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Towards Future Electricity Networks

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Für den Inhalt und die Schlussfolgerungen ist ausschliesslich der Autor dieses Berichts verantwortlich.

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Abstract

The project is motivated by the need to develop new transmission planning tools in restructured power networks to face the challenges that arise due to economic, environmental and social issues. Transmission, generation and energy policy planning have to be integrated to support a common strategy towards sustainable electricity networks

In the first phase of the project the main focus was the definition of criteria and inputs that are most likely to affect sustainable transmission expansion plans. Models, concepts, and methods have been developed in order to study the impact of internalization of external costs in power production. To consider external costs in the planning process a concurrent software tool has been implemented, capable of studying possible development scenarios. One model outcome are “integrated” price signals, reflecting not only economic properties, but also environmental and societal cost. The calculation of such multi-dimensional price signals intends to provide incentives for the different market participants, such as generation companies, transmission system operators and customers to follow sustainable strategies for power system usage and expansion.

Additionally, a complementary concept has been developed to identify congested transmission lines or corridors as well as to evaluate the dependencies between the different market participants. The concept is the so-called Degree of Independency (DoI), where the impact of new transmission and/or generation facilities can be evaluated through the use of that indicator.

1. Initial Position

Description of the Problem

According to the European Union [1], electric power systems should be designed to meet the following criteria:

- security of supply
- environmental compatibility
- economic viability

These three criteria form an “assessment basis” concerning the sustainability of power systems, as not only technical properties but also economic as well as environmental properties are of importance. When it comes to generation and transmission planning, security of supply, environmental compatibility and economic viability can be used as three major indicators to guide the system development, i.e. possible expansion plans have to be suggested and implemented in order to improve not only the technical system performance, but also to facilitate the functioning of the internal market or to reduce emissions.

However, the long term planning and analysis of electric power systems has been traditionally based almost solely on the power production side of the electric power system and its capability to satisfy the different load scenarios without considering any restrictions or limitations imposed by the electric transmission network. Expansion plans have been identified according to the annual energy balance, which is still an important part of the power production planning, but not sufficient when market rules are applied on the network and when environmental issues are taken into account. Therefore, one has to include the transmission network in the investigations as well, in order to consider topological changes and power exchanges capability. This is the main objective of the project “Towards Future Electricity Networks” which expands the original European Pathways project [2] to include a detailed investigation on possible pathways to future energy networks by also including the transmission grid in the analysis.

According to the aforementioned requirements and challenges a multi-targeted approach is needed in order to take into consideration the preferences of the system planner, [3] .

Approach

Figure 1 depicts the basic idea of the project. It describes the transition to the future state through bridging innovative generation technologies, transmission capability, financial instruments and policies, which are going to constitute the connector between environment, society and market.

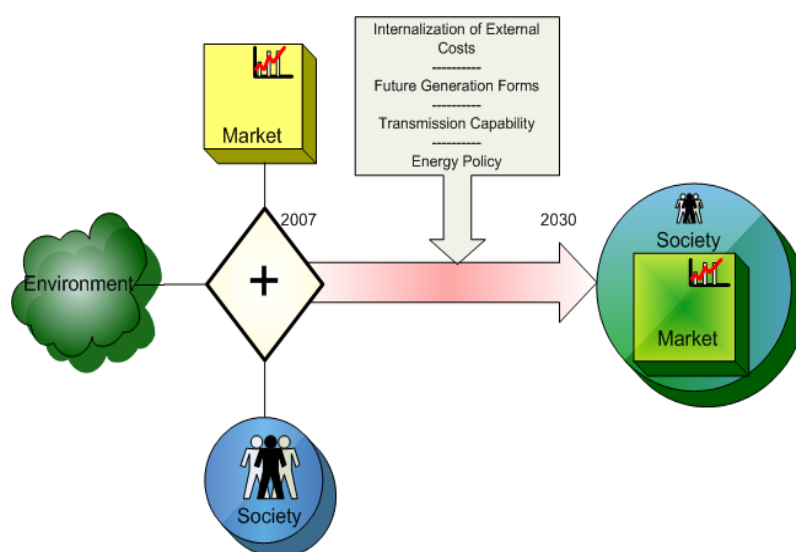


Figure 1: Combination of environmental aspects, market issues and societal standards together with external costs of power production, energy policies and future generation and transmission capability on the way to a sustainable future electricity network.

The main question that was to be answered during the first project phase was how an investment plan can be evaluated. In order to give a rational answer one has to look into the evaluation criteria, the indicators and the optimization methods that are going to be used. Such a multi-dimensional modeling and analysis approach was an important assumption for all further research work within the project.

2. Goals

The overall goal of this project is to develop an analysis and planning tool that takes into account economic, environmental and social considerations. Furthermore, based on studies and investigations using that tool, sustainable transmission investment plans supporting the transition to future grids should be developed. More explicitly the tool should, in addition to standard power planning tools, embrace

- Future power plants
- Power transmission system
- Indirect costs caused by the electric power system
- Environmental standards
- Security of supply

From a Swiss perspective this project is particularly of interest because of the often exhausted transmission capability at the borders, as well as the well known “Stromlücke”. Furthermore, pump storage hydro power plants will in the future play an important role as balancing and regulating power, and if this should be used to balance e.g. wind generation in Germany, adequate transmission capacity should be available. With the tools and models to be developed all these issues can be further studied and analyzed.

3. Method

The selected approach is to consider the economic concept of internalization of external costs for a multi-objective optimization transmission planning method in order to find an optimum considering environmental and societal benefits while minimizing electricity cost. The idea is to use an optimal power flow (OPF) as algorithm basis and to extend the common OPF framework by integrating environmental and societal cost. Such an improved OPF is called Sustainability based OPF (SOPF). It is able to evaluate prospective transmission projects based on a multi-objective social welfare analysis.

The aggregated characteristics of the SOPF are:

- Long-term multi-objective optimization that takes economy, environment and security of supply into account.
- A sensitivity analysis will be used considering weighting factors and trade-off curves to help along the transmission plan identification.
- Inclusion of internal and external costs for each generation technology
- Simulation of market behavior with the aid of nodal prices
- Consideration of topological grid issues and losses

The SOPF will also give information about the dependencies of the network participants using the Degree of Independency (DoI) which is a new concept developed in the project. The DoI is a bilateral

quantitative indicator of the network state. It signifies that when the network participants are very active in power trading and the lines are overstressed, the independencies between the nodes are very small. It is defined as the remaining transmission capacity between two nodes divided by the energy balance at a node. Table 1 gives the meaning of DoI in several cases:

DoI	meaning
zero	congested line between nodes
positive	exporter node
negative	importer node
$\rightarrow \infty$	balanced node

Table 1: DoI legend

An example is given in fig.2 for explanatory purposes. Three nodes with both consumption and production and three transmission lines to connect them to each other are assumed. As shown two lines are congested (2-3) and (1-2), while the capacity of the line (1-3) is much bigger than the needed exported power of node 1. Node 2 is completely dependent on the other two as the production capability is very small in comparison to the demanded power at the node.

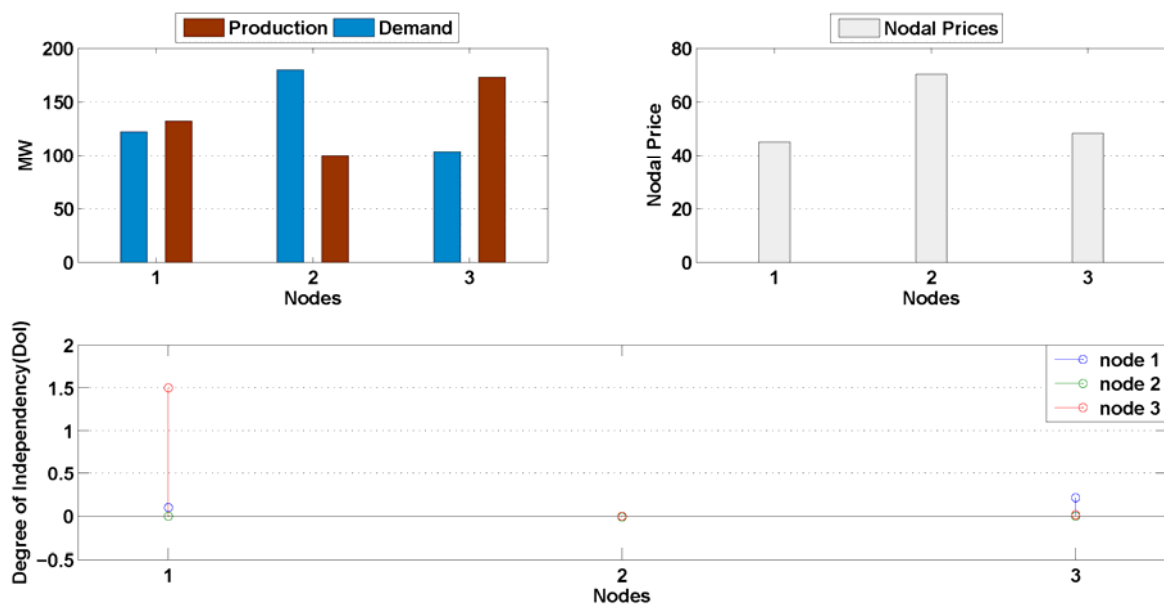


Figure 2: Results of a conceptual network for a better understanding of DoI

Through the internalization of external costs, price signals also contain information regarding environmental and societal cost. Such integrated price signals are supposed to deliver incentives according to the criteria security of supply, environmental compatibility and economic viability, which can be used to facilitate the transmission planning process and to avoid market failures. The internalization in form of additional cost (i.e. taxation) into the marginal costs of production has also been of interest inside the project. The internalization could represent a projection of future marginal prices on the present power system. Consecutively, each prospective expansion plan is evaluated based on the impact on the aggregated sustainability benefits that result from the internalization, i.e. environmental benefits, social and technical benefits.

4. Results

First results of the project were reported to the BFE in July 2008 in the report PanEuropean Network Participants Analysis, [4]. The main result of this report is an inventory of the European power production and transmission assets and overview of the power balances of European countries. The problems of the existing European interconnected system were also discussed. An overview of costs of investments was given and tools of Optimal Power Flow (OPF) and external costs were developed.

In the first project phase a major achievement is the development of SOPF algorithm, i.e. the Sustainability based Optimal Power Flow together with the implementation of a method for social welfare analysis [5], [6]. In the calculations the marginal production costs, the maximum generation capability, the transmission capacity and the transmission network connectivity together with the demanded power are mandatory inputs.

Using linear demand functions and linear or stepwise supply functions [7] the produced quantity of conventional power plants decreases, when external costs are considered. Thus, environmental and societal benefits occur which can compensate the loss of social welfare due to higher production prices. On the other hand the internalization results in higher dependencies between the network participants, which means that more power is being traded, which can lead to more network congestions, [5]. The beneficial effect of the internalization is that the profits obtained could be used to finance the required transmission capacity to enhance the market and to promote the integration of the technologies needed for a sustainable future. This is discussed more in detail in [6].

In general, it can be concluded that the internalization leads to a promotion of "green" technologies in comparison with conventional production technologies. Furthermore, due to relocation of generation facilities, congestion is likely to arise at "new" locations. Subsequently, an optimal power flow analysis was employed to determine which European transmission lines that have to be reinforced. The simulations showed that adding new lines does not always leads to congestion relief or improved reliability. Similar results have also been reported in [8]. New lines as well as new generation capacity change the system topology, where their influence is highly dependent on the demand pattern and the specific operating criteria. Furthermore, considering the limited production capacities of renewable energy sources, an increase of the transmission capacity may not always be beneficial for environmental concerns, as the increased transmission capacity also improves trading possibilities for conventional power plants. Thus, investments in the transmission network must be complemented by investments in environmental friendly production technologies in order to develop a sustainable European power system.

The main results are presented in the reports of Appendix 1 where the methodology is described and a specific transmission expansion plan has been evaluated.

5. Discussion

The methodology is associated with uncertainties regarding the monetarization of the external costs. A common framework for the estimation of external costs estimation does not exist. Models in the literature exhibit different properties and the considered influences may be different among several analyses [9]. Besides, the main criticism claims that the monetary valuation of the human life is not possible. For that reasons external cost values may differ considerably.

Another debate concerns the external cost of nuclear energy. It is considered to be the energy form with the least external costs and thus the cheapest. In [10] it is claimed that the external costs are already internalized in the cost of nuclear-generated electricity. In the context of the here described project, external costs of nuclear generation are calculated according to the framework used in the ExternE project [11]. These values are very small but not zero.

As long as specific values for the external costs are difficult to be set, their internalization in terms of taxation or subsidy includes significant uncertainties. Therefore weighting the external costs together with a multi-objective planning tool seems to be a reasonable approach to solve the problem. Ideas regarding the level of internalization of externalities combined with the level of utilization of the transmission network are presented in [6].

Assumptions have to be made also in the economic models used, as the major problem is the lack of aggregated models including financial generation data. A reduced European transmission model including all needed data for future studies is developing at the moment and will be finalized in 2009.

6. Conclusions

In the framework of the first phase of the project models and concepts have been developed to internalize external costs in a so-called sustainable OPF. Emphasis has been given to the evaluation criteria of possible expansion plans.

The proposal for the second project phase has been already submitted, where an interesting and fruitful cooperation with SFOE and Chalmers is expected. A European benchmark model will be created and case studies for Swiss as well as for the European transmission network will be executed. The introduced time dependency of the input variables will help to evaluate and identify optimal transmission investment plans on the way to a sustainable future European electricity network including technical, economic and ecological requirements.

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Appendix

In the Appendix the paper that has been presented in the 28th USAEE North American Conference is attached, together with the working paper for Powertech 2009 and the July's report to SFOE.

Namely:

1. Appendix 1 – paper 28th USAEE North American conference
2. Appendix 2 – abstract Powertech 2009
3. Appendix 3 – report SFOE July 2008

APPENDIX 1

Optimal Electric Power Transmission Planning Taking Environmental Constraints into Account

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Abstract

As environmental criteria become more and more important for the energy systems operation and planning, this paper proposes a method that can support the decision makers in future electricity systems planning. The evaluation of future electric power transmission investment plans is based on a social welfare analysis when the external costs of production are internalized. The social benefit can be further used to compensate the investments required for market enhancement and sustainable development.

1 Overview

1.1 Introduction

The worldwide reconstruction of the electric power systems is taking place under increasing end-user energy demand, environmental changes and active trading markets. The realization of a common market in Europe as well as power supply improvements are not possible without investments in the transmission sector. These investments can be either in new transmission lines or in line capability upgrades using new technologies, e.g. FACTS devices. This means that the transmission planning and analysis of electric power systems cannot remain the same as it was 10 or 20 years ago.

The generation sector and the energy balance is an important part of the electric power systems planning, but the present requirements in Europe and other places in the world call for new methods and tools to analyze the

development of the electricity system, including the transmission and distribution systems [1]. The topic is sensitive due to the fact that transmission investments create winners and losers [2].

The following analysis is based on social welfare, i.e. consumer benefits minus producer costs. The considered requirements are the environmental impact of energy consumption and accordingly production, the impact of the transmission capacity increment on the market, as well as the benefit or the deficit in social welfare.

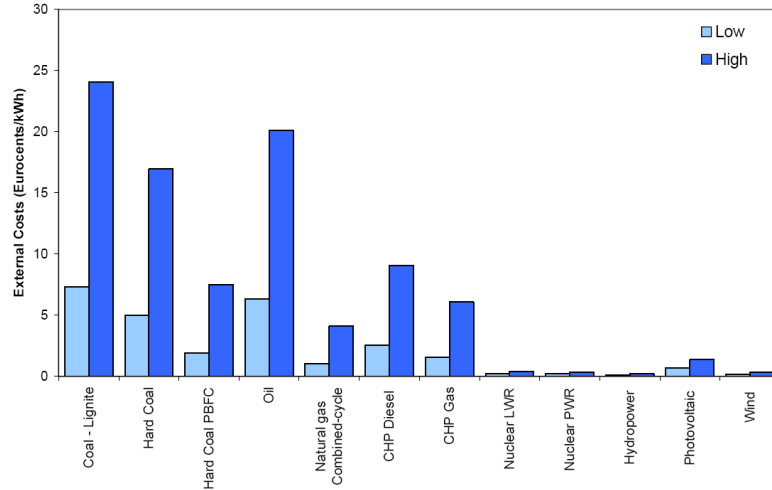
The energy production is commonly associated with negative effects. Fossil fuel power plants are much cheaper and competitive than other types of power plants but not sustainable. They are the main sources of CO₂, NO_x, SO₂ and fine particles. Hence, a number of negative effects are arising, the costs of which are not represented in the electricity prices and correspond to market insufficiencies. These are known as external costs. They refer to environmental damages, health impacts and climate change respectively. The discussion how and whether it is possible to estimate the monetary values of external costs is not the subject of this paper, but how it is possible to consider them in the electric power transmission planning and operation. This paper, accordingly, emphasizes the compensation of transmission investments from the social benefit that arises from the internalization of external costs.

1.2 External costs of electricity production

In the power production sector the most considerable external effects are negative effects, the worst being health disorders and deterioration of the environment, basically due to the usage of fossil fuels in energy production. Fossil fuels power plants produce dangerous and harmful gases (CO₂, SO₂, NO_x, etc.) which have negative impact on the environment and on the human health. Secondary effects emerge also from the extremely high risk of environmental impact in case of an accident in a nuclear power plant, or the ecologic and aesthetic disturbance of windmills in farm fields, or even of overhead transmission lines.

According to the monetary valuation each generation technology except for its public advantages is characterized by a value of damage. Many projects supported by the European Commission like ExternE, NEEDS, CAFE, CASES have tried to estimate this imposed damage and to present it as a monetary value in order to internalize the additional social costs in the market operation. Top-down models have been used as first approach to the problem but for higher accuracy of the resulted values of the external costs the bottom-up models are more suitable as they are more detailed and focused on the available technologies. Therefore the ExternE methodology has been highly approved as the most appropriate method for the estimation of the external costs [3].

According to the drivers that define the values of each production technology, the external costs have been estimated and presented in fig. 1.



Data source: ExternE-Pol, 2005 ; CAFE, 2005 ; European Environment Agency/ETC.

Figure 1: Low/High estimation of external costs

Among the other fossil fuels lignite holds the first place in the rank of hazardous production technologies and then follows oil and hard coal. In fact, if one looks closer at the emitted contaminants for the same produced quantity using different fuels, lignite emits the most in the whole life cycle. As shown in figure 2, SO_2 , CO_2 and particulate matter PM_{10} are the main emitters in case of lignite, resulted from an internal study. Moreover SO_2 and PM_{10} are the most harmful for the human health and thus they strongly affect the external costs.

2 Methods

2.1 Direct Current - Optimal Power Flow (DCOPF)

The analysis is based on Optimal Power Flow (OPF). An OPF is a static optimization method that solves the problem of power flow when different criteria are to be satisfied subject to equality and inequality constraints. In the simplest case, an OPF can be viewed as a method that solves the problem of minimizing an objective function, e.g. the total cost, satisfying the power flow equations [4].

The OPF problem can be formulated as [5]:

$$\begin{aligned}
 &\text{minimize } f(u,x) \\
 &\text{s.t. } g(u,x) = 0 \\
 &\quad h(u,x) \leq 0
 \end{aligned}$$

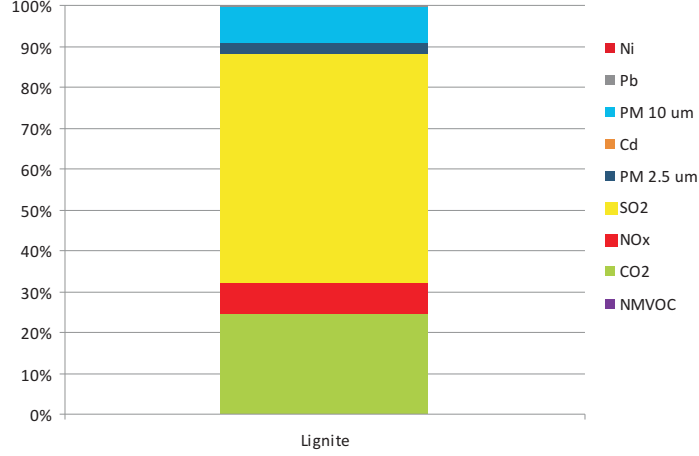


Figure 2: Emitted contaminants of lignite

where $f(u,x)$ is the objective function, $g(u,x)$ and $h(u,x)$ represent the power flow equations and inequality constraints respectively, u corresponds to the decision variables and x to the states that minimize the objective function.

As described in [6] the OPF is capable to represent the characteristics of the modern liberalized electricity market and to support the market-based system analysis [7], [8], as well as to solve the problem of multiple energy carriers [9]. Furthermore, the OPF is able to combine conflicting and independent variables to the overall optimum.

In this paper a DCOPT without losses consideration has been used in order to maximize the social welfare, to calculate the nodal prices and determine the production levels of the generators. Transmission and generation limits as well as external costs are considered in the optimization formulated below:

$$\text{minimize}\{-SW\} = \text{maximize}\{CB - PC\} \quad (1)$$

	equalities	inequalities
s.t.	$G_i - L_i = 0$ $L_i = a_i + b_i D_i$ $b_i = \frac{\Pi_{0_i}}{\varepsilon G_{0_i}}$ $a_i = \Pi_{0_i} - b_i G_{0_i}$	$G_i, L_i > 0$ $G_{i_{min}} < G_i < G_{i_{max}}$ $-TCL \leq Pf_{ij} \leq TCL$

where

Π_{0_i}, G_{0_i} the initial values for inelastic demand

ε the mid-term price elasticity

TCL the transmission capacity limit

CB the consumer's benefit

PC the producer's cost

2.2 Internalization of external costs

In the following analysis the role of internalization of external costs has been thought to be a tool for providing right price signals during the transmission planning avoiding market failures. Additionally it could be used as policy strategy to finance the required transmission plans enhancing the market and promoting the integration of green technologies towards a sustainable future.

Under market conditions there are different economic tools for internalizing the external costs in the power systems operation. Namely one could use either taxes expecting that the utilization of emitting technologies will decline, or to subsidize the green cleaner technologies in order to become more competitive against the traditional, or even to combine both methods for aggregating the advantages. The best solution might be to use one of these methods but on the other side to promote the R&D sector together with a load management concept. Of course there are also other mechanisms that can influence the behavior of consumers and producers like communication or normative mechanisms [10].

Focusing on economic tools a policy of internalization of external costs leads to a cost supplement either for the government or for the industry. The internalization of external costs means that the price for the same quantity of produced energy will be higher in case of taxes or lower in case of subsidy. According to that the produced quantity of more expensive power plants is going to increase, while on the other hand the production of cheaper power plants will decrease. Figure 3 describes the situation after the internalization representing the marginal costs of a relative cheap power plant i.e. coal power plant and the demand as linear functions. The surface A-B-C represents the social welfare loss in that case.

A similar situation would arise if a step-wise cost function would have been used fig. 4. The social welfare will be then equal to the consumer surplus, obviously smaller than in the previous case.

As shown a social welfare deficit will occur due to the price increment, defined again from the area A-B-C. This deficit is however smaller than the external cost reduction, as will be shown in section 3. As in the case of additional costs for underground cables that are considerably lower than the social benefits of avoiding landscape degradation from overhead lines [11].

The above analysis refers to the case of additional fee, e.g. taxation. In case of subsidy, i.e. reduction of the supply curve, the social welfare would be higher, which has to be compared with the extra costs upon the

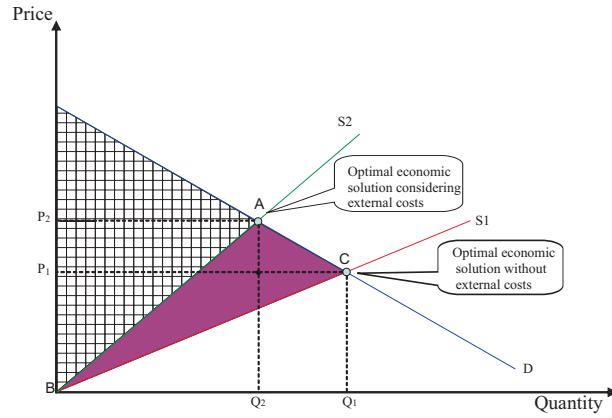


Figure 3: Internalization of external costs in a linear supply function, loss of social welfare $\Delta A-B-C$

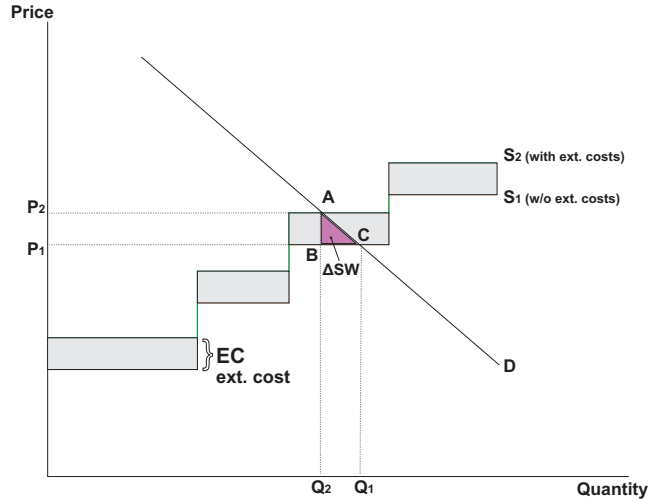


Figure 4: Internalization of external costs in a stepwise supply function, loss of social welfare $\Delta A-B-C$

government. The internalization of external costs in form of additional cost (i.e. taxation) into the marginal costs of production will be investigated here. The internalization could represent also a projection of future marginal prices on the present power system.

The stepwise marginal production costs function for power plant i is:

$$\Pi_i = m_i Q_i \quad (2)$$

The external costs function for power plant i is:

$$EC_i = \sum_i V d_j * G_j^i \quad (3)$$

where

\mathbf{EC}_i the externality cost

\mathbf{Vd}_j the value of damage for several emitters

\mathbf{G}_j the emitted quantity produced

After the internalization the production cost function is:

$$\Pi_i = m_i Q_i + EC_i \Rightarrow \Pi_i = e_i Q_i \quad (4)$$

where

$$e_i = m_i + \sum_j Vd_j \quad (5)$$

The following example will allow a better understanding of the internalization effects in a very simple network of 4 nodes. The network consists of 3 generators, one load and 8 transmission lines. It is assumed that a coal fired power plant, a nuclear station and a hybrid distributed generation system corresponds to each of the generators respectively. The marginal costs of the generators are given considering the nuclear as the cheapest technology and the distributed generation system as the most expensive. According to the estimated values for the external costs, the internalization entails higher production prices using lignite instead of hybrid distributed generation, for the same quantity produced. Thus, the feeding of each generator into the system changes as well, as shown in figure 5.

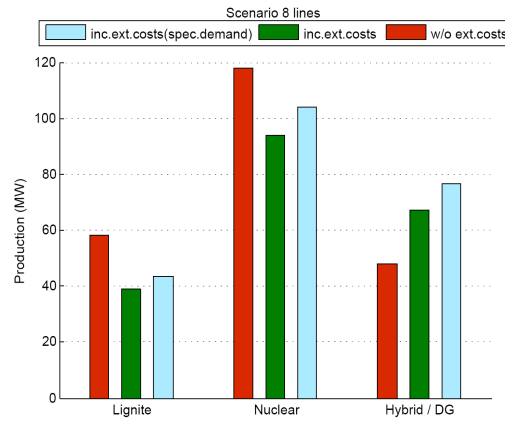


Figure 5: Production mix change for several cases: w/o ext. costs on the left (red), considering ext. costs in the middle (green), considering ext. costs and inelastic demand on the right side (blue)

The case of specific demand refers to inelastic demand which brings the equilibrium closer to the initial state but gives a more expensive solution as

it is non-optimal. In general one can imagine that the new green technologies become more competitive and more advantageous in comparison with the old common production technologies. Furthermore, it appears a reallocation of congestion as depending on the infeed location.

Eventually, a loss of social welfare is been expected due to the fact that the nodal prices get higher. However as already commented the deficit is not larger than the aggregated profits. The social benefits from the internalization through the reduction of negative effects, are able to compensate this loss.

The social benefit for a power plant is calculated as:

$$SB_i = \Delta G_i * EC_i \quad (6)$$

while the total profit of the internalization will be:

$$TP = \sum_{i=1}^n SB_i + \Delta SW \quad (7)$$

where

$$\Delta SW = SW_{withexternalcosts} - SW_{basecase} < 0 \quad (8)$$

The latter framework aims at environmental and societal considerations in the following cost benefit analysis.

2.3 Degree of Independency (DoI)

A new concept regarding topological issues, the so called degree of independency (DoI), is introduced in this paper. Between two interconnected nodes (nodes could represent a part of a greater system), which are operating under market conditions, not only the capability to satisfy their own demand is important, but also the availability of transmission capacity for power trade. The DoI is defined as:

$$I_{ij} = \frac{RTC_{ij}}{DP_i}, i, j = 1, 2, 3 \dots n_{nodes}, i \neq j \quad (9)$$

while

$$RTC_{ij} = NTC_{ij} - Pf_{ij} \quad (10)$$

$$DP_i = P_i - D_i \quad (11)$$

where

RTC_{ij} the remaining transmission capacity

DP_i the the energy balance at a node

\mathbf{NTC}_{ij} the net transmission capacity

\mathbf{Pf}_{ij} the power flow over a line

\mathbf{D}_i the demand at a node

\mathbf{P}_i the production at a node

For a single node the DoI is defined as:

$$I_i = \sum_j I_{ij} = \frac{\sum NTC_{ij} - \sum Pf_{ij}}{D_i - P_i} \quad (12)$$

In a complex meshed network, the operation of one node affects the others. Under the acceptance that every node is participating in a common market, nodes are dependent or not completely independent from each other. The DoI is a bilateral quantitative indicator of the network state which will help us in the following analysis. It signifies that when the network participants are very active in power trading and the lines are overstressed, the independencies between the nodes are very small.

DoI	meaning
zero	congested line between nodes
positive	exporter node
negative	importer node
$\rightarrow \infty$	balanced node

Table 1: DoI legend

An example is given in fig.6 for explanatory purposes. Three nodes with both consumption and production and three transmission lines to connect them to each other are assumed. As shown two lines are congested (2-3) and (1-2), while the capacity of the line (1-3) is much bigger than the needed exported power of node 1. Node 2 is completely dependent on the other two as the production capability is very small in comparison to the demanded power at the node.

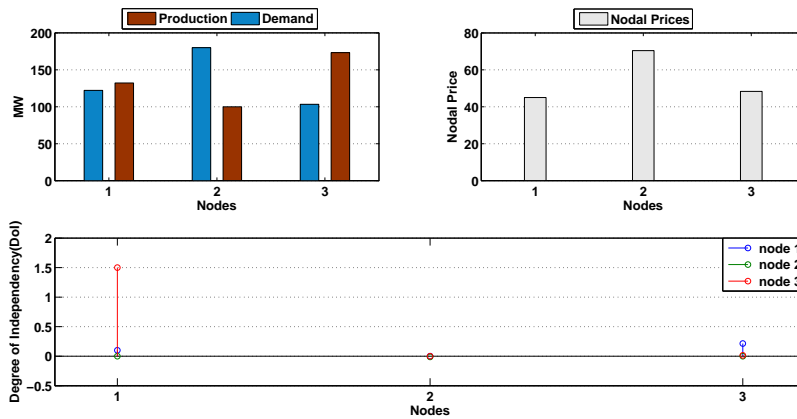


Figure 6: Results of a conceptual network for a better understanding of DoI

2.4 Model description

The studied system is a model of a transnational European electricity network including the four countries Germany, Belgium, France and the Netherlands, originating from the COMPETES (Competition and Market Power in Electric Transmission and Energy Simulator) study of the Dutch Energy Research Center [12]. The Benelux system is represented by five nodes with both consumption and production (Zwol, Krim, Maas, Merc, Gram). Germany and France are modeled by one node each. Additionally some nodes exist, but they just serve as interconnectors, see fig. 7. The model includes

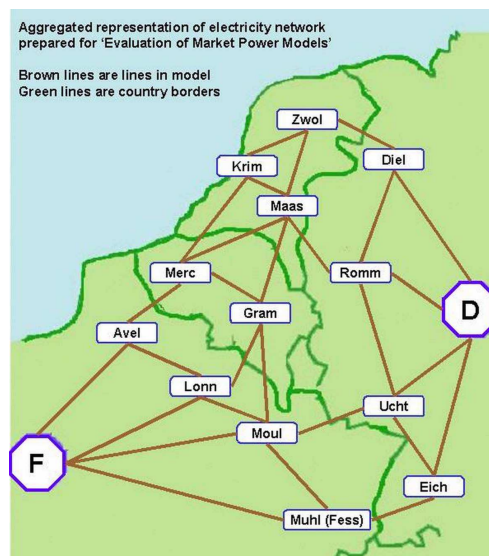


Figure 7: The studied network

82 generation companies represented by step-wise marginal cost functions where the external costs have been internalized. The generation data are mainly based on the World Economic Power Plant (WEPP) database of the year 2001 [13] and public available data of EDF, EnBW, RWE and EoN. Each generator has a certain marginal cost per MWh and a maximum capacity. The external costs have been selected according to the mean values of power plants efficiencies [14] in each country, based on 150 €/MWh for coal and 100 €/MWh for gas power stations. For nuclear thermal plants the external costs have been assumed at 10 €/MWh, while for hydro and renewables have been set to zero.

In table 2.4 the assumed efficiencies and external costs for coal and gas power stations are given.

		BE	FR	DE	NL
Coal	efficiency	0.38	0.39	0.39	0.41
	external cost (€/MWh)	154	150	150	142.5
Gas	efficiency	0.48	0.34	0.34	0.44
	external cost (€/MWh)	59	100	100	70.5

Table 2: Assumed efficiencies and external costs for coal and gas power plants

The loads are represented by mid-term linear demand functions for peak and off peak loadings. The linear factors have been obtained using a price elasticity of -0.3. Additionally the transmission capacity limits and the reactances according to [12] have been used.

Using the aforementioned welfare analysis and the collected data a priority project of the European Union, identified as EL1, between France and Belgium will be evaluated.

3 Results

The results for the different scenarios are presented in the following subsection. Simulations have been executed for winter and summer, peak and off-peak load. The market participants and the DoI are shown only for winter peak loadings as they behave similarly in the other cases as well.

3.1 Base case scenario

The generators that participate in the market in order to satisfy the optimal solution are illustrated in fig. 8.

It is clear that France is the major producer of the region based on huge capacity of nuclear power and then follows Germany based on coal. However, the high generation of Germany is not enough to cover the demanded power during winter period and thus is depicted as importer in fig. 9. There

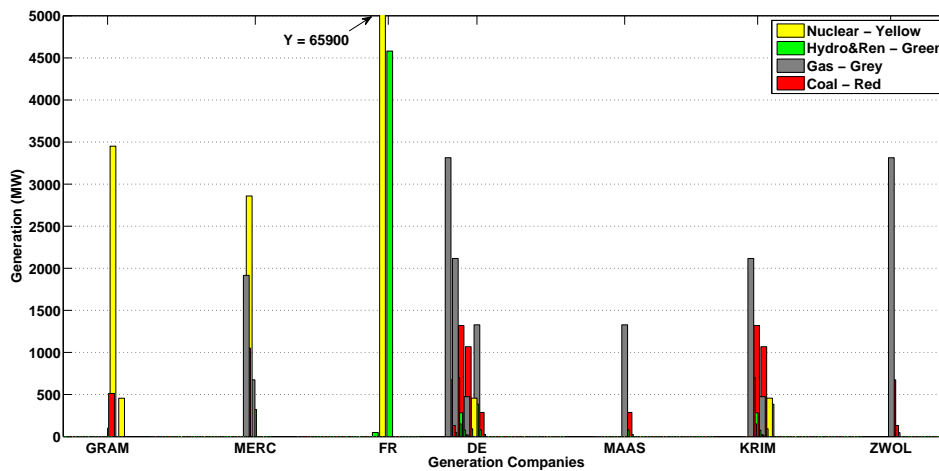


Figure 8: Generation companies in base case scenario

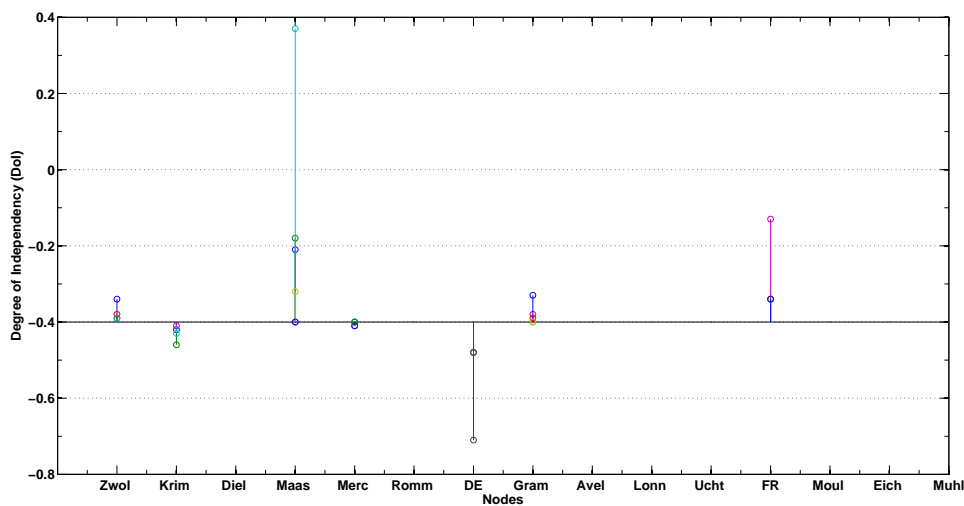


Figure 9: Nodal independencies in base case scenario

is shown that the nodes FR and Maas are quite balanced and therefore the most independent with export capability. Power is also exported from Zwol and Gram without any congested lines at the borders except for the line between Gram and Moul and two other lines between Belgium and Netherlands, Maas - Merc and Maas - Gram.

3.2 Scenario internalizing external costs

Considering the external costs of power production a modification of the price - quantity equilibrium results, according to the theory described in 2.2. As shown, fig. 10, the quantity produced by coal, gas and nuclear

power plants has been reduced due to new entrance of new members into the market or the increase of production levels at other units. More expensive technologies become more competitive but their maximum generation capacity is limited and so the trading is being encouraged. Therefore the market participants depend more on each other and the network lines more loaded, as described in fig. 11. One more line in addition to the base case is congested between the Netherlands and Germany, the line Mass - Romm.

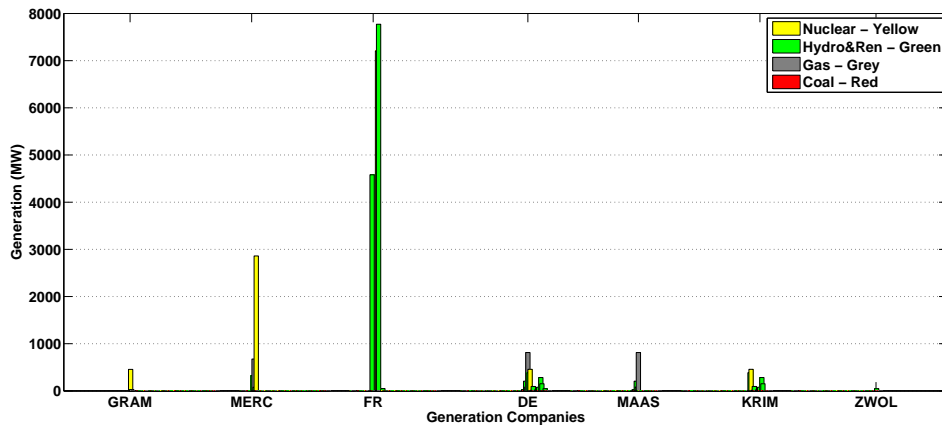


Figure 10: Production companies considering external costs

According to the DoI diagram Germany doesn't play the role of the the importer any more and belongs to the group of exporters together with FR and Gram. The by far largest DoI of FR means that supply and demand in France is very well balanced and the borders are available for export. All other small DoIs, practically zero, indicate that the transmission lines are very close to their capacity limits.

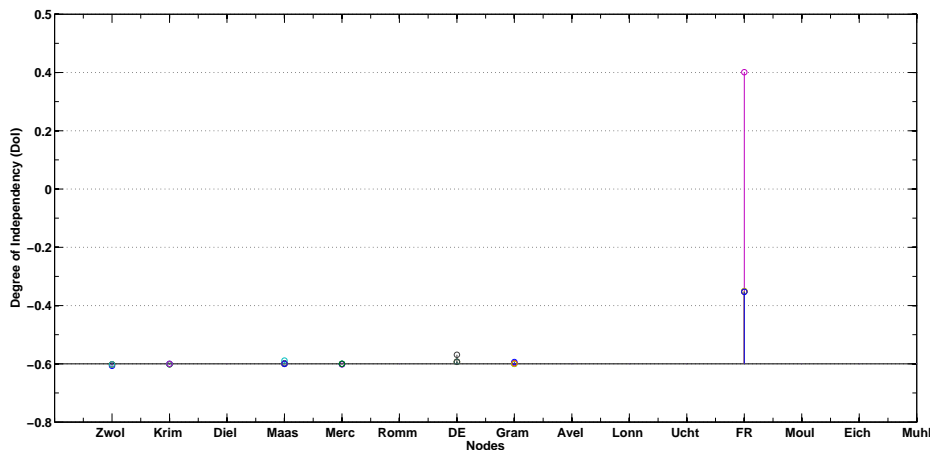


Figure 11: Nodal independencies considering external costs

The environmental and consequently the social benefits from the internalization are presented in the table 3.2 below. As expected Germany profits the most from this action as it reduces the production of coal power plants that represent the biggest amount of external costs. The other countries take also the advantage of providing environmental friendly power.

	NL (€/h)	DE (€/h)	FR (€/h)	BE (€/h)
Winter peak	$0.81 \cdot 10^6$	$7 \cdot 10^6$	$0.59 \cdot 10^6$	$0.34 \cdot 10^6$
Winter off-peak	$0.53 \cdot 10^6$	$3.29 \cdot 10^6$	$0.49 \cdot 10^6$	$0.17 \cdot 10^6$
Summer peak	$0.54 \cdot 10^6$	$5.58 \cdot 10^6$	$0.43 \cdot 10^6$	$0.21 \cdot 10^6$
Summer off-peak	$0.38 \cdot 10^6$	$2.36 \cdot 10^6$	$0.32 \cdot 10^6$	$0.13 \cdot 10^6$
Total per year	$4.37 \cdot 10^9$	$3.08 \cdot 10^{10}$	$3.73 \cdot 10^9$	$1.53 \cdot 10^9$

Table 3: Total social profits, TP eq. (7), after the internalization

3.3 Scenario EL1

As noted above the internalization of external costs promotes the power trading in order to satisfy the demand that cannot be covered by the "domestic" green power plants due to their limited production capability. For that reason new transmission investments are needed. We will evaluate the impact of an already voted plan by the European Union, in the list of the so called priority projects towards a common electricity market, on the environmental profits of the involved and neighboring countries.

The aim of this project is to increase the NTC by 60-65% between the borders of France and Belgium by installing a second circuit on the Aveline (FR) - Avelgem (BE) line (50%) and on the Moulaine (FR) - Aubange (BE) line (10-15%) [15]. In the studied model these lines are represented by Gramm - Moul and Merc - Avel. A 50% increment of the NTC between Gramm and Moul leads to an additional capacity of 400MW and a 15% improvement on the Merc - Avel line corresponds to another 1033MW. The costs of the project burden FR with 17M€ and both FR and BE with 17M€.

Fig. 12 depicts that some of the new market players lost their position and they disappeared from the market or some others decreased their production. The level of generation of German companies remain the same and only one gas company in France has increased its production.

France continues to be the major exporter in the system but more dependent on the other nodes as the exported power is larger in this case. The additional capacity didn't have any impact on the already congested lines due to the fact that the dependencies between the nodes became stronger, see fig. 13.

The total social profits, TP, for one of the two involved parties, France, are either negative or zero. It means that without any coordinated investment in green technologies the augmented exports will again be based on

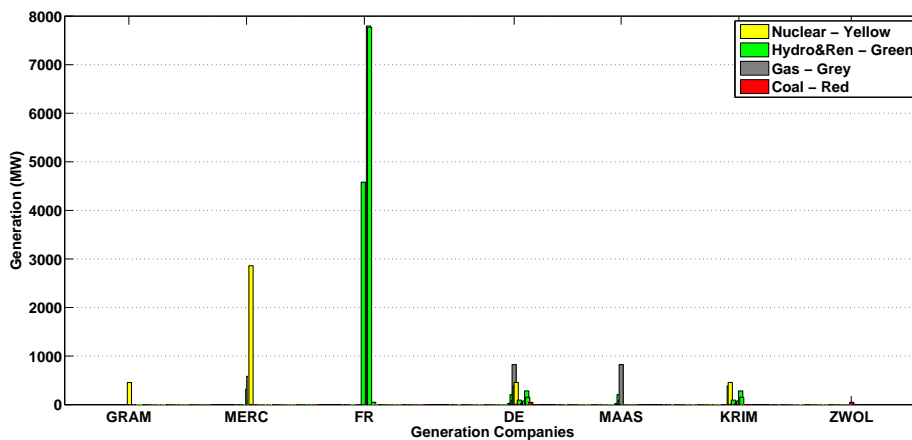


Figure 12: Production companies including external costs and increased capacity

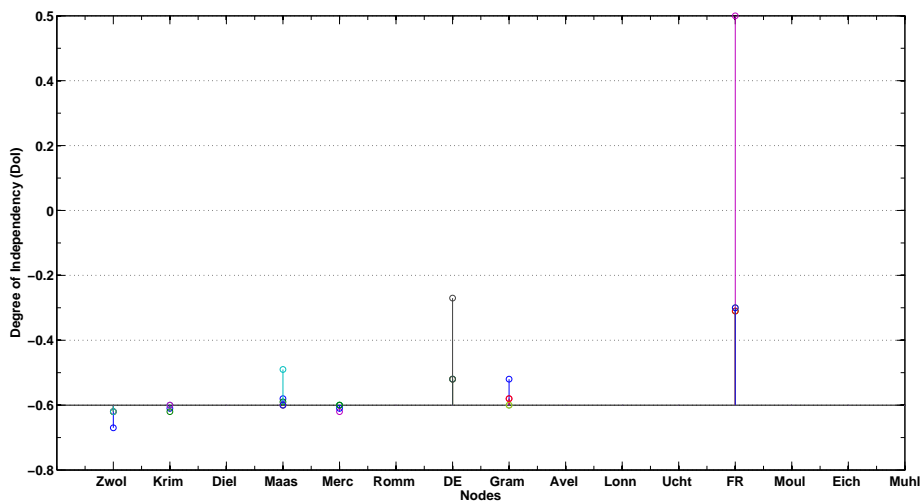


Figure 13: Nodal independencies including external costs and increased capacity

conventional power plants. The expansion is only beneficial to Belgium owing to a total reduction of nuclear power by 300MW. Otherwise, regarding Germany and congested lines the capacity reinforcement has no influence.

Obviously the listed plan is not the optimal decision regarding environmental issues in case the external costs of production have been taken into account. Of course this plan is optimal considering security of supply and power trade as it is reported in [16]. However, a modern investment that costs 17M€ exclusively to France and another 22M€ to both France and Belgium should at least glance at other concerns except for market strengthening, in order to promote the sustainable development of power

	NL (€/h)	DE (€/h)	FR (€/h)	BE (€/h)
Winter peak	$-0.82 \cdot 10^4$	0	$-5.91 \cdot 10^4$	$5.38 \cdot 10^4$
Winter off-peak	0	0	$-5.85 \cdot 10^3$	$2.5 \cdot 10^3$
Summer peak	$9.71 \cdot 10^4$	0	0	$5.35 \cdot 10^4$
Summer off-peak	0	0	0	$4.15 \cdot 10^3$
Total per year	$82.78 \cdot 10^6$	0	$-25.68 \cdot 10^6$	$117.3 \cdot 10^6$

Table 4: Total social profits, eq. (7) after the internalization and the expansion

systems.

As noticed in the subsection 3.2 the internalization of externalities is profitable for every participant in the regional market. Indeed the costs that burden the society at the moment are remarkable larger than the costs of a transmission investment. Using the right internalization policy these costs could change to profits and support investments in future electricity networks. The critical question is who should pay the additional costs and who should be the one who will utilize the arisen profits which is out of the scope of this paper. This question together with a scheme for coordinated multi-objective transmission planning will be the subject of oncoming research.

Conclusions

The results show that the internalization of external costs in that region promotes new entrants in the market but increases the dependencies between the participants. Furthermore, it causes a deficit in social welfare which is much smaller than the total social benefit from the decrease of the fossil fuel power plants production. This profits could be returned to the system including the society, financing new investments and thus accelerating the transition period to future sustainable power systems.

As long as specific values for the external costs are difficult to be set, the taxation or the subsidy is inefficient. Therefore weighting the external costs together with a more completed multi-objective planning tool might be a more reasonable handling of the problem.

Instead of building unsustainable networks based only on antiquated criteria, waiting for the best generation technology to come into the market, is better to force the right price signals and modify the investments criteria as soon as possible. Cause the transition period needs more than 30 years if one imagine that the reinforcement of a transmission line lasts for 10-15 years and more 10-15 years pay back period. Policy initiatives should take the lead in transmission planning before any optimal plan identification.

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APPENDIX 2

Sustainability Based Optimal Power Flow A New Planning Tool

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Abstract—This paper proposes a multi-objective transmission planning tool in order to facilitate the decision of an optimal transmission investment. The analysis is based on economic, environmental and societal criteria, in terms of security of supply, using trade-off curves and weighted internalized external costs. The results show that the level of internalization is a key issue in order to compensate the negative environmental impact of high utilization of transmission lines.

I. INTRODUCTION

Traditionally the planning and analysis of electric power systems have put a lot of emphasis on the power production side of the electric power system. Quite often the main purpose has been to show that the annual energy balance can be satisfied, and for that purpose different expansion plans have been evaluated. This is still an important part of the power production planning, but the present requirements in Europe [1] and other places in the world call for new methods and tools [2] to analyze the development of the electricity system, including the transmission and distribution systems.

The reconstruction of the electric power systems around the world is done under increasing end-user energy request, environmental changes and active trading markets. The existing power plants are either insufficient or over-aged and have to be replaced by more effective, competitive and environmentally friendly "green" technologies. As the interconnected systems were primarily built to increase reliability and security, which means that the interconnections were not dimensioned for continuous bulk power transfer required by the current market situation, congestions and outages have become more and more frequent [3]. As a consequence, most often not only new generation is needed but also new transmission capacity to support the extra generation capacity.

As presented in [4] adding new lines does not always mean congestion relief or reliability increment. New lines as well as new generation capacity change the system topology and their influence on an existing system is highly dependent on the range of demand and the operating criteria respectively. This paper presents a new planning tool which investigates

the impact of generation and transmission investments on the market, the society and the environment. More explicitly the tool in addition to standard power planning tools, embraces

- Power plants of the future
- Load patterns
- Power transmission system
- Indirect costs caused by the electric power system
- Environmental and societal standards.

II. SUSTAINABILITY BASED OPTIMAL POWER FLOW

This planning tool is called Sustainability based Optimal Power Flow (SOPF). It is an optimal power flow that takes into account external costs of energy production as well as transmission constraints, in order to allow for a social welfare analysis that incorporates not only economic criteria, but also criteria of environmental and societal prosperity together with grid security issues. In the simplest case, an OPF can be viewed as a method that solves the problem of minimizing an objective function [5], e.g minimizing the total operational cost, subject to a number of equality and inequality constraints. In general, OPF is applicable when studying a problem that requires interactive use of conventional power flow and for cases involving conflicting and independent variables and requirements [6] like in our case.

The OPF problem can be commonly formulated as in [7]:

$$\begin{aligned} &\text{minimize } f(u,x) \\ &\text{s.t. } g(u,x) = 0 \\ &\quad h(u,x) \leq 0 \end{aligned}$$

where $f(u,x)$ is the objective function, $g(u,x)$ and $h(u,x)$ represent the power flow equations and inequality constraints respectively, u corresponds to the decision variables, in our case scenarios for new transmission lines, demand growth and new power plants, and x to the states that minimize the objective function. In the proposed methodology the objective function refers to the social welfare, which is defined as:

$$SW = \sum_{i=1}^k CB_i - \sum_{i=1}^n PMC_i \quad (1)$$

where

CB: Consumer benefit
 PMC: Producer marginal cost
 k: number of consumers
 n: number of producers

For linear demand function and stepwise production marginal costs the equation (1) can be written:

$$SW = \sum_{i=1}^k (a_i D_i + 0.5 b_i D_i^2) - \sum_{i=1}^n (G_i * MC_i) \quad (2)$$

where

G_i : quantity supplied (MW)
 D_i : quantity demanded (MW)
 MC_i : marginal cost of a power plant (€/MWh)

The aggregated characteristics of the SOPF are:

- Weighted optimization that takes economy, environment and security of supply into account.
 A sensitivity analysis has been used considering weighting factors and trade-off curves to help along the transmission plan identification.
- Inclusion of internal and external costs for each generation technology according to the updated estimations of several projects.
- Simulation of market behaviour and power trading
- Consideration of topological grid issues and losses

III. INTERNALIZATION OF EXTERNAL COSTS

As shown in [8] the internalization of external costs promotes new entrants in the market and increases the power trading which results to higher dependencies between the participants. Furthermore, as shown in fig. 1 it causes a deficit in social welfare due to price increment, which is much smaller than the total social benefit from the decrease of the fossil fuel power plants production.

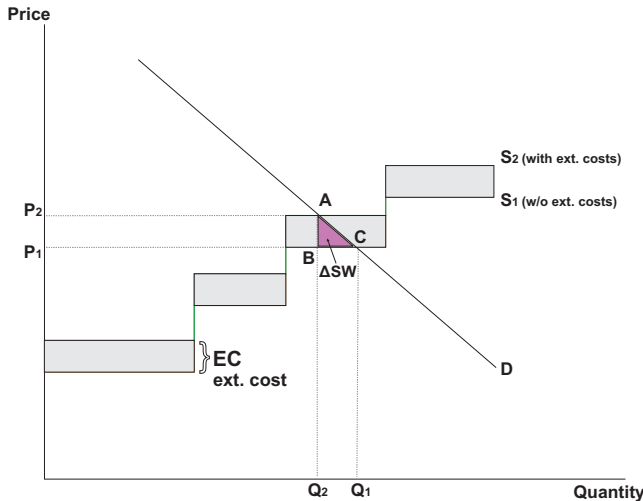


Fig. 1. Internalization of external costs in a stepwise supply function

The arisen social, mainly environmental benefits for power plant i are calculated as:

$$SB_i = \Delta G_i * EC_i, i = 1...n \quad (3)$$

where

EC_i : external cost of a power plant (€/MWh)

while the total profit of the internalization will be:

$$TP = \sum_{i=1}^n SB_i + \Delta SW \quad (4)$$

On the other hand when the transmission lines are used at their limits in order to serve the market requests, the network becomes very vulnerable but the social welfare increases because cheaper power can be dispatched.

As environmental and societal issues are part of the network operation the transmission planning is not a single dimension process any more and the identification of optimal projects turns to a subject of the decision maker preferences. That's why this paper proposes a multi-objective optimization tool for transmission planning using weighting factors for the internalization of external costs because of the high calculation uncertainty of their monetary values.

IV. MULTI-OBJECTIVE OPTIMIZATION PROBLEM

The multi-objective optimization problem maximizes the social welfare, for different internalization levels of external costs and volatile transmission security, taking into account transmission losses and linear demand function, subject to the following equality and inequality constraints. The problem described in [9] and [10] is defined in (5):

$$\max \sum_{t=1}^n \{(1-w) * SW + w * SW_{externalcosts}\} \quad (5)$$

such that:

equalities	inequalities
$G_i - L_i = losses$	$G_i, L_i > 0$
$L_i = a_i + b_i D_i$	$G_{i_{min}} < G_i < G_{i_{max}}$
	$TCL \leq TCL * a$
	$0.8 \leq a \leq 1.1$
	$0 \leq w \leq 1$

where

TCL: Transmission capacity limit

a: Transmission utilization factor

w: Ext. costs weighting factor

V. RESULTS

The presented results have been obtained using a dummy "copper plate" model consisting of five nodes and eight transmission lines. Each node is able to produce and consume power and the trading between them is allowed based on nodal prices. As depicted in fig. 2 the social welfare is minimum where the external costs are fully internalized and a security level of 80% is considered. In case that the maximum social welfare is of preference then the security of supply becomes questionable and externalities are not counted.

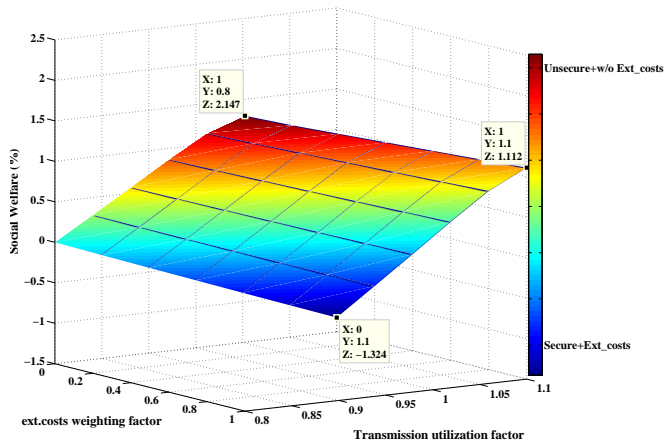


Fig. 2. Trade-off curve social welfare

The aggregated benefits can be either positive or negative according to the level of internalization. High network utilization means that cheap power which comes from conventional power plants is promoted and thus the environmental benefits decrease. A higher internalization level is required in order to compensate the negative impact of low security constraints, fig. 3.

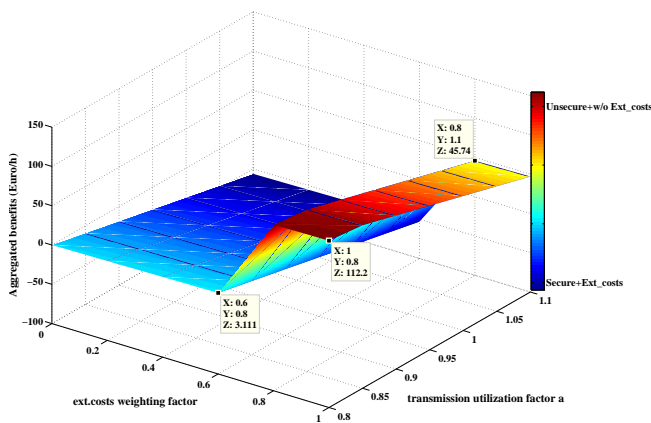


Fig. 3. Trade-off curve aggregated benefits

The final paper will focus on transmission planning, the impact of new transmission capacity and evaluation of future transmission investment projects. A detailed description and implementation of the above mentioned methods as well as an analytical documentation and evaluation of simulation results of a test power system will be presented.

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Appendix 3 PanEuropean Network Participants Analysis

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Zurich, 12th December 2008

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Introduction

Common electricity market means one common electricity network which will be operated under common norms and rules, promoting indiscriminate competition for lower prices and higher quality of service. Towards the common European electricity market one should have a closer look at the existing situation and operational environment, knowing the obstacles that may appear Europe-wide keeping in mind that this market is based on a physical network with technical constraints. The following report is focused on the European electrical power scheme, giving information about the market environment and energy balances as well as about the problems of the existing interconnected network and the plans for new transmission lines in the UCTE network, in South Eastern Europe and Scandinavia. The past applications of Optimal Power Flow (OPF) are also presented in order to motivate that the OPF is a suitable tool for the internalization of the external costs in energy production process.

It is the the first report in the framework of the project "Towards future electricity networks" which is ongoing at the Power Systems Laboratory, ETH Zurich, supported by the Swiss Federal Office of Energy.

Chapter 1

Countries Overlook

Theoretically, although the liberalization is implemented in Europe, in praxis shown that big companies dominate the national markets and sharing the biggest part of generation capacity. This situation is described in the table 1.1.

Table 1.1: Generation companies in Europe

Country	Largest Co	Other significant Co
Austria	VERBUND	RWE, E-ON, EDF
Belgium	ELECTRABEL	EDF, ESSENT, NUON, CENTRICA
Czech Rep	CEZ	RWE, E-ON
Denmark	ELSAM	E2, VF, E-ON
Finland	FORTUM	VF, E-ON
France	EDF	ELECTRABEL, ENDESA
Germany	RWE	E-ON, VF, EDF
Greece	PPC	—
Hungary	MVM	EDF, E-ON, RWE
Italy	ENEL	ELECTRABEL, ENDESA, EDISON, VERBUND
Netherlands	ELECTRABEL	ESSENT, NUON, E-ON
Poland	BOT	PKE, PAK, ELECTRABEL, EDF
Portugal	EDP	ENDESA
Slovakia	ENEL	TEKO, RWE, EDF, E-ON
Slovenia	HSE	—
Spain	ENDESA	IBERDROLA, EDP, ENEL, UNION FENOSA
Sweden	VF	E-ON, FORTUM

source: DG TREN estimates

CHAPTER 1. COUNTRIES OVERLOOK

The following section is a glance over the wholesale market regarding utilization and regulation issues in the participants of the European energy market. The following figures represent the energy balances in a time period between 2001 to 2006 in order to help the reader to understand the role of each country in the interconnected system.

1.1 Austria

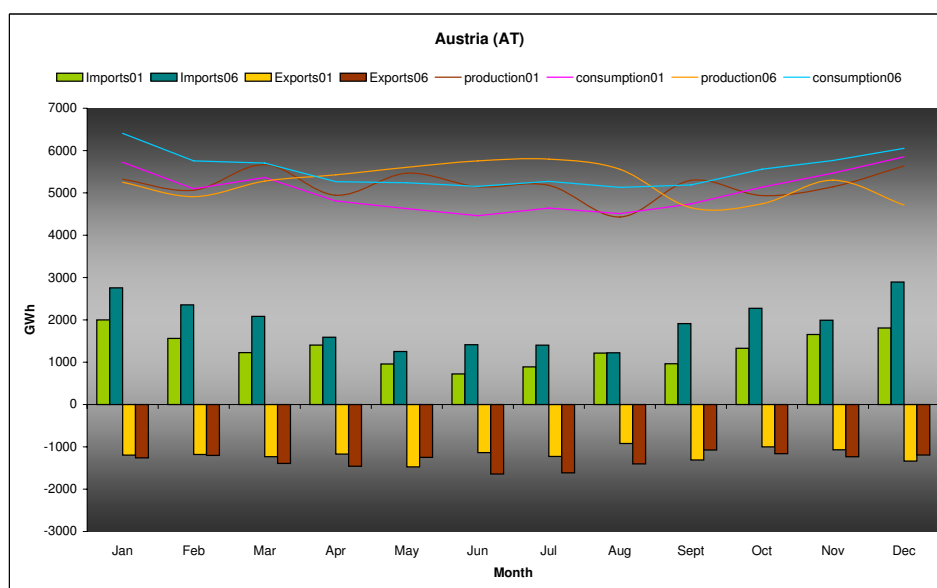


Figure 1.1: Power balance of Austria (2001 and 2006)

The Austrian electricity network is divided in three regions (North, South and West) and so the market as well. Each region (control area) has its own Transmission System Operator (TSO), TIWAG, Verbund, VKW. The wholesale market is the less concentrated market but the main problem is the high level of public ownership of electricity companies. Seven companies out of fourteen are fully possessed by the state, which form an obstacle for foreign investors. Despite the liberalization and the existence of a common wholesale market (EXAA) there is still a lack of information and transparency [1]. At the borders the only interconnection that is not congested is the one to Germany. Investments in the direction of building new lines through the country have been blocked because of environmental issues. One would say that Austria itself is the weakest link in the middle of the UCTE network. (<http://www.tiwag-netz.at/>, <http://www.verbund.at/>, <http://www.vkw-netz.at/>)

1.2 Belgium

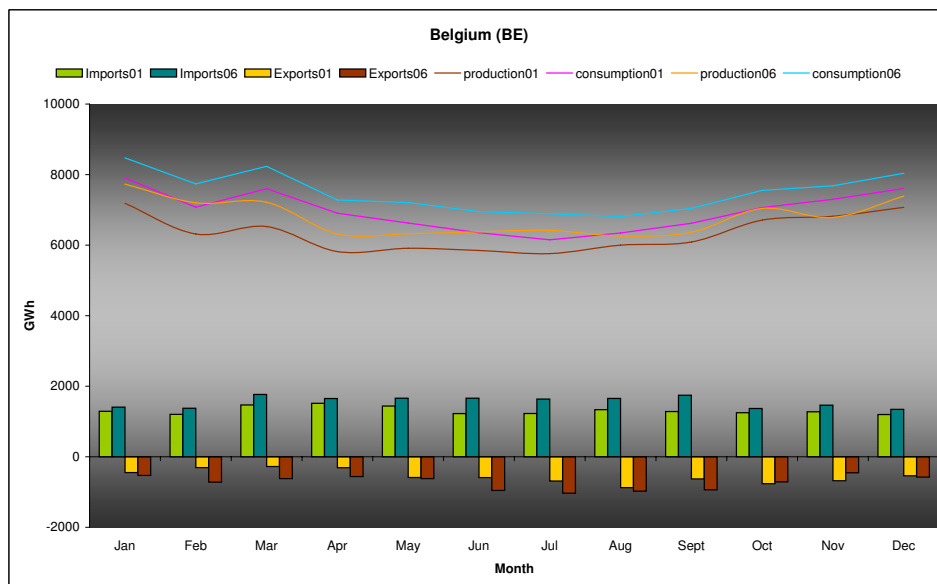


Figure 1.2: Power balance of Belgium (2001 and 2006)

Two companies (Electrabel and SPE) operate the most of Belgian system and dominate the production market. The prices in the wholesale market are not regulated, but they are still rather high as the nuclear energy was put in detention and the renewables were most promoted. The nuclear phase-out is estimated to pose an extra cost of around $2,000M\text{€}$ in 2030 [2]. Belgium is highly integrated in the UCTE network owning a large interconnection capacity to the neighbouring countries except Germany. The Belgian market BELPEX, is a member of the trilateral market coupling along with France and the Netherlands. Hence it is operating most of the time as a common price area with the Netherlands. The available capacity over the interconnections is offered monthly or daily without long term contracts in force. (<http://www.elia.be/>)

1.3 Czech Republic

In Czech Republic the retail market is fully liberalized but the wholesale market does not exist at all. Three major companies dominate the production (CEZ Group, E.ON Group and PRE Holding Group) and keep prices rather high. No congestions appear on the national grid but the interconnections to other countries are very weak and cannot support the demanded export of energy. The borders to Germany and Austria are most of the time

CHAPTER 1. COUNTRIES OVERLOOK

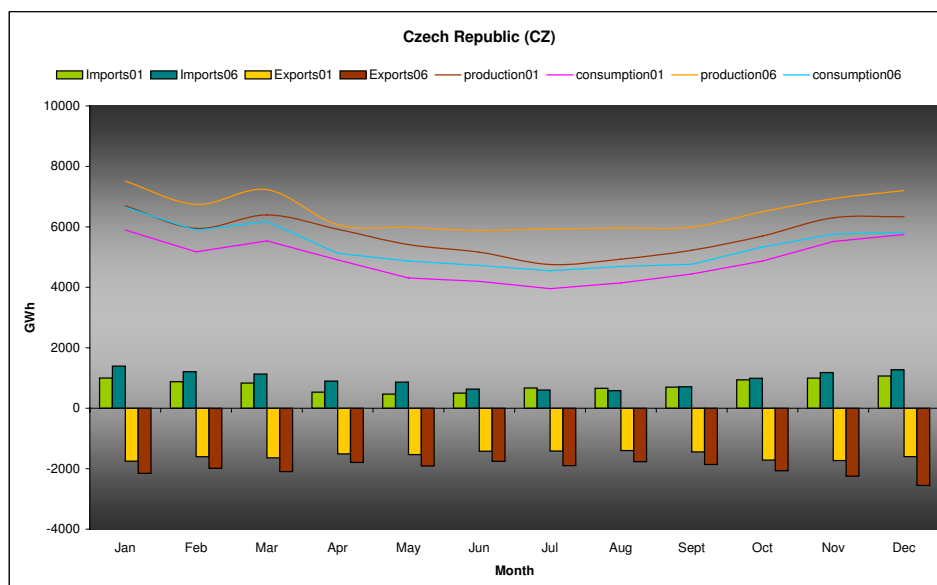


Figure 1.3: Power balance of Czech Republic (2001 and 2006)

congested and investment plans have already been accepted for the time period 2007-2014. (<http://www.ceps.cz/>)

1.4 Denmark

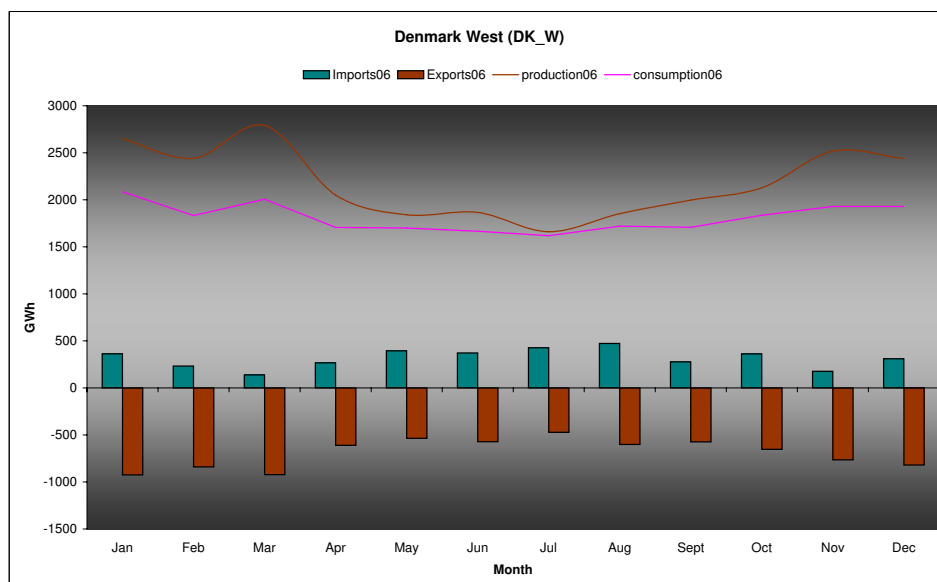


Figure 1.4: Power balance of Denmark (2001 and 2006)

Denmark is divided in Eastern and Western market without a physical connection between them. Only the Western part belongs to the UCTE network as the eastern part belongs to the Nordic cooperation (Nordel) and participates in Nord Pool market. Generation capacity seems to be sufficient for the next years without interest of new entrants. The development of the network has been focused on transmission capacity and new links which are supposed to increase competition and decrease the price differences between Sweden and Denmark. The existing HVDC interconnections (Kontiskan to Norway, Skagerrak to Sweden, Kontek to Germany) play a very important role in the coordination of the Nord Pool with markets in central Europe. The 600MW HVDC link planned for 2010, between the two parts of Denmark will help further the development of the Nord Pool. (<http://www.energinet.dk/>)

1.5 France

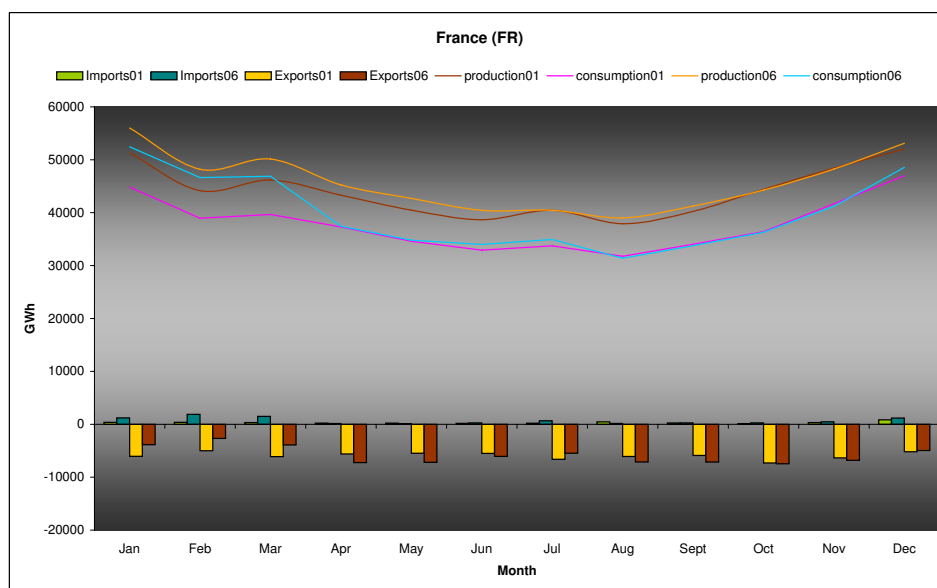


Figure 1.5: Power balance of France (2001 and 2006)

The French electricity market is characterised by a monopoly which is secured by law. EDF owns 87% of the electricity production and controls the transmission by its daughter company RTE which operates as Transmission System Operator since 2005. France is a member of the trilateral market coupling together with Belgium and the Netherlands but the insufficient interconnections capacity to Germany, Spain and Italy doesn't allow the development of a competitive, transparent local market, although the priority transmission contracts to these countries have been cancelled. Only

the interconnection to Switzerland is still operated under the regime of contracts. As the electricity in France is produced the most by nuclear power plants at low prices, France is a main exporter in the UCTE network providing electricity mainly for Italy and Switzerland. As long as the prices are set at so low level there are no initiatives for new entrants and new investments. (<http://www.rte-france.com/>)

1.6 Germany

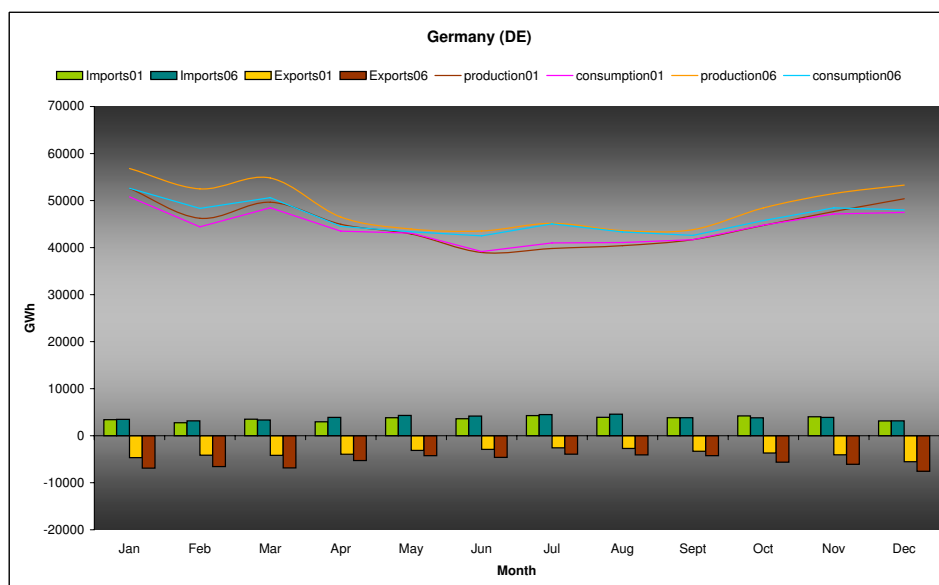


Figure 1.6: Power balance of Germany (2001 and 2006)

The German electricity market is dominated by four large producers (RWE, Eon, Vattenfall and EnBW) which occupy 80% of the total electricity generation and they share the biggest part of the wholesale market. One could say that Germany is divided in four regions which are controlled by each of the four big companies. These four companies own the interconnections and they operate the cross-border transactions of their control area's in close cooperation with the regional utilities. The remaining 20% of the market is distributed to smaller players but the profit margins are very low [3]. Germany is well interconnected to the neighbouring countries but this is not enough to satisfy the demands due to huge amount of energy trade. Interconnections are most of the time congested which is trying to be managed using market-based congestion management procedures. Unfortunately a big amount of cross-border capacity is reserved for long-term contracts with France or the Netherlands which doesn't allow a more active and real-time capacity allocation. The only not congested interconnec-

tion is the one to Austria. (<http://www.enbw.com/content/de/index.jsp>, <http://www.eon-netz.com/>, <http://www.rwettransportnetzstrom.com/>, <http://transmission.vattenfall.de/>)

1.7 Hungary

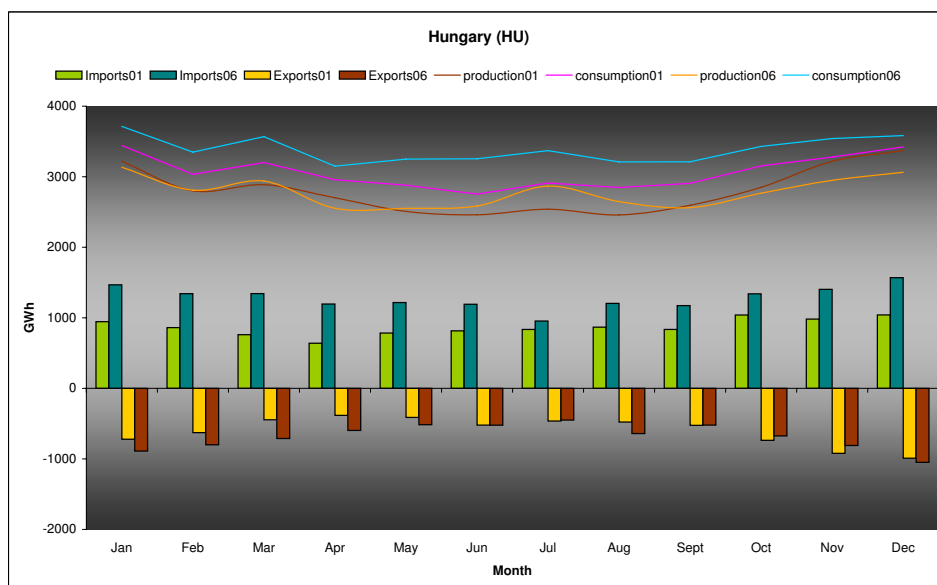


Figure 1.7: Power balance of Hungary (2001 and 2006)

The Hungarian energy market is a relative small liberalized market. In generation sector the major capacity is in possession of Magyar Villamos Művek (MVM), which except from its own generation is obliged to buy the produced energy from independent generators through the wholesale market. Hungary is a net import country of UCTE and at the same time a very important transit node for the connection between North and South, see fig. 1.7. These transit flows burden the transmission lines of the national network, which were not designed to carry this extra power flow. Projects for new transmission lines and renewal of old power plants are already on the way expecting to increase competition and transmission capacity. (<http://www.mavir.hu/>)

1.8 Italy

The Italian electricity scheme appears to be rather problematic. On market level it seems to work well since a fully functioning market does exist (IPEX) and five companies own more than 5% each of electricity generation. The

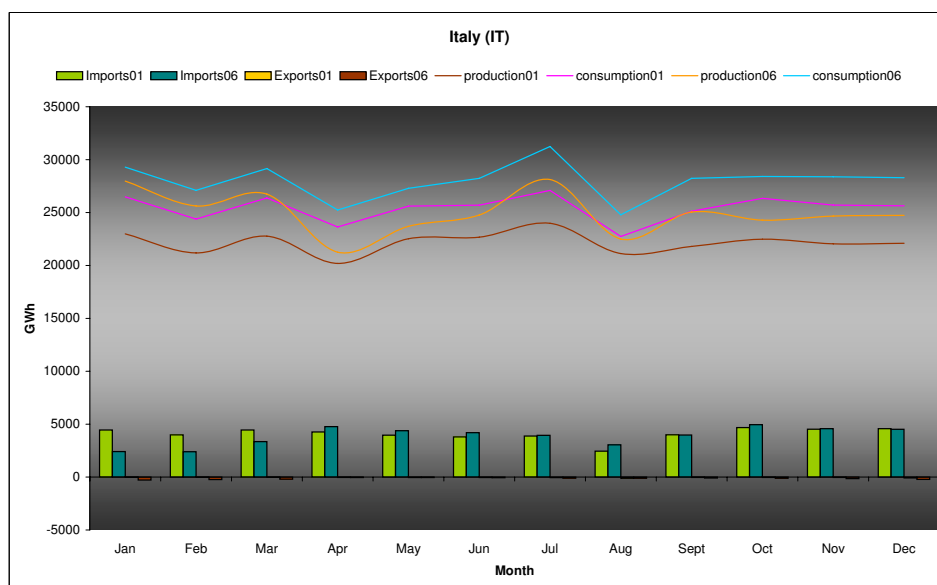


Figure 1.8: Power balance of Italy (2001 and 2006)

generation prices are still very high almost the highest in UCTE network. Hence, a price cap regulation scheme for generation bids up to 500€/MWh is applied, in order to control the prices. On production and transmission level the situation is not that promising. The lines in North and South Italy are often congested and the production capacity there seems also to be inadequate. As a result in order to cover the local demand, huge amounts of power flow from neighbouring countries (Switzerland, France, Greece and Slovenia) during the whole year. In fact the imports are limited due to congestions. (<http://www.terna.it/>)

1.9 Luxembourg

Luxembourg operates completely in dependence on the neighbouring countries. The electricity market is integrated in the German and Belgian markets and the transmission network is part of the transmission network of those countries as well. It doesn't own much generation capacity and for that reason is a net importer, basically from Germany, fig. 1.9. The capacity of interconnections is sufficient to satisfy the need for imports. (<http://www.cegedel.lu/>)

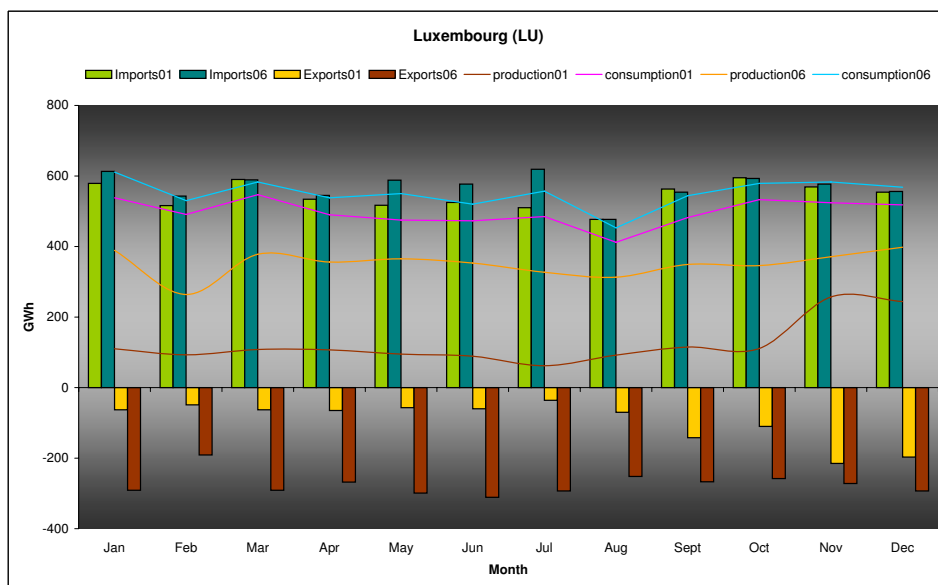


Figure 1.9: Power balance of Luxembourg (2001 and 2006)

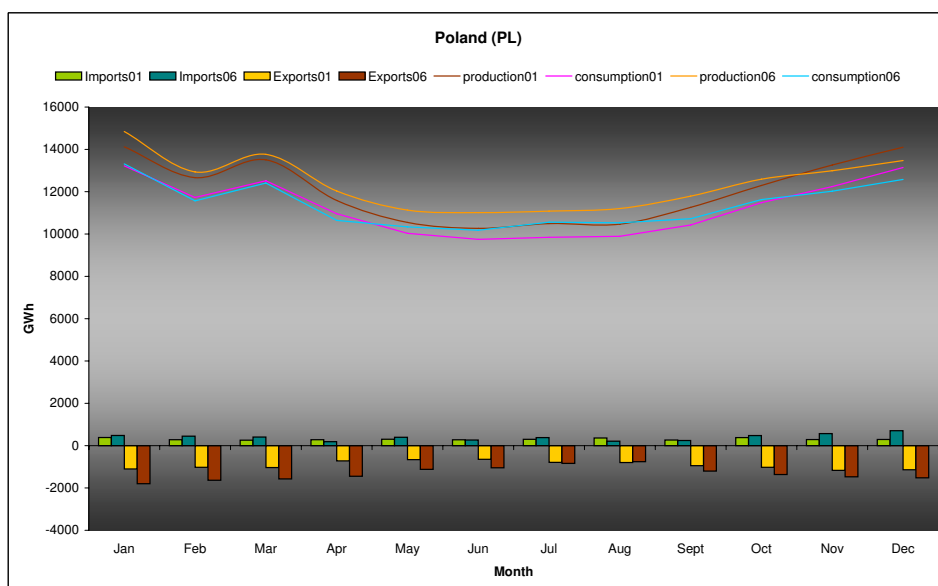


Figure 1.10: Power balance of Poland (2001 and 2006)

1.10 Poland

The Polish energy market is not developed enough to allow clear competition and new investments. The prices are regulated and electricity is traded by long-term contracts inside and outside the country. The major companies in

CHAPTER 1. COUNTRIES OVERLOOK

generation sector are BOT and PKE which together own more than 45% of the total power production. The Polish TSO (PSE) who acted as monopoly in the past, now operates under legally unbundling conditions trying to increase the liquidity of the market. The producers don't have the opportunity to sell their imbalances in a spot market and that leads to high balancing costs. The Polish network is interconnected to Czech Republic, Germany, Sweden and Slovakia. Cheap energy is produced from Coal and Lignite and thus PSE cooperates with the neighbouring countries exporting energy mainly to Czech Republic, but also to Germany, Sweden and Slovakia. Cross-border capacity is more a matter of regulation and coordination than a matter of investments. The 600MW HVDC interconnection to Sweden (SWEPOL), operated for the first time in 2000 plays an important role towards a common market and demand balance between the two countries and will do so in the future, as also the committee for the Baltic Ring Electricity co-operation (Baltrel) estimates [4]. (<http://www.pse-operator.pl/>)

1.11 Portugal

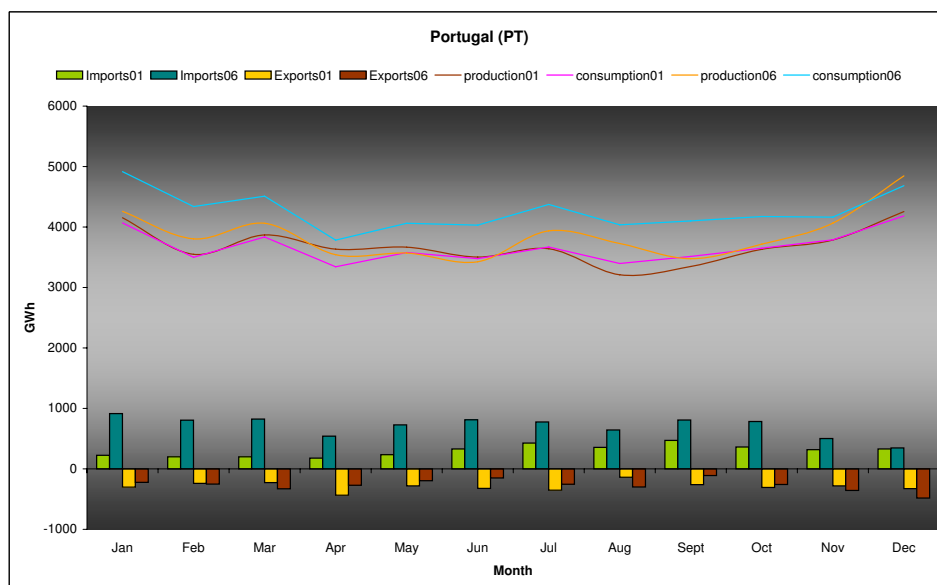


Figure 1.11: Power balance of Portugal (2001 and 2006)

The Portuguese electricity market is a small market which is dominated by three big companies (EDP, Tejo Energia, and Turbogas). An Iberian energy market (MIBEL) joint with Spain was established in 2001 but an effective competition is unable to be developed since Portugal has a small amount of production capacity, neighbours only with Spain and so is completely depended on it. Portugal is characterised as a net importer in the

European energy system according to the figure 1.11. There are three interconnections to Spain which are insufficient to satisfy the need for energy transactions. For that reason investment projects are on the way to double the interconnection capacity. (<http://www.ren.pt/>)

1.12 Slovakia

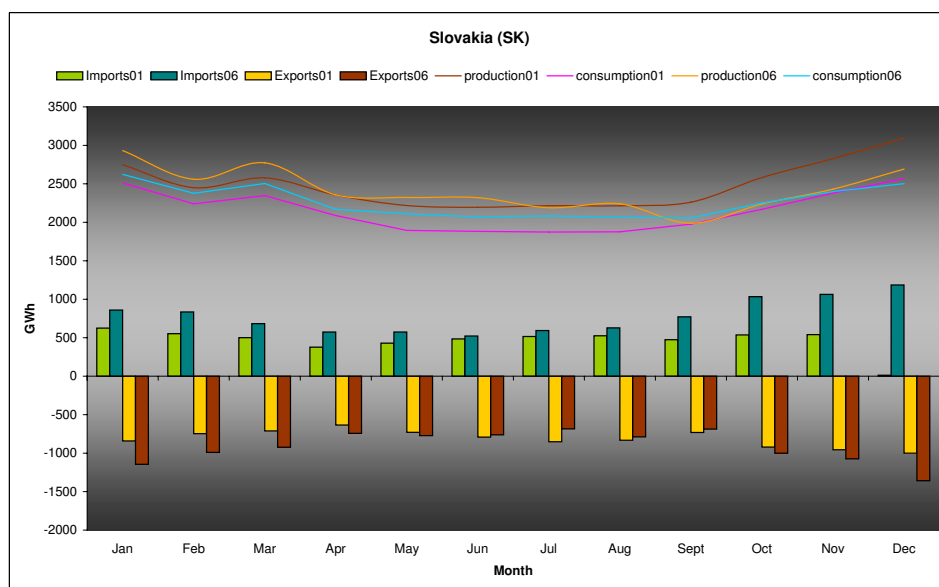


Figure 1.12: Power balance of Slovakia (2001 and 2006)

The Slovak energy situation is characterized as a monopoly. Slovenska Elektrane (SE) owns 80% of the total generation while at the same time the state gives it a hand by regulating the energy prices. Generation capacity is still sufficient, but in order new traders to entry the market, there are thoughts to decrease production creating a deficit which is going to be covered by imports. So far energy has been conveyed to Hungary and Ukraine. A new 400KV transmission line to Austria is planned which will be the direct gate to the western transmission system and is going to support the transmission from east to west. (<http://www.sepsas.sk/>)

1.13 Slovenia

The electricity market in Slovenia is practically non existent. The major problem is that the Regulator is not powerful enough and thus cannot regulate the market inside the country and cooperation with neighbouring countries is very weak. The Slovenian transmission network is overstressed be-

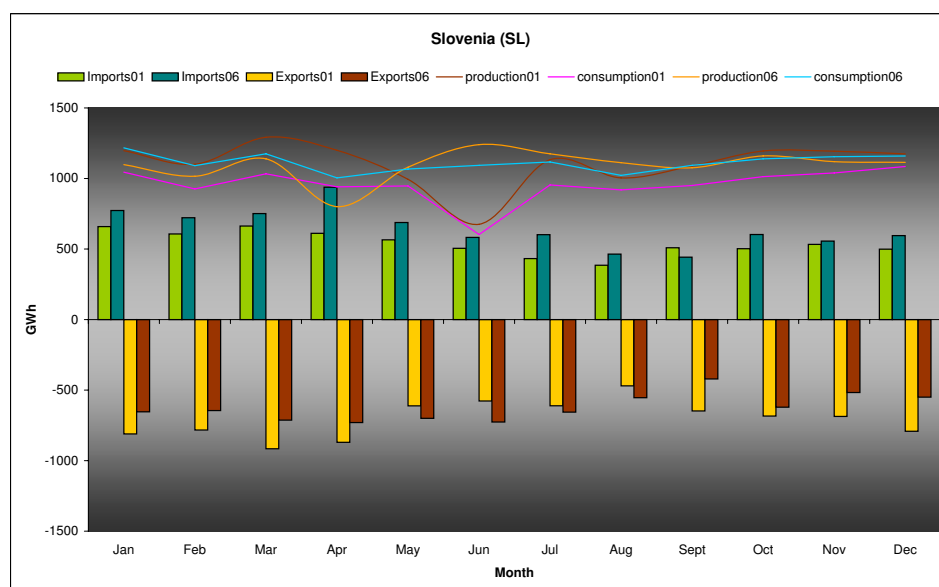


Figure 1.13: Power balance of Slovenia (2001 and 2006)

cause of additional transit flows through the system. In the figure above is remarkable that Slovenia is not any more a net exporter all the year round, but it's export capability has been limited to 6 months only. The reason for that is not that clear and can be based on operational changes in other countries, on climate change or even on a different market strategy the last years. (<http://www.tso.eles.si/>)

1.14 Spain

The Spanish market is also controlled by three big companies without any new companies being foreseen. The prices are regulated at a low level and the incentives for new generation entrants are missing. Spain dominates the problematic Iberian market but has no power on the European market as a result of low interconnection capacity to France. Most of the time energy is exported to Portugal and sometimes just transits energy from France to Portugal. Since the consumption of Portugal has been increased without the same increment of production, Spain has to change strategy slowly and produce more than the inland demand, as is represented on the figure 1.14. There are three interconnections to Portugal and three to France but more cross-border transmission lines are needed in order to be more integrated in the European interconnected system. (<http://www.ree.es/>)

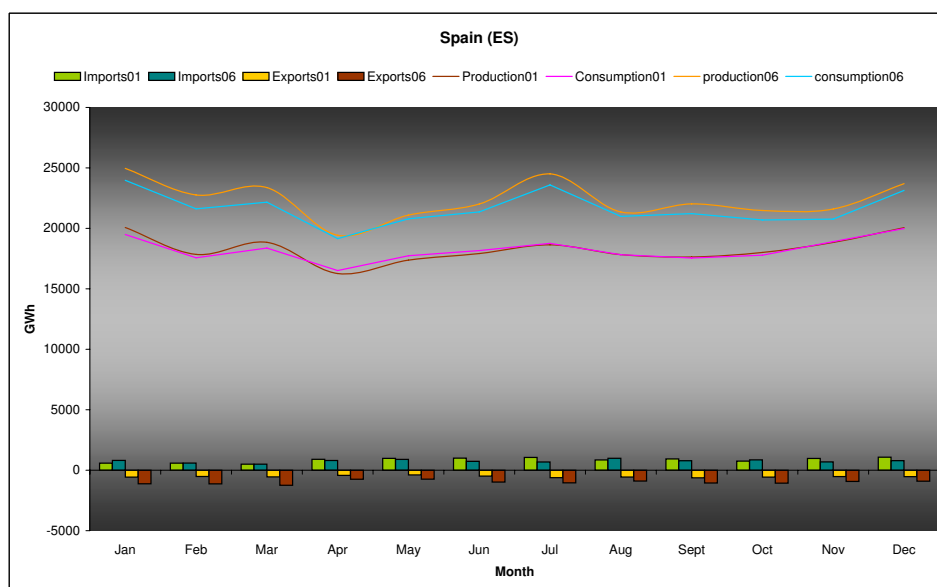


Figure 1.14: Power balance of Spain (2001 and 2006)

1.15 Switzerland

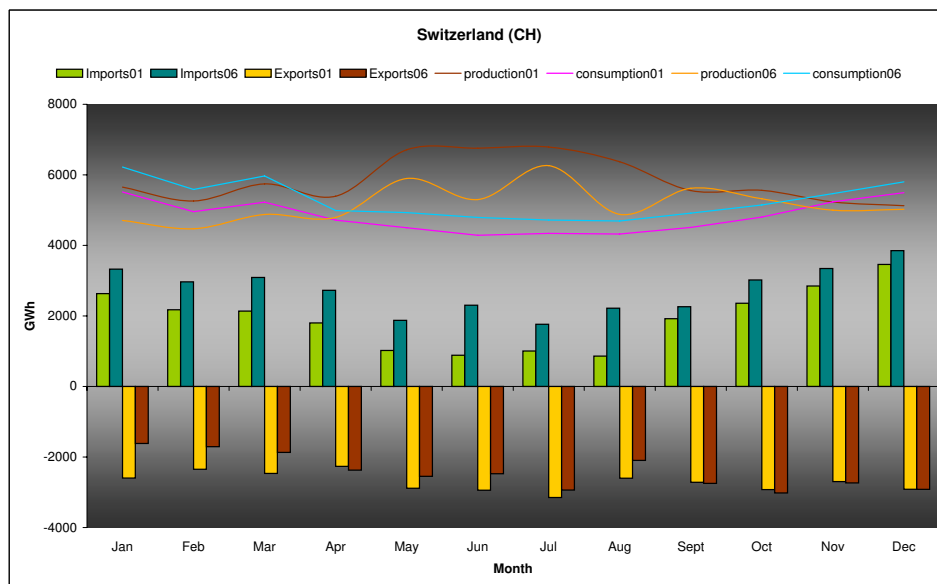


Figure 1.15: Power balance of Switzerland (2001 and 2006)

The Swiss electricity market is a newly liberalized electricity market since 2007, but the new regulatory framework will not come into force until October 2008 [5]. Switzerland is at the moment the most important node

CHAPTER 1. COUNTRIES OVERLOOK

in the interconnected European system because of its geographical position. As it is located in the middle of Europe it controls a big amount of imports and exports and leads the operational center of UCTE network. The Swiss regulator is every minute of the day very well informed of the situation in Europe and has to be in contact with countries around Europe in order to secure the uninterrupted energy flow. The cross-border capacity is mostly reserved from bilateral contracts but also auctions are taking place. Basically Switzerland is identified as exporter and only during the winter it is depended on imports, mainly from France, figure 1.15. As long as the interconnection between France and Italy remains insufficient, transit energy flows also through Switzerland overburden its transmission network. The main reason for congestions inside the country could be characterized by the transit and loop flows produced from energy trading actions between neighbouring countries. The Swiss Federal Council has already approved new transmission projects considering in the majority of cases 380-400kV lines to Italy. (<http://www.swissgrid.ch/>)

1.16 The Netherlands

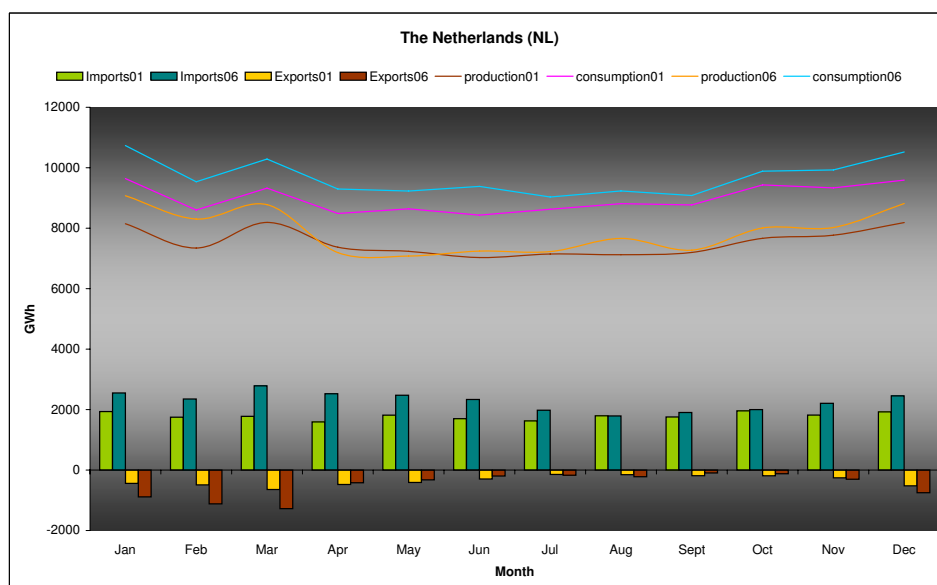


Figure 1.16: Power balance of the Netherlands (2001 and 2006)

The Dutch electricity market is the most de facto liberalized in the UCTE network. Four big companies (Electrabel, EON Benelux, Essent and Nuon) control 65% of the total generation but there is still opportunity for other participants in the market. Although the prices for end-customers are quite low, resulting from the full market competition, the prices in the wholesale

market remain on higher levels than in the neighbouring countries because electricity is basically generated from gas power plants. That means that the Netherlands need to import cheap energy from other countries, as it is also shown in the figure 1.16. The 700MW HVDC connection to Norway (NorNed), which is in service since November 2007, is going to help in that direction providing cheap hydro energy from Norway. On the continental side there are eight interconnections to Belgium and Germany which seem to be sufficient but more capacity is welcome. There are some ideas to increase cross-border capacity such as to adjust the security level according to the customer's preferences in their security of supply. (<http://www.tennet.org/>)

1.17 NORDEL

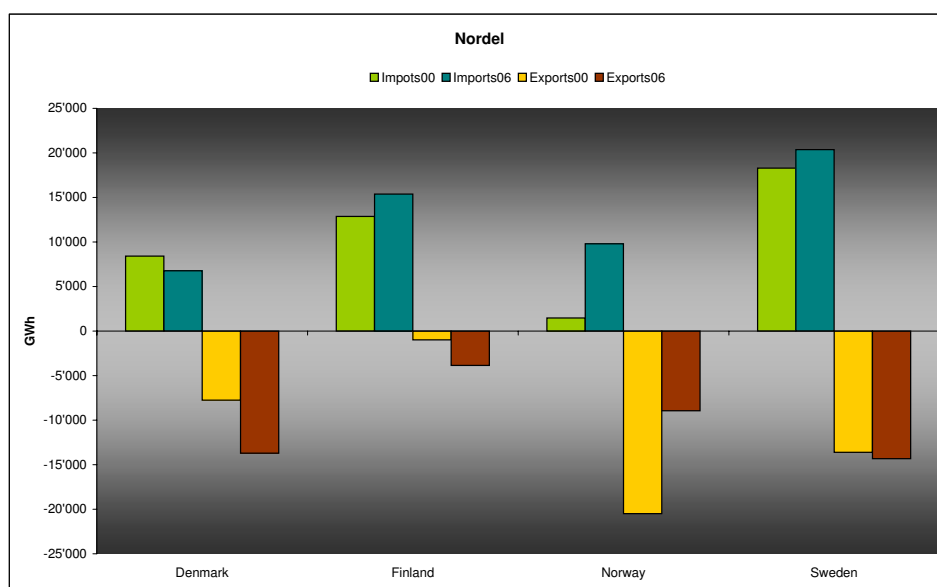


Figure 1.17: Exchange of electricity in Nordel (2000 and 2006)

Nordel is the organization of the Nordic Transmission system Operators (TSOs), namely Energinet from Denmark, Fingrid from Finland, Landsnet from Icelnad, Statnett from Norway and Svenska Kraftnät from Sweden. Nordel is the pioneer in market coupling and collaboration between countries for energy trading. The wholesale market, Nord Pool, is an open, transparent and liquid market although some phenomena of power gaming in production still do exist. There is a big interest for renewables and small-scale generation mainly in Finland and Sweden which is going to allow new entrants in the market. The transmission network is well developed but new investments are of importance to strengthen the weak points i.e. in Sweden, in Norway or between the countries. Generally bottlenecks do

not prevent trading, however, a discussion is on the way, whether Sweden should be considered as a single price zone or should be divided in more because of some congestion that appear on the South. Nordel concentrates the biggest amount of capacity operating through HVDC lines. The HVDC connections from Nordel to UCTE are going to influence strongly the future of the internal market in central Europe [6].

1.18 South Eastern Europe (SEE)

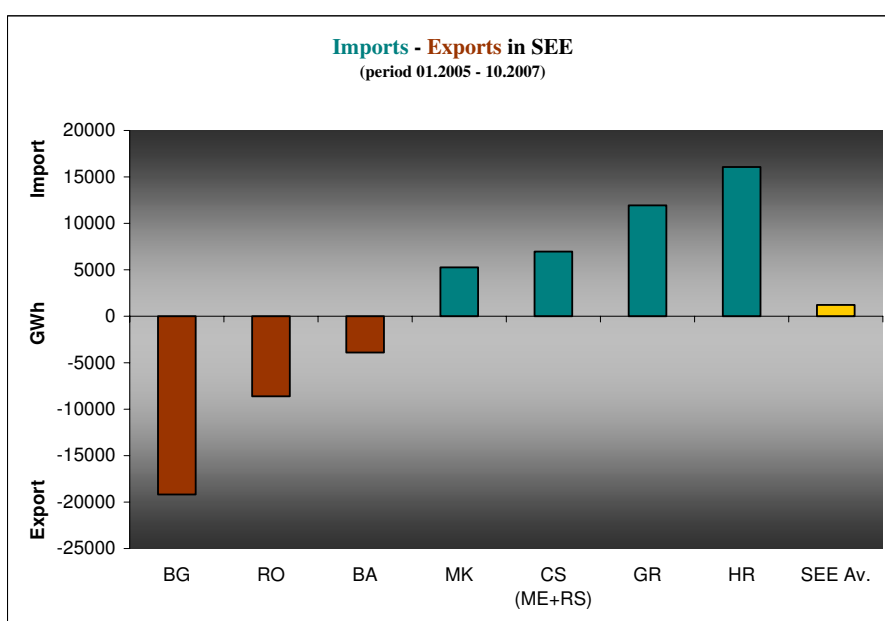


Figure 1.18: Total exchange of electricity in SEE (2005 - 2007)

SEE are the countries Bosnia & Herzegovina, Bulgaria, Croatia, Greece, Former Yugoslav Republic of Macedonia (F.Y.R.O.M.), Albania, Rumania, Serbia and Montenegro, known as 2nd UCTE synchronous area. This region is considered to consist of rather new members of UCTE region due to war destructions in the former Yugoslav. The prices are regulated in the majority of the cases and a regional electricity market is on the way, but due to remarkable political and economical differences among the countries the process will be behind schedule [7]. The region is pretty well integrated in the 1st UCTE synchronous area on the west side to Italy through a 400KV HVDC connection from Greece and on the north side through 4 interconnections to Hungary and Slovenia. On the east side the existing interconnection from Bulgaria to Turkey and the not yet fully operated interconnection from Greece to Turkey is only for stabilization and balancing. Inside the SEE region Serbia is the north gate and except for imports and exports is considered

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as a very important transit node. Bulgaria and Romania with high nuclear production share are the main exporters of the region and Greece along with Croatia are the main importers, see figure 1.18.

In any case SEE is an interesting area for investments as reconstruction is needed. Many changes are going to be observed since the renewal of old power plants, the detention of the nuclear power in Bulgaria, the build up of new transmission lines in order to cover the increasing demand in more and more developing economies. During this reconstruction more clear energy should be taken under consideration as the region is environmentally heavy burdened.

Chapter 2

Problems of the existing European interconnected system

In addition to the described market imperfections in chapter 1 the present European interconnected electricity system faces also other problems related to technical and environmental issues, as follows:

1. Cross-border trading / consumption doubled last decades.

After liberalization the cross-border connections became very loaded in order to serve the big amount of energy that was demanded from the countries in order to keep national prices low or just to balance their system, figure 2.1. Besides the economic growth of the European coun-

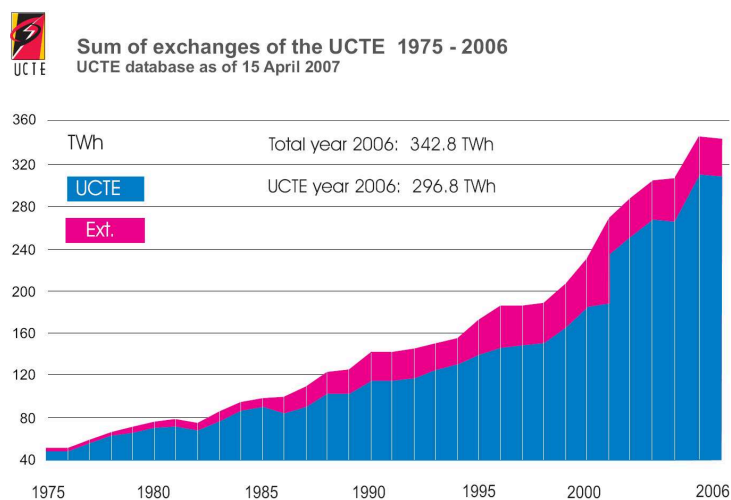


Figure 2.1: Sum of exchanges of the UCTE 1975-2006

CHAPTER 2. PROBLEMS OF THE EXISTING EUROPEAN INTERCONNECTED SYSTEM

tries the need for energy in developing countries inside Europe lead to increased consumption about 0.8-1% every year [8]. The problem is that often certain transmission lines are operated at their capacity limits, and specific congestion management schemes must be implemented to allocate the transfer capability between the different actors.

2. Frequent Outages / Blackouts

As the transmission lines are operated at their capability limits, the transmission system has become more stressed and more prone to failures that could lead to wide spread power outages, blackouts. This is reflected in the occurrence of blackouts and near-blackouts during the last years.

3. Inevitable Renewal of Power Plants

The majority of the power plants in Europe are old and many of them will be decommissioned before 2030 [9] for political, environmental or economical reasons. The generation expansion plants refer either to repowering of existing sites or brownfield expansion as it's also called, or to bigger new power plants in other locations. The first option doesn't seem so promising because the existing sites are near residential areas, are small and even if they use green energy will not be able to cover the demand. The second option includes new larger power plants, nuclear, gas powered, etc, built to replace outdated plants, which will not be built on the same geographical locations as the old ones, while the consumers can to a large extent be assumed to remain at the same geographical locations.

4. Non-dispatchable production

Renewable energy sources have been used and will be more and more according to the latest EU directive [10] for environmental compatibility. Plans to install substantial amounts of wind power in many countries, in addition to the existing significant wind power capacity, will consequently impact more the operation and stability of the system.

5. Increased transmission distances in the interconnected system

Very often the transmission from production to consumption place crosses the borders of one or two countries. Hence losses are higher and the capacity of the transmission system becomes narrowed due to loop flows. A typical example is the decreased capacity in the Swiss transmission network because of the energy transits from France to Italy.

6. Negative effects of electricity production

CHAPTER 2. PROBLEMS OF THE EXISTING EUROPEAN INTERCONNECTED SYSTEM

The energy production in Europe is based primarily on fossil fuels which are much cheaper and competitive but not sustainable due to emission and environmental concerns. The fossil fuel power plants, as well as other types of power plants, are the main sources of CO_2 , NO_x , SO_2 and fine particles (PM). Hence, a number of negative effects are resulting, whose costs are not represented in the electricity prices, known as external costs, figure 2.2. These costs associated with the power production refer to environmental damages, health impacts and climate change respectively. The external costs will be analyzed later on.

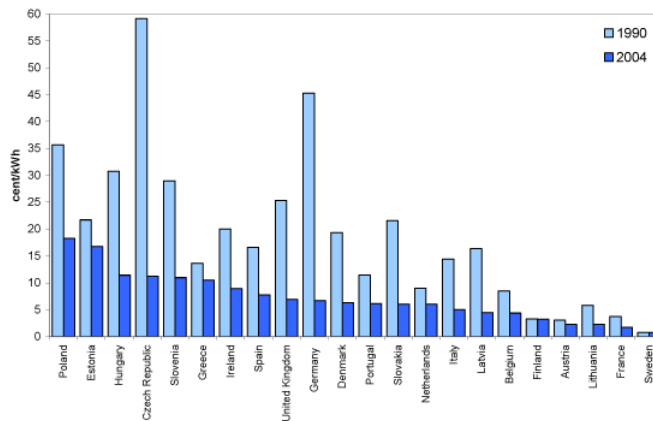


Figure 2.2: External costs of energy production EU-25, high estimate

Chapter 3

Investments in transmission lines

To overcome the above mentioned problems the long-term planning for electricity should not be based only on generation planning but also on new transmission projects. Transmission projects ,may be new transmission lines or installation of new technologies e.g. FACTS devices. As the [11] also concludes, the present European interconnected network is insufficient to become the backbone of the future electricity network. Of the members of ETSO around 63% are legally unbundled [12]. However investments in transmission are not promoted from the vertically integrated companies. The reason for that is that they don't want to risk their market share increasing the transmission capacity. As the table 3.1 depicts the reinvested congestion revenues from vertically integrated companies in the period 2001 - 06.2005 was only 16.8%.

Table 3.1: Ownership unbundling in EU-15

	Ownership unbundled TSO_s	Vertically integrated TSO_s
Congestion revenue (2001-6/2005)	387	623
Interconnector investment	129	104
Share of reinvested congestion revenue	33.3%	16.8%

source: Energy sector inquiry

Of course not only the limited ownership unbundling put barriers for new transmission lines but also the previous described differences between the countries regarding the operation of the electricity market which draw an

CHAPTER 3. INVESTMENTS IN TRANSMISSION LINES

unclear framework. In order to propose new transmission projects one should consider also policy and terminology differences in the involved countries shown at the end of this chapter, table ???. This also means that the time to build a transmission line varies significantly between countries, and the completion is often hard to forecast, [13].

Summarizing the obstacles for new transmission lines investments, as they are also described in [14], one could mention:

- Limited ownership unbundling
- Transmission investments practices and public acceptance differs from country to country
- Financial transmission rights are not enough to provide investment incentives when the investments are based on economies of scale
- Lack of a centralized authority to monitor the investors in order to avoid profitability modifications of the system
- High negotiation costs in order to avoid the obstacles

After the liberalisation of the electricity market the decision criteria are based on many uncertainties like future power plants, load growth prediction, demand elasticity, market prices, bilateral contracts, bidding behaviour etc. [15]. As an example in SEE the TSO's still use the same criteria as before liberalisation without implementing any market behaviour in their planning process [16].

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According to a study that has been completed for the European Union in order to estimate the costs for new transmission lines [17], for a double circuit 380kV overhead line the cost range is shown on the table 3.2 (as base case cost has been considered 401,000€/km):

Table 3.2: Transmission investment costs 380kV overhead line

	Euro '000/km	Specific cost factors
Finland, Sweden	200 - 300	Flat land(fewer towers), less populated
Greece, Portugal	200 - 300	Low costs (land, labour)
Denmark, Norway, Spain	300 - 400	Close to base case
Belgium, Nether- lands, Italy	400 - 500	Close to base case, heavily populated
France, Germany	500 - 600	Heavily populated, high labour costs
UK(England & Wales)	600 - 800	n-2 standard applied, more towers/km, high right-of-way costs, heavily populated
Austria, Switzerland	600 - 800	High environmental issues, topography, high wind pressure limits, high labour costs

At the moment there are 29 projects running in the central and north Europe, called priority projects in different phases of the transmission planning [18]. These projects target at higher capacity of the interconnected lines in order to relieve congestion while on the other hand 3 projects in SEE, to be completed by the year 2009, tend to increase the reliability of the system [19].

Below follow a summary of transmission planning practices in different countries [20]:

CHAPTER 3. INVESTMENTS IN TRANSMISSION LINES

Table 3.3: Planning practices in the various member countries

Country	Environmental Impact Assessment	Public Consultation Meeting	Con-sultation	Compensation to Landown-ers	Right of Way for double circuit lines	Special Solu-tions Compact Designs etc.	Time span for ap-provals
Austria	Full above 110 kV if exceeding 15 km route length	Yes for de-tailed study		Yes for af-fected use of land but no for EMF or visual Impact	110 to 380 kV up to a corridor of 2x30 m	Compact designs advo-cated, camou-flage & each tower inves-tigated by a specialist	Not specified
Belgium	For lines of 220 kV and more, of 15 km or longer, not for under-ground cables or substations	Possible for lines and cables, pending on the size and tension	for and de-pending on	Yes, if land is bought or used for sub-stations, lines or cables. No for EMF or vi-sual impact	No right of way is fore-seen in the Belgian leg-islation	Special design when obliged by a competent authority	From half a year for under-ground cables of 36 kV, up to more than 8 years for 380 kV lines
Czech	Not specified	Not specified		Yes for af-fected use of land but no for EMF or visual impact	110 to 400 kV up to a distance of 20 m from outside conductor	Not specified	Not specified
Denmark	Full above 100kV	Not specified		Yes if a new 400 kV line will pass less than 50 m from a farmhouse, for 132/150 nearer than 35m	Yes but not specified	Special designs of towers are looked for through design competitions	Not specified
Finland	Full for 220 kV for lines 15 km long Below de-pending on appropriate Authority	Yes for trans-mission lines and substa-tions		Yes for af-fected use of land but no for EMF or visual Impact	Yes but not specified	Not specified	From 3 to 5 years

CHAPTER 3. INVESTMENTS IN TRANSMISSION LINES

France	Full above 63 kV	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	Yes but not specified	Special designs where dictated by a competent Authority	Not specified
Germany	Lines and cables in areas under nature protection	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	110 to 380 kV specified to the line and the landowner	Special design due to local situation in agreement with the authority	From 3 to 5 years
Italy	Full for 380/220 kV transmission lines longer than 15 km, below depending on Regional Authorities laws. For 150/130 kV transmission lines depending on Regional Authorities laws	Authorisation procedure requires the entity in charge of the realisation of the new facility to make public announcement to the interested parties, in order to collect all the objections (if any)	Yes for the permanent disadvantages they have to suffer	130 to 380 kV up to a corridor of 50 m	Compact designs where dictated by a competent Authority	From 2 to 8 years
Luxembourg	Full above 65 kV	Not specified	Yes for affected use of land but no for EMF or visual Impact	65 kV to 220 kV up to a corridor of 60 m	Special designs where dictated by a competent Authority	Not specified
Netherlands	Full for 220 kV for lines 15 km long. Below, depends on appropriate Authority	Not specified	Yes for affected use of land but no for EMF or visual Impact	Not specified	Not specified	Not specified
Norway	Full above 33 kV	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	Yes but not specified	Special designs where dictated by a competent Authority	From 2 to 3 years
Poland	Full above 110 kV but between 110 and 220 kV depending on appropriate Authority	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	110 to 400 kV to a corridor of 2 x 33,2 m	Not specified	Not specified

CHAPTER 3. INVESTMENTS IN TRANSMISSION LINES

Portugal	Full above 110 kV	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	Yes but not specified	Not specified	From 3 to 5 years
Slovenia	Not specified	Not specified	Yes for affected use of land but no for EMF or visual Impact	110 - 400 kV up to a corridor of 50 m	Not specified	From 3 to several years
Spain	Full for 220 kV for lines 15 km long Below depending on appropriate Authority	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	Yes but not specified	Special designs where dictated by a competent Authority	Not specified
Switzerland	Full for transmission works	Yes for transmission lines and substations	Yes for affected use of land but no for EMF or visual Impact	Yes but not specified	Special designs where dictated by a competent Authority	From 5 to 15 years

Chapter 4

The Optimal Power Flow (OPF)

Since new transmission investments are required in order to reinforce the present transmission system, a new planning tool considering the new challenges is also necessary, as also referred in [21]. This planning tool could be based on the well known Optimal Power Flow as explained in this chapter. The power flow calculation is a method to find out which direction the power flows and how this power is distributed on the transmission lines, with given generation and load data. It gives also information about the system conditions e.g. bus voltages, transferred reactive power, overloaded lines etc . In a similar manner an optimal power flow (OPF) is a static nonlinear optimization method that solves the problem of power flow when different criteria are to be satisfied subject to equality and inequality constraints. In the simplest case, an OPF can be viewed as a method that solves the problem of minimizing the total cost, or mathematically minimizing an objective function satisfying the power flow equations [22].

The OPF problem can be formulated as [23]:

$$\begin{aligned} & \text{minimize } f(u,x) \\ & \text{s.t. } g(u,x) = 0 \\ & \quad h(u,x) \leq 0 \end{aligned}$$

where $f(u,x)$ is the objective function, $g(u,x)$ and $h(u,x)$ represent the power flow equations and inequality constraints e.g. line loadings respectively and u, x are the requested values that minimize the objective function.

In general, OPF is applicable when a) studying a problem that requires interactive use of conventional power flow, b) for cases involving conflicting and independent variables and requirements [24] like in the case of minimizing the operational costs considering environmental impacts of energy production and network reliability.

A detailed survey of the OPF literature from 1930 to 1991 can be found in [25]. There it is shown that the OPF is the oldest (for the first time presented in 1962) operational planning method in power systems. The mostly applied objective functions for operational planning as described in [26] are presented here:

- **Minimization of production costs**

$$\min C = \sum_{i=1}^n (C_{G_i})$$

Before the liberalization of energy markets the power dispatch was a result of an OPF whose only optimization objective was to minimize the total production cost of the power plants. After the liberalization, the OPF has been modified, at least in some markets, to be used to determine the clearing price and the dispatched generators based on the bids of the generators but still the problem was to minimize the operational cost.

- **Minimization of active power losses**

The active power losses are the losses on the transmission lines and are measured like as the difference of the total generated power to the total power consumed.

$$\min P_{Loss} = \sum_{i=1}^n (P_{G_i} - P_{L_i})$$

- **Fast transition from a violated to a non-violated network state**

When a contingency occurs the system has to recover as fast as possible in order to avoid instability problems and dispersion of the occurrence. So the optimization problem is time dependent but as the OPF does not consider time variable, the idea is to find a steady state where no constraints are violated, with the minimum control variables movements.

$$\min F = w^T * 1$$

Over the years, due to the flexibility and the easy modification of the equality and inequality constraints, the OPF became a very useful tool able to handle also other problems under market conditions like:

- **Generation expansion planning**

In that case the OPF has been used in order to allocate the new generation capacity [27]. In the objective function the new capacity is presented as quadratic cost function with negative coefficients and the existing capacity as generators with constant output. The obtained capacities from the minimization of the production costs satisfy the system constraints.

- **Transmission expansion planning**

The OPF based on probabilistic power flow has been used for the calculation of the locational marginal prices (LMP) in order to characterize the candidate buses for new lines installation [28]. The latter approach uses AC-OPF even though the comparison between AC and DC for the calculation of LMP's [29] brings the DC-OPF in the first place just because it is faster. Also together with sensitivity analysis, it has been used for decision making [30] or educational purposes [31] in transmission planning.

- **Maximization of social welfare**

Under the open market environment a commonly used indicator for the assessment of the market operation and the several future scenarios is the social welfare implemented in the power flow optimization [32, 33].

As described in [34] the OPF is capable to represent the characteristics of the modern liberalized electricity market and to support the market-based system analysis [35], [36], as well as to solve the problem of the multiple energy carriers [37]. Furthermore, the OPF is able to combine conflicting and independent variables to the optimal point. Hence it is eligible for solving the problem of aggregation of contradicting interests in power systems, the so called multi-objective optimization problem as described in [38] and [39]. Indeed the multi-objective optimization tool gets more and more the attention of policy and decision makers due to the need for studying bigger, more complex and more realistic systems.

Chapter 5

External effects in energy production

Although the concept of the external effects was known in the economic community almost a century ago, the problematic in the energy supply and the estimation of its external effects started in the eighties. Firstly only as a research field in the academic community and then as energy policy issue while the impacts were becoming more and more noticeable. The energy production, as all other industrial activities, is associated with external effects (externalities) that are imposed on others [40], and usually are not included in the market price. The external effects, as they are described from P. Eisenhut [41], are costs or profits, that arise during the production or the consumption of goods, however they are not carried or enjoyed from the source or the receiver, respectively. Thus, the external effects can be either positive or negative.

Positive (external benefits): are the external effects when their impact is beneficial not only for the producer/consumer but also for third persons, like e.g. the usage of renewable energy sources for the energy production.

Negative (external costs): are the external effects when their impact is disadvantageous for third parties e.g. the noise disturbances of cars or loud music.

In the energy sector the most considerable external effects are negative effects, which affecting external costs, because of the usage of fossil fuels in energy production. Fossil fuels power plants produce dangerous and harmful gases (CO₂, SO₂, NO_x, etc.) which have negative impact on the environment and on the human health. Another example of external costs is the extremely high risk of environmental impact in case of an accident in a nuclear power plant, or the ecologic and aesthetic disturbance of wind mills in farm fields, or even of overhead transmission lines. The comparison of the negative impacts is a difficult issue as they are very independent on each other. Some effects have areal influence while others global. Some live for

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short time other for long time etc. The external/indirect costs can be characterized as environmental and societal, which is summarized in the figure 5.1.

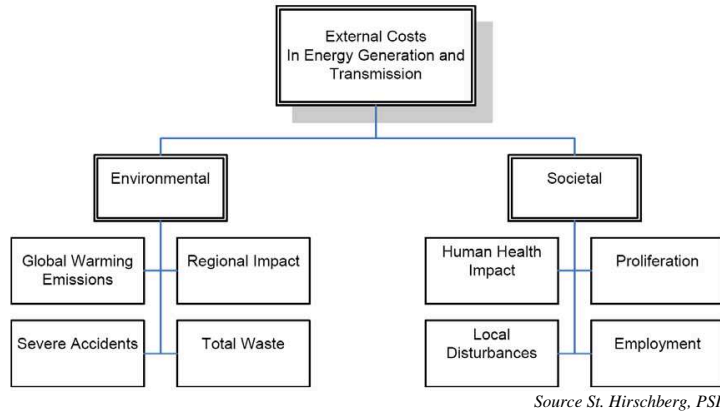


Figure 5.1: External costs in generation and transmission

In order to be able to compare several technologies and their external impacts, the least common denominator has to be found. The most accepted denominator is the monetarization of the external effects.

Each generation technology except of its social advantages is characterized by a value of damage. Many projects supported by the European Commission like ExternE or CASES try to estimate this imposed damage and to present it as a monetary value in order to internalize these values in the market operation. According to the drivers that define the values each production source, the external costs have been estimated, see fig. 5.2:

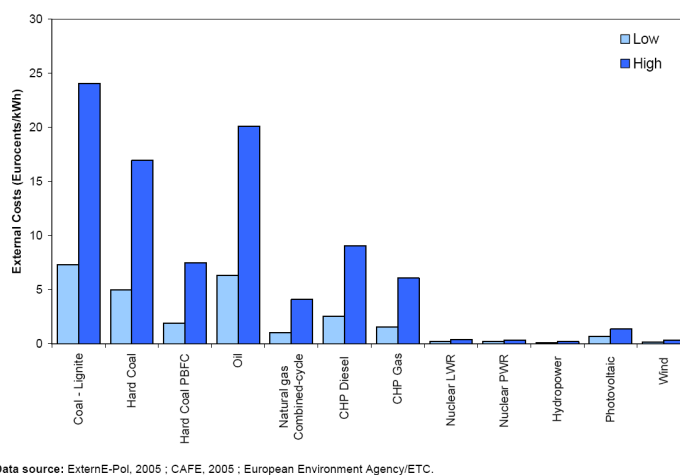


Figure 5.2: Low/High estimation of external costs

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The internalization of external costs means that the price for the same quantity of produced energy will be larger due to the consideration of the imposed costs in generation process. According to the market behaviour the produced quantity is going to decrease as well. The figure 5.3 describes the situation after the internalization.

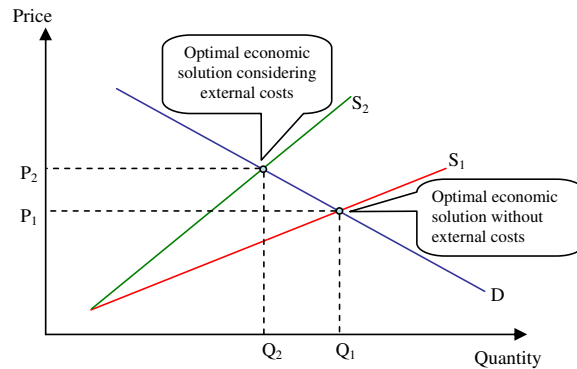


Figure 5.3: Internalization of external costs

As a result one could imagine that the new green technologies become more competitive and more advantageous in comparison to the old used production technologies. Furthermore, although the prices get higher and one could expect a loss of social welfare, the social benefits from the internalization are able to compensate this loss.

A more detailed explanation of the problematic and the methods for estimating the external costs will follow within this project.

Conclusions

Concluding, the outcome of this report is that to create a PanEuropean Electricity Market, coordination between market players and decision makers under a common regulation framework is required. A functioning wholesale market is existing but is still characterized by many imperfections that narrow the market tolerance for new entrants.

It has been argued that the present European interconnected network is insufficient to become the backbone of the future electricity network. While the demand is increasing new coordinated sustainable investments in transmission and generation are needed in order to secure the supply and enforce the market without burdening the environment. This means that a new planning tool based on multi-objective optimization is needed to consider all these new criteria in transmission and generation expansion planning and this planning tool could be based on the Optimal Power Flow considering the external costs of energy production in trying to maximize the social welfare for the next generations.

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