METIS Studies

Study S02

Assessing TYNDP 2014 PCI list in power

METIS Studies
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EXECUTIVE SUMMARY

Interconnectors between national electricity networks offer opportunities for the integration of a larger share of variable renewables, i.e. more sustainable energy, more resilience in case of disruption of supply and more opportunities for the electricity market.

The present study assesses the impact of a list of interconnectors (from the ENTSO-E's TYNDP 2014 project list), following the ENTSO-E methodology. For this purpose, the METIS software, developed by Artelys, IAEW, ConGas and Frontier Economics for the DG ENER, was used to measure several criteria related to economic, environmental and security of supply topics. These are the same criteria used by ENTSO-E to perform cost benefit analysis of PCI projects.

The analysis was performed on two 2030 contexts, with different RES shares, based on two ENTSO-E visions in terms of demand and power generation capacities. The benefits brought by the PCIs on the list are assessed by comparing annual power optimal dispatch at hourly time step (on ten years of weather realizations), with the current power transmission network on the one hand, and after adding the studied PCI the other hand. The individual impact of each interconnector is not studied in this report.

The simulations show that the studied PCIs (with 75 GW of additional interconnector capacity) are beneficial on various aspects, especially in a context with high RES share. The PCI list allows to improve security of supply (avoiding 70% to 93% of the loss of load), RES integration (avoiding up to 19 TWh of RES curtailment) and market integration (avoiding about 1 000 hours of price divergence, in average on all European interconnectors). Furthermore, for scenario with high carbon price, the PCIs decrease gross CO_2 emissions by 7%. Finally 2 to 4 billion € per year of fuel costs would be saved, and the increase of European Socio Economic Welfare is assessed at 3 to 5 billion € per year, while the annual cost of implementing the studied PCI list is estimated by ENTSO-E at 2 billion € per year.

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1. Abbreviations and definitions

1.1. Abbreviations

Abbreviation	Definition
ACER	Agency of Co-operation of Energy Regulators
CBA	Cost Benefit Analysis
CCGT	Combined Cycle Gas Turbine
CEER	Council of European Energy Regulators
EENS	Expected Energy not Served
EEPR	European Energy Program for Recovery
ENTSO-E	European Network of Transmission System Operators
GTC	Grid Transfer Capability
KPI	Key Primary Indicator
LOL	Loss of Load
LOLE	Loss of Load Expectation
NRA	National Regulatory Authority
NTC	Net Transfer Capacity
OCGT	Open Cycle Gas Turbine
PCI	Project of Common Interest
RES	Renewable Energy System
SEW	Socio Economic Welfare
TSO	Transmission System Operator
TYNDP	Ten Year Network Development Plan

Table 1- Table of abbreviations

1.2. Definitions

Concept	Definition
Congestion rent	The price difference times the flow over a network constraint.
Consumer surplus	The difference between the consumers' willingness to pay for a commodity and the actual price paid by them.
Expected Energy not Served / Loss of load	Total volume of energy which was demanded but not supplied during a year.
Loss of Load Expectation	The expected number of hours per year for which the available generation capacity is insufficient to cover the demand.
Producer surplus	Difference between the generation revenues and the generation costs.
RES curtailment	RES generation spillage.
Socio Economic Welfare	Economic indicator used by ENTSO-E to measure the benefit of a project.

Table 2 - Table of definitions

2. Introduction and background

2.1. Foreword

The present document has been prepared by Artelys in response to the Terms of Reference included under ENER/C2/2014-639[1]. Readers should note that the report presents the views of the Consultant, which do not necessarily coincide with those of the Commission.

2.2. Introduction

The European energy policy is increasingly oriented towards an Energy Union in which interconnectors between bidding zones are of primary concern. As a matter of fact, an interconnected grid will increase Europe’s security and reliability of supply and will allow more affordable prices due to enhanced competition (which leads to price convergence when there is no congestion). It will also help ensuring a sustainable development (by integrating RES to the market and by reducing the need for investments in peak generation capacity).
To help create an integrated EU energy market, the European Commission can select interconnector projects as “projects of common interest”. These projects should:

- have a significant impact on the energy markets of at least two EU countries such as by contributing to the integration of their networks;
- increase competition in energy markets by offering alternatives to consumers;
- enhance the EU's security of supply by allowing countries to receive energy from a greater number of sources;
- contribute towards the EU's energy and climate goals, for example by facilitating the integration of renewable energy into the grid.[2]

These projects may benefit from accelerated licensing procedures, improved regulatory conditions, and access to financial support.
The general aim of this study is to assess, using METIS, the effect of power network PCIs (from the ENTSO-E's TYNDP 2014 project list) in terms of security of supply, sustainability, economy and market integration. The studied contexts are the ones of 2030 ENTSO-E Visions - V1 (“slow progress”) and V3 (“green transition”) - in terms of demand and power generation capacities. Simulations of annual power optimal dispatches at hourly time step on ten years of weather realizations are performed, and results obtained with the current power transmission network are compared to the ones obtained when the current network is increased according to the PCI list.

[1] http://ec.europa.eu/dgs/energy/tenders/doc/2014/2014s_152_272370_specifications.pdf

[2] This definition of PCI comes from http://ec.europa.eu/energy/en/topics/infrastructure/projects-common-interest.

2.3. Modelling setup

The study has been performed with the use of METIS software using the following configuration.

Metis Configuration	
METIS VERSION	METIS v1.1
Modules	Power system
Scenarios	ENTSO-E TYNDP 2014 – Visions 1 and 3 - Year 2030 With current (2014) NTC values of interconnections
Time granularity	Hourly (8760 consecutive time-steps per year)
Asset modelling	Fleet level at country granularity
Uncertainty modelling	10 years of weather data

Table 3: METIS Configuration used for study S02

3. LITERATURE SURVEY

3.1. COMMISSION INITIATIVES FOR AN INTEGRATED MARKET

3.2. ELECTRICITY INTERCONNECTION TARGET FOR 2020

Achieving the interconnection of at least 10% of the installed electricity production capacity by 2020 (and 15% by 2030[3]) is part and parcel of the European englobing energy strategy. By 2020, each member state should have in place a power transmission network that allows at least 10% of their installed electricity generation to be transported across its borders. The European Council also mandated the Commission to bear in mind the broad goal of a 15% target by 2030. Currently, 12 member states, particularly those on the fringe of the EU remain below the 10% target.

3.2.1. EUROPEAN ENERGY PROGRAM FOR RECOVERY

The EEPR belongs to the economic recovery plan implemented to remedy the effects of the 2008 financial and energy crisis. It aims at identifying the most relevant interconnector projects across the EU and mobilizing financial resources. Since 2009, when it took effect, 904 million Euros have been spent on 12 electricity interconnector projects. The selected projects focus on clearing bottlenecks and integrating isolated countries such as the Iberian Peninsula or Ireland.

3.2.2. INTRODUCTION OF PROJECT OF COMMON INTEREST LIST

The first PCI list was adopted in 2013 and was composed of 248 projects from which 52 were devoted to electricity interconnectors. It is a flexible list that is expected to be updated every two years. The first criteria for a PCI is to be part of the latest TYNDP (Ten-Year Network Development Plan) for electricity developed by ENTSO-E, which offers results of cost benefit analysis (CBA) performed on all presented projects (reference can be made to 3.3.2 for more details on the CBA).
The PCIs benefit from accelerated granting procedures, robust regulatory conditions, lower administrative costs, increased visibility for investors, better public participation and finally, possible access to financial support.

3.3. REVIEW OF THE PCI PROCESS

3.3.1. PROCESS OF THE IDENTIFICATION OF PCIS

The identification of PCIs is based on a regional approach and is mainly carried out by Regional Groups[4] as follows. Project promoters submit project proposals for which the status of PCI is sought to Regional Groups for assessment. Then, the national regulatory authorities advise the Regional Groups on the feasibility of the proposed projects. After

[3] http://www.consilium.europa.eu/en/policies/climate-change/2030-climate-and-energy-framework/

[4] Four Regional Groups are defined for electricity: Northern Seas Offshore Grid, Baltic Energy Market interconnector Plan, North-South interconnectors in West-Europe and North-South interconnectors in Central and South Eastern Europe. These regional groups gather representatives from national regulatory authorities, transmission system operators, project promoters and other relevant stakeholders such as representatives of the European Commission and the European Agency for the Cooperation of Energy Regulators (ACER).

that, the Regional Groups evaluate the projects against the general and specific criteria as defined in the CBA by ENTSO-E and compile a regional list of PCI. Lastly, it is incumbent upon the EC to adopt a union-wide list of PCIs, with the advice of the Agency.

Figure 1 - The PCI identification process

3.3.2. Cost Benefit Analysis

3.3.2.1. Indicators of the CBA

The quantitative assessment of benefits that the implementation of a project would bring is carried out by the CBA developed by ENTSO-E. The last version was adopted by the Commission early 2015. It does use 9 indicators explained below.

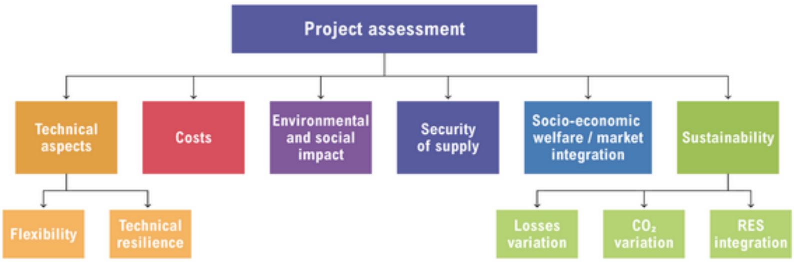

Figure 2 - The indicators of CBA (Source ENTSO-E)

Criterion	Meaning of the criterion	Measure of the criterion
System flexibility	Ability to be adequate in different future development paths or scenarios	Qualitative : Scoring 3 Key Performance Indicators (++/+/0)
Technical resilience	Ability to withstand extreme system conditions	Qualitative : Scoring 3 Key Performance Indicators (++/+/0)
Costs	Total project expenditures	Price consistency with project characteristics (e.g. km of lines)
Environmental and social impact	Environmental impact on protected areas Social impact on urbanized areas	Mostly qualitative, except for : Number of km a line or cable may run through environmentally or socially sensitive areas
Security of supply	Ability to provide an adequate and secure supply in ordinary conditions	Market-based approach: LOLE (hours/year) Network-based approach: LOL (MWh/year)[5]
Socio-economic welfare, market integration	Ability to reduce congestion and increase Grid Transfer Capacity between two bidding areas	Generation cost approach: Reduction in total generation costs associated with the GTC variation created by the project (in €/year) Total surplus approach: Adding the consumer and producer surplus and the congestion rents for all price

[5] See Study S4 for more details about VoLL, LOLE and LOL (EENS).

		areas. The benefit is the variation of this total surplus (in €/year).
Losses variation or energy efficiency	Evolution of thermal losses in the power system	Variation in losses with and without the project (in MWh)
CO_2 variation	Evolution of gross CO_2 emissions in the power system	Variation in the volume of gross CO_2 emissions
RES Integration	Ability to allow the connection of new RES plants Ability to increase the GTC between an area having an excess of RES generation and other areas.	Connected RES (MW): Additional amount of RES generation Avoided RES spillage (MWh): Reduction of renewable generation curtailment

Table 4 - Description of the criterions of the CBA

3.3.2.2. Scenarios

For each project, the analysis of costs and benefits is made for at least two scenarios of the future. It takes into account economic key parameters (economic growth, fuel prices, CO_2 prices…), a generation portfolio (power installation forecast, type of generation…), a demand forecast (rate of growth, load management, sensitivity to temperature…) and exchange patterns with the zones outside the region considered. The 2014 version of the TYNDP covers four scenarios for 2030. Primary analysis of PCIs should be based on these scenarios. Then, secondary analysis could be made on longer-term scenarios (in the ENTSO-E 2050 report for e.g.).

4. METHODOLOGY

4.1. METIS MODEL

The METIS model is complementary to long-term energy system models (like PRIMES from NTUA and POTEnCIA from JRC), by providing a more detailed analysis of the impact of (higher shares of) variable renewables or infrastructure questions at an hourly level. Installed capacities are therefore inputs for METIS and are based on ENTSO-E 2030 v1 and v3 scenarios for this study.
More specifically, METIS is a modular energy modelling software covering with high granularity (geographical, time) the whole European energy system for electricity, gas and heat. Simulations adopt a MS-level spatial granularity and an hourly temporal resolution (8760 consecutive time-steps per year). Uncertainties regarding demand and RES power generation are captured thanks to 50 years of temperature scenarios, which influence the demand (through a thermal gradient), and 10 years of wind and irradiance, which are translated into PV and wind generation hourly time series. The historical spatial and temporal correlations between temperature, wind and irradiance are preserved.
Generation plans are simulated using an optimal dispatch at an hourly time-step, taking into account the contributions and constraints of storage along with interconnectors (under NTC constraints) between countries. In this study, thermal units are modeled at fleet level while reserve constraints are not modeled[6]. The merit order is based on fuel and CO2 prices; specific country level constraints (for instance maximum annual use of coal units) or market distortions are not included within the model.

[6] Refined models of thermal unit technical constraints (start-up costs, minimum stable generation, min off-time, reserve procurement…) have been added more recently in METIS.

4.2. Simulation process

Simulations of optimal power dispatch at an hourly time-step over ten years of weather realizations are performed on two different 2030 contexts (corresponding to ENTSO-E visions "slow progress" and "green transition"). For each 2030 context, the simulation results are compared under two different network hypothesis[7]: first, the NTC values of the current network; second, the NTC values of the current network added with the NTC values of the studied PCI list (Figure 3).
The metrics used to compare the different situations are also based on ENTSO-E's (loss of load volume, socio-economic welfare, generation costs, interconnector congestion, gross CO2 emissions and RES curtailment). As the main topic of the study is the PCI impact assessment, most of the results are presented as differences between two contexts: with and without the PCI list.

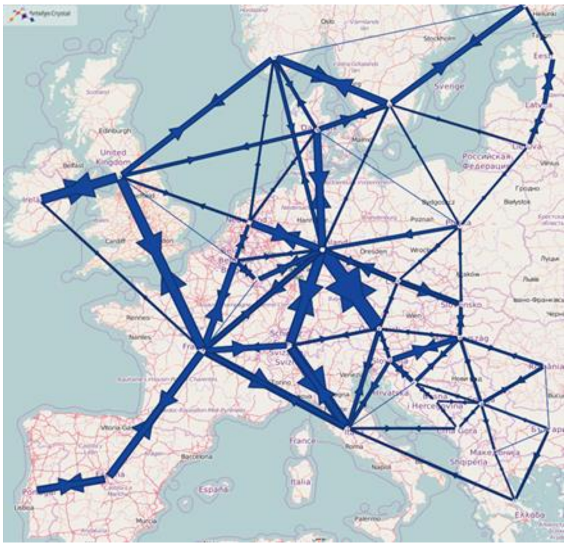

Figure 3 - Current network added with the NTC values of the studied PCI list

4.3. Criteria used for impact assessment

Table 5 summarizes the METIS KPIs helping measure the criteria used by ENTOS-E to perform a Cost Benefit Analysis.[8]

ENTSO-E Criterion	Measure of the criterion: METIS KPI
Security of supply	LOLE (hours/year) and LOL (MWh/year)
Socio-economic welfare	Generation cost approach: Reduction in total generation costs associated with the GTC variation created by the project (in €/year)
	Total surplus approach: Adding the consumer and producer surplus and the congestion rents for all price areas. The benefit is the variation of this total surplus (in €/year).
Market integration	Variation in the number of hours of marginal costs convergence
CO2 variation	Variation in the volume of gross CO2 emissions
RES Integration	Reduction of renewable generation curtailment (MWh)

Table 5 - ENTSO-E criteria implemented in METIS

[7] In order to adopt a methodology similar to the ENTSO-E approach, which, for each PCI, compares the impact of the full PCI list to the impact of the same list without the considered PCI.

[8] A METIS quick user guide precisely describes how to use METIS to perform an impact assessment.

5. PCI IMPACT ASSESSMENT

5.1. PCIS INCREASE SECURITY OF SUPPLY

Implementing the list of PCIs[9] would result in a European-wide decrease of Loss of Load, all the more true in a context of high RES rate such as the 2030 Vision 3 from ENTSO-E (V3: "green transition", see Appendix 7.1.2 for further details). In fact, comparison of the results of annual optimal power dispatches (simulated at hourly time step on ten years of weather data) performed with the current network on the one hand and with the current network increased with PCIs on the other hand, shows that 222 GWh of Loss of Load would be avoided in Europe globally under ENTSO-E's 2030 Vision 1 (V1: "slow progress" vision) and 602 GWh under Vision 3 (see Table 6).

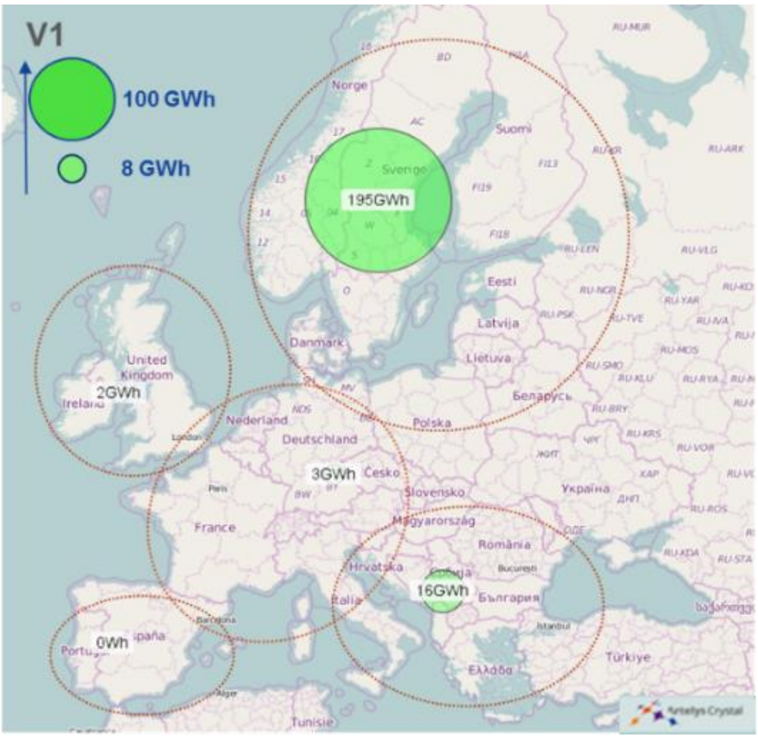

Figure 4 - Avoided Loss of Load due to PCIs by region (GWh)

	LOL without PCI (GWh)	LOL with PCI (GWh)	LOL decrease (%)
2030 V1	233	17	-93%
2030 V3	865	263	-70%

Table 6 - European loss of load decrease due to PCIs

The impact of PCIs is particularly significant in northern regions, as shown by Table 7.

[9] Not all PCIs are considered for this study; see Appendix 7.1.1 for more details.

	2030 V1		2030 V3	
	No PCI	With PCI	No PCI	With PCI
North	0.049	0.001	0.099	0.004
South	0.004	0.002	0.006	0.002
Center	0	0	0.018	0.011
Iberia	0	0	0	0
UK	0.001	0	0.004	0

Table 7 - Part of unsatisfied demand by zone[10] (%)

5.2. PCI IMPACT ON SUSTAINABILITY

5.2.1. PCIs SUPPORT RES INTEGRATION

PCIs would enable the integration of an increased share of energy coming from renewable sources. The reinforced transmission network allows to transport energy generated by RES (which otherwise would have been curtailed) from zones with a RES production surplus towards zones where thermal power generation is more prominent.

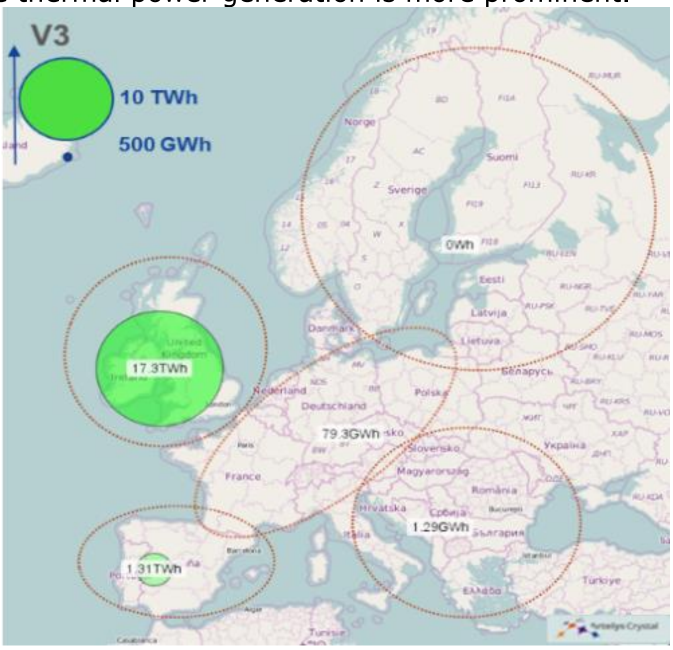

Figure 5 - Avoided RES curtailment due to PCIs by zone (TWh)

Hence, the European volume of curtailment decreases by 83% for V1 and 60% for V3 (Table 8). As depicted by Figure 5, PCIs are the most beneficial to regions which used to be isolated such as the UK or the Iberian Peninsula.

	No PCI	With PCI	Curtailment decrease (%)
2030 V1	0.78	0.13	-83%
2030 V3	31.3	12.7	- 60%

Table 8 - European volumes of Curtailment (TWh)

[10] The description of zones is depicted in Appendix 7.4.

5.2.2. PCI IMPACT ON GROSS CO_2 EMISSIONS DEPENDS ON CO_2 PRICE

Network reinforcement leads to an optimization[11] of the European power generation dispatch insofar as interconnectors enable to exchange electricity from baseload sources instead of using more expensive local power plants.
However, reducing generation costs with interconnectors does not imply that gross CO_2 emissions would necessarily drop. The impact on gross CO_2 emissions depends on the merit order implied by fuel and CO_2 prices, associated with the considered scenario. Table 9 presents variable costs (including CO_2 emission rates) listed by technology and scenario.

Fleet	Gross CO_2 emissions (t/MWhe)	Variable costs including CO_2 (€/MWh)	
		2030 V1	2030 V3
Oil	0,7	186	182
OCGT	0,5	112	123
CCGT	0,3	66	73
Coal	0,8	55	95
Lignite	1,1	40	108

Table 9 - Variable costs by fleet

Under V3 assumptions, carbon pricing is set in such a way that electricity production based on gas (with CCGT) is preferred to coal. Consequently, in the V3 context, PCIs induce a global decrease in hard coal generation of 30 TWh, which brings about 31 Mt gross CO_2 emission savings.
On the contrary, CO_2 price in the V1 context implies that coal and lignite plants are preferred to gas. That is why, when adding PCIs in the V1 scenario, hard coal generation is increased by 28 TWh at the European level leading to a rise of 7 Mt in gross CO_2 emissions.

	No PCI	With PCI	Gross CO_2 emissions variation (%)
2030 V1	737	744	1%
2030 V3	432	401	- 7%

Table 10 - European Volume of gross CO2 emissions (Mt)

Figure 6 shows the variations in gross CO_2 emissions when implementing PCIs. Under V1 assumptions, the impact on central and northern regions is negative[12] whereas it is globally positive for the "green scenario" V3[13].

[11] The optimization is based on economic criteria (see section 2.2.5 on power generation costs).

[12] Generation from coal and lignite in North and center is used to avoid gas generation in other regions.

[13] Except for UK: Generation from coal in UK is exported to North zone, to avoid peak generation.

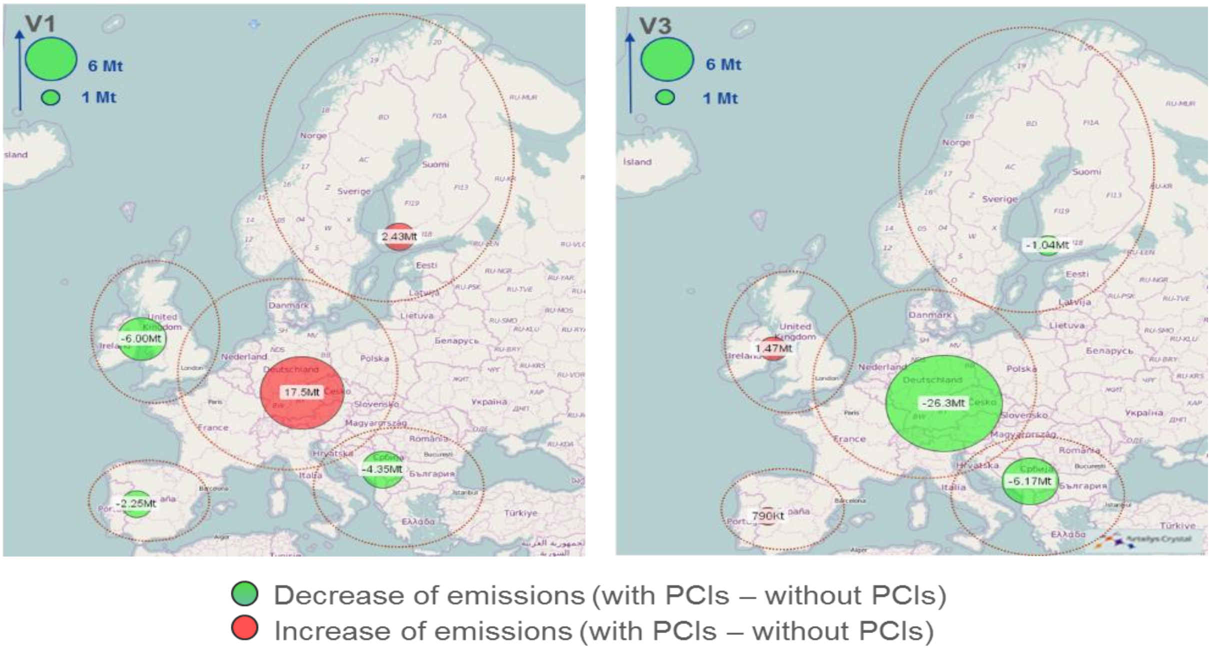

Figure 6 - Variations in gross CO_2 emissions by regions (Mt)

5.3. PCIs BENEFIT TO MARKET INTEGRATION

The *number of price divergence hours* is an adapted indicator to assess PCI impact on market integration. It consists in the number of hours for which the marginal costs on both sides of the given interconnector are different. The marginal costs on both sides of a border are actually similar as long as the interconnectors is not saturated. Table 11 presents the number of prices divergence hours averaged on all European interconnectors. It points out that the network reinforcement allows to improve market integration by reducing the European average number of price divergence hours.

Figure 7 also highlights that PCIs reduce the disparity in electricity prices across the European area. In fact, annual averaged marginal costs would range from 47€/MWh to 67€/MWh in southern and central countries and from 38 €/MWh to 74 €/MWh in northern countries without the additional capacities from the PCI list. Hence, the amplitude of price variation would have been respectively equal to 20 €/MWh and 36 €/MWh for these areas. Implementing PCIs would reduce the amplitude of variation to 4 €/MWh for southern and central countries and to 3 €/MWh for northern countries.

	No PCI	With PCI	Hours decrease (%)
2030 V1	2 117	998	-53%
2030 V3	3 509	2 585	-26%

Table 11 - European average number of price divergence hours (h)

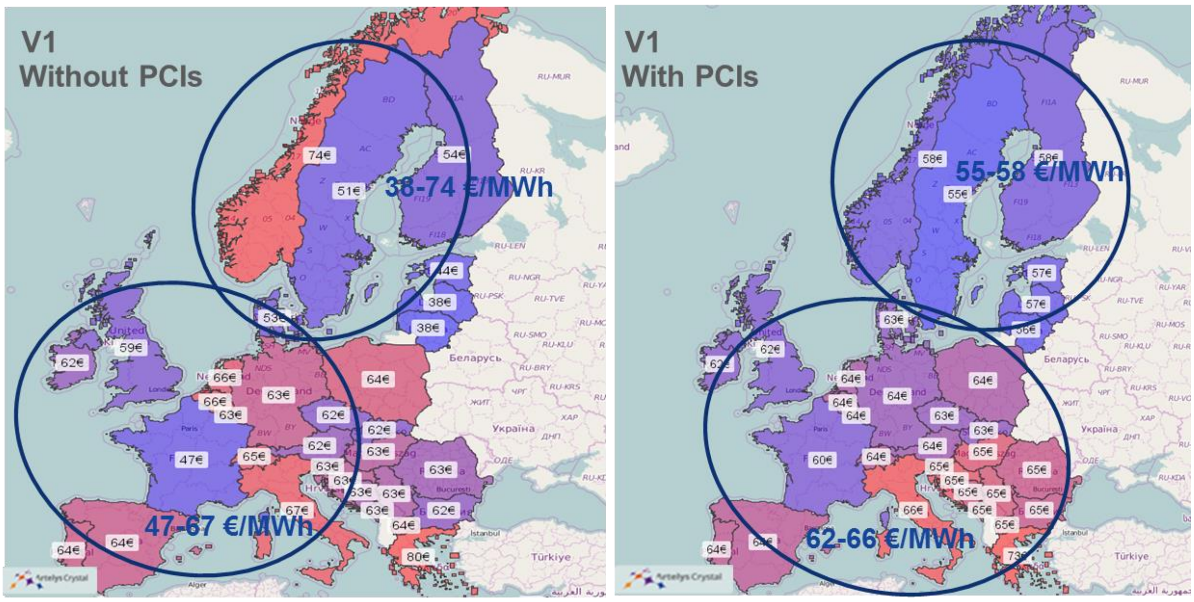

Figure 7 - Impact of PCIs on annual averaged marginal costs by country (€/MWh)[14]

5.4. Distribution of the PCI impact between countries

Since the disparities between marginal costs are reduced, the impact of PCIs on a given country is not necessarily positive.

- Countries that used to rely significantly on peak load generation benefit from the reinforced network to the extent that they import electricity generated by baseload sources. Marginal costs decrease for these countries.
  For instance, considering a summer week, Italy reduces its generation from gas (indicated by the purple area in Figure 8). It is partially replaced by French imports (grey areas) when adding PCIs, and Italy's marginal cost decreases.

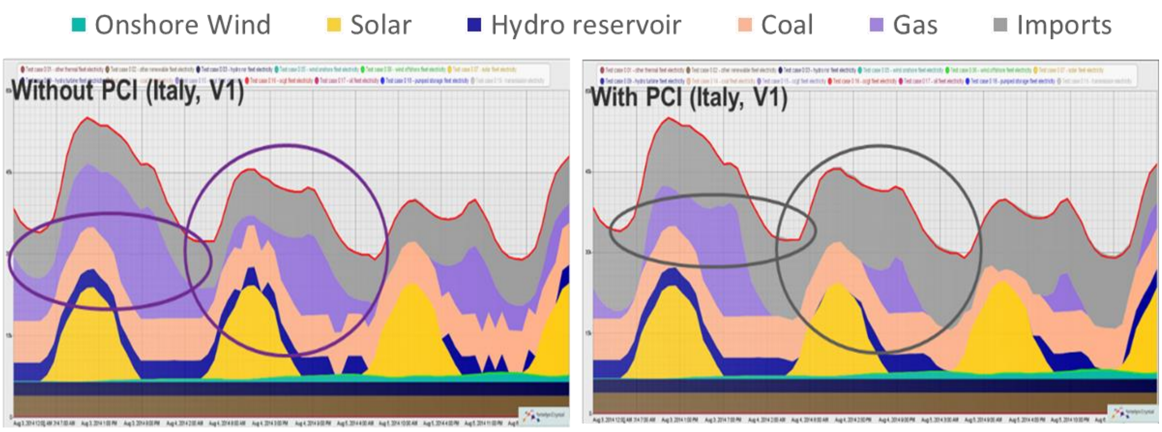

Figure 8 - Cumulative generation chart for Italy at first week of August

- While total costs are reduced at the European level, prices can increase for some countries, like France[15]. Without PCI, France only uses renewable and nuclear energy (ochre area in Figure 9) during the 3 summer days illustrated below. With increased interconnector capacity, prices converge in Germany, France and Italy.

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[14] The figure represented the PCI impact on marginal cost for V3 is presented in Appendix 7.2.4 (Figure 19).

[15] The optimization is performed under an economic criterion, at European scale.

This leads to higher exports from France but it also leads to the French marginal cost being set by German coal units.

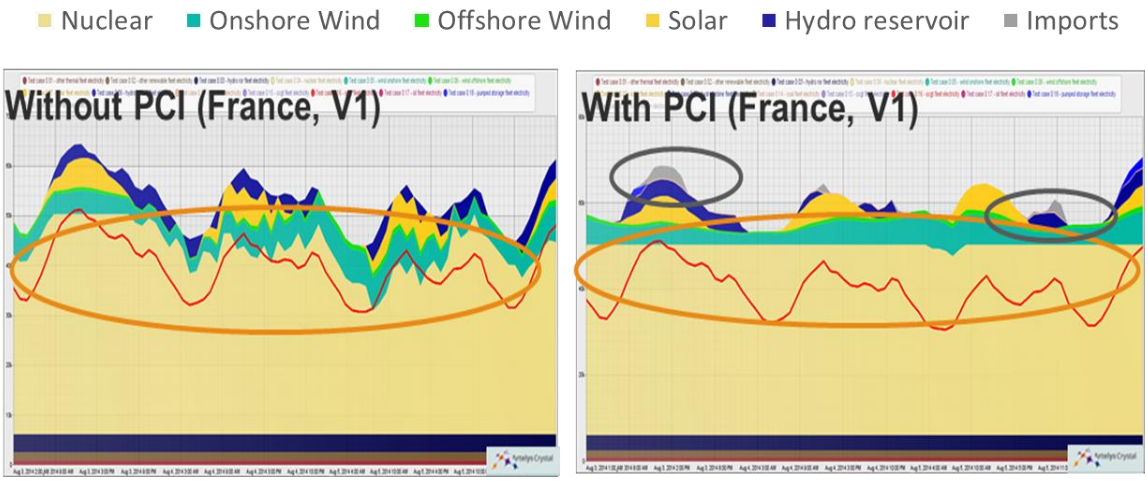

Figure 9 - Cumulative generation chart for France during three days in summer

The German exports to France are generated by coal plants (the orange area in Figure 10). Hence, French marginal cost increases from the nuclear variable cost to the coal one.

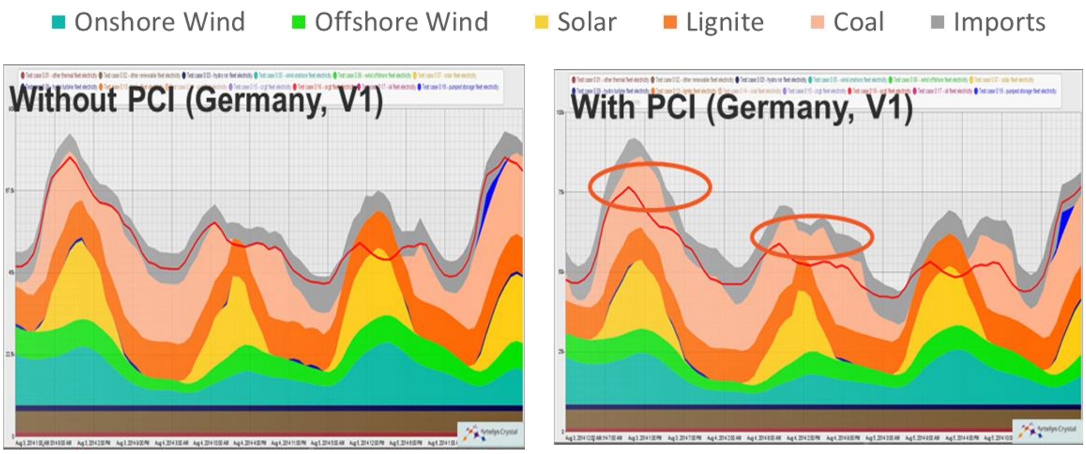

Figure 10 - Cumulative generation chart for Germany at first week of August

Consequently, marginal costs increase for countries sharing their base load and decrease for countries which benefit from more net imports. Thus, the impact on the Social Economic Welfare[16] for a given country does vary.
However, the impact on social welfare is positive at the European level, as shown in Table 12. Also, it must be noted that the annual investment cost of PCIs varies from 1.8 to 2.2 billion €/year according to the TYNDP (see Appendix 7.1.1), and that economic impact of PCI is globally positive.

[16] Social Economic Welfare: Economic indicator used by ENTSO-E to globally quantify the economic benefits for the whole society. More details about the link between the SEW and marginal costs can be found in Appendix 7.2.5 and 7.2.6.

	Social welfare increase (in billion €/year)
2030 V1	3.0
2030 V3	5.5

Table 12 - European social welfare increase

5.5. PCIs GLOBALLY REDUCE POWER GENERATION COSTS

European power generation costs are globally reduced by 1.8 billion € for V1 and 3.7 billion € for V3 thanks to the network reinforcement induced by the PCIs (Table 13).
Average marginal costs are also reduced in most countries as illustrated by Figure 7.

	No PCI	With PCI	Generation cost decrease (%)
2030 V1	64	62	3%
2030 V3	91	87	4%

Table 13 - European sum of power generation costs (in billion €/year)

6. CONCLUSION

In order to assess the impact of the PCI interconnector list, the key performance indicators currently used by ENTSO-E to perform cost benefit analysis were implemented in the METIS software. These indicators allow to measure several criteria related to economic, environmental and security of supply topics.
At the European scale, implementing the PCI list would have a positive effect from several points of view, and to a greater extent when the 'Green Transition' scenario is considered. By increasing transmission capacities between bidding zones (by 46%, from 164 GW to 239 GW), the projects would enable to reduce loss of load by up to 600 GWh (70% of the loss of load without PCI, for the highest RES studied scenario V3) and thus to strengthen the European security of supply. They would also act as a catalyst for increased sustainability in two ways. First, they would significantly reduce RES curtailment (up to 19 TWh, which represents 60% of RES curtailment for V3). Second, when carbon pricing is set at sufficiently high levels, reinforcements would lead to gross CO_2 emission savings (31 Mt). Furthermore, they would increase market integration by relieving congestions and thus reducing price divergence between zones. Finally, they would increase European Socio Economic Welfare by 3 to 5.5 Bn€/y depending on the considered 2030 scenario, with 1.8 to 3.7 Bn€/y of fuel cost savings. The cost of the PCI list is assessed by ENTSO-E at 2 Bn€ per year.

7. Appendix

7.1. Scope of the study

7.1.1. PCI studied

The studied interconnector projects are the 35 candidate projects (Figure 11) from ENTSO-E's PCI list. The studied projects have been gathered in 7 new interconnectors and 17 interconnector reinforcements[17].

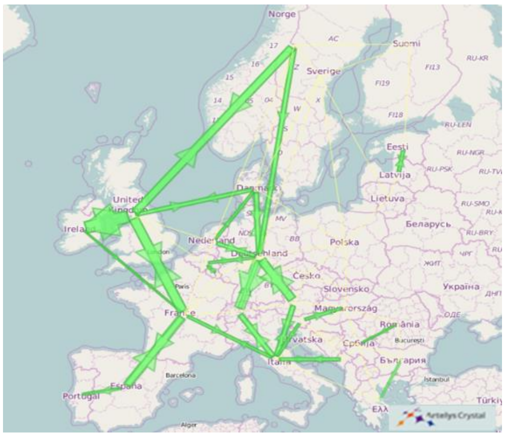

Figure 11 - Studied PCI map

Two power networks are considered for the study. The first one corresponds to the current power network (without the PCI projects) and current NTC values of interconnectors are considered. The second one corresponds to the sum of the current interconnectors and of the studied PCI. The associated NTC values of all PCI projects are presented in Table 14.[18]

From	To	NTC (MW)
AT	IT	1450
AT	DE	2900
AT	IT	150
BE	LU	700
BE	DE	1000
BG	GR	648
CH	IT	1000
CH	IT	800
CH	DE	1400
DE	NO	1400
DE	BE	1000
DE	NL	1400
DE	CH	3400

From	To	NTC (MW)
UK	IE	1500
UK	FR	1000
UK	FR	1400
UK	DK	1400
UK	NO	2800
GR	BG	82
HU	SI	765
IE	UK	660
IE	UK	570
IE	FR	700
IE	UK	1900
IE	UK	1500
IT	ME	1000

[17] Some projects of the PCI list involve the same border.

[18] Iceland is not represented, so that its interconnector with UK is not taken into account. Furthermore, the IE/UK interconnector of 660 MW and the UK/BE interconnector are not studied.

From	To	NTC (MW)
DE	DK	400
DE	DK	1000
DE	AT	2900
DE	DK	500
DK	DE	400
DK	DE	720
DK	NL	700
DK	UK	1400
DK	DE	500
EE	LV	450
EE	LV	600
ES	PT	1000
ES	FR	2500
ES	FR	500
FR	IT	1200
FR	UK	1000
FR	UK	1400
FR	ES	2200
FR	IE	700
FR	UK	1000
FR	ES	100
UK	FR	1000

From	To	NTC (MW)
IT	CH	950
IT	SI	700
IT	CH	800
IT	FR	1000
IT	AT	1350
IT	AT	150
LU	BE	700
LV	EE	450
LV	EE	600
ME	IT	1000
UK	IE	580
UK	IE	570
NL	DK	700
NL	DE	1400
NO	UK	2800
NO	DE	1400
PT	ES	400
RO	RS	737
RS	RO	453
SI	HU	1085
SI	IT	800
UK	IE	1900

Table 14 - List of PCI projects considered in this study

7.1.2. Scenarios considered for the analysis

The PCI impact assessment is performed on two different 2030 contexts, corresponding to two different ENTSO-E visions:

- **Scenario 2030 v1:** "The first scenario is Vision 1 [developed by the ENTSO-E in their TYNDP], *Slow progress*. Vision 1 reflects slow progress in energy system development with less favorable economic and financial conditions. Vision 1 fails to meet the EU goals for 2030 […]. Compared to the present days, the consumption and generation mix have evolved by less than in other Visions entailing a lower pressure for more market integration and interconnection capacity"[19]. V1 is the scenario with the lowest RES development, although the main change in installed capacities is the increase of wind and solar, mostly in Germany. Besides, Germany, Belgium and Switzerland are assumed to plan a nuclear phase-out while other countries are expected to build new units. On a European level, the share of RES in the power generation reaches 41% (1 500 TWh) for a demand of 3600 TWh.
- **Scenario 2030 v3:** "The third scenario is Vision 3, *green transition*. Vision 3 reflects an ambitious path towards the 2050 European energy goals, where every

[19] SOURCE: ENTSO-E's 10-year Network development plan.

Member State develop its own effort achieving overall 50% of European load supplied by RES in 2030. Vision 3 meets the EU goals by 2030. However in this Vision, every country tends to secure its own supply independently from the other, resulting probably into an overinvestment in generation assets at European level."[20] This scenario is characterized by a large RES development and a more important decrease in nuclear power capacity, including a phase-out of the Netherlands and a reduction of capacity in France. This scenario is also characterized by high CO2 prices (93 €/ton compared to 31 €/ton in Vision 1), resulting in coal units becoming more expensive than CCGT power plants. On a European level, the share of RES in the power generation reaches 50% (about 2 100 TWh) for a total demand of 4 100 TWh.

The installed capacities and generation mix of both scenarios are illustrated on the figures below. The higher level of demand and the larger share of RES in V3 result in a more important total installed capacity compared to V1. On the generation side, as a consequence of the permutation between coal- and gas-fired power plants in the merit order, coal represents 18% of the generation in Vision 1 and only 1% of the generation in Vision 3. CCGTs produce 10% in Vision 1 and 24% in Vision 3.

[20] SOURCE: ENTSO-E's 10-year Network development plan.

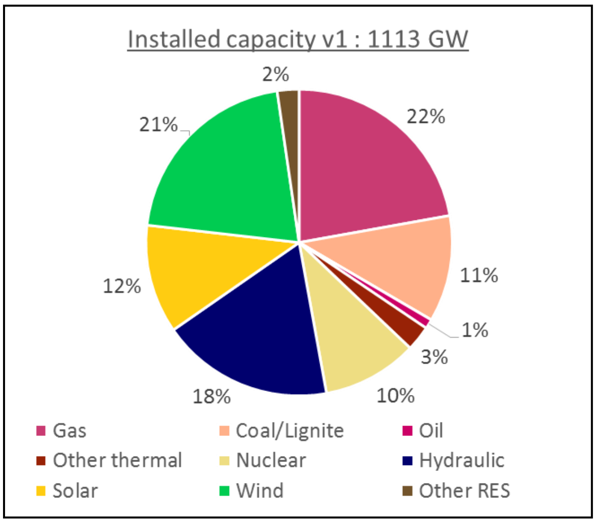

Figure 12 : Installed capacity for scenario 2030 v1

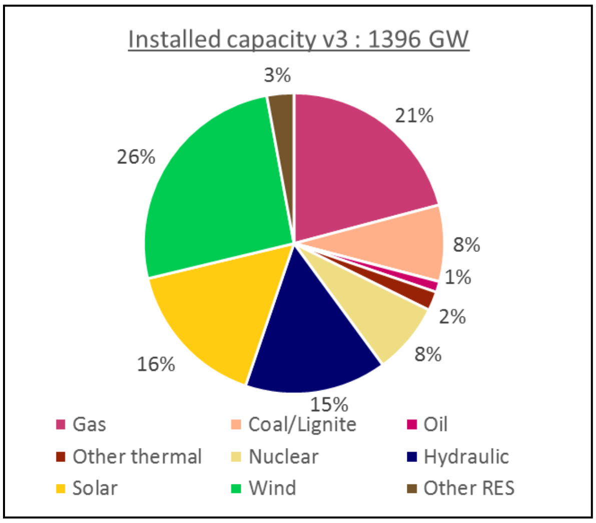

Figure 13 : Installed capacity for scenario 2030 v3

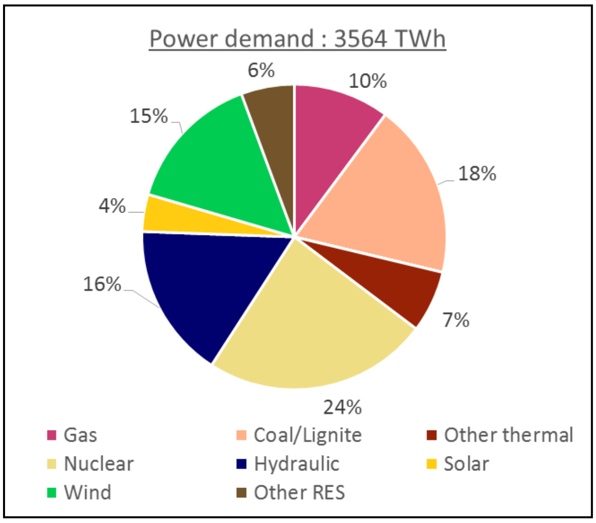

Figure 14 : Generation mix for scenario 2030 v1, averaged on 10 weather data realizations

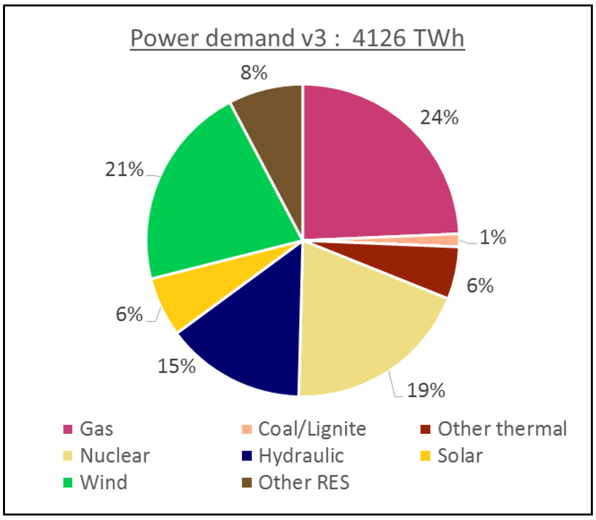

Figure 15 : Generation mix for scenario 2030 v3, averaged on 10 weather data realizations

Installed capacities of power generation assets are also the ENTSO-E ones. In order to adopt a methodology similar to ENTSO-E's approach[21], results of simulations of optimal power dispatch are compared in two network frameworks: the NTC values of the current network[22] and NTC values of the current network added with the NTC values of the studied PCI list.

[21] Which, for each PCI, compares impact of the full PCI list to impact of the same list without the PCI.

[22] The reconstitution of NTC values is presented in 7.3.

7.2. Detail results of the study

7.2.1. Avoided loss of load

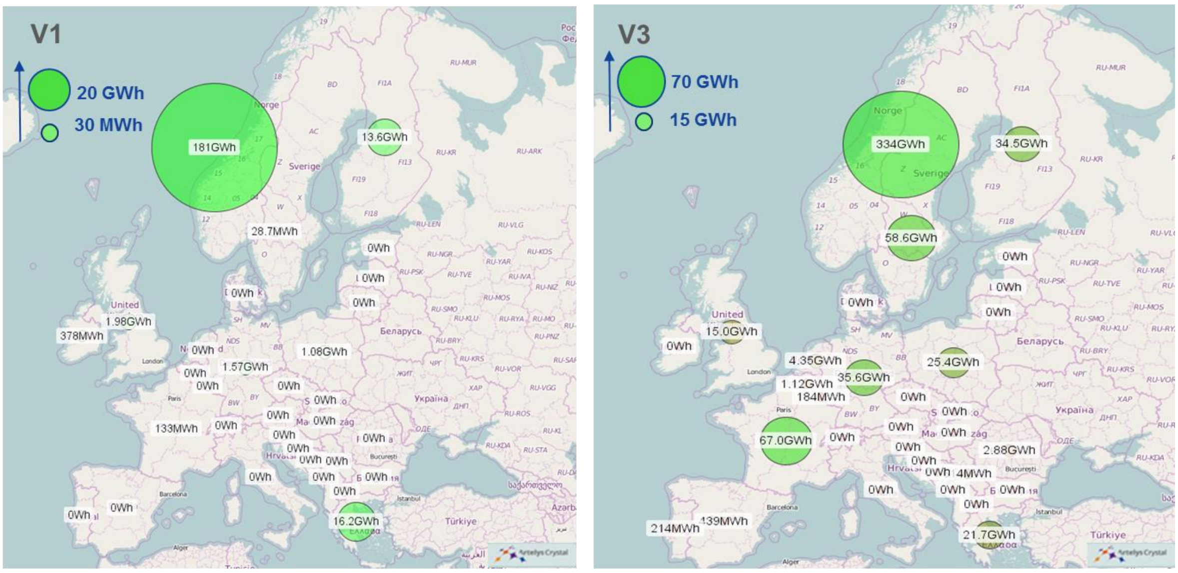

Figure 16 - Volumes of avoided Loss of Load by country

	2030 V1		2030 V3	
	Without PCI	With PCI	Without PCI	With PCI
AT	0,00	0,00	0,00	0,00
BA	0,00	0,00	0,00	0,00
BE	0,00	0,00	1,12	0,00
BG	0,00	0,00	0,00	0,00
CH	0,00	0,00	0,00	0,00
CZ	0,00	0,00	0,00	0,00
DE	1,57	0,00	35,60	0,00
DK	0,00	0,00	0,00	0,00
EE	0,00	0,00	0,00	0,00
ES	0,00	0,00	0,44	0,00
FI	16,05	2,41	51,76	17,30
FR	0,13	0,00	67,80	0,81
GR	28,03	11,85	39,70	17,95
HR	0,00	0,00	0,00	0,00
HU	0,00	0,00	0,00	0,00
IE	0,38	0,00	0,00	0,00
IT	0,00	0,00	0,00	0,00
LT	0,00	0,00	0,00	0,00
LU	0,00	0,00	0,18	0,00
LV	0,00	0,00	0,00	0,00
ME	0,00	0,00	0,00	0,00
MK	0,00	0,00	0,00	0,00
NL	0,00	0,00	4,60	0,25
NO	180,89	0,00	334,22	0,00
PL	3,81	2,73	247,72	222,31
PT	0,00	0,00	0,21	0,00
RO	0,00	0,00	4,02	1,14
RS	0,00	0,00	0,61	0,00
SE	0,03	0,00	60,10	1,48
SI	0,00	0,00	0,00	0,00
SK	0,00	0,00	0,00	0,00
UK	1,98	0,00	16,57	1,54

Table 15 - Loss of load by country (in GWh)

7.2.2. AVOIDED CURTAILMENT

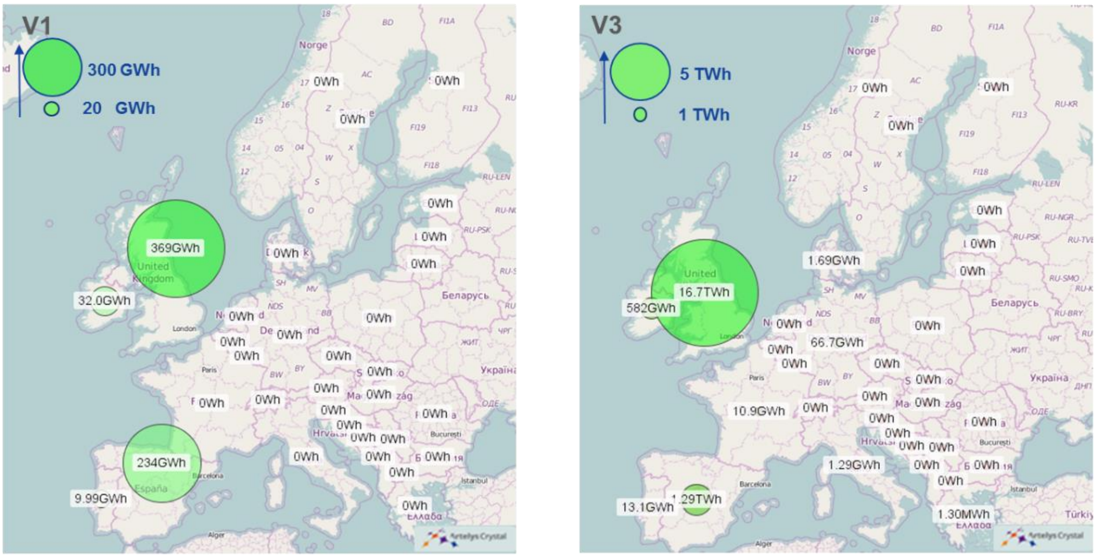

Figure 17 - Avoided curtailed energy by country (in GWh)

	2030 V1		2030 V3	
	Without PCI	With PCI	Without PCI	With PCI
AT	0,00	0,00	0,00	0,00
BA	0,00	0,00	0,00	0,00
BE	0,00	0,00	0,00	0,00
BG	0,00	0,00	0,00	0,00
CH	0,00	0,00	0,00	0,00
CZ	0,00	0,00	0,00	0,00
DE	0,00	0,00	84,83	18,12
DK	0,00	0,00	1,87	0,19
EE	0,00	0,00	0,00	0,00
ES	35,69	12,33	3230,42	1935,96
FI	0,00	0,00	0,00	0,00
FR	0,00	0,00	20,27	9,34
GR	0,00	0,00	0,00	0,00
HR	0,00	0,00	0,00	0,00
HU	0,00	0,00	0,00	0,00
IE	3,21	0,02	832,19	250,65
IT	0,00	0,00	1,29	0,00
LT	0,00	0,00	0,00	0,00
LU	0,00	0,00	0,00	0,00
LV	0,00	0,00	0,00	0,00
ME	0,00	0,00	0,00	0,00
MK	0,00	0,00	0,00	0,00
NL	0,00	0,00	0,00	0,00
NO	0,00	0,00	0,00	0,00
PL	0,00	0,00	0,00	0,00
PT	1,62	0,62	46,81	33,67
RO	0,00	0,00	0,00	0,00
RS	0,00	0,00	0,00	0,00
SE	0,00	0,00	0,00	0,00
SI	0,00	0,00	0,00	0,00
SK	0,00	0,00	0,00	0,00
UK	369,35	0,07	27099,41	10417,49

Table 16 - Curtailment by country (in GWh)

7.2.3. GROSS CO_2 EMISSIONS EVOLUTION

	2030 V1		2030 V3	
	Without PCI	With PCI	Without PCI	With PCI
AT	7,48	8,06	8,77	7,85
BA	13,14	13,14	3,32	2,43
BE	8,04	7,30	14,49	14,43
BG	29,35	30,03	5,58	5,32
CH	0,24	0,22	1,66	1,49
CZ	34,17	34,47	9,33	7,84
DE	239,96	251,38	86,08	68,09
DK	9,89	13,36	5,73	4,57
EE	0,32	0,25	0,86	0,75
ES	33,99	31,83	24,89	25,73
FI	5,27	7,84	3,36	2,48
FR	3,64	4,02	9,97	8,86
GR	26,78	26,21	18,66	18,33
HR	6,38	7,32	4,89	4,39
HU	5,25	5,37	9,86	9,34
IE	6,39	5,50	3,76	3,29
IT	99,68	93,76	84,68	86,47
LT	0,24	0,27	1,50	1,52
LU	0,25	0,26	0,67	0,63
LV	0,36	0,38	0,75	0,79
ME	5,12	5,12	1,95	0,14
MK	3,59	3,63	1,97	1,84
NL	34,31	33,57	29,75	27,98
NO	0,20	0,12	0,47	0,41
PL	63,32	65,97	51,93	51,19
PT	5,41	5,33	5,59	5,55
RO	15,45	15,91	12,23	11,82
RS	37,51	37,53	12,27	8,62
SE	0,04	0,00	0,07	0,02
SI	4,36	4,38	1,70	1,52
SK	1,67	1,69	1,31	1,13
UK	34,93	29,83	13,94	15,87

Table 17 – Gross CO_2 emissions by country (in Mt)

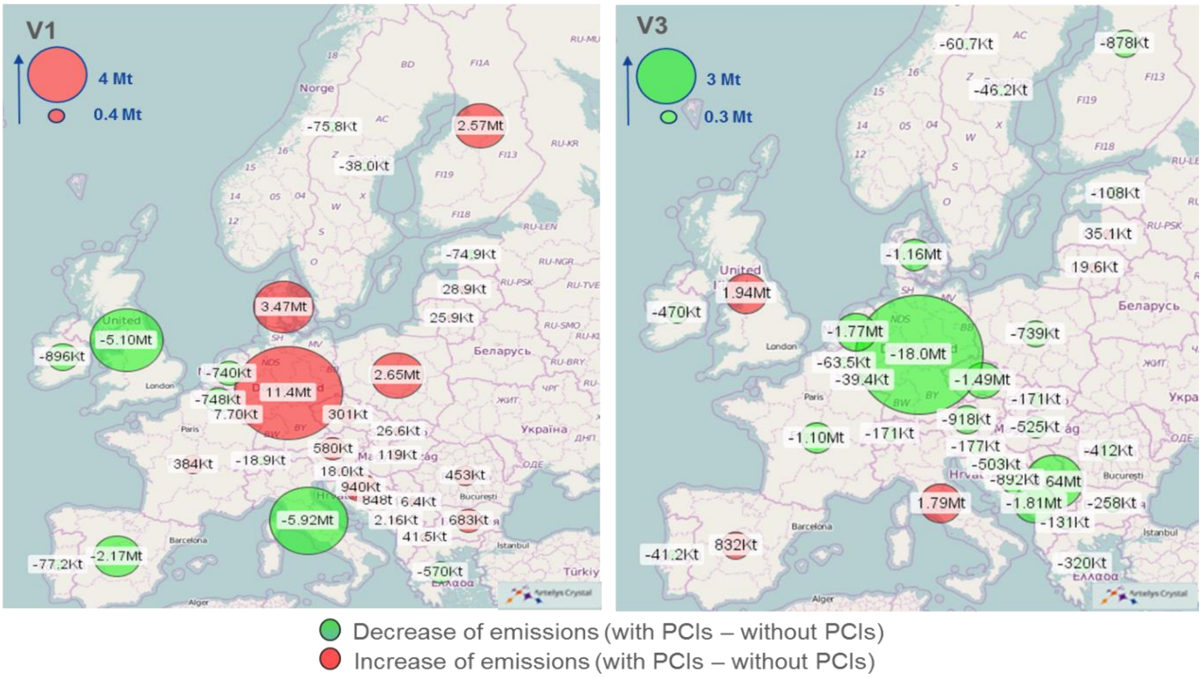

Figure 18 - Variations in gross CO_2 emissions by country (in Mt)

7.2.4. MARKET INTEGRATION

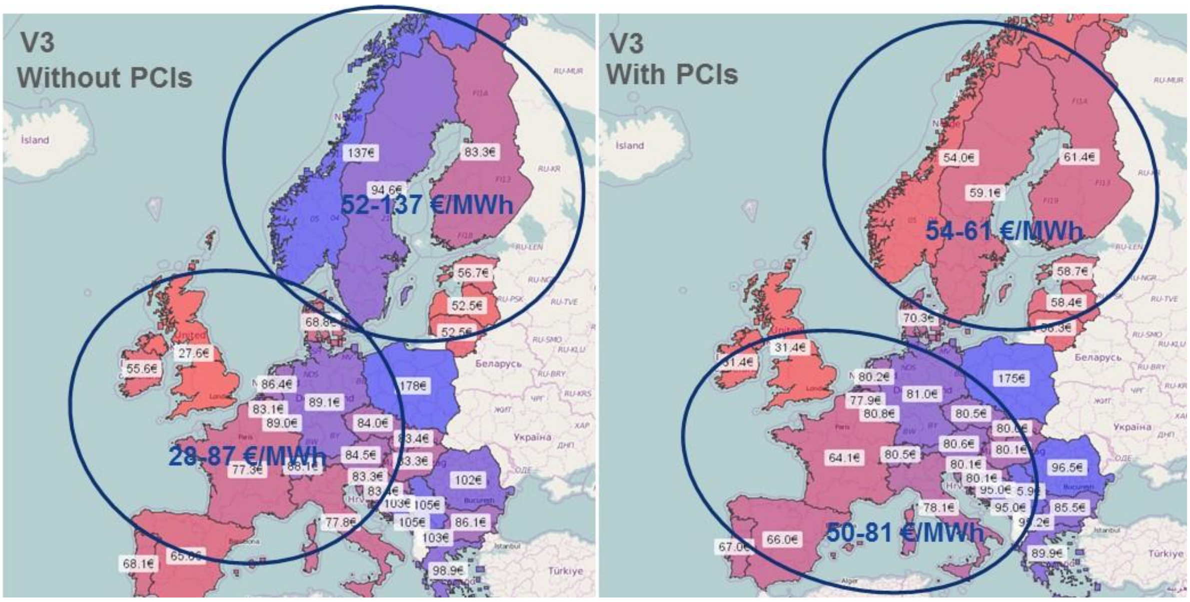

Figure 19 - Averaged annual marginal costs by country (in €/MWh)

	2030 V1		2030 V3	
	Without PCI	With PCI	Without PCI	With PCI
AT	63,0	64,8	103,2	95,0
BA	65,8	63,9	82,9	78,0
BE	61,9	64,6	86,0	85,6
BG	65,5	64,1	87,9	80,5
CH	0,0	0,0	0,0	0,0
CZ	61,6	63,3	84,0	80,6
DE	63,2	63,7	88,9	81,1
DK	52,5	63,2	68,8	74,6
EE	43,7	57,2	56,5	67,6
ES	63,5	64,2	65,7	66,8
FI	53,9	57,7	83,1	71,7
FR	46,9	59,8	78,7	68,1
GR	79,8	72,7	99,0	89,9
HR	63,1	64,8	83,4	80,1
HU	63,1	64,8	83,3	80,1
IE	62,4	61,5	56,5	51,6
IT	67,2	65,8	77,8	78,1
LT	38,5	56,2	52,3	67,2
LU	63,1	63,7	88,8	80,9
LV	38,5	56,8	52,3	67,3
ME	63,0	64,8	104,7	95,0
MK	64,1	65,2	103,1	95,2
NL	65,6	63,8	86,0	80,3
NO	74,3	57,5	136,9	65,8
PL	64,2	63,9	178,4	174,6
PT	63,7	64,2	68,1	67,8
RO	63,0	64,7	101,7	96,4
RS	63,0	64,8	104,7	95,9
SE	51,5	55,2	94,4	70,0
SI	63,1	64,8	83,3	80,1
SK	61,5	63,3	83,4	80,1
UK	59,2	61,5	42,9	51,6

Table 18 - Averaged marginal costs by country (€/MWh)

7.2.5. Impact of PCIs depending on stakeholders

7.2.5.1. Increase of consumer surplus

The variation of "Consumer surplus" when adding the PCI list is computed (in a context of inelastic demand), as[23] the sum, for every hour of the year of:

(marginal cost of the area x total consumption of the area)$_{\text{without the PCI list}}$

– (marginal cost of the area x total consumption of the area)$_{\text{with the PCI list}}$.

As the total consumption of the areas does not change and as the marginal cost globally decrease (the PCI, which reinforce the network, are used to optimize the European power dispatch under an economic criteria gathering the whole Europe), the consumer surplus is globally increased by adding the PCI.
As the marginal costs do not decrease in each country[24] (for instance the marginal costs increase in Spain, France, UK, and Baltics when adding PCI in Vision 1), the consumer surplus also decrease in some countries.

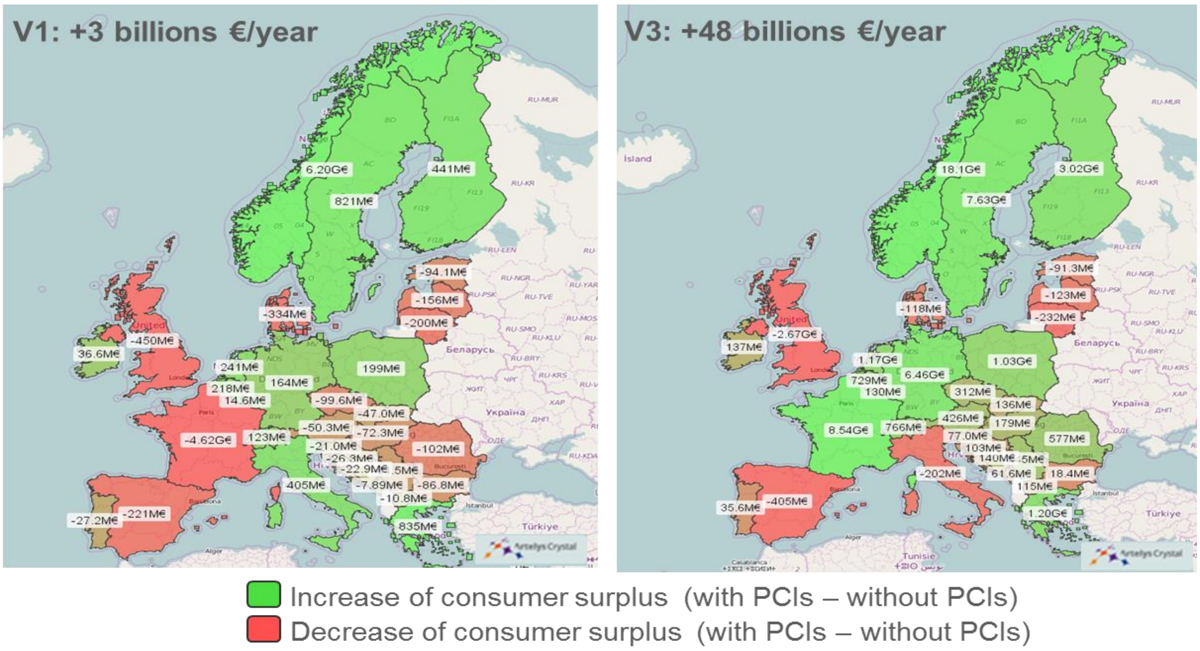

Figure 20 - Variations in consumer surplus by country (in M€)

7.2.5.2. Producer surplus evolution

The "Producer surplus" is the difference between the generation revenues and the generation costs, and the variation of "Producer surplus" when adding the PCI list is computed as[25] the sum for every hour of the year of:

[(marginal cost of the area – generation cost) x total production of the area]$_{\text{with the PCI list}}$

- [(marginal cost of the area – generation cost) x total production of the area]$_{\text{without the PCI list}}$.

As studied in paragraph 5.4, when adding the PCI, the marginal costs increase for the countries sharing their base load; for these countries, the gap between marginal cost and base load generation cost also widens and the benefits of their base load producers increase.

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[23] It is the definition given by ENTSO-E in the TYNDP 2014, footnote 91, page 454: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf

[24] As described in paragraph 5.4.

[25] The definition of generation revenues is the ENTSO-E one, given in the TYNDP 2014; footnote 92, page 454: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf

Otherwise, as the marginal costs decrease for countries which benefit from more net imports, the gap between the marginal cost and the intermediate load generation cost is reduced and the intermediate load producer benefits decrease. Besides, the PCIs reduce peak generation in these countries, and make the benefits of peak load producers decrease as well.

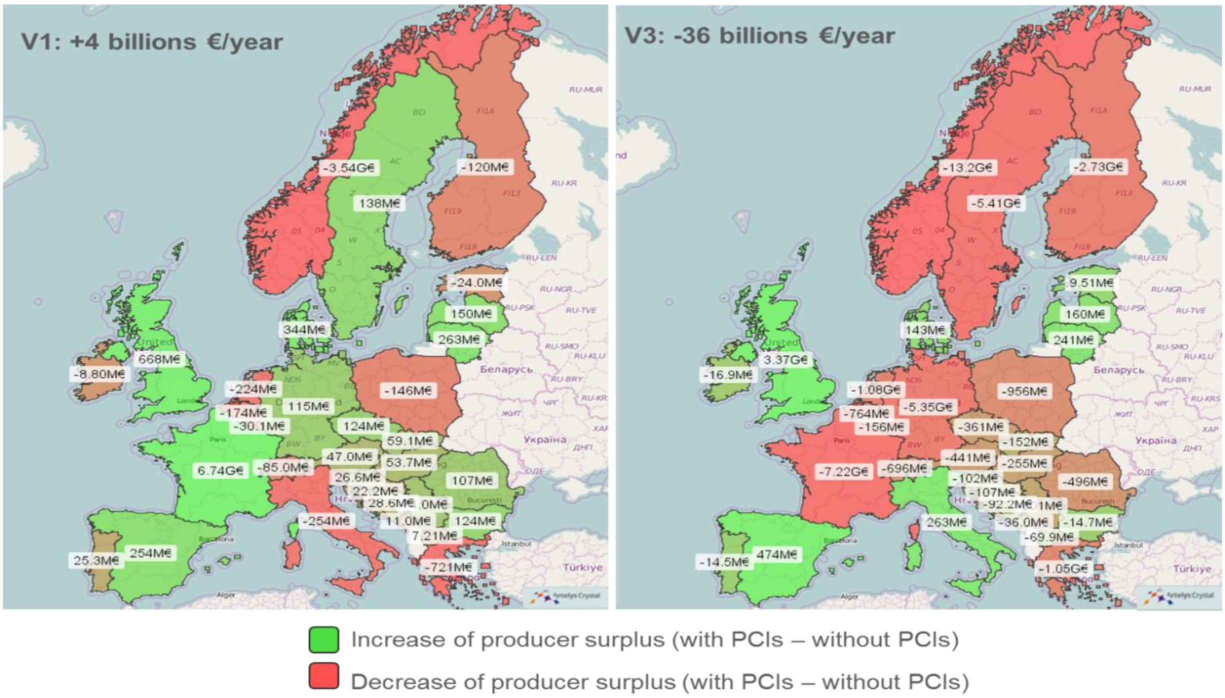

Figure 21 : Variations in producer surplus (in M€)

7.2.5.3. Decrease of congestion rent

The congestion rent is computed, for each interconnector, as[26] the absolute value of:

(Marginal cost of Export Area – Marginal cost of Import Area) x flows on the interconnector.

The congestion rent is also linked to the marginal cost convergence; as adding the PCIs supports price convergence, the PCIs make the congestion rent decrease.

7.2.6. IMPACT ON SOCIO ECONOMIC WELFARE

The socio economic welfare – SEW - is an economic indicator used by ENTSO-E to measure the benefit of a project. The impact of the PCI list of the socio-economic welfare is calculated by[27]:

Change in welfare =
change in consumer surplus + change in producer surplus + change in total congestion rents.

Figure 22 shows a decomposition of the change in SEW by country. As the congestion rent is an indicator computed by interconnector (and not by country), when computing the SEW, the change in congestion rent due to an interconnector is attributed equally between the two bordering countries linked by the interconnector. Under this hypothesis, Figure 22 highlights that the PCI impact by country is the following:

---

[26] ENTSO-E formula, from the TYNDP 2014; footnote 93, page 455: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf

[27] ENTSO-E formula, from the TYNDP 2014; page 454: https://www.entsoe.eu/Documents/TYNDP%20documents/TYNDP%202014/141031%20TYNDP%202014%20Report_.pdf

- The SEW increases for the countries sharing their base load (the consumer surplus decrease is balanced by the producer surplus increase) as well as for the countries for which loss of load decreases.
- The SEW decreases for the countries in which generation is mostly from intermediate base load and for the countries in which congestion rent is strongly reduced by PCI (due to price convergence).

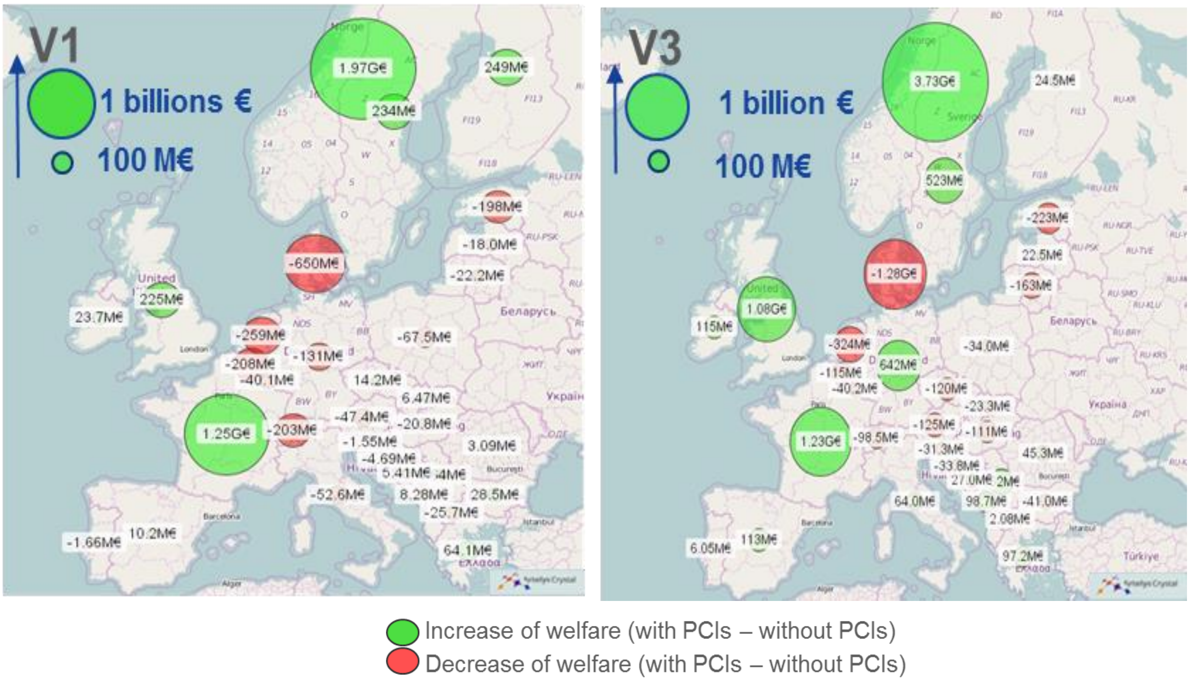

Figure 22 - Social welfare variation by country (€), computed on one realization of weather data

7.3. METHODOLOGY FOR RECONSTITUTING CURRENT NTC VALUES

The cross-border transmission capacities among European interconnected countries are calculated as the maximum over time (from year 2012 to year 2015) of day-ahead and year-ahead net transfer capacities time series from the ENTSO-E Transparency website (https://transparency.entsoe.eu/, as downloaded on February, 24th of 2016).
The missing data are complemented with the results of the following data completion procedure:

- First, additional data are collected:
    - the TYNDP year 2020 NTC values (https://www.entsoe.eu/major-projects/ten-year-network-development-plan/maps-and-data/Pages/default.aspx, Market Modeling Data)
    - the list of the projects of common interest (PCI) and the associated grid transfer capability (GTC) increases (https://www.entsoe.eu/major-projects/ten-year-network-development-plan/maps-and-data/Pages/default.aspx, Final Project List);
- Then, the year 2020 NTC values are decreased by the GTC of the PCI that are assumed to be commissioned within 2020.

7.4. DESCRIPTION OF THE REGIONS

Some results of the present study are presented using a regional decomposition. This paragraph defines the countries included in each region:

- **Center**: Austria, Belgium, Czech Republic, Denmark, France, Germany, Hungary, Luxembourg, Netherlands, Poland, Slovakia, Slovenia, Switzerland
- **Iberia**: Portugal, Spain
- **North**: Estonia, Finland, Latvia, Lithuania, Norway, Sweden
- **South**: Bosnia and Herzegovina, Bulgaria, Croatia, FYR of Macedonia, Greece, Italy, Montenegro, Romania, Serbia
- **UK**: Britain, Ireland

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