in Fig. 240):

- Portugal to Spain and France;
- North Sea to France, via the UK or Denmark and Germany;
- Serbia to Germany.

Note that the transmission corridors passing through the UK or Denmark and Germany might yield a more efficient dispatch.

Fig. 240: A first set of transmission requirements that might solve the ENS issues during week 6.

WEEK 12 – ENS in Italy and Scandinavia

Week 12 - Average

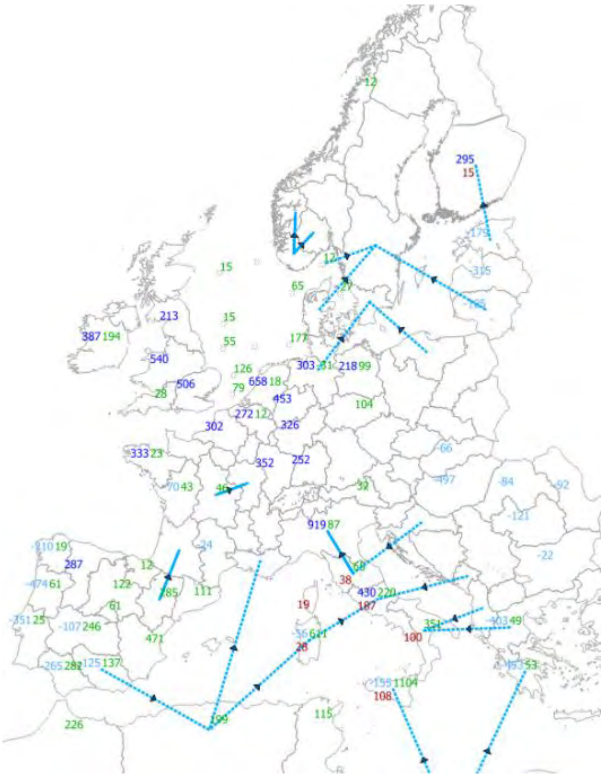

Fig. 241: Expected, average hourly results over all Monte Carlo years in week 12.

LEGEND:
ENS > 10 MW
Thermal re-dispatch > 200 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 10 MWh/h
Arrows:
1500 €/MWh < MCV < 5000 €/MWh
5000€/MWh < MCV < 10000 €/MWh

Week 12 – Worst year

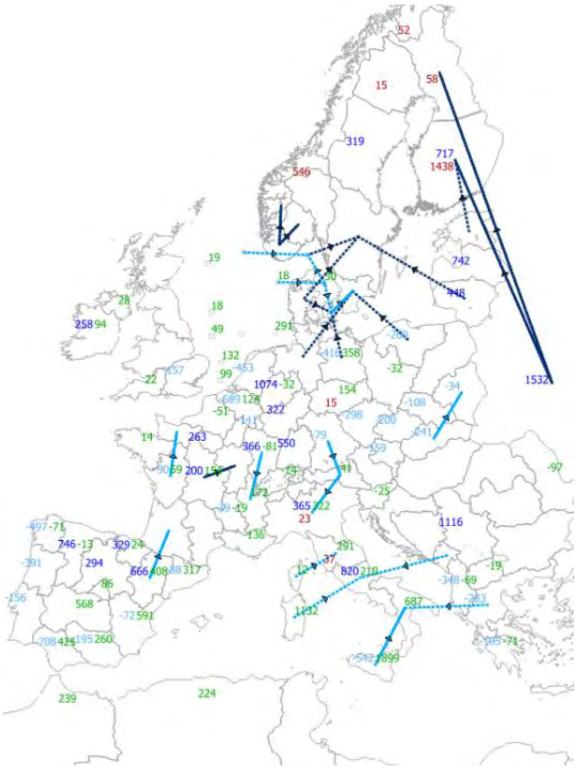

Fig. 242: Expected hourly results in the Monte Carlo year with the highest ENS in week 12.

LEGEND:
ENS > 10 MW
Thermal re-dispatch > 200 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 10 MWh/h
Arrows:
1500 €/MWh < MCV < 5000 €/MWh
5000€/MWh < MCV < 10000 €/MWh

Week 12 and the weeks with a similar pattern jointly represent 8% of the annual ENS volume. ENS mainly occurs in Italy and Scandinavia. In Scandinavia, ENS is less frequent. This ENS issue is due to the end of winter, the beginning of maintenance of thermal assets and a high demand (cold spell).

To alleviate these ENS issues, power source in the vicinity of Italy and Scandinavia could be

- Thermal capacity in Greece;
- Thermal capacity in the Baltic countries;
- Thermal capacity in Eastern Europe;
- Spillages in the North Sea and Northern Germany.

Note that the congestion patterns on the interconnections between Italy and the Balkan and Greece again re-appear in week 12. The flows on the transmissions system in the Northern part of Europe however reverse: power tends to flow from continental Europe to Scandinavia, while in other periods of the year this typically is reversed.

A ‘worst case’ analysis on the Monte Carlo year that exhibits the highest ENS volume in week 12 highlights the ENS issues in Scandinavia. In Finland, most ENS occurs during the night and peaks early in the morning around 6 a.m. Similarly, in Norway ENS peaks at 8 a.m. In Italy and Northern Sweden, ENS peaks during the evening peak (up to 4 GW in Italy, up to 100 MW in Sweden). The power surpluses as listed above persist during the worst Monte Carlo year, as well as the congestion patterns, indicating flows from continental Europe to Scandinavia.

To alleviate ENS issues in week 12, a first set of transmission requirements (solid lines in Fig. 243) that could be considered consists of connections between

- Greece and Italy (4 GW);
- Germany, via Denmark, to Sweden (5 GW);
- The Baltic states, where thermal margin is available, to Finland (4 GW).

In a second step, the latter link could also collect thermal generation margin from Poland (dotted lines in **Fig. 243**).

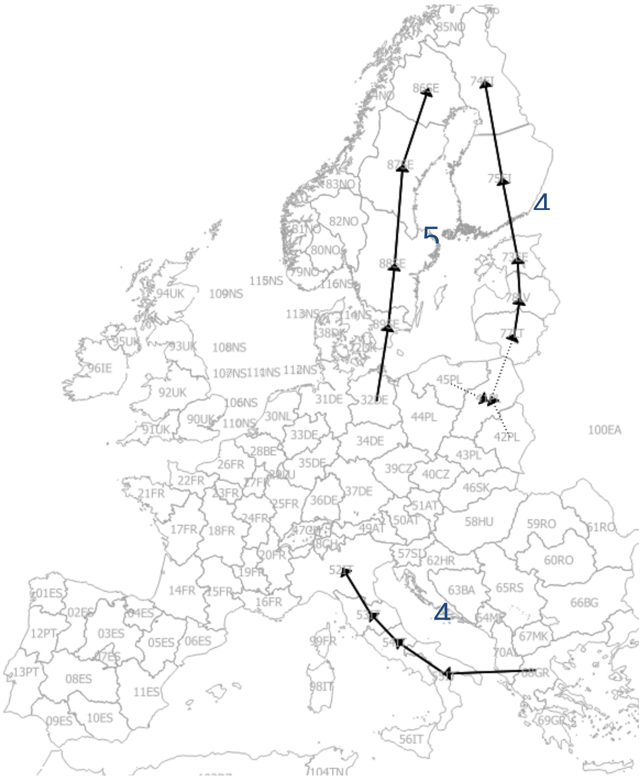

Fig. 243: A first set of possible transmission requirements to alleviate ENS in week 12.

WEEK 26 & 36 – ENS in Italy

Week 26 – Average

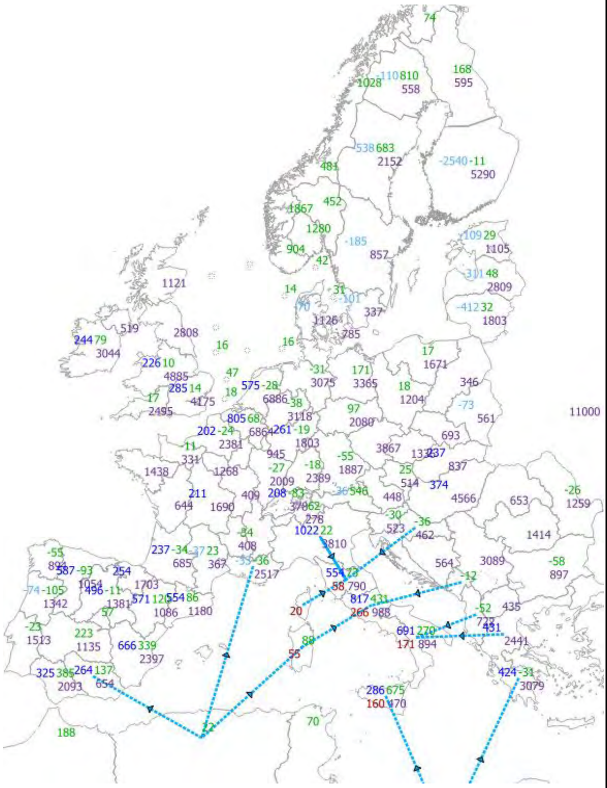

Fig. 244: Expected, average hourly values over 99 Monte Carlo years in week 26.

LEGEND:
ENS > 10 MW
Thermal re-dispatch > 200 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 10 MWh/h
Thermal margin >200 MW
Arrows:
1500 €/MWh < MCV < 5000 €/MWh
5000€/MWh < MCV < 10000 €/MWh

Week 26 – Worst year

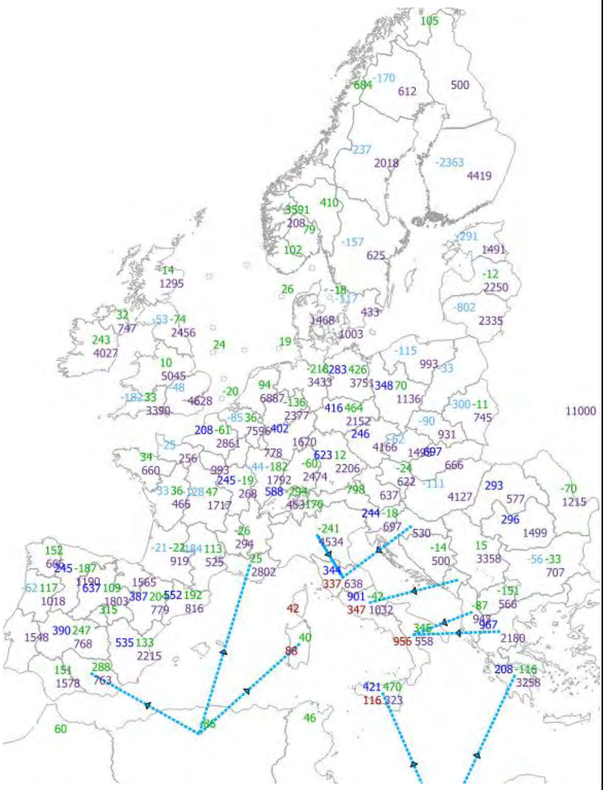

Fig. 245: Average hourly values in the Monte Carlo year with the highest ENS volume in week 26.

LEGEND:
ENS > 10 MW
Thermal re-dispatch > 200 MWh/h
Thermal re-dispatch < -20 MWh/h
Increase spillage > 10 MWh/h
Thermal margin >200 MW
Arrows:
1500 €/MWh < MCV < 5000 €/MWh
5000€/MWh < MCV < 10000 €/MWh

As week 26 and 36 showed similar congestion, ENS and spillage patterns, results for only week 26 are discussed in detail. The weeks with similar characteristics as week 26 represent around 14% of the total ENS volume. During these weeks, ENS occurs in Italy between 4 and 8 p.m.

To address these ENS issues, possible power surplus include

- Spilled wind and hydro power in Austria and Scandinavia;

- Thermal margin in Greece, the Balkan area and Hungary.

Note that we do not include spilled solar power from North Africa, Spain or Italy as ENS occurs asynchronously (not at the same moment in time) with these spillages. Furthermore, note that the thermal margin selected above was not used in the 'copperplate simulation' (no negative re-dispatching values). This thermal capacity may therefore be more expensive (compared to the cheap biomass that is re-dispatched in the Baltic States and Scandinavia).

In Monte Carlo year with the highest ENS volumes in week 26, ENS volumes in Italy reach up to 7 GWh/h. Simultaneously, high spillages volumes are recorded in Austria (up to 6 GWh/h), while a significant amount of cheap thermal generation and spillages in Scandinavia and the Baltic states is available. Thermal generation (which is more expensive than the capacity in Scandinavia) is available in Greece (7 GW), the Balkan (1 GW in Croatia, 1 GW in Bosnia Herzegovina) and Hungary.

Therefore, the different possible reinforcements that would solve the ENS issues in Italy include

- Hungary via Austria to Italy (up to 6 GW);
- Croatia to Italy (1 GW);
- Bosnia Herzegovina (1 GW);
- Greece to Italy (up to 6 GW);
- Norway – Sweden via Germany and Austria to Italy (up to 6 GW).

Note that the latter reinforcement would not only help to solve the ENS issues in Italy, but would also allow for a greater operational efficiency in the dispatch.

Fig. 246: A first set of possible reinforcements to solve ENS in week 26 in Italy

WEEK 15 – highest increase in spillages in Europe

Although ENS reduction will be treated in priority (given the value attached to ENS), especially in the early phase of the grid development, it is interesting to analyze the flow patterns in Europe during periods of large increases in spillages. The transmission requirements to solve ENS as identified above may correspond to those needed to transport excess RES-based generation to the load centers.

During week 15, the increase in spillages is the highest. In the South, solar energy is spilled. Especially in Sicily, Sardinia, Italy and southern Spain high volumes of solar energy are curtailed. To a lesser extent, solar energy is unutilized in North Africa. Wind energy is mainly spilled in and around the North Sea, especially in the clusters connected to Germany. Simultaneously, positive re-dispatching occurs in the UK, Ireland and Central-West Europe (France, Belgium, the Netherlands and Germany). This increase in thermal generation is mainly an increase in expensive gas-fired generation.

The high MCV values show some hints on some congestion between the South of Europe/North Africa and continental Europe and the UK. Note the high MCV values for the connections between Italy and Greece and the Balkan, as well as on the internal connections.

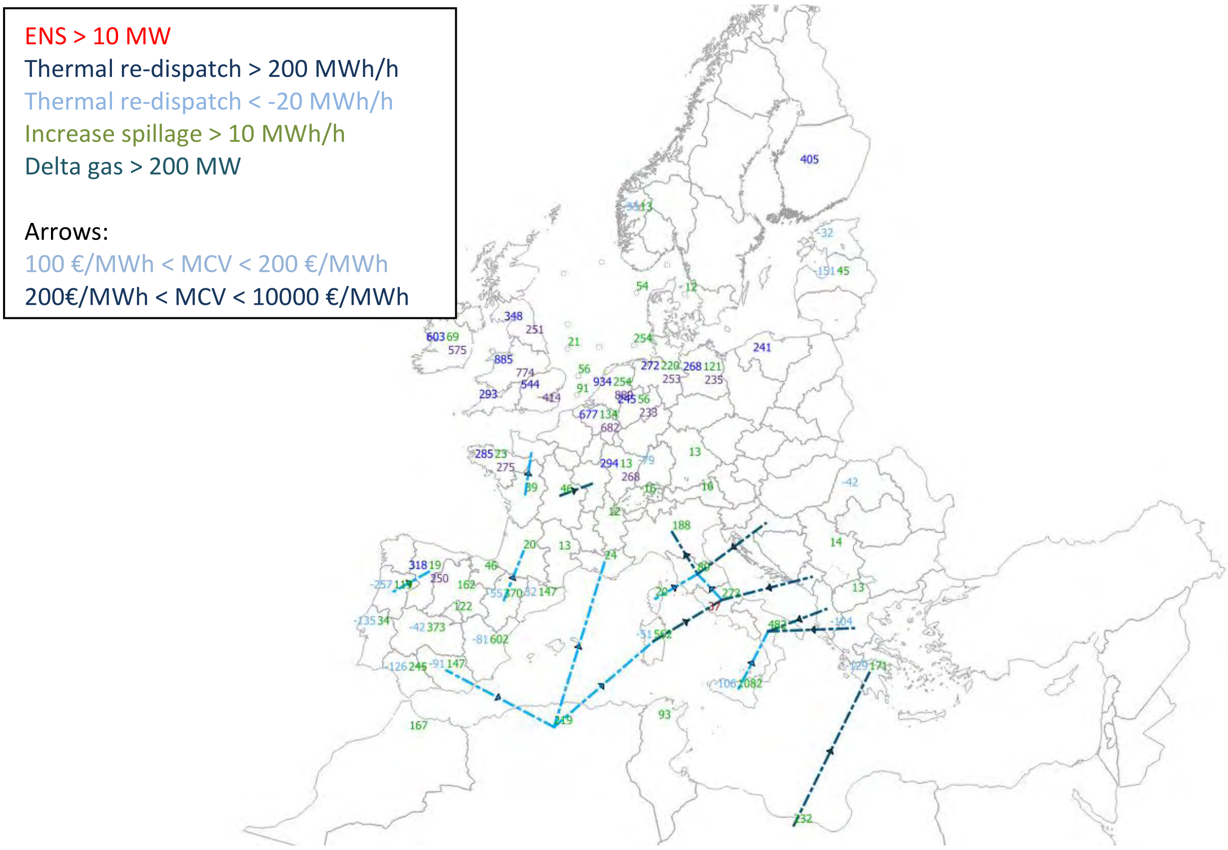

Fig. 247: Expected, average hourly results on the 99 Monte Carlo years on week 15.

Based on the analysis above, one can identify the following corridors:

- North Sea to Germany;

- Southern Spain via Madrid to Belgium;
- Sardinia and Sicily, via Italy, to Southern Germany.

These corridors are important and their reinforcement may lead to an economically more efficient dispatch, by connecting RES-based generation to the major load centers in Europe. The demand in these load centers would otherwise be satisfied by running expensive gas-fired units.

Fig. 248: A first set of possibly economically interesting transmission requirements for week 15.

Overall Conclusions

Based on the analysis above, one can identify a number of common transmission requirements among the different representative weeks. These are shown in Fig. 249.

The transmission requirement between the UK and Norway amounts to 9 GW. This connection collects hydro, wind and cheap thermal generation from Norway to satisfy the demand in load centers in the south of the UK (especially in weeks like 48).

Similarly, the analysis for week 48 showed that there is an additional transmission requirement of 8 GW between Sweden and Denmark and Northern Germany. This transmission corridor could allow solving ENS issues in continental Europe by transferring spilled energy and cheap thermal generation to Denmark and Germany. In the analysis performed for week 12, this transmission corridor could be beneficial to solve ENS issues in Scandinavia. During these weeks, the transmission requirement would however be lower (about 5 GW). Furthermore, this corridor could help to improve the efficiency of the dispatch (e.g. see the analysis for week 6).

The connection between Finland and Poland, via the Baltic States, could solve ENS issues in Scandinavia and Poland. During winter weeks, ENS issues in Poland could be addressed by importing spilled energy and cheap thermal generation from Finland and the Baltic states. During weeks similar to week 12, the thermal generation in the Baltic States could be a cost-efficient option to meet the load in Finland and the rest of Scandinavia. The transmission requirement is set by the analysis for week 48, leading to a capacity requirement of 5 GW.

To address ENS-issues in Spain, the analysis for week 48 showed that a transmission corridor between Portugal and Barcelona, via Madrid, could be beneficial. This transmission corridor would collect thermal power from Portugal to meet the load in the big cities. The transmission requirement is once more set by week 48 and amounts to 2 GW.

Italy showed to be the country with the highest ENS volume, amounting to 64% of all ENS. A first transmission requirement that could address the issues in Italy would be the interconnection between Greece and Italy. The North of Greece would be connected to the South of Italy, but the transmission corridor should connect all clusters in Italy as well. Based on the analysis presented above, the size of this corridor is estimated to be 6 GW.

Note that the analysis presented above showed multiple alternatives to solve ENS issues in Italy (e.g. see the analysis for week 26). However, the selected solution seems beneficial in all studied weeks, therefore it is selected first.

In Central-Western Europe, we have not yet found any ‘evident’ transmission corridors that would solve the ENS issues in e.g. France. The transmission requirements presented above may already address some of the ENS issues in CWE. The remaining ENS volumes, spillages and re-dispatching issues will have to be analyzed taking into account the effect of the transmission requirements presented above.

The presented set of transmission requirements is a first set that could help to decrease ENS, spillage and re-dispatching volumes in Europe. However, the presented measures will not be sufficient to bring ENS-volumes to acceptable levels or to optimize the dispatch. To identify the transmission corridors and their respective sizes to achieve these goals, one first needs to study the impact of the first set of transmission requirements.

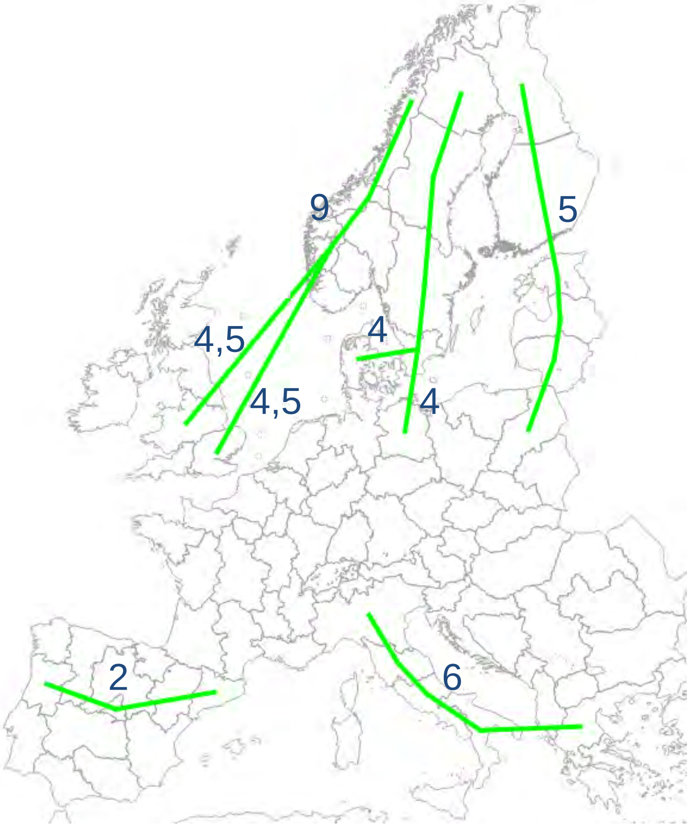

Fig. 249: The first set of transmission requirements-X-16.

Annex E : Refurbishment of existing Over-Head Lines

The measure of refurbishment in the analyses is seen as the possibility to use the tower-system of an existing OHL and replace the mounted conductors and insulation. The transmission capability of an OHL can be increased in two ways. The voltage level of the circuit can be increased of the maximal current is increased by increasing the ampacity of the single conductors. What is feasible depends strongly on the different situations. An increase of the voltage level requires higher insulation and safety distances and thus is limited by the size of the towers and the width of the corridor. To increase ampacity it is usually necessary to mount conductors with thicker cross-sections that can be utilized with higher currents. This possibility also is limited by the load-carrying limitations of the towers. But also in case of high temperature conductors which do not necessarily increase the weight of a conductor section latter way is limited by thresholds for electro-magnetic emissions an OHL is allowed to emit.

In today’s transmission grid we find AC voltage levels of up to 380kV throughout Europe. For the analysis in task 2.3 it is therefore assumed that all lines can be refurbished with this technology – either by increasing the number of conductors or by switching to high-temperature conductors. For shorter term grid planning (up to ~10years) precise information is available for the OHLs at stake. This means one can decide on a case to case situation what is the best possibility to increase the transmission capacities of existing OHLs. Here also higher voltage levels, which go beyond today’s level of 380kV are an option. Depending on the circumstances it provides advantages to not increase the current to realize an increased transmission capacity but to increase the voltage level. The integration of higher AC voltage level in the 380kV system is connected with an additional investment in new transformers. Yet these extra costs are exceeded by benefits in operation and the lower losses on longer transmission distances. 550kV and 750kV AC connections are already used in different regions of the world and should definitively be considered for the grid development planning on a shorter time horizon. From a European perspective 550kV seems the more suitable alternative. In comparison to 750kV this voltage level requires smaller insulation distances, thus smaller tower systems, which are in the same order of magnitude as 380kV lines. Also the cabling of 550kV holds less technical challenges than with 750kV. Both points lead to lower problems with public acceptance of 550kV. 750kV connections are mainly designed for very long distance OHL connections for bulk power transmission, which is not required in this dimension in the meshed European transmission system.

An alternative towards higher AC voltage levels is given by DC transmission systems. These technologies are mainly designed for long distance transport of high capacities, thus are a considerable option for refurbishment. Voltage levels today in discussion are ±320kV, ±500kV and ±600kV. Also here we find the possibility to use existing transmission corridors and towers systems, thus increasing public acceptance for new transmission lines. Yet the combined operation of AC and DC voltage circuits on one tower system holds operational challenges due to electromagnetic interferences on these hybrid-systems. DC voltage has its advantages for long distances, especially when a high share of cabling is desired. Also with DC transmission the situation is that insulation distance and therefore tower dimensions are increased when rated voltages increase.

An exhaustive discussion of the technology alternatives is made in WP3. Here the technical characteristics of the transmission technologies are described in detail and their suitability for the transmission system is assessed.