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In the jungle of regulatory instruments

Analysis of the interaction of regulatory instruments dealing with the market failures of the electricity sector

PhD dissertation

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Budapest, 2014

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Acknowledgements

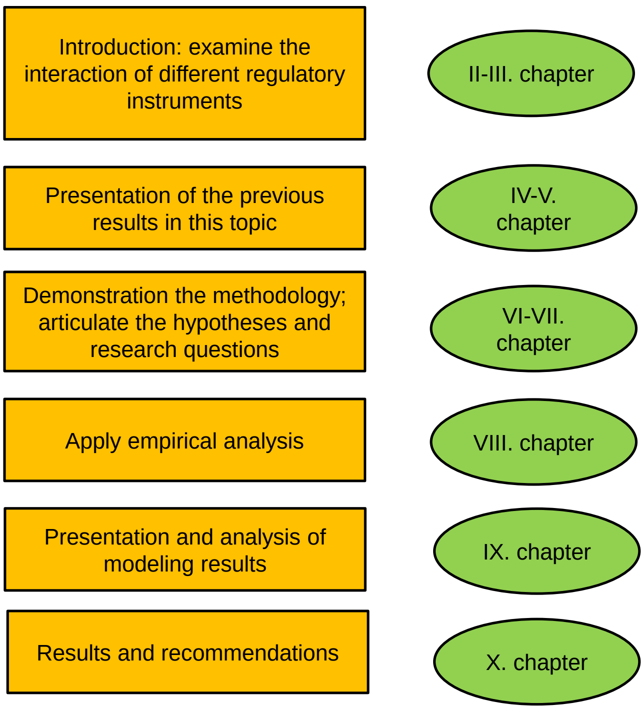
I would like to express my gratitude to my supervisor, Gabriella Szajkó, who awaked my interest in environmental markets, supported from the beginning and always gave helpful advice. I owe to thanks to Zsuzsanna Marjainé Szerényi, who helped my dissertation as the head of department. I would like to thank László Szabó, László Paizs and Sándor Kerekes for their valuable review of the draft thesis. Thanks to colleagues of REKK for encouragement, moral support and helpful advice. Finally, I am grateful to my family for their patience, help and supporting. Especially thanks to my Father, who introduced me to the scientific world and gave valuable comments to the dissertation as well.

I. INTRODUCTION

In the electricity market there are a number of market failures that lead to inefficient allocation of resources from the perspective of society. These include the emissions of power plants, which generate substantial negative externalities. Another market failure is the insufficient volume of investments into energy efficiency. The European Union, having recognised these failures, have set targets that help to augment social welfare. In 2009 the EU adopted the new Climate and Energy Package targeting by 2020 a 20% reduction of greenhouse gas (GHG) emissions, 20% lower primary energy use and a 20% share for renewable energy use. By reaching these goals, the previously mentioned market failures can be substantially eased. In order to get closer to fulfilling the targets, the European Union and the member states have introduced different types of regulatory instruments: a uniform emission trading system, renewable support schemes, excise taxes on the use of fossil fuels, and support for investment into energy efficiency. These instruments, nevertheless, exhibit their effect partly through similar mechanisms, therefore different instruments may cancel or even reinforce each other, as also confirmed by the "Green Paper - A 2030 framework for climate and energy policies" (COM 2013/169) published by the European Commission in March 2013. The document emphasized that the individual policy instruments need to be harmonised so that they would strengthen, instead of offsetting each other's impacts.

Our thesis aim is to inspect the level of efficiency to which the listed regulatory instruments can work along each other, and whether it is necessary to introduce such a wide range of instruments to handle partly overlapping problems.

Figure 1 Structure of the dissertation



In the dissertation firstly we describe the main market failures of the electricity market. In the third chapter we describe the theory and practice of the renewable support scheme, emissions trading, the excise tax and the support for energy efficiency investments. In the fourth and fifth chapters we look at the impacts that these regulatory instruments deliver to the price of electricity, renewable and conventional generation, carbon-dioxide emission, and energy efficiency investments. We also analyse each instrument on its own, inspecting how their introduction effects the most important factors in the electricity market, and we also examine their interaction: what happens after the simultaneous introduction of several instruments. To do this, we consult the literature and carry out our own research as well.

In the sixth chapter we describe a simulation tool, the European Electricity Market Model that enables us to inspect the interaction of specific regulatory instruments. Next we articulate the hypotheses and research questions to be investigated. In the eighth chapter we apply empirical analysis to examine the interaction of different regulatory instruments, especially the markets of carbon-dioxide trading and tradable green certificates, and the impact of the Energy Efficiency Directive on the price of the carbon-dioxide credit. In the ninth chapter we use modelling to analyse the interaction of specific regulatory instruments, and also examine the mix of instruments to see which combination can achieve the European 20-20-20 targets. Based on the modelling results we investigate how many different instruments are justified to use and the corresponding quantitative results. We also show the Hungary specific modelling results for each combination of instruments. Finally, in the last chapter we summarise our most important results and make recommendations.

II. KEY FAILURES WITHIN THE ELECTRICITY MARKET

Market failures appear as sub-optimal allocation of resources, that is, Pareto efficient resource allocation is not achieved. They can be driven by a number of factors, the main market failures that can be observed in electricity markets are listed below:

- negative environmental externalities
- insufficient level of investments into energy efficiency
- security of supply
- regulatory failures
- dominant market power
- network externalities.

Below we introduce the two most critical market failures in connection with the topic of the thesis: environmental externalities and market failures associated with energy efficiency investments. For more on the rest of the market failures see Gillingham et al. (2009), Gillingham-Sweeney (2010).

II.1. Environmental externalities emerging through the life cycle of the power plant

Regardless of the type of the electricity producing facility, in relation to its manufacturing, operation and closure there are a large number of processes that involve externalities that are not internalised, generating substantial losses for society. During the life cycle of a power plant emissions can be substantial, increasing for example the costs of agricultural production (SO_2 emissions, for instance, reduce agricultural productivity) and healthcare expenditures, since the emissions of particulate matter raise the risk of asthma and reduce expected longevity. Likewise, CO_2 emissions also create externalities, contributing to global warming, substantially raising the costs to society (Stern, 2006). Moreover, the operation of power plants can be very noisy which may unintentionally reduce the welfare of affected people.

Since the early 1990s the European Commission has provided a lot of support to the so called ExternE project, seeking to quantify the negative externalities within the electricity sector. A full life cycle analysis has been carried out for each power plant type and each country within the EU15 group. Table 1 offers a summary of the results of this exercise.

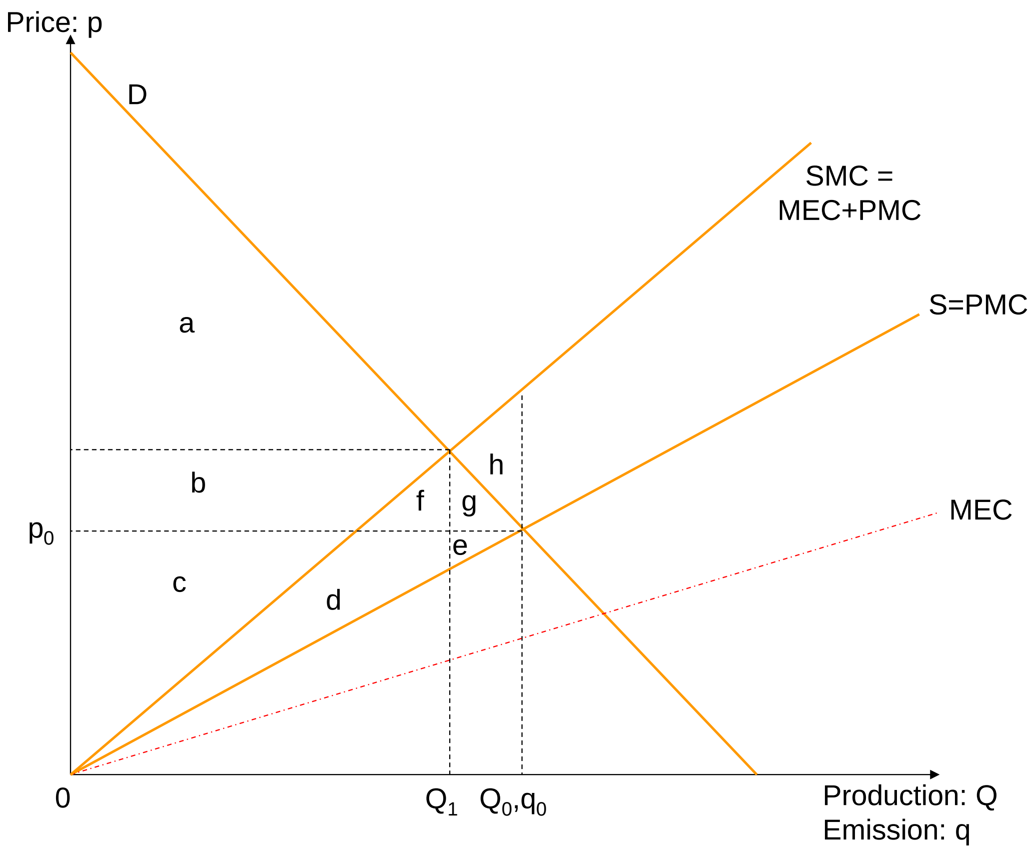
Table 1 Quantification of the negative externalities based on the ExternE project for different technologies and countries, €c$_{(2005)}$/kWh

	Coal and lignite	Peat	Oil	Gas	Nuclear	Biomass	Hydro	PV	Wind
AT				1-3		2-3	0.1		
BE	4-15			1-2	0.5				
DE	3-6		5-8	1-2	0.2	3		0.6	0.05
DK	4-7			2-3		1			0.1
ES	5-8			1-2		3-5			0.2
FI	2-4	2-5				1			
FR	7-10		8-11	2-4	0.3	1	1		
GR	5-8		3-5	1		0-0,8	1		0.25
IE	6-8	3-4							
IT			3-6	2-3			0.3		
NL	3-4			1-2	0.7	0.5			
NO				1-2		0.2	0.2		0-0.25
PT	4-7			1-2		1-2	0.03		
SE	2-4					0.2	0-0.7		
UK	4-7		3-5	1-2	0.25	1			0.15

Source: ExternE (2005)

Negative externalities substantially change social welfare, as depicted by Figure 2.

Figure 2 The impact of negative externalities on social welfare



Without perfectly competitive market conditions and state intervention the quantity of production is in equilibrium when the Private Marginal Cost (PMC) equals Demand (D). The consumed quantity is Q_0, while the market price is p_0. The producer surplus is equal to the area of c+d+e, while the consumer surplus is a+b+f+g. Without the existence of externalities, the total social welfare would be equal to the sum of the consumer surplus and the producer surplus. At this level of consumption the negative externality is the sum of d+e+f+g+h, that is how much social welfare is reduced by:

- consumer surplus: CS= a+b+f+g
- producer surplus: PS = c+d+e
- negative externality: EXT = d+e+f+g+h.

Social welfare is the sum of consumer surplus and producer surplus, minus negative externalities. As a formula:

- net welfare: SW = CS + PS - EXT = a+b+f+g+c+d+e-(d+e+f+g+h) = a+b+c-h.

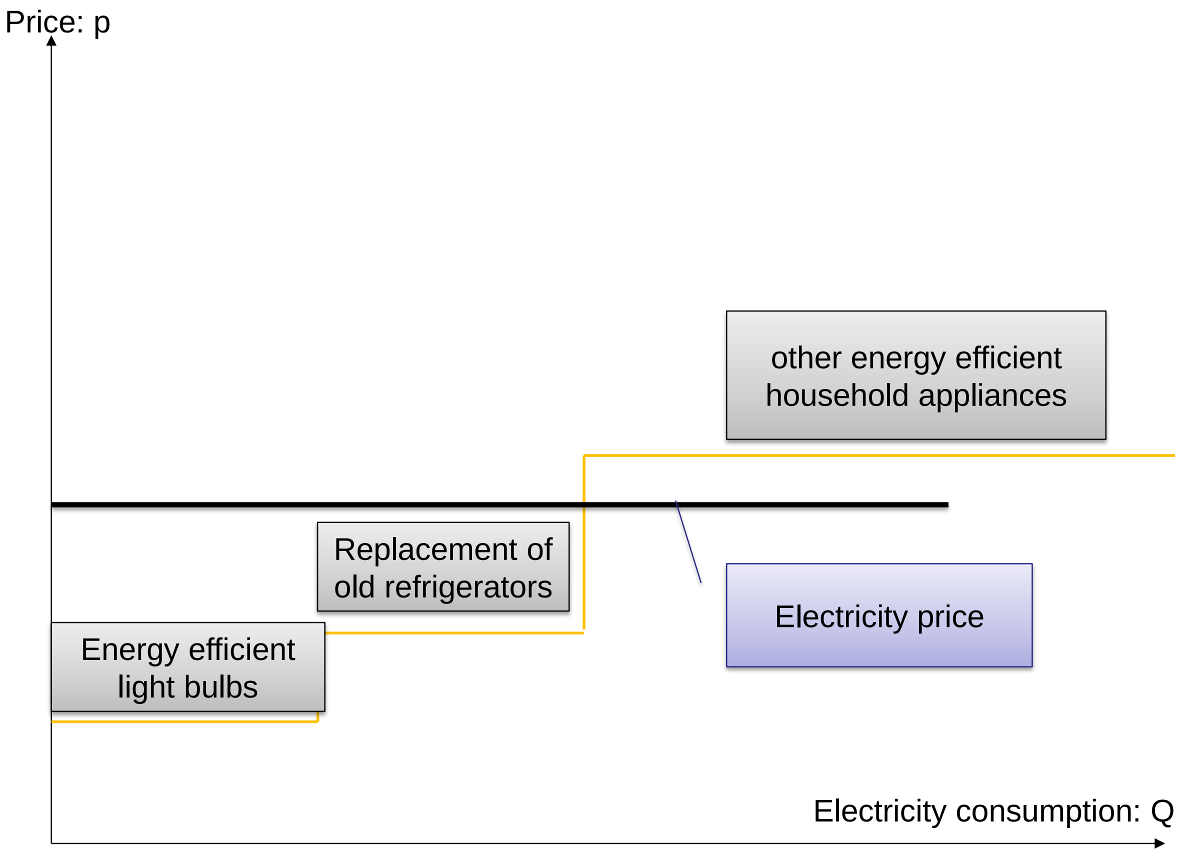
Social welfare keeps rising in parallel with the decline of production as long as the avoided negative externality exceeds the drop in consumer and producer surplus. This holds all the way until production level Q_1, from where social welfare starts to decline, that is, social welfare can be maximised at the quantity of Q_1. This happens when the social marginal cost (SMC), that is, the sum of private marginal cost (PMC) and marginal external cost (MEC) equals demand (D). Apparently, from the perspective of society absolutely zero pollution is not efficient, there is an optimal level of emissions.

In a competitive market environment, therefore, it is not in the interest of the producing company to limit its production to Q_1, as it can maximise its profit at Q_0. This state, however, is not efficient for society as a whole, as social welfare declines by the area of *h*. The system will leave this level of production only as a result of a regulatory intervention.

II.2. INSUFFICIENT LEVEL OF ENERGY EFFICIENCY INVESTMENTS

Within the electricity sector a number of otherwise profitable investments are not carried out. Figure 3 describes the types of investments that would be profitable at a given price of electricity. In an imaginary case at the price characteristic to a given country replacing traditional light bulbs with energy efficient ones, as well as the replacement of old refrigerators would make economic sense. The investment cost of other energy efficient household appliances, however, is so high that investing into them at the given electricity price is not any more economic. McKinsey (2010) looked at the US energy market to determine the average energy price at which certain energy efficiency investments would generate a return. Results pointed to a number of investments within the electricity sector that are profitable at the prevailing electricity price, but still do not take place.

Figure 3 The average cost of specific energy efficiency investments and the price of electricity, an illustration



Insufficient energy efficiency investments can be traced back to the following market failures (based on Jaffe-Stavins, 1994; Gillingham et al., 2009; Gillingham-Sweeney, 2010; Kaderják et al., 2012):

- average cost based pricing
- application of a high discount rate
- lack of access to sources of financing
- insufficient information; obtaining information is expensive
- owner-tenant problem.

Small consumers, including household consumers, typically encounter one or just a few electricity tariffs at most. Meanwhile, on the wholesale market of electricity there are significant differences even between hourly prices. Therefore when these small consumers make a decision about an energy efficiency investment, they calculate the saving with the electricity tariffs applicable to them, which is not the same as the wholesale market price of electricity for a given hour. Thus, if the consumer plans to make energy efficiency investments that save energy for the hours with typically high wholesale prices of electricity, then it enjoys only part of the return of the investment, and does not consider the rest of the saving. One can easily imagine that in this case the investment will not any more be profitable for the consumer, and therefore it will not carry it out either.

The literature is ambiguous with respect to judging if the application of high discount rates is a market failure or not. Jaffe-Stavins (1994) argues that the high discount rate applied by households should not be viewed as market failure, since this is the factor through which households express their expectation for highly variable future energy prices, therefore consumers attach a price to uncertainty through this variable. Gillingham-Sweeney (2010), on the other hand, claims that while this is true, uncertainty alone does not justify such a high premium for the discount rate. The premium should be much lower, therefore the high discount rate should be treated as a market failure. According to Blumenstein et al. (1980) the high discount rate originates from another market failure. Investments into energy efficiency may occasionally require substantial capital. Small consumers, however, do not necessarily have savings, while access to loans may be expensive.

Difficulty to access financing sources may also lead to market failure. A low income household without savings and collateral for loan can access loans only very expensively, or maybe not at all, therefore it cannot carry out the energy efficiency investment, even if that would break even in a year or two.

Lack of information or asymmetrical information is often behind lower levels of energy efficiency investments than economically justified. A situation with inadequate information may be caused by overly expensive searching costs.

And finally, the last major market failure leading to less investment into energy efficiency is that the owner of a given property is not always the same as the one who pays the energy bill (tenant). In this case the tenant does not necessarily have an interest in accomplishing the energy efficiency investment, since the investment may break even only after several years. If the tenant moves during this period, then part of its saving is lost, making the return of the investment questionable, since getting the investment partly acknowledged by the owner may turn out to be difficult.

III. THE THEORETICAL AND PRACTICAL APPLICATION OF EACH REGULATORY INSTRUMENT

III.1. MANAGING PRODUCTION RELATED NEGATIVE EXTERNALITIES

Earlier we showed that in case negative environmental externalities are not considered when decisions over production are made, then production of the given good will be excessive, reducing social welfare. Social welfare can be enhanced through two ways: either through the mutual agreement of parties, in other words by applying the Coase theorem, or via some state intervention. Two main subspecies of the latter can be distinguished: so called "first best" and "second best" solutions. The former includes those regulatory instruments when the activity generating the negative externality is directly targeted by the regulation (e.g. tax, norm or emission trading). In the latter case the regulation supports the less polluting alternative products/producers, those that generate less negative externality. In essence, power plants that would be idle in the absence of regulation, will now crowd out power plants with larger negative externalities, therefore the total externality endured by society decreases. Within the electricity sector this typically entails the support of renewables. Next we describe different variations of these two solutions.

III.1.1. The first best solutions

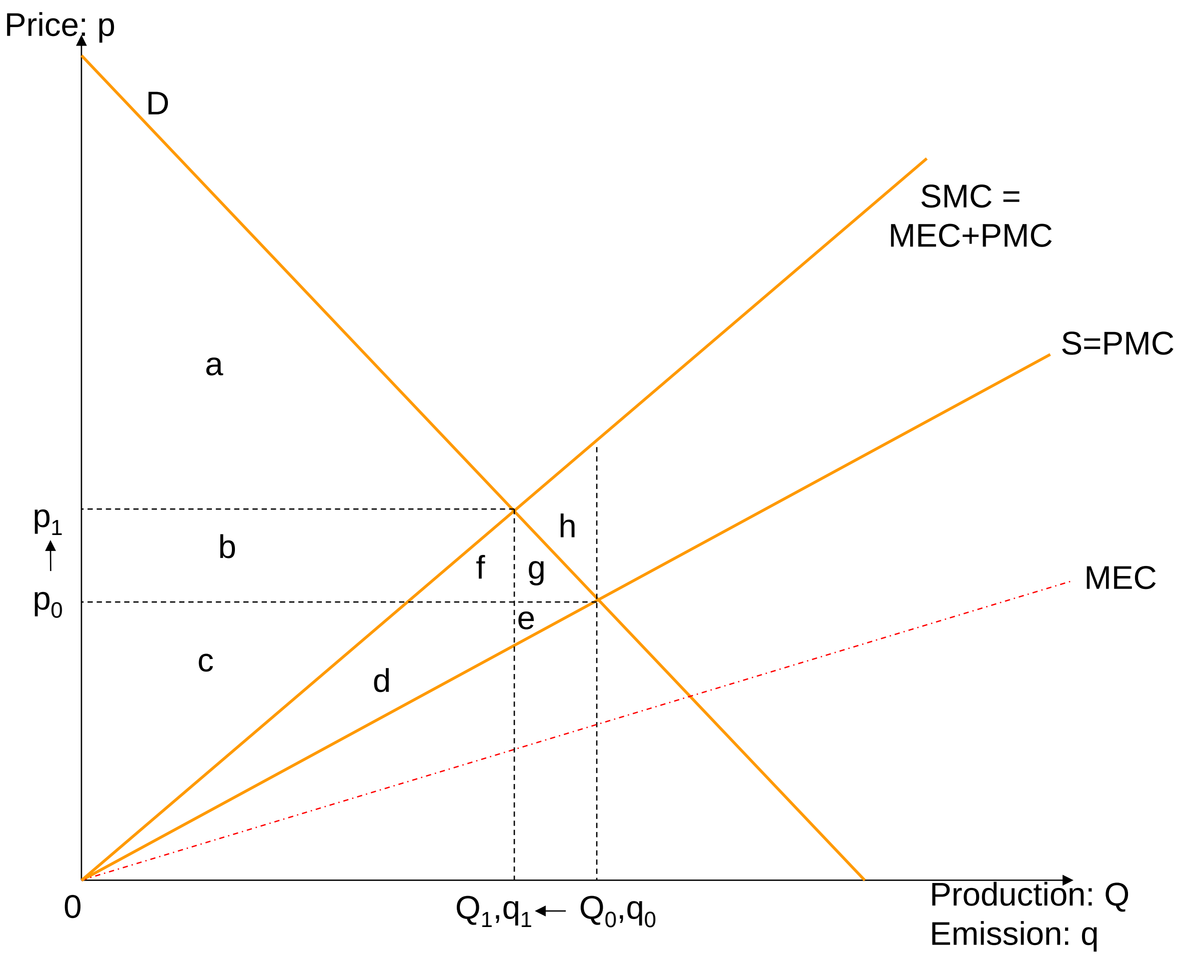
The main principle of the first best solution is that it introduces a regulation based on which producers make production decisions relying not only on their private marginal cost, but they also consider part or all of the external marginal cost as well. This can be attained through a number of ways, as detailed later in the chapter. First, though, we inspect how the first best regulation enhances social welfare.

Earlier we showed how social welfare and its components develop without state intervention. The introduction of the first best regulation, however, may notably change the size of social welfare. Let's imagine a situation in which the regulator introduces an instrument through which it can fully internalise negative externalities, that is, the producer makes decisions based on the social marginal cost curve. The consumed quantity thus declines from Q_0 to Q_1, while the equilibrium price rises to p_1 (Figure 4). Consequently, the components of welfare take the following values:

- consumer surplus: CS= a
- producer surplus: PS = b+c+d+f
- negative externality: EXT = d+f
- net social welfare: SW = a+b+c.

Depending on the regulatory instrument a portion of the producer surplus may also appear as tax revenue for the state, it is not necessarily retained by the producers. This, however, does not change the net welfare, which notably increases (with the area *h*) compared to the initial state. From the perspective of society Q_1 is the optimal level of production: more or less production would be socially sub-optimal.

Figure 4 Welfare in case negative externality exists, before and after the introduction of first best regulation



Kocsis (2002) assigns environmental regulation into four groups along two dimensions: depending on whether the state or the market decides on the price and volume of pollution. Table 2 reviews potential cases and typical corresponding methods.

Table 2 Environmental pollution - regulation matrix

		Volume of pollution	
		determined by the state	determined by the market
Price of pollution	determined by the state	Direct regulatory instruments	Environmental taxes
	determined by the market	Emission trading	The Coase negotiation

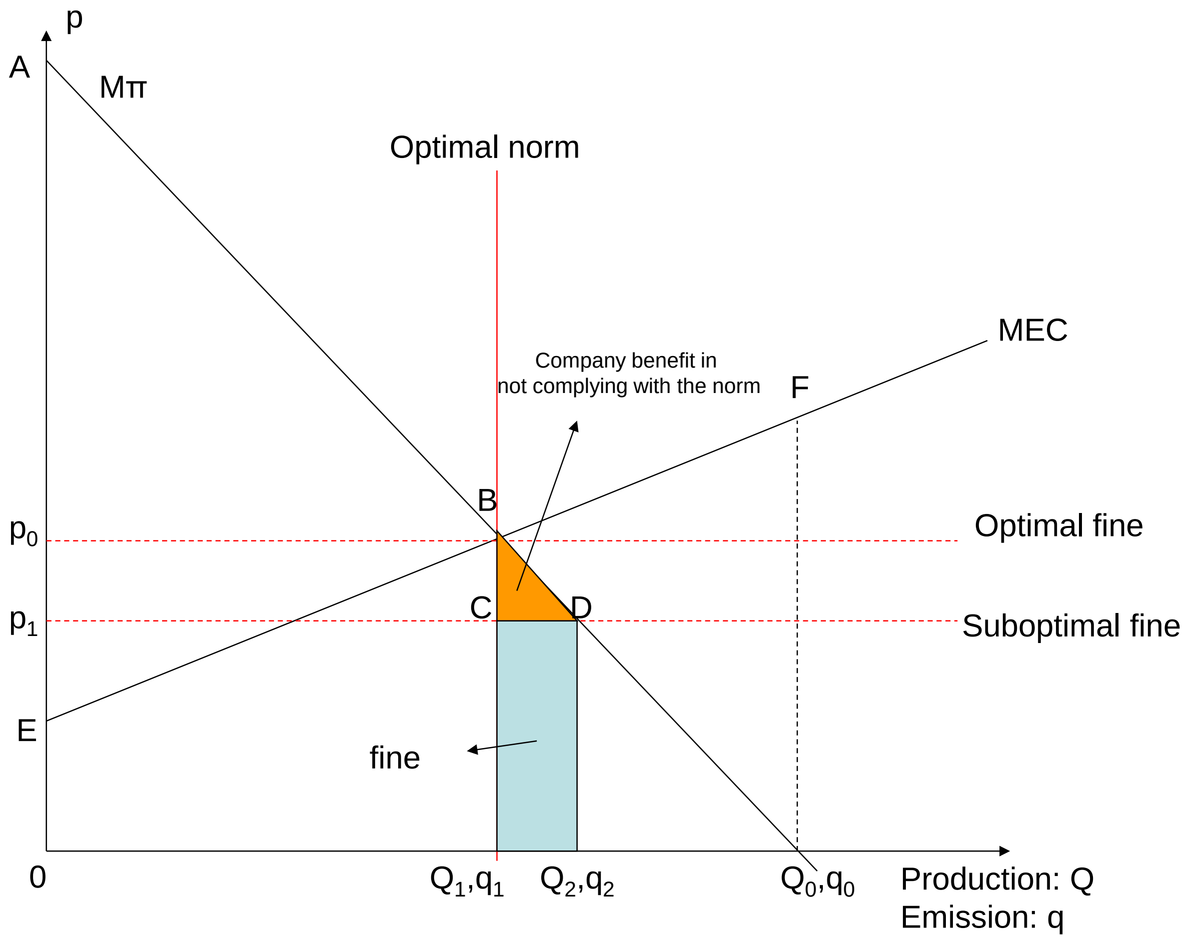
Source: Kocsis (2002)

III.1.1.1. Direct regulatory instruments

One extreme is when the state determines both the quantity and volume of emissions. This type of environmental regulation is called direct or command-and-control regulation (Kerekes, 2007). Different types of norms and standards belong here. The latter includes the minimal technical specifications required of a given technology, while, as an example, the state imposed annual SO_2 emission limit of a power plant is a norm. If emissions exceed the prescribed limit during their operation (which, for some pollutants, may be the complete ban), then a substantial fine can ensue. The norm without a fine (which is not necessarily a direct financial penalty, it may even entail revoking the production license of the company) is useless, since without it companies are not forced to comply with the norm. Figure 5 graphically describes the impacts of a fine below the optimal level.

As a simplification, let pollution be proportionate to the level of production. Let the marginal benefit of the company be $M\pi$, while the marginal external cost curve is described by MEC. In the absence of state intervention (and assuming that the parties do not make an agreement on pollution abatement) the produced quantity is Q_0, generating a pollution level of q_0. Thereby the benefit of the producer can be depicted with the AQ_00 triangle, while as a result of the production generated emission, society has to endure negative externalities of $0EFQ_0$.

Figure 5 The ineffectiveness of the norm at a suboptimal level of fine



Source: Kiss-Pál (2006)

The optimal norm should be set so that the private marginal benefit of the regulated company equals the marginal external cost, because the net social welfare can only be maximised in this case. At the same time, from a financial perspective the company does not have an interest in the voluntary reduction of its production to Q_1 (that is, reducing its emissions to q_1) since it would thus leave a notable sum of profit on the table. Therefore the norm has to be combined with a fine in all cases.

The level of the optimal fine is p_0, thus the company decides to reduce its production to Q_1, maximising its private profit. If it decided on a higher level of production, then the marginal cost of the fine would exceed its marginal benefit. If the regulator, however, sets the fine at p_1, then the producer does not any more have an interest in complying with the norm. At the illustrated suboptimal level of fine the company will produce Q_2, and pollute q_2. In this case the company pays a fine of CDQ_1Q_2, but generates a profit of BDQ_2Q_1 from production, therefore even after paying its fine, on the whole it still achieves more profit than if it complied with the level of emission set by the norm, the difference being the area of the BCD triangle. In the case of the norm, therefore, apparently both the volume and the price needs to be set by the regulator.

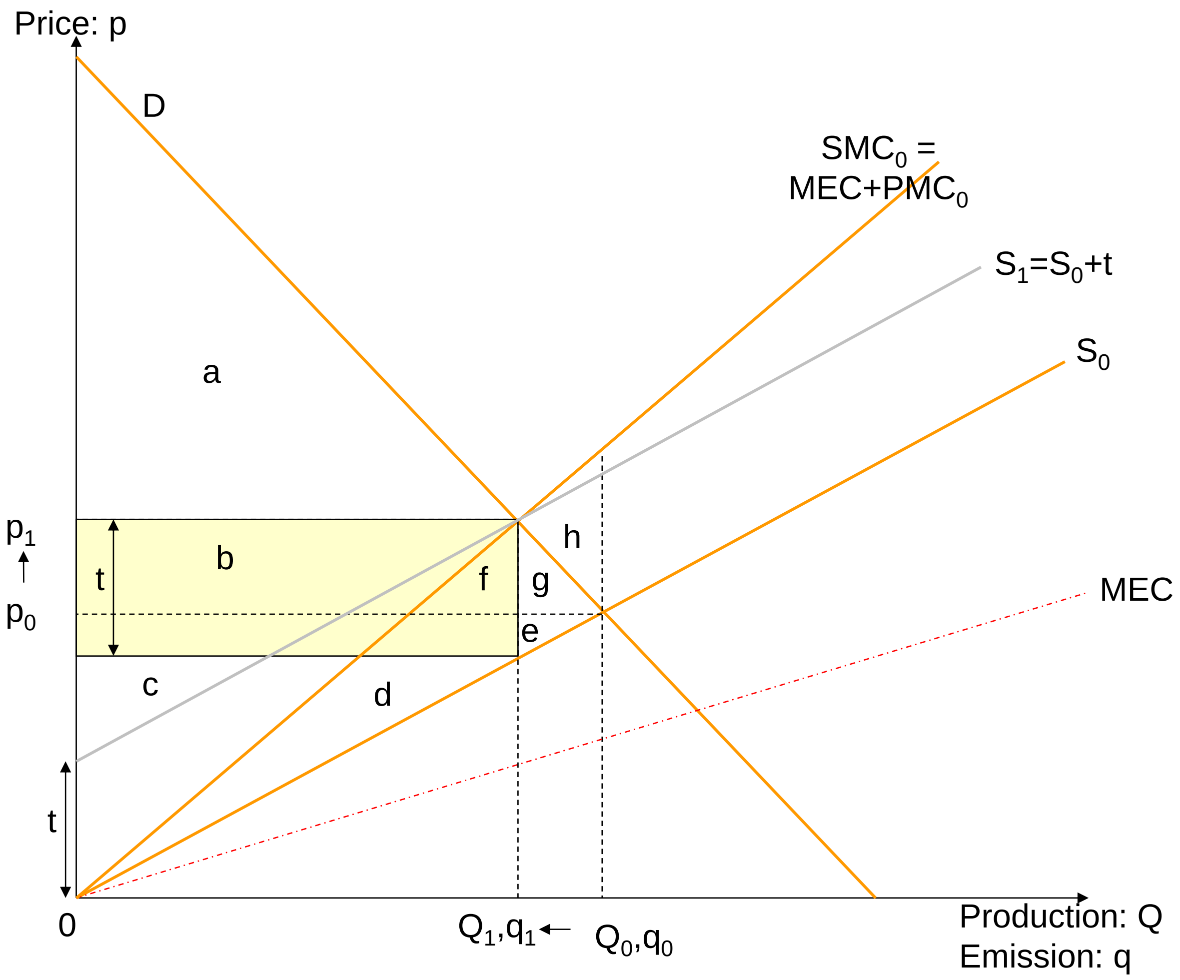
III.1.1.2. The Coase negotiation

The other end of the matrix on environmental pollution is when the state does not directly intervene to manage externalities. In this case any agreement on the level and cost of pollution is up to the involved parties. The theoretical foundation of this field was described in an article by R. Coase (Coase, 1960), emphasizing that under specific circumstances the problem of externalities can be handled even without direct state intervention. The most important role for the state is the assignment of the initial property rights. For a detailed description of the Coase theorem see Kerekes (2007).

III.1.1.3. The theoretical operation of the environmental tax

One of the hybrid solutions is when the state only regulates either the quantity or the volume. These are sometimes called quantity based and priced based regulatory instruments. A typical example of price based regulation is taxation, the operating mechanism of which is introduced by Figure 6.

Figure 6 The socially optimal tax, the Pigouvian tax



In the absence of environmental regulation, the intersection of the demand and supply curves results in a production level of Q_0 and a pollution level of q_0 at a price of p_0, assuming that pollution is directly proportional to the production of the given company. If the regulator imposes tax t on each unit of pollution, then the optimal level of production for the company, at which it can maximise its profit, is at Q_1. In this case the welfare indicators are as follows:

- consumer surplus: CS= a
- producer surplus: PS = b+c+d+f - tax
- negative externality: EXT = d+f
- tax payment: q_1*t
- net welfare: SW = a+b+c.

As also described by the figure, the regulator sets the level of the tax, but the corresponding level of pollution is determined by the demand and supply characteristics of the product.

A specific tax needs to be mentioned, the tax at which the resulting equilibrium also generates a socially optimal level of pollution. This is the Pigouvian tax[1]. In the previous figure welfare was shown at this specific level of tax.

III.1.1.4. The theory of emission trading

The other group of hybrid solutions is when the regulator sets the quantity and let the market determine the price. The typical example for this is the tradable norm, or the emission trading.

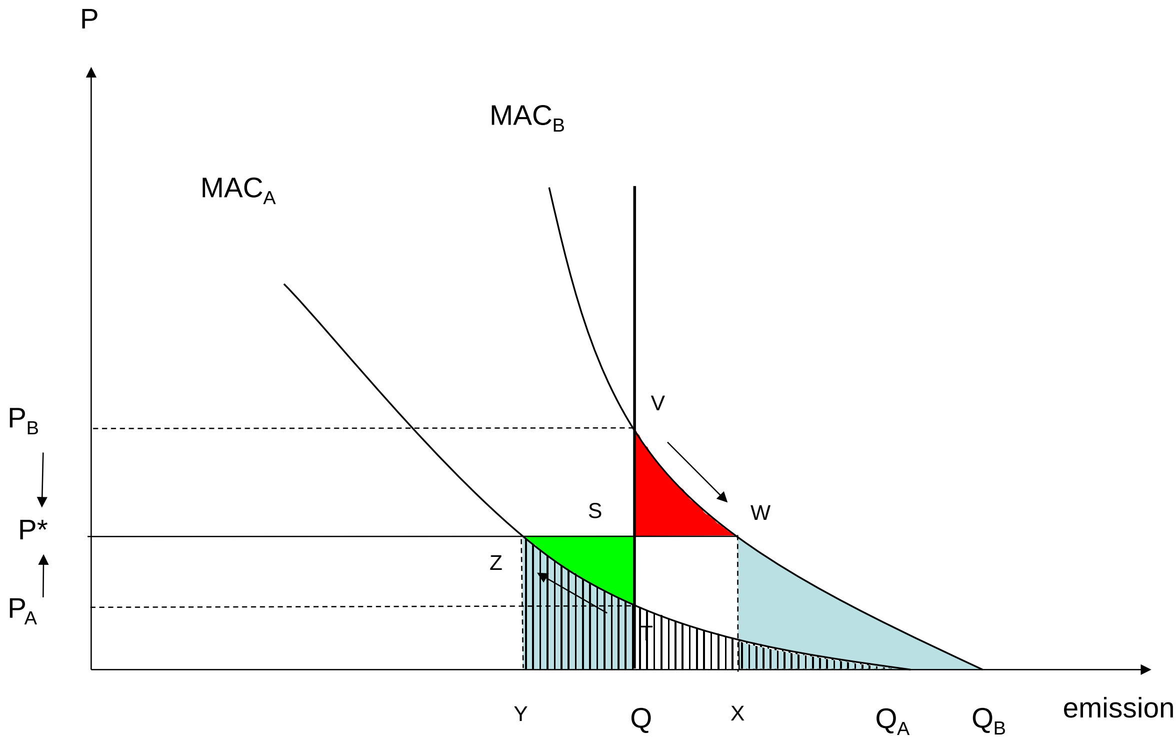
During the trading of emission credits the regulator determines the maximum volume that is allowed to be emitted from a given pollutant in a given period. Then it allocates the credits among the companies that are subject to the trading scheme (credits are handed out for free or in exchange of a fee), after which it creates the opportunity for the unrestricted trade of the credits. Through trading the total cost of emission abatement decreases to a minimal level, while the price of the emission units changes. Figure 7 reviews how this price is achieved in a two polluter case.

Let the marginal pollution abatement curves of the two companies be MAC_A and MAC_B. The regulator sets a cap of 2Q on emissions. If emission trading was not allowed, then company A would face a cost of TQQ_A due to pollution abatement, while company B would incur a cost of VQQ_B. This situation, however, is not socially optimal, since company B reduced its last unit of emission at a much higher cost than company A. If emission trading is allowed then trading will take place between the two companies until their marginal pollution abatement costs become equal, at a total emission level of 2Q. At this time, credits will fetch an

[1] In the case of the Pigouvian tax optimum takes place when the marginal cost of production equals the marginal external cost of pollution. This, nevertheless, assumes that the demand curve of the product is perfectly inelastic, or, in other words, a change in consumer surplus is not considered.

equilibrium price of p*. The increase of welfare due to trading is equal to the difference between two areas: QVWX and YZTQ.

Figure 7 Cost efficient pollution abatement through tradable emission credits in case of two companies with different abatement cost curves



Source: Lesi-Pál (2005)

Apparently, through the trading of emission credits the regulator may determine the volume of total emissions, but the price of emission is shaped by the market.

III.1.1.5. Practical application of first-best regulations in the electricity market

Within the electricity market we can encounter a number of first-best type regulations that aim to manage externalities related to production. Table 3 reviews those that we judge to be the most important.

Table 3 Typical examples of the environmental pollution - regulation matrix within the electricity sector

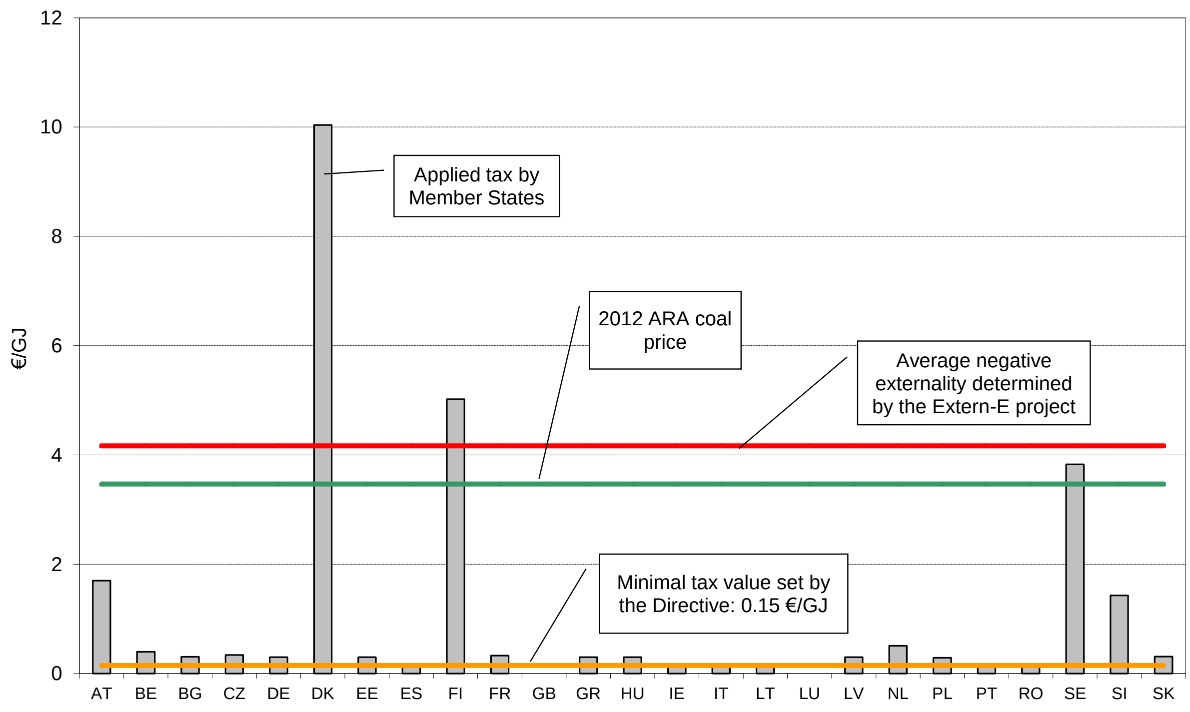
		Volume of pollution	
		determined by the state	determined by the market
Price of pollution	determined by the state	Emission norms	Excise tax
	determined by the market	European Emission Trading System	-

III.1.1.5.1 Excise tax

Directive 2003/96/EC was adopted by the European Union in 2003, introducing a uniform minimum excise tax on coal, lignite, coke, bitumen and its compounds, natural gas and electricity, for each category of consumption (industry, household, electricity generation etc.). In addition to uniform taxation, the reasons behind the introduction of the Directive included the protection of the environment and the contribution to the achievement of the Kyoto targets.

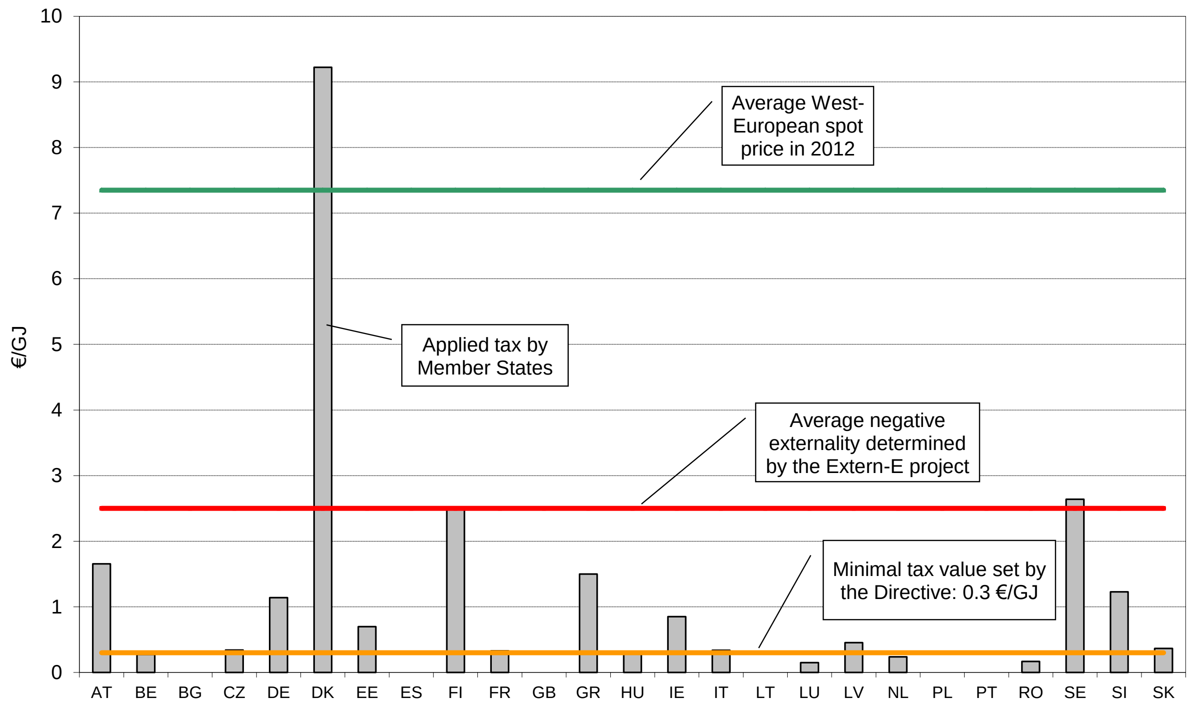
The Directive set minimal values according to fuel type and the area of consumption as well. With the next two figures we show the level of the excise tax in case of power plant use, and how this compares to the price of fuel and the average negative externality determined by the Extern-E project (see Table 1). In case of negative externalities we applied average power plant efficiency for the calculations, therefore we could get negative externality per unit of fuel use through a reverse calculation. It should be emphasized that Figure 8 includes the price of ARA coal in the port (Antwerp-Rotterdam-Amsterdam), locally mined coals can be cheaper than this.

Figure 8 Excise tax on the coal input of power plants, the price of fuel, and the marginal cost of externality in EU member states, €$_{(2011)}$/GJ



Source: ExternE (2005), EEX (2012), EC (2012)

Figure 9 Excise tax on the natural gas input of power plants, the price of fuel, and the marginal cost of externality in EU member states, €$_{(2011)}$/GJ



Source: ExternE (2005), ICE (2012), EC (2012)

The following two statements apply to both fuel types. First, subject to specific conditions, the Directive provides a temporary relief to given member states from the application of the minimal excise tax. Many member states have taken advantage of this. The second important statement is that with the exception of three member states (Denmark, Sweden and Finland) the applied tax stays substantially below both the price of the product, and - even more critically - the negative externalities generated by combustion. In the case of natural gas the level of negative externality is about ten times the minimal excise tax, while in the case of coal this ratio is close to 30.

In 2011 the Commission submitted an overarching proposal (COM 2011/169) in order to amend and harmonise the excise taxes on different fuel uses. The basis of the tax would be determined by two factors: first, CO_2 intensity, that is, emitted levels of carbon-dioxide at a given fuel use. According to the proposal the excise tax would have been € 20 after each ton of emitted carbon-dioxide, while the rest of the tax payment would be based on the energy content. According to the explanatory memorandum, the primary objective of the excise tax is to increase revenues, while providing incentives for consumers to switch to cleaner and more efficient energy use is only of secondary importance. Meaningfully, in accord with the proposal companies that are part of the European Emission Trading System (ETS) do not have to pay the tax component based on CO_2 intensity, they are only subject to paying the energy content based tax. The size of the excise tax to be paid based on the energy content is

0.15 euros per gigajoule, independent of the fuel type. This equals the level of the current minimal tax on coal, and half of the tax on natural gas use.

III.1.1.5.2 The Emission Trading System of the European Union, the ETS

In 1992 the European Commission prepared a proposal (COM 226/1992) based on which it would have introduced the carbon tax to the whole European Union. The aim of this proposal was to increase financial revenues on the one hand, and to cut carbon-dioxide emissions on the other. Following the successful lobbying efforts of a number of member states and industry, the proposal was officially withdrawn in 1997. The renewed endeavours to limit European carbon emissions were accelerated by the signing of the Kyoto Protocol.

Some of the signatories of the Kyoto Protocol, including the United States, proposed a global carbon emission regime in which emission trading would be the instrument applied to reduce greenhouse gas emissions, as opposed to a carbon tax. In this spirit, the following four types of flexibility mechanisms were incorporated into the Kyoto Protocol: Joint Implementation (JI), Clean Development Mechanism (CDM), International Emission Trading (IET) among governments, and the so called bubble policy. For details see e.g. Hepburn (2007), Christiansen (2003), Fazekas (2009) and Lesi-Pál (2004).

In 2001 the European Commission adopted a proposal according to which the European Union would introduce a GHG emission trading system (COM 581/2001), out of which the so called ETS (Emissions Trading System) Directive (2003/87/EC) was born two years later, laying the foundation for carbon-dioxide trading within the EU. The birth and development of the ETS is reviewed in detail by, among others, Convery (2009) and Zapfel (2008).

According to the Directive, as of 1 January 2005 the obliged facilities can emit carbon-dioxide only if they possess an emission permit, and they are also obliged to track and annually report their emissions. At the end of each year facilities have to redeem sufficient numbers of EU carbon-dioxide emission allowances (EUAs) to cover their carbon-dioxide emissions for the year.

The three phases of ETS

Initially the Directive established two phases: the first, so called trial phase covers the period of 2005 to 2007, while the second phase lasts from 2008 to 2012. The latter is the same as the compliance period set by the Kyoto Protocol. Later on a third phase (2013-2020) was also added. There are significant differences among the three phases, as summarised by Table 4.

Table 4 Comparison of the three phases of EU ETS

	Phase 1	Phase 2	Phase 3
Compliance period	2005-2007	2008-2012	2013-2020
GHGs covered	CO_2	CO_2	CO_2, N_2O, PFCs
Sectors covered	Electricity production; energy intensive industrial production	Electricity production; energy intensive industrial production; aviation starting on 1 January 2012	Electricity production; energy intensive industrial production; aviation
Participating countries	EU25; from 1 January 2007 Romania and Bulgaria	EU27+Iceland, Norway and Liechtenstein	EU28+Iceland, Norway and Liechtenstein
Total number of credits determined by	Phase 1 National Allocation Plans	Phase 2 National Allocation Plans	EU cap
Total number of credits available for allocation	Member state competence, typically based on past emission data	Member state competence, typically based on past emission data	Benchmark based
Auctioned quantity	Maximum 5% of EUAs can be auctioned	Maximum 10% of EUAs can be auctioned	As a main rule, within the electricity sector 100% of EUAs auctioned, in the other sectors partially or wholly free allocation
Level of penalty	40 €/t + redemption of the allowances	100 €/t+ redemption of the allowances	In 2013 100 €/t+ redemption of the allowances, enhanced by inflation

Source: Own editing based on EU (2012); EP (2011); KVvM (2012)

During its first two phases ETS covered only carbon-dioxide[2], from the third period supplemented with dinitrogen-oxid and PFC emitted by specific industries. While in 2005 the total number of facilities covered by the Directive was 10495, by 2011 this number increased to 12995, as new countries joined the scheme, and additional industrial sectors were added. In 2011 the electricity sector was responsible for 72.41% of total ETS emissions, with the rest emitted by the industrial sectors[3] (EEA, 2013). By 2011 the installations covered by ETS already made up 45% of the total GHG emission of the EU (EU, 2012).

An important difference between the first two periods and the third period is the method applied to determine the number of credits that can be allocated. During the first two periods member states themselves had to elaborate and describe in detail the number of allowances to be allocated for free and against a payment to the companies covered by the Directive. This was explained in the National Allocation Plans. The European Commission had to approve only the establishment of the total volume that can be allocated. Indeed, during Phase 2 the Commission relied heavily on this right, the reason for which will be described in detail later. The total volume that can be issued in a given period can be found in the National Allocation

[2] ETS also covers other pollutants for selected facilities, but their number is rather limited.
[3] Each combustion equipment with capacity in excess of 20 MWth.

Plans[4]. This method was replaced starting in Phase 3. Currently the total volume to be issued (the cap) is determined by the European Union for a given year. From 2013 this cap is reduced by 1.75% per year, resulting in 21% lower emissions in 2020 than in the base year of 2005.

If the facilities cannot redeem a sufficient number of allowances to cover their emission, then they are subject to the payment of a penalty, the level of which increased from 40 €/t to 100 €/t. Furthermore, the payment of the penalty does not exempt the facility from the obligation to redeem the allowances.

Free allocation and auctioning

Whether allowances should be allocated for free or against a payment was one of the most important questions during the introduction of the ETS. In order to ease the introduction of the scheme and avoid a considerable drop in the profit of the obliged installations, free allocation was chosen at the end, gradually being replaced by allocation for a fee.

The method of allocation, free or payment based, however, does not influence the individual optimum of emissions, therefore it does not impact the price of electricity. More detail about this is in Lesi-Pál (2005), Cramton-Kerr (2002), Neuhoff et al. (2006).

Free allocation is favourable as this way the introduction of the system faces much lower resistance. If allowances are allocated for free, then the scarcity rent generated by the introduction of the carbon-dioxide credit is mostly retained by the producers. If, on the other hand, allowances are allocated in exchange for a fee, then the rent is enjoyed by the government, from which it can provide some sort of a compensation to either the producers or the consumers, but it can also use this revenue for other purposes.

During Phase 1 member states were allowed to allocate up to 5% of the allowances against payment, this ratio increased to 10% in Phase 2. Nevertheless, few countries utilised this option in either periods. Between 2005 and 2011 altogether only 2.1% of allowances were allocated for a fee, all the rest was handed out for free to participants of the ETS. Member states were in a position to determine the basis of free allocation at their own discretion, but typically they started off based on past emissions data.

Partly as a result of free allocation some participants were able to book a windfall profit, that is, their profit increased after the regulation was introduced. Two factors stood behind this shift: first, the short run marginal cost of fossil fuel based power plants increased, thus raising the price of electricity, favouring power plants without CO_2 emissions (like nuclear plants). Secondly, some participants received a higher number of free allowances than their actual

[4] The total volume that can be allocated is called cap.

emission, being able to sell the surplus in the market. For more on this see Mezősi (2007), Mezősi (2008b), Ellermann-Buchner (2006), Sijm et al. (2006).

In Phase 3, however, the method of allocation substantially changed. As a general rule, there is a 100% auction based allocation within the electricity sector. The industrial sector was split to two by the regulation. Decision makers determined which industrial sectors are exposed to international competition, the competitiveness of which can be substantially endangered by having to pay for the allowances. In these selected sectors the Commission continues to apply 100% free allocation even after 2013. In those industrial sectors where such a competitive disadvantage was not detected by the Commission, initial free allocation was set to 80%, to be gradually reduced to 0% by 2027. In both segments free allocation makes use of benchmarks. In the aviation sector all through Phase 3 85% of the allowances are handed out for free among obliged airlines.

Demand and supply side factors influencing the price of allowances

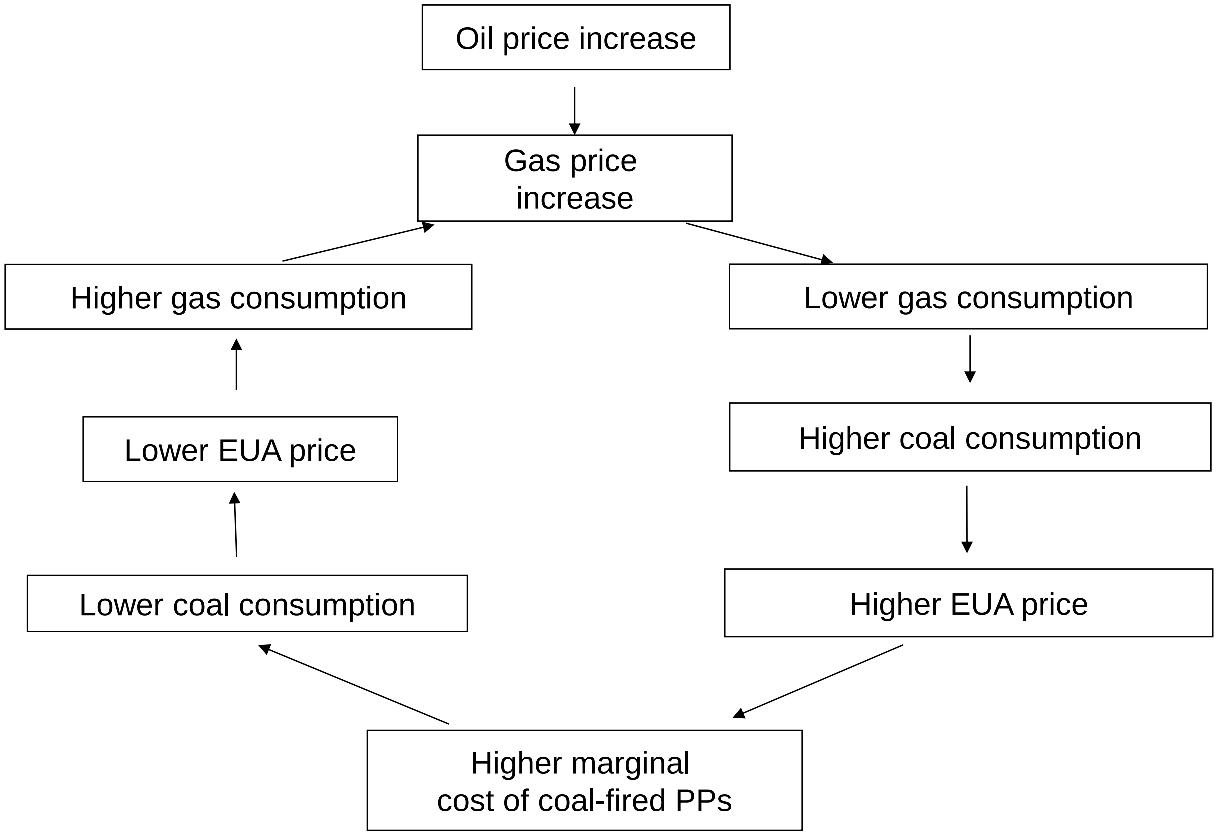
The factors influencing the price of EUA can be assigned to two groups: demand and supply side elements, to be outlined below. For a literature review of the factors driving the price of allowances see e.g. Chevallier (2011).

The demand side of the EUA market is made up by the obliged installations which have to account for their carbon-dioxide emissions every year. The demand curve of the individual installations originates from their marginal abatement cost, therefore the demand for EUAs is the same as the aggregated marginal abatement cost curve of the obliged installations. The demand curve is influenced by a number of factors: economic growth, the price of crude oil, weather as well as technological development.

The economic growth of the countries that participate in ETS impacts the EUA market primarily through the production of the ETS sectors, and indirectly through the change of their energy demand. Accelerating economic growth goes hand in hand with increased demand for EUA, while a slowing European economy emits less CO_2.

The price of crude oil has a substantial effect on the market price of EUA, even if the direction of this relationship is not at all obvious. Figure 10 depicts a situation in which the price of crude oil rises.

Figure 10 The impact of oil price on the price of EUA



When the price of crude oil rises, the unit cost of production in oil and gas fired power plants increases, since not only the price of heating oil, but the price of natural gas is also linked partly to the price of oil. The higher gas price creates a competitive disadvantage for natural gas based power plants, increasing the production of coal fired power plants. Since coal based electricity generation has higher unit emissions of CO_2, demand for the allowances increases, resulting in higher prices. At higher EUA prices the competitiveness of natural gas based productions starts to improve again, and a new equilibrium may take place at higher prices. Even this simple thought process nicely illustrates that the price of oil has a significant impact on the price of the carbon-dioxide credit, but the direction of this impact is not at all obvious.

The price of allowances is also markedly influenced by weather: first, the production of power plants and district heating companies substantially depends on the actual weather. A colder or longer winter than average increases heat and electricity consumption, a hotter or longer summer also raises electricity consumption. Under such circumstances the carbon-dioxide emissions of the two sectors will be larger than expected.

The other meteorological factor is the level of precipitation, since that directly impacts the production of hydro power plants. If electricity production of hydro plants in a given year is above average, fossil fuel based power plants will reduce their production, and thus also their carbon-dioxide emission. When precipitation is below average, the generation of fossil based plants as well as their CO_2 emissions rise.

Technological development can also be viewed as a notable demand side factor. The more progressive technological development is, the more steeply the cost of carbon-dioxide abatement falls, together with the price of allowances.

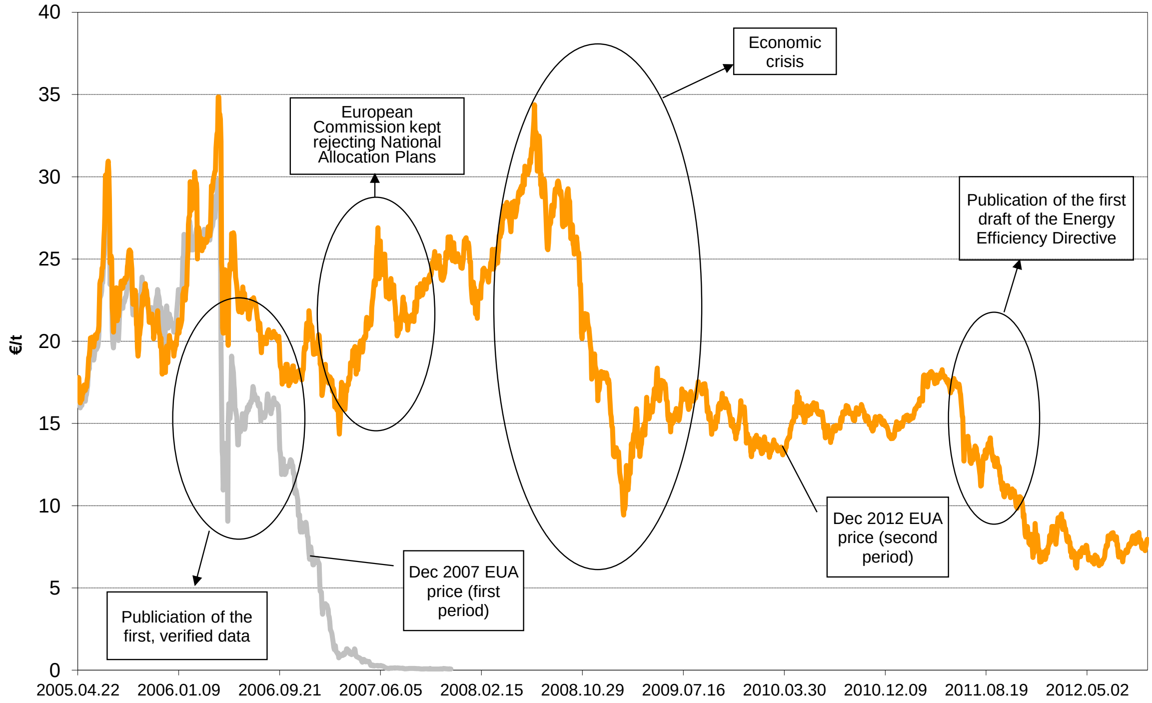
The price of EUA can be depicted with a perfectly inelastic supply curve. While during the first two phases of the trading scheme supply is made up of the number of allowances set in the European Commission approved national allocation plans of the participating countries, third phase supply is equivalent to the total number of allowances available for allocation as determined by the European Commission. Due to its administrative nature supply can be regarded as perfectly inelastic (zero price elasticity). In other words, supply does not change with price.

The price of EUA is therefore determined by an inflexible supply and demand aggregated from individual marginal abatement costs. Importantly, as already mentioned, the price of the credit is independent of the system used for its allocation, whether allowances are provided for free or against a payment (Lesi-Pál, 2005).

Development of the price of EUA

As we have already detailed, according to the EU regulation within a compliance period carbon-dioxide credits can be transferred from one year to the other, but they cannot be transferred from the trial period to the second compliance period. The reason for this is that a possibly inappropriately set first period cap should not influence the price of allowances in the second period. Allowances from the second period, however, can be transferred without a limit. This, in essence, means that the cap is not set for each year separately, but for the whole period together, thus the shortage or surplus of a given year can be rolled over/brought forward. Therefore the price of the allowance is more stable, more predictable and less volatile.

Figure 11 The price of carbon-dioxide allowances in the first and second compliance periods, 2005-2012, €/t



Source: EEX (2012), ICE (2012)

We can draw a number of conclusions from the Figure 11, in which the price of allowances for the first period (grey line) and the second period (orange line) are also indicated. The most important is that the prices of the two allowances moved together until May 2006, when suddenly they started to diverge. The price of first period allowances dropped and by mid-2007 they were worth practically nothing (0 €/), while second period allowances were traded between 15 and 25 €/t. The reason for this price divergence is that the first period allowances were not allowed to be transferred to the second period. The May decline of the price of first period EUA is due to the first deadline for installations to report their verified emissions. Earlier there had been only estimates on the carbon-dioxide emissions of these companies. The new information was immediately incorporated into prices, revealing that the total number of allocated allowances is higher than the total volume of emissions. For the second period, however, participants believed that the cap would be tight. This notion was reinforced by the action of the European Commission, which, during the first half of 2007, kept rejecting National Allocation Plans claiming that the caps in those plans were too generous, thus requiring member states to allocate a lower number of allowances to the installations operating in their countries. For a detailed description of EUA price trends, see Lepone et al. (2011).

Two more important conclusions can be derived from Figure 11: first, the economic crisis greatly impacts the price of allowances. Lower electricity consumption and the falling production of industrial facilities both decrease the demand for EUA, which in turn reduces the price of allowances. The second, and from the perspective of the thesis a rather important statement is that the publication of the first draft of the Energy Efficiency Directive (COM 2011/370) also substantially influenced the price of carbon-dioxide credits. The announcement of the Proposal itself was sufficient to elicit expectations from market participants for a significantly lower future demand for carbon-dioxide credits. As a result, prices fell by more than 20% in two days, providing a nice example of how the two instruments - emission credit and support for energy efficiency investments - can interact with each other.

III.1.1.5.3 Emission norms

A frequently applied instrument within the electricity sector is the emission norm. Next, we introduce one of the most influential norm based regulation from the perspective of the European electricity industry: the LCP Directive (Large Combustion Plant Directive, 2001/80/EC) and the related NEC Directive (National Emission Ceiling Directive, 2001/81/EC).

It was already established during the early 90's that predominantly sulphur-dioxide and nitrogen-oxides are responsible for acid rain. Since these are cross-border pollutants, an international treaty is needed to curb their emission. Therefore under UN auspices the Gothenburg Protocol was signed, establishing country-specific emission reduction targets. In order for European countries to successfully fulfil the targets set in the Protocol, Directives 2001/80/EC and 2001/81/EC were adopted. The former, the so called LCP Directive specified the maximum unit emissions of sulphur-dioxide, nitrogen-oxide and particulate matter for power plants with a capacity of at least 50 MWth, while the latter defined the country-wide ceiling of total emissions.

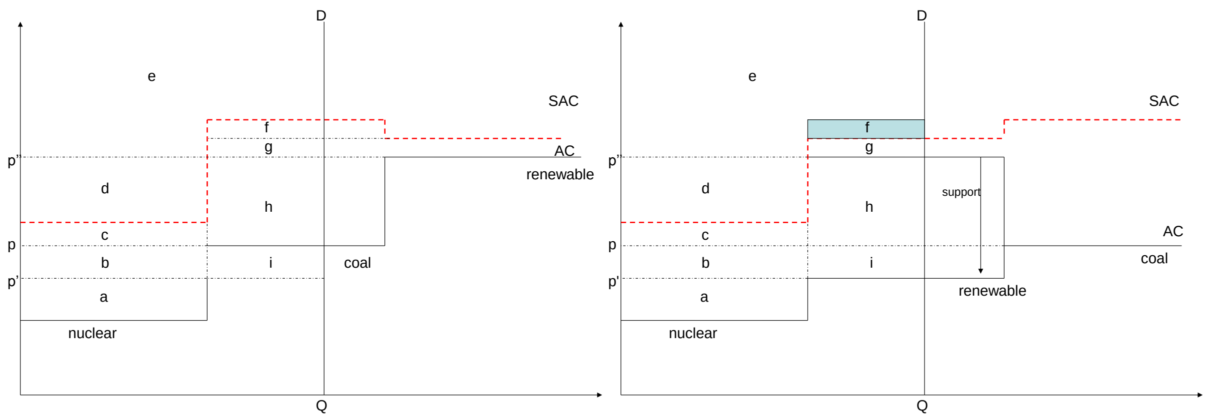
After having joined the European Union, these directives became obligatory also for Hungary. Based on Government Decree 21/2001 installations are subject to a penalty for above limit emissions. The fine on sulphur-dioxide and nitrogen-oxide emissions increased eight-fold between 2002 and 2005. As a result, some of the power plants stopped production (e.g. Bánhida), others switched from the combustion of coal, which has the highest sulphur content, to the use of natural gas or biomass (e.g. Pécs, Ajka, Borsod power plants), or installed desulphurisation technology (Mátra and Oroszlány power plants). As a consequence, by 2007 the sulphur-dioxide emissions of large power plants fell to 5% of the 2001 level, while the emission dropped to 49% and 3% in case of nitrogen-oxide and particulate matter, respectively. We can conclude that regulation through norms proved to be quite effective (MEH, 2012).

III.1.2. The second-best solutions

Previously we introduced the different types of first-best regulations, when an environmental regulation is introduced in order to internalise negative externalities. The essence of second-best regulations, on the other hand, is providing assistance to less polluting technologies, those that generate less negative externality. As a result of the support, polluting technologies may be crowded out, creating a more efficient state on the level of society. Figure 12 illustrates how a second-best regulation enhances social welfare.

Let's assume three producers: a nuclear power plant, a coal fired plant and a renewable electricity generator. Their cost is described by the AC function, while the social cost including the negative externalities due to their production is indicated by the SAC curve. For the sake of simplicity let demand be perfectly inelastic, the demand curve indicated by D.

Figure 12 Welfare surpluses without (left hand figure) and with renewable support (right hand figure)



In the absence of support to renewables the equilibrium price is p, while the total volume of electricity generation is Q. In this case the nuclear power plant operates at full capacity, about half of the coal based capacity is utilised, while the renewable producer is left without any production. The different types of welfares are as follows:

- consumer surplus: CS= c+d+e+f+g+h
- producer surplus: PS = a+b
- negative externality: EXT = $TEC^{5}_{nuclear} + TEC_{coal}$ = a+b+c+f+g+h
- net welfare, therefore equals the d+e area.

If we introduce a second-best regulation with which we support cleaner technologies, then the equilibrium wholesale price decreases to p`, while as a result of the inflexible demand curve demand does not change. The different types of welfares are as follows:

[5] TEC: Total external cost

- consumer surplus: CS= b+c+d+e+f+g+h+i
- producer surplus: PS = a
- negative externality: EXT = $TEC_{nuclear} + TEC_{renewable}$ = a+b+c+g
- support: h+i.

Net welfare is equal to the sum of the consumer surplus and the producer surplus, minus the negative externality and the support. Therefore the net welfare equals the area of d+e+f. Noticeably, due to the second-best regulation, net welfare grows by area f. Moreover, it should be highlighted that substantial transfers (area b) have taken place among consumers and producers.

Renewable support schemes can be grouped based on whether the volume and the price are set by the regulatory authority or the market. Similarly to the matrix of environmental pollution (see Table 2), Table 5 depicts the different variations.

Table 5 The renewable support matrix

		Renewable quantity	
		determined by the state	determined by the market
Renewable prices	determined by the state	Limited purchase obligation for regulated quantity at regulated prices	Feed-in tariff
	determined by the market	Renewable energy quota obligation	Limited purchase obligation for regulated quantity with tendering

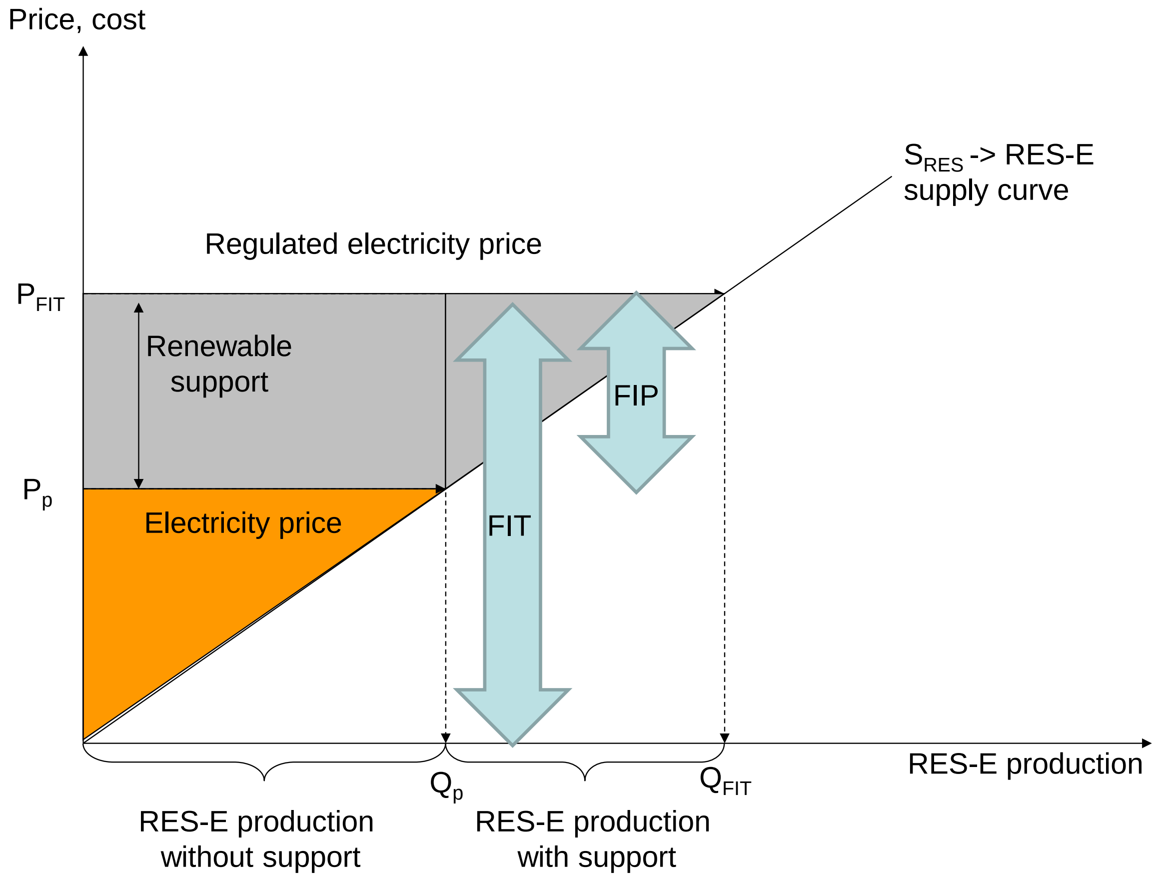
Source: ERRA (2010), p.37.

Next we provide a detailed description of the operating principles of the two typical cases: tradable green certificates, and feed-in tariff based support schemes. It needs to be emphasized that all of the upcoming cases qualify as production based support. In addition, there are a number of other renewable support schemes that are not directly linked to production, such as different tax breaks and investment grants. These, however, typically supplement the production related support schemes that are to be elaborated below.

III.1.2.1. Feed-in tariff

In case of a feed-in tariff the regulator sets the purchase price of the electricity generated from renewable sources, at which price the renewable producer can definitely sell the produced electricity. Figure 13 describes the operation of the feed-in tariff (FIT) based renewable support scheme.

Figure 13 The operation of the feed-in tariff based renewable support scheme



Let S_{RES} be the supply curve of renewable producers, and P_p the market price of electricity. Without support renewable production of Q_p is attained. Afterwards, a feed-in tariff based support scheme is introduced by the state, based on which a price of P_{FIT} is received by the renewable producer after each kWh of generated electricity. The official price indirectly determines the volume of renewable electricity generation, Q_{FIT}. Nevertheless, it needs to be emphasised that the authority is uncertain about the actual volume of production, since it does not know the precise shape of the S_{RES} function.

Feed-in tariffs can be subdivided based on the way they are set: they may be set as a fixed price by the authority (P_{FIT}, indicated with FIT in the figure), or they may be a so called premium price tariff (indicated with FIP in the figure), when the renewable producer sells the generated electricity in the competitive market, but receives a price supplement of P_{FIT}-P_p after each kWh of sold electricity. In the latter case the renewable producer faces an increased risk because of the uncertain wholesale price compared to a case in which it could sell the generated energy at a fixed, official price.

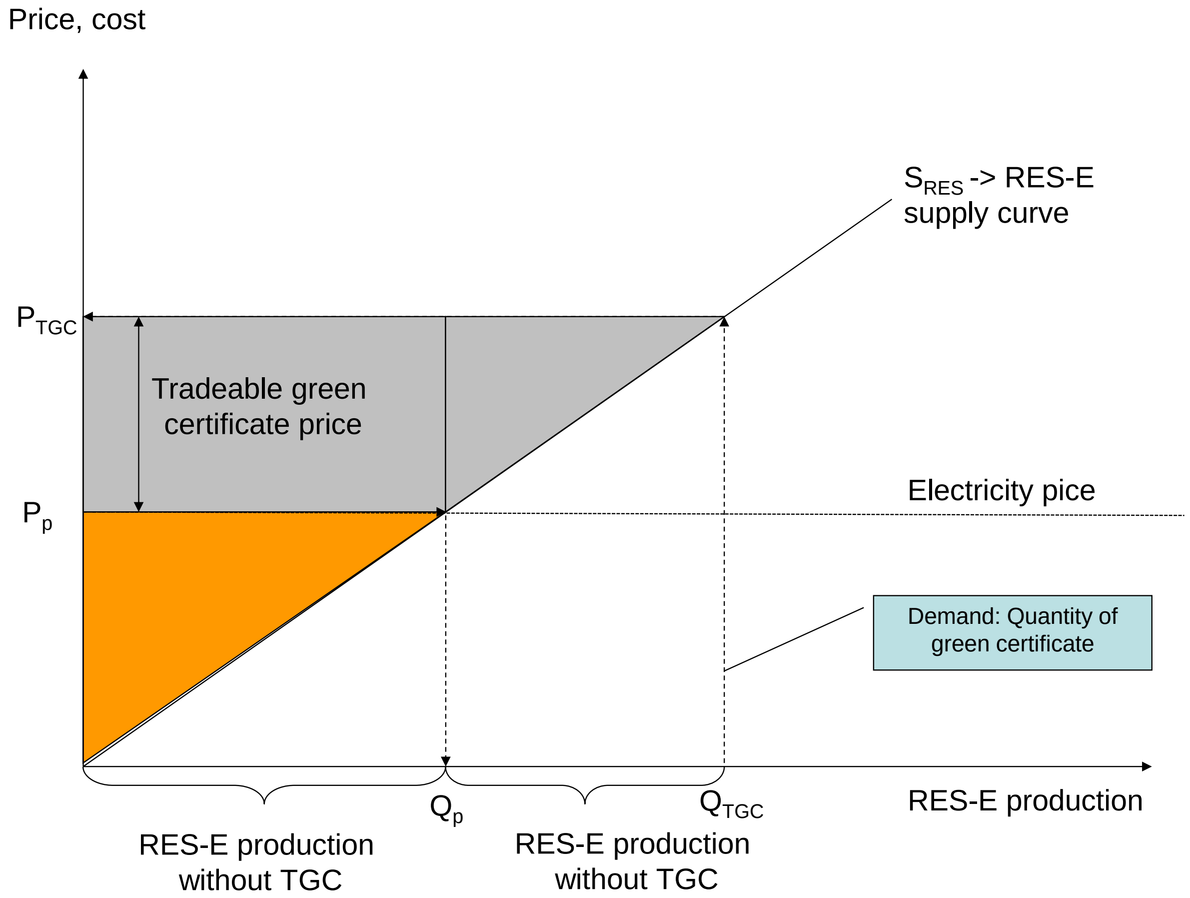
Since we assumed that each producer receives a price of P_{FIT} in exchange for the produced electricity (irrespective of whether the tariff system is premium or feed-in based), the producer surplus of the renewable producers is the sum of the orange and grey areas, part of which is made up of the support. If the supply curve of renewable producers becomes less steep as a result of technological development, then we may face the following changes: since the P_{FIT} price is unchanged, the equilibrium quantity will increase, that is, there will be more renewable based production. Furthermore, producers will retain the gains from improved efficiency (=the producer surplus increases), that is not passed to consumers. This system therefore provides incentives to renewable producers to improve their efficiency.

III.1.2.2. The tradable green certificate

In case of tradable green certificates the regulator sets the volume (and type) of green electricity that can be sold with support for each period. Tradable certificates verify that the given unit of electricity has been produced on a renewable basis (also recognised by the regulation). These certificates can be traded without restriction, while obliged companies have to hold such certificates in a number set by regulation at the end of each period. Thus, an obliged company does not have to purchase electricity (and thereby the green certificate) directly from the renewable producer, it can also acquire green certificates from another participant, even through the exchange. Consequently, trading the produced electricity and the green certificates gets fully separated from each other, each can be traded on its own, independently of the other.

The authority thus sets the volume, as a result of which price becomes uncertain. Using Figure 14, let's inspect the operation of the green certificate system.

Figure 14 Operation of the green certificate system



In the figure - similarly to the case of feed-in tariffs - S_{RES} indicates the supply curve of renewables, and P_P stands for the competitive market price. In the absence of renewable support, renewable energy based power plants will still generate electricity of Q_p.

The state can determine the absolute quantity or the proportion of renewable electricity that obliged participants[6] have to accept in a given period. In order for participants to meet their purchase obligation, there is always a penalty in green certificate markets. If the level of this penalty is high enough then renewable producers will deliver the required volume, only the price remains to be seen. As Figure 14 depicts, the last renewable producer can generate a quantity of Q_{TGC} at a price of P_{TGC}.

Nevertheless, it needs to be emphasized that the revenue of renewable producers is composed of two parts. They sell the generated electricity for a market price of P_P, while they also receive a revenue of $P_{TGC} - P_P$ from the sale of green certificate after each kWh of sold electricity. The price of green certificates therefore depends on the market price of electricity

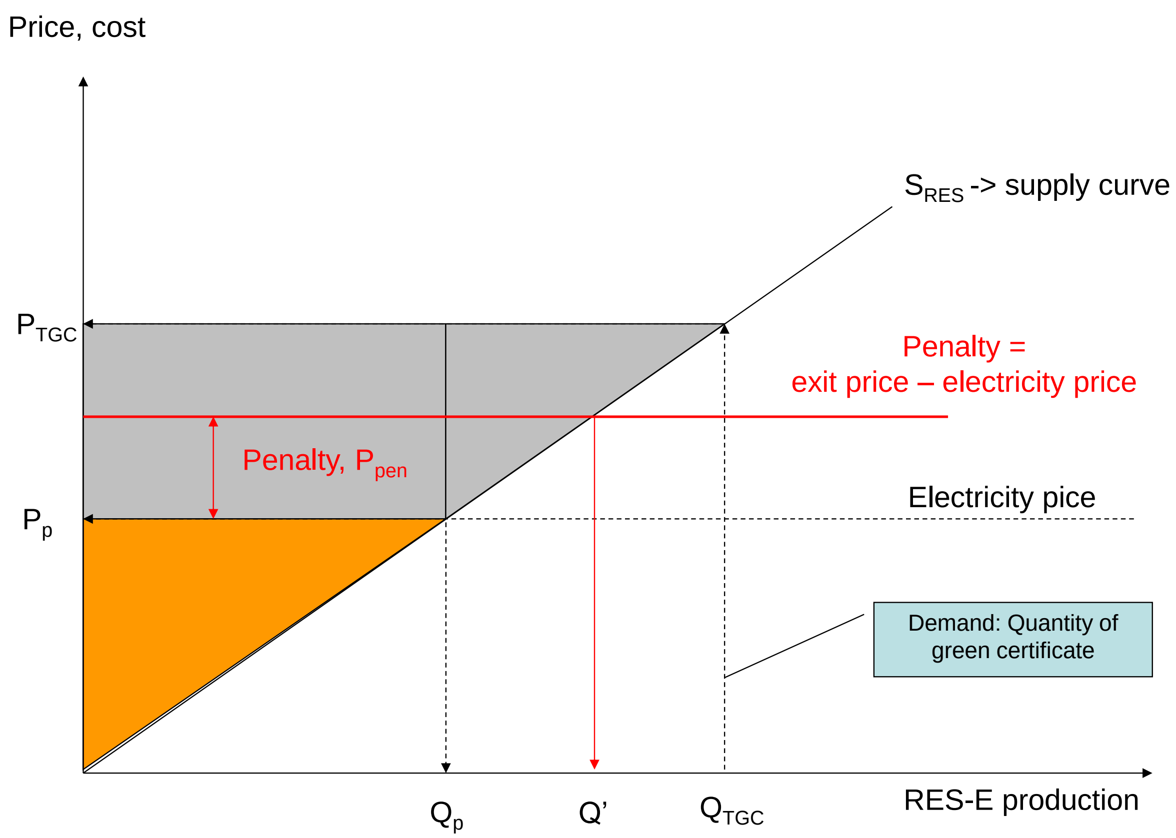
[6] Participants with an obligation are typically not the final consumers, since verification of each consumer would be costly, therefore usually traders, retail suppliers are obliged to purchase the volume in question. There are systems, however, in which producers are obliged to take over a given volume of renewable electricity (e.g. in Italy).

(P_P) and the supply curve of renewable producers (S_{RES}). For a given supply curve the price of the certificate rises if the market price of electricity decreases, and vice versa, in case of an increasing electricity price, the price of green certificates declines. The total revenue of renewable producers, however, remains unchanged, only its composition shifts.

Apparently, in the case of green certificates the regulator sets the quantity to be purchased, but it does not have an influence on the price of green certificates which is determined by the supply curve of renewable energy generators.

A widely applied practice to control the price of green certificates is supplementing the regulation with a so called exit price. Under this concept the obliged participants either purchase green certificates in the market, or substitute them by paying a specific level of penalty, thus maximising the price of green certificates. Figure 15 shows the operation of this piece of regulation.

Figure 15 The role for the exit price in a tradable green certificate system



If the penalty was very high, then the price of green certificates would be P_{TGC}, while the quantity of renewable based electricity would be Q_{TGC}. If the authority introduces a penalty of P_{pen}, then after a while the obliged participants will not purchase green certificates, but instead choose to pay the penalty. Then the quantity of produced renewable electricity declines to Q', while the price of green certificates equals the level of the penalty. In this case, therefore, the renewable target set by the regulator is not fulfilled, but at least prices can be contained. This piece of regulation operates just like the fine under a pollution norm regime. We should also note that this regulation cannot any more be considered as a purely volume based regulation, since with the introduction of the penalty a price based regulatory piece also emerges.

As we observed for the system based on regulated prices, when the supply curve of renewable producers becomes flatter due to technological development, or the already operating power plants become more efficient, then the benefits arising from technological development and efficiency improvement are retained by the producers. The outcome, however, is different in the case of green certificates. The demand for green certificates - determined by the regulator - does not change with the improvement of efficiency. As the slope of the supply curve of renewable generation declines, the equilibrium price of green certificates decreases and the benefit from lower prices is enjoyed by the consumers.

Even though green certificates ensure that a given volume of renewable based electricity can be generated at the lowest cost, the lower predictability of prices makes this renewable support scheme less attractive to investors than the feed-in tariff system.

III.1.2.3. Interim support schemes[7]

In addition to the two clear-cut regulations, in which the regulator sets either only the price (official price with obligatory purchase) or only the quantity (tradable green certificates), there are transitions in-between as well. In these cases the regulator sets both the price and the quantity. Two such variations can be distinguished: first, there is a purchase obligation of renewable based electricity generation, but only up to a limit. Under the second method the regulator opens a tender for renewable producers.

Limiting the quantity of energy eligible for price support is guided by the regulator's intention to control the sum spent on renewable support, thus alleviating the rise of final consumer prices. To this end, the price support scheme is amended so that the supported price is not available to all renewable energy producers, only a specific total volume of renewable energy is eligible for support. The key issue within these systems is the method through which the regulator selects the participants receiving the credits that make them eligible to sell at the regulated, supported price. The most frequently applied instrument is the „first-come-first served" allocation to new entrants, that is, those investors receive the production credit that disclose their intention to invest earlier. In case of excess demand renewable generators either pay for the credit or accept a discounted price support, that is, they offer to produce green electricity at a price below the official, supported price. The latter case, however, should already be viewed as tendering.

In case of tendering the authority issues a tender at regular intervals on renewable electricity generation (or the corresponding capacity), setting the quantity in advance, and the investors

[7] Based on REKK (2009)

with an interest in renewable investments compete with each other on the sales price. The advantage of tendering is that the price is driven by competition and ideally the least cost investment is carried out. If the production credit is allocated through a market, then the scarcity rent related to the credits is retained by the state. Under this solution, however, the number of interested investors may not be sufficient.

III.1.2.4. Comparison of the renewable support schemes

Table 6 summarises the advantages and disadvantages of the above described systems.

Table 6 Comparison of renewable support schemes

	Merit	Drawback
Feed-in tariff	Security of sales for producers, low risk of return on investments, low capital costs, much investment	Prices regulated, regulatory trap, dependent constituency, can create stranded cost
Limited purchase obligation for regulated quantity at regulated prices	Relatively low risk for incumbent producers, who might compete for support	Non-transparent distribution of incumbent status means loss of efficiency, rent-seeking, rent siphoning
Limited purchase obligation for regulated quantity with tendering	Support scheme remains flexible, able to increase efficiency and welfare when R&D is fast	Low level of security for producers, high risk return on investments, few investment
Renewable energy quota obligation	The most cost-efficient of support instruments: the most renewable energy at the lowest cost; non-destorted prices: stable price signals for investors	Safety valve needed on cost: exit fee acts as regulated prices; too low exit fee sets too low quantity; stable certificate market needs many producers, liquidity

Source: Szajkó (2009)

The main advantage of the feed-in tariff system is that it offers financial predictability to investors on a longer time horizon, thereby leading to a quicker penetration of renewables. The extra profit of producers (excessive rents enjoyed by renewable producers), however, may exist on the long run as well, while that is absent from a properly working green certificate market. The green certificate system is the most cost efficient renewable support system, but because of the price risk an exit price may need to be applied, setting the level of which may prove to be difficult and pose specific dangers. If the exit price or penalty is set too low, then the green certificate system may turn into a price based regulatory scheme.

To conclude, initially price based support schemes are the proper way to support renewable energy, which can later on be replaced by volume based support schemes (REKK, 2009).

III.1.2.5. Application of renewable support schemes in practice

Although within the EU15 almost every country supported renewable electricity generation already in the early 2000's, none of the countries that joined the EU during the 2000's had a renewable support regime (Klessmann et al., 2011). This was considerably changed by Directive 2001/77/EC on renewable electricity support, introduced in 2001, as a result of which the new member states also started to introduce different renewable support systems one after the other.

III.1.2.5.1 The renewable regulation of the European Union

The main purpose of Directive 2001/77/EC is spelled out as follows:

"The Community recognises the need to promote renewable energy sources as a priority measure given that their exploitation contributes to environmental protection and sustainable development. In addition this can also create local employment, have a positive impact on social cohesion, contribute to security of supply and make it possible to meet Kyoto targets more quickly."

The Directive required that member states set non-binding targets on the generation of electricity from renewable sources of energy. According to the Directive, within the EU15 the ratio of renewable production compared to electricity use should increase from 13.9% in 1997 to 22% by 2010. With the 2004 enlargement of the EU, when new member states also had to assume targets, the 22% figure decreased to 21%. As a result of the Directive between 2001 and 2005 new member states introduced various regimes to promote the generation of renewable electricity.

It should be emphasised that the Directive allows member states to select the support scheme to be introduced, that is, gradually moving towards more uniform support systems was not a priority.

In 2009 the 2001 Directive was replaced by Directive 2009/28/EC, providing a critical element of the '20-20-20' targets - that is, 20% GHG reduction, 20% reduced primary energy use and 20% share of renewable energy use by 2020 on the level of the EU - outlined by the new Climate and Energy Package of the European Union. In this spirit, for the Community as a whole a 20% renewable share is to be reached within total gross energy consumption, and this is a binding target. This number, however, is differentiated among the countries. When determining country specific renewable targets, the 2005 share of renewables and the per capita GDP of the country were also considered. In case of biofuels, however, by 2020 all member states are uniformly obliged to reach a minimal 10% share within the total energy consumption of the transport sector.

The new Directive requests that each member state submits a so called Renewable Energy Action Plan to the Commission, detailing the instruments through which the targets are intended to be reached, and the predicted renewable energy use by 2020.

The Directive provides strong incentives for member states to cooperate: on the one hand, it creates an opportunity to recognise renewable electricity generated by a renewable producer in a country outside the EU as domestic production, and on the other hand, it makes it possible for member states to operate a common support scheme and to execute statistical transfers. The main point of the latter is that the certificate on renewable production, which also certifies the achievement of the targets, can - with some restrictions - be sold by one member state to the other, thus the exchanged volume of renewable production is accounted towards the obligation of the purchasing country.

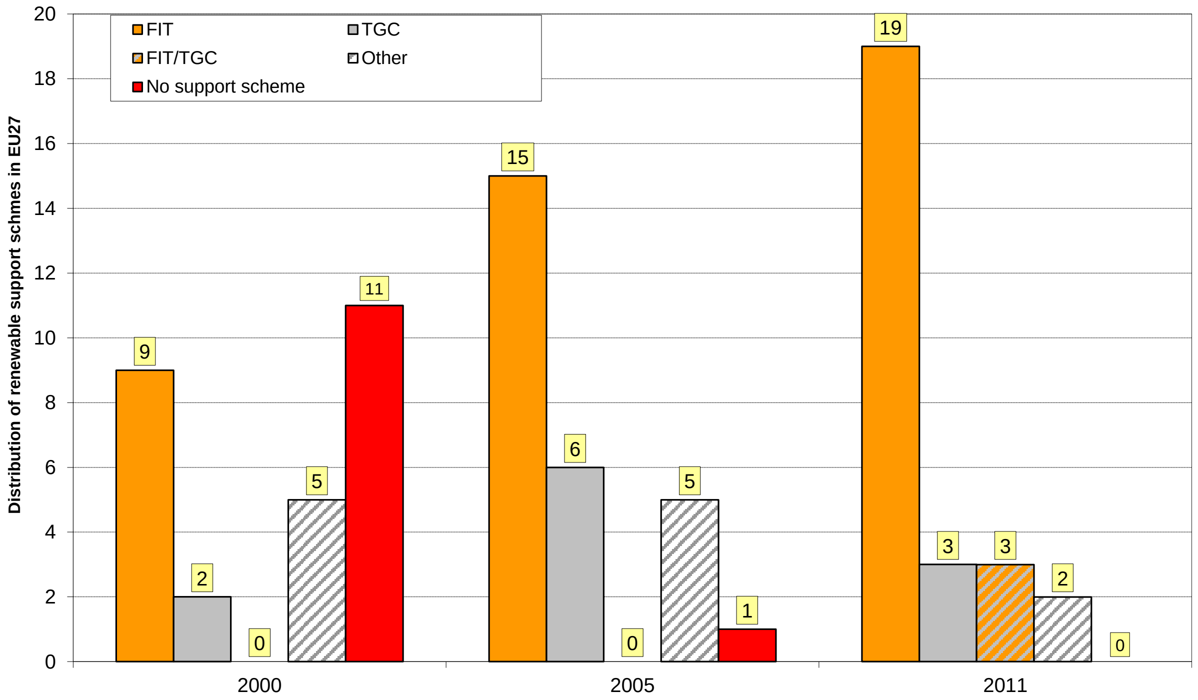
We should note that this scheme is equivalent to the introduction of the tradable certificate system on the level of the member states. It is similar to the direct trading of emission credits, as laid down in the Kyoto Protocol. Therefore, based on the new European regulation member states themselves may decide if they introduce green certificates, feed-in tariffs or any other sort of renewable support scheme, and in addition, they can trade with each other with little restriction in order to reach the targets. This scheme is particularly interesting if in a country the system of tradable green certificates happens to be the currently applied support scheme. In this case an equilibrium price of green certificates is reached within the country, providing a clear price signal for the government in case it intended to trade certificates with another country under the statistical transfer system. [8] The degree to which member states will utilise this instrument remains to be seen, but the introduction of a practically two-level support scheme is interesting enough in itself. The harmonisation of renewable support has been covered in detail by Gephart et al. (2012), and Del Rio et al. (2012).

III.1.2.5.2 Support schemes applied in Europe

With regard to the instruments applied in order to support renewables substantial changes have taken place within the EU27 for the last two decades. As illustrated by Figure 16, in 2000 only 16 of the 27 member states applied any renewable support regime. Only two countries had green certificate systems, and the predominant mode of support used to be guaranteed purchase through feed-in tariffs. In five countries, nonetheless, tax breaks and tenders were also utilised. By 2005 the situation notably changed, thanks to the adoption of the Renewable Directive, which also prompted new member states to help renewable electricity generation with subsidies. In 2005 there was only one country that did not support renewable electricity generation, while the most widely applied form of support continued to be obligatory purchase through feed-in tariffs, utilised in 15 member states. At the same time, the green certificate system had already spread to six countries (Figure 16).

[8] The fact that the targets have been set for three sectors (electricity sector, heat utilisation, and transport) together may slightly distort this signal.

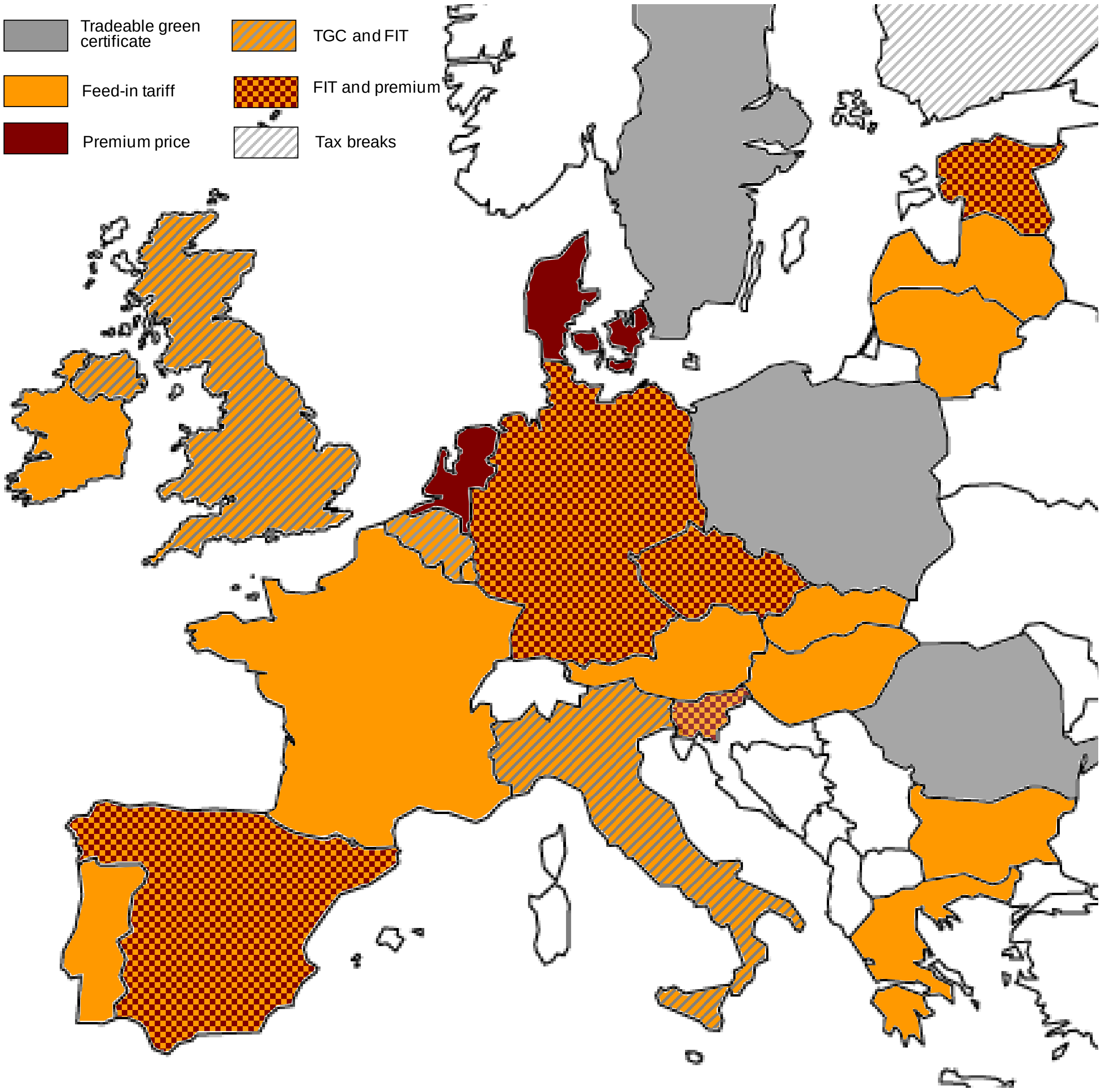
Figure 16 The dominant instrument for renewable support in the EU27 countries



Source: Own editing based on p. 42 of Klessmann et al. (2011)

By 2011 the prevalence of feed-in tariffs further increased. Of the 27 member states this is the dominant form of support in 19, while three countries have green certificate systems (Poland, Romania and Sweden), a combination of the two schemes is applied by another three countries (Belgium, Italy, United Kingdom), while one country (France) supports renewable electricity generation through tax breaks (Figure 17).

Figure 17 Support schemes applied by the member states of the EU to promote the generation of renewable electricity in 2011



Source: Own editing based on p. 43 of Klessmann et al. (2011)

III.2. Managing the market failures related to energy efficiency

Market failures in case of energy efficiency investments (for a detailed description of market failures see II.2) can be reduced in four ways:

- financial incentives
- system of energy efficiency certificates
- setting standards
- information campaigns, labelling.

Next, we analyse the first two options in detail, then in the second half of the chapter we introduce the new Energy Efficiency Directive of the European Union.

III.2.1. Financial incentives

The appropriate application of financial incentives may prove to be an efficient instrument in managing the previously described market failures, which result in a sub-optimal level of investments into energy efficiency. Based on WEO (2008) we can distinguish three main types of financial incentives.

One of the most frequently applied financial incentives is investment support. Since energy efficiency investments typically require a lot of initial capital, without a need for additional capital later on, while benefits due to energy savings continue to be generated, investment support can be a proper way to promote investments into energy efficiency improvement. This scheme can include, for instance, grants for the insulation of buildings, modernisation of the heating system, or even support provided to replace different household appliances (e.g. refrigerators) with more energy efficient ones.

Another typical financial incentive is the preferential loan. This instrument is useful to manage the market failure originating from a situation in which households lack adequate savings and taking out a loan can be costly or problematic for them. A household without savings and a low level of income can access loans only at an interest that is too high for the investment to break even. Under preferential loan schemes the benefits arising from energy savings make it possible to repay the loan.

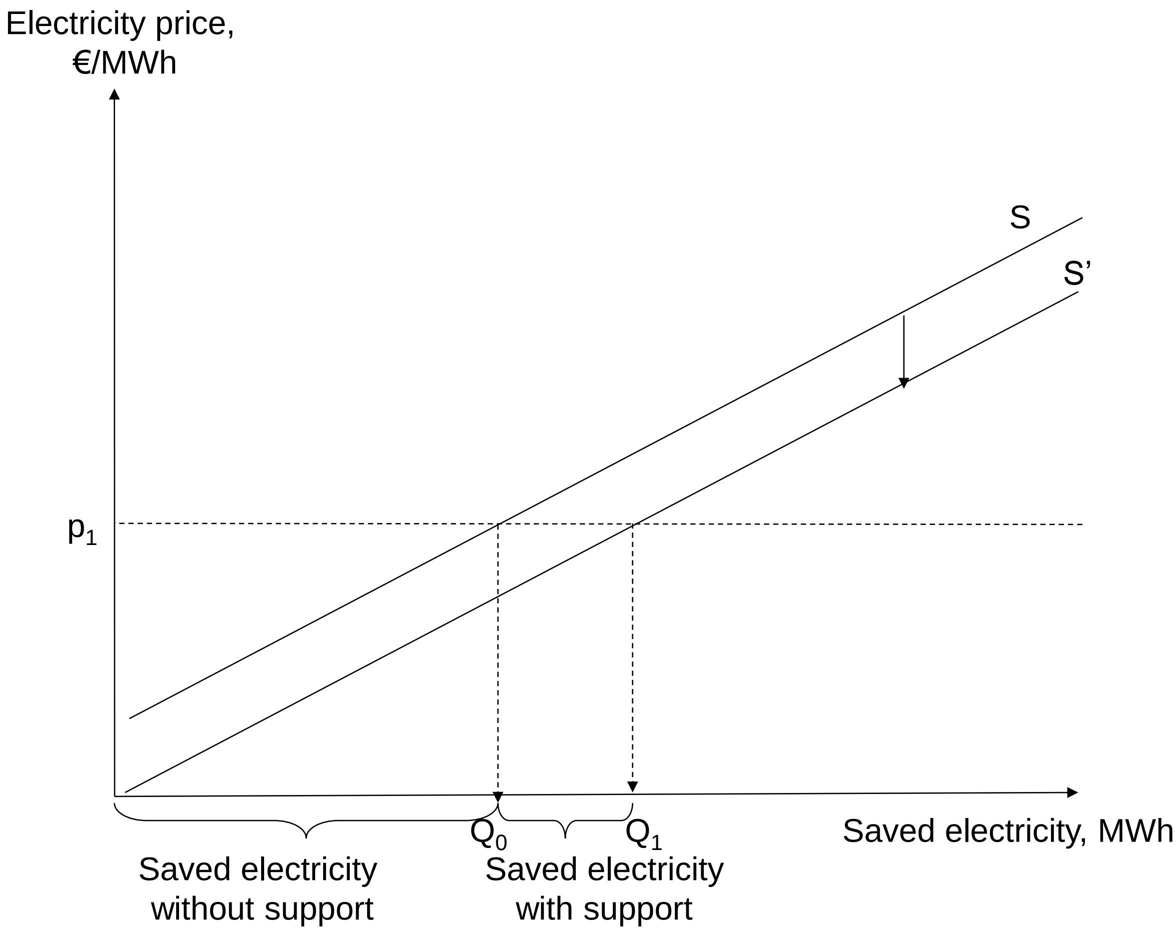
The third frequently applied financial incentive is the preferential tax, typically the partial or full exemption from paying the excise tax or a reduced VAT rate. An example for the latter is the reduced rate of VAT for energy efficient light bulbs.

III.2.2. The system of energy efficiency certificates

The system of energy efficiency certificates is rather similar to the system of green certificates for renewable support. The regulator obliges designated participants (typically energy suppliers) to achieve a certain level of energy saving at their customers in a given period. Under an advanced version of this system the achieved savings can be traded by the suppliers or any other participant. When trading is allowed, we can talk of white certificates (Bertoldi-Rezessy, 2006). Compared to green certificates the system of energy efficiency certificates involves larger monitoring costs since in this case a baseline scenario - that is, the predicted future energy consumption without any energy efficiency investment - also needs to be established. Furthermore, savings are also difficult to measure, therefore the regulators usually recognise standardised saving values related to the execution of standardised investments. Figure 18 illustrates the operation of the market of energy efficiency certificates.

The horizontal axis represents the saved volume, while the vertical axis stands for the price of electricity, and the S curve indicates the supply of energy efficiency investments. These investments take place even in the absence of an energy efficiency certificate scheme: energy efficiency investments of Q_0 still take place. After the introduction of the energy efficiency certificate system, which shifts the supply curve downward (to S') the volume of saved energy grows to Q_1.

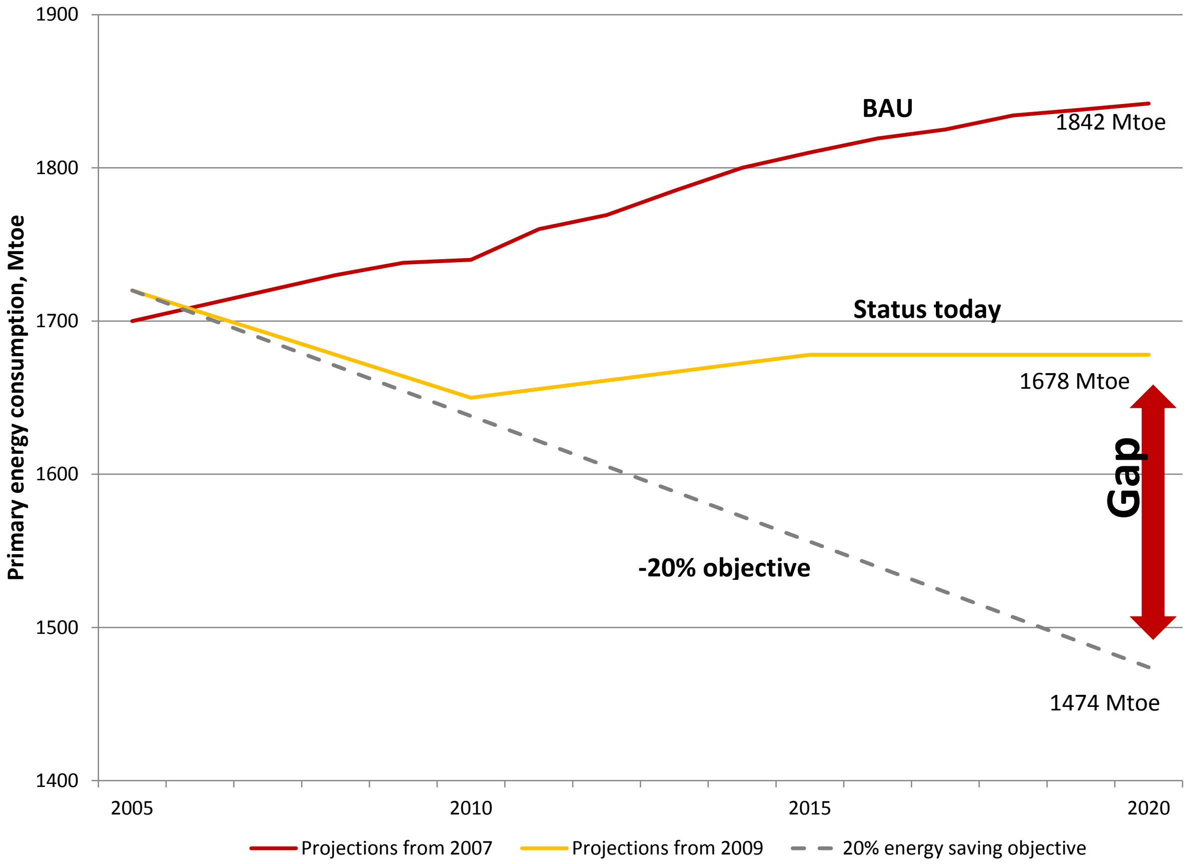
Figure 18 The impact of energy efficiency certificates on the level of energy efficiency investments



III.2.3. The Energy Efficiency Directive of the European Union

In March 2007 the European Union decided that by 2020 it would reduce primary energy consumption by 20% compared to the baseline (COM 2008/772). The Commission continued to monitor the results of energy efficiency investments and realised that based on 2009 modelling results current measures are not sufficient to achieve the 20% reduction of primary energy use, only about half of it.

Figure 19 The 2020 primary energy use target of the EU, and the forecasted primary energy use pathways based on the 2007 and 2009 modelling results

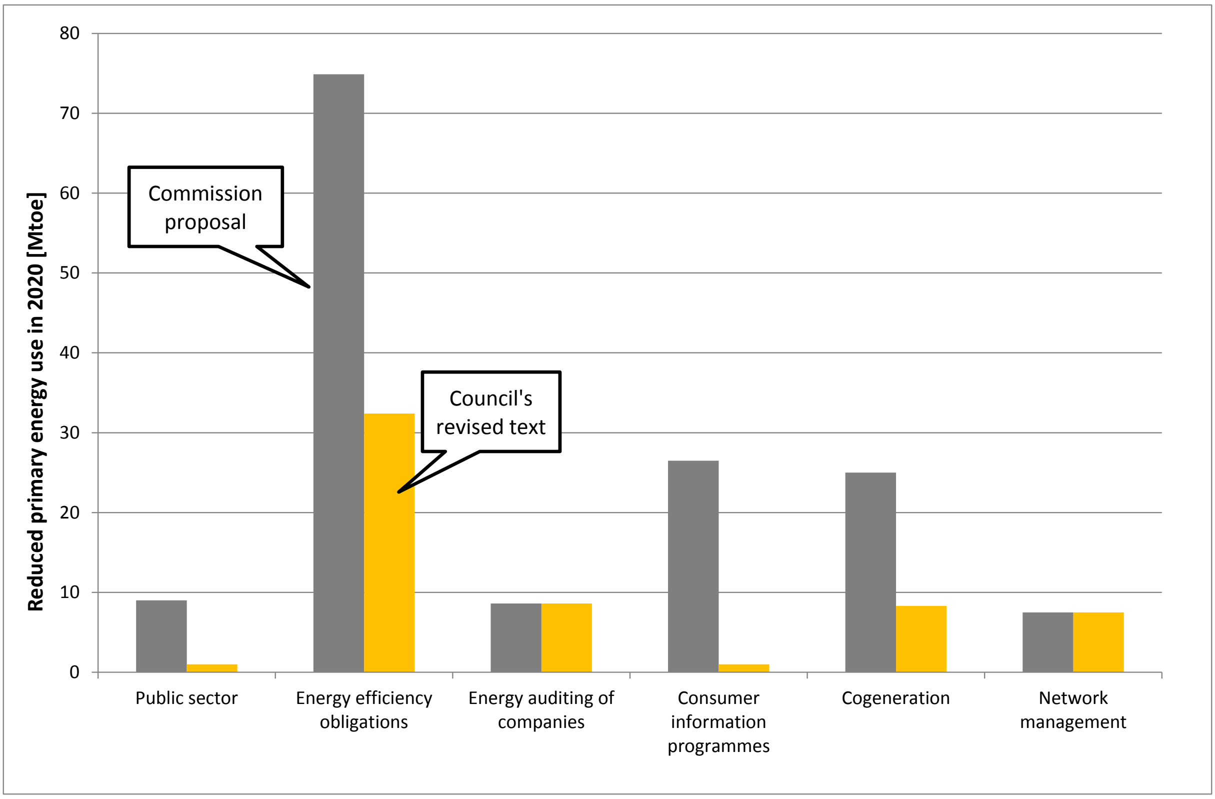


Source: DG Energy (2011)

As pictured, there is a substantial difference between the 2007 and 2009 reference pathways. This difference, however, is not driven by investments into energy efficiency, instead, the primary energy use fell drastically as a result of the economic crisis. Between 2007 and 2010 the energy intensity of the GDP improved by less than 1% according to Eurostat data. There is an approximately 200 Mtoe difference between the 2020 primary energy use forecasted based on the current pathway and the targeted primary energy use of 1747 Mtoe. This is what the proposed amendment of the Energy Efficiency Directive (SEC 2011/779), published by the Commission on 22 June 2011, tried to mitigate. Based on this document the largest additional saving potential is available in the household sector (about 50 Mtoe) and the energy sector (about 80 Mtoe), while the missing 70 Mtoe could be supplemented by the industrial, transport and tertiary sectors. Based on the recommended measures of the proposal in total 151 Mtoe of energy efficiency measures could take place, as a result of which a deficit of only 50 Mtoe would be left by 2020. The Council, however, diluted this proposal and set significantly lower targets, therefore the planned measures of the new Directive are expected to deliver 58 Mtoe of energy savings for 2020. Consequently, without additional measures the expected path will run notably above the targeted level that is based on 20% savings from energy efficiency improvement.

Under both variants one of the most critical elements is the system of energy efficiency obligations, while there is also a notable role for energy savings related to the enhanced penetration of cogeneration, and the Commission proposal also relies on substantial energy savings due to supplying more information to consumers, as described by Figure 20.

Figure 20 Primary energy savings broken down to measures under the original proposal of June 2011 and the April 2012 version of the Directive



Source: Non-paper, 2012

Finally, the Energy Efficiency Directive was adopted on 25 October 2012, with the following main principles:

- By 30 April 2013 each member state has to set energy efficiency targets and submit them to the Commission for approval.
- Starting in 2014 each year at least 3% of the total floor area of the buildings of the central government (that is, the buildings of local governments are excluded) has to be renovated in accordance with the minimum requirements imposed by Directive 2010/31/EC.
- Public offices can procure only products that are highly energy efficient, unless this is in contrast with cost effectiveness or economic feasibility.
- Each member state is obliged to implement energy efficiency obligation schemes. Under this system, as a main rule, the obliged companies (distributors or traders) have to achieve annual energy savings of 1.5% in selected consumer segments. The 1.5%

obligation, however, can be reduced by one-quarter through the following options (Pató, 2012):

- gradual implementation of the 1.5% target (2014 and 2015: 1%; 2016 and 2017: 1.25%; 2018-2020: 1.5%; on average 1.28%),
- exclusion of the industrial energy use of facilities under the EU ETS from the energy efficiency obligation scheme,
- exclusion of the savings achieved during energy transport (district heating, smart networks) from the energy efficiency obligation scheme, and
- recognition of early energy efficiency savings (measures prior to 2008 with their impacts lasting until at least 2020).

IV. THE INTERACTION OF SPECIFIC REGULATORY INSTRUMENTS – REVIEW THE RESULTS OF THE PREVIOUS RESEARCHES

As laid out in its energy and climate package, adopted in 2009, by 2020 the EU intends to lower GHG emissions by 20%, increase the ratio of renewable energy sources to 20% and reduce primary energy use by 20%. The main purpose of these actions is the mitigation of market failures: reaching a certain emission level (to internalise the costs of CO_2 emissions), implementing energy efficiency investments (taking care of market failures associated with insufficient levels of investment), and lowering the share of fossil fuels by supporting renewables, thereby reducing the negative externalities generated by fossil fuel based power plants. The main aim of the dissertation is to analyse the interactions of the instruments used for mitigating market failures. In order to reach these targets, the EU introduced four main regulatory instruments: excise tax on both energy consumption and the fuel used by fossil fuel based power plants; an emission trading system; measures to improve energy efficiency; and renewable support schemes that vary by member states, but are present in all of them. The listed regulatory instruments considerably impact each other, since the regulation is directed partly or wholly to the electricity sector.

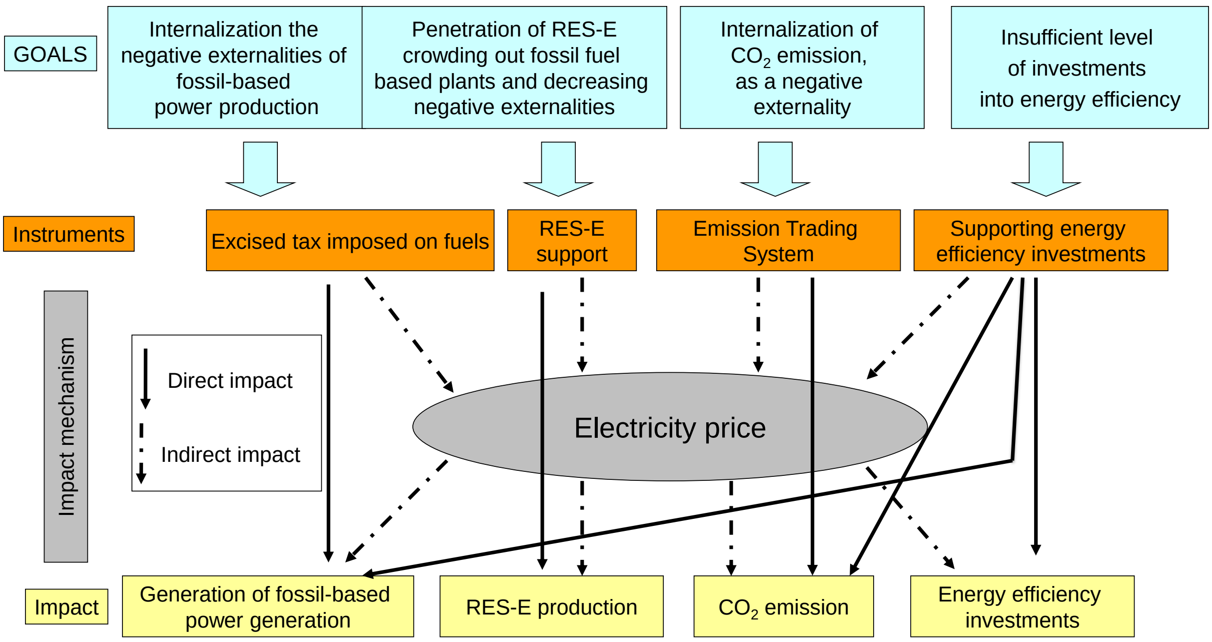
Sorrel-Sijm (2003), Del Rio (2007) and Bertoldi et al. (2005) state that in principle a regulatory instrument may deliver two types of impacts on a given participant: direct and indirect impacts can be distinguished. While in case of a direct impact the effect of a given regulatory instrument on a specific participant is straightforward - for example, renewable support provides an incentive for the penetration of renewables -, in case of an indirect impact the regulatory instrument in question also generates unintended side impacts. An example for this is the excise tax, which can also improve the competitiveness of renewables by making electricity generation from fossil fuels more expensive.

As a consequence, the interaction of two regulatory instruments may also be direct or indirect. We can talk of direct interaction when the target groups and goals of the two instruments are identical or overlap. A carbon-dioxide trading system coupled with a regulatory instrument that provides an incentive for companies to lower their CO_2 emissions, such as a CO_2 based excise tax can be an example for this. In case of indirect interactions both an indirect and a direct or indirect regulatory instrument apply to a given target group. To give an example, on top of a carbon-dioxide trading system, which increases the price of electricity for households, an excise tax on final electricity consumption is also introduced. In this case electricity consumption declines because of the higher prices, and the corresponding carbon-dioxide emission also decreases. In short, in addition to the indirect regulation (excise tax on electricity consumption) a direct regulatory instrument (carbon-dioxide trading) is also introduced.

Del Rio (2007) notes that the two certificate systems can connect in a number of ways. One of the options is that the credits used by the two regulatory instruments (e.g. green certificate and emission trading) can be freely transferred between the two markets, that is, in the market of green certificates carbon credits can also be recognised and vice versa. One-way recognition is also a possibility, while in the third case the two regulatory instruments impact each other only indirectly. Under the current EU and national regulations even if there is a green or a white certificate system in a given country, the generated credits are not recognised in the other system or under the ETS. Therefore certificates impact each other only indirectly.

Thus, the most important link between two regulatory instruments from the perspective of interactions may be direct or indirect. Figure 21 provides an illustration of the regulatory goal related direct and indirect impacts of the four main regulatory instruments that we examine.

Figure 21 The goals and impact mechanisms of the inspected regulatory instruments



Each regulatory instrument has its primary goal. The goal of the excise tax imposed on fuels is the reduction of generation by fossil fuel based power plants. Renewable support promotes the penetration of renewable based electricity generation, thereby crowding out fossil fuel based plants, mitigating some of the negative externalities of the electricity sector. The key purpose of the emission trading system is curbing carbon-dioxide emissions. Finally, the purpose of promoting investments into energy efficiency is an increased volume of these investments, thus reducing the insufficient level of investments stemming from asymmetric information and other market failures.

Renewable support directly impacts renewable based electricity generation. A similar direct interaction is observable between the emission trading system and carbon-dioxide emissions, as well as between the excise tax on fuel use and the production of fossil fuel based power plants. Measures targeting energy efficiency deliver two types of direct impacts: on the one hand, the number of investments into energy efficiency will increase, and on the other, as a result of lower electricity consumption, the production of fossil fuel based power plants will decline, similarly to the corresponding carbon-dioxide emission. The realignment of the supply side effects carbon-dioxide emissions, the penetration of renewables and indirectly the level of investments into energy efficiency through the change of electricity prices. In a similar fashion, the other instruments also generate indirect impacts through the price of electricity.

IV.1. THEORETICAL LITERATURES

One of the most important questions is what the effect of a renewable support scheme on the electricity price. Bye-Bruvoll (2008) prove in theoretical way that introducing a green certificate support scheme may increase or decrease as well the electricity price, it is dependent on the elasticity of supply and demand curves and the total quantity of green certificates. Jensen-Skytte (2003) state the similar argument. The direction in which the final consumer price moves depends on the shape of the demand and supply curves as well as the level of support. In the article the authors also seek to understand whether the emission trading system or the renewable support scheme is more efficient in case of a single target (emission reduction or renewable share). In their view if only a renewable target is set then the green certificate alone is more efficient, that is, the introduction of a supplementary emission trading scheme is not necessary. In case of an emission target the regulatory instrument to be applied depends on the correlation between the price of the green certificate and the final consumer price of electricity. When the correlation is positive, in other words, a higher renewable target increases the final consumer price, then it makes sense to use emission trading, otherwise green certificates are more suitable. If we seek to fulfil renewable and emission targets simultaneously and there is positive correlation between the price of green certificates and consumer price, then the instruments should be applied in line with the goals. In case of a negative correlation, the green certificate alone should be applied.

The impact of the green certificates is dependent on the connection of their neighbours. Skytte (2006) notes that the green certificate system does not effect the wholesale price of electricity in the country, while the retail price rises. The assumption behind the unchanged wholesale price is that the given country is well connected to its neighbours, therefore a relatively modest increase in renewables will not change conventional power plant generation. The renewable support, however, is to be paid by the consumer of the country in question, therefore the retail price will increase.

Böhringer-Rosendahl (2009) analyse the interaction of the emission trading and green certificate systems. According to the authors the green certificate system provides support exactly to the most polluting technologies, since renewable support lowers the price of carbon-dioxide credits, increasing the competitiveness of polluting power plants. They inspect this notion with a simplified electricity market model that assumes competition. The model in question simulates only the German market, considering net import as an exogenous factor, and covers three trading periods that are independent of each other. According to the results in case of an increasing number of green certificates (that is, with a higher renewable target) the final consumer price decreases for all target groups and the price of carbon credits also becomes lower. A similar analysis was also carried out by Rathmann (2007) who inspects the impact of adding a renewable support regime to an existing emission trading scheme in the German market. In his calculations he applies a linear relation for both the supply curve of renewables and the carbon-dioxide abatement curve. Based on this simplified calculation, the introduction of the renewable support scheme results in a lower price of carbon-dioxide credits, and the final consumer price also declines.

Using microeconomic relations Sorrell et al. (2009) analyse the interaction of the white certificate and emission trading. The authors conclude that not even the direction in which the wholesale price moves is certain: while prices are increased by the emission trading system, they are lowered by the white certificate system. In their opinion retail prices probably increase, depending on the slope of supply and demand curves, and the extent to which energy efficiency investments are supported. The price of carbon-dioxide credits, however, is clearly destined to decrease as white certificates appear. Table 7 sums up the results.

Table 7 The main impacts of introducing a white certificate system along an emission trading scheme

	Emission trading scheme	introducing a white certificate system along an emission trading scheme
RES-E production	increase	may increase and decrease as weel
Conventional power generation	decrease	decrease
Total consumption	decrease	decrease
Wholesale price	increase	may increase and decrease as weel
Retail price	increase	probably increase
CO2 emission	decrease	no change
Energy efficiency	increase	increase
CO2 price	-	decrease
Producer surplus	increase	may increase and decrease as weel
Consumer surpus	decrease	may increase and decrease as weel

Source: Sorrell et al. (2009) p. 36.

Del Rio (2010) analyses the interaction of the renewable support, the energy efficiency and the emission trading systems. Much detail is devoted to inspecting how the wholesale price, the retail price, renewable generation and energy efficiency investments would be impacted if on top of a regulatory instrument on energy efficiency a green certificate or feed-in tariff system was also introduced. Based on microeconomic relations he describes how given characteristics (e.g. low level of penalty, minimum price, differentiated support) of the green certificate and the feed-in tariff regulation influence the impacts on the above mentioned variables.

Table 8 The impact of introducing specific regulatory instruments

	Emission trading scheme with RES-E support regime	Emission trading scheme with support of energy efficiency investments	Introducing energy efficiency support schemes to on operating emission trading scheme and RES-E support regime	Introducing RES-E support schemes to on operating emission trading scheme and energy efficiency support regime
RES-E investment	increase	decrease	decrease	increase
RES-E production	increase	decrease	no change	increase
Conventional power generation	decrease	no change	no change	decrease
Total consumption	no change	decrease	decrease	no change
Wholesale price	increase	decrease	decrease	decrease
Retail price	no change	no change	no change	no change
CO2 emission	no change	no change	no change	no change

Source: Del Rio (2010), p. 4981.

Fischer-Preonas (2010) depict the mechanism through which given overlapping regulatory instruments impact each other. In each instance we supplement the already existing emission trading system with another regulatory instrument: a renewable support scheme or an excise tax. The authors of the article show that if an existing ETS is supplemented with a renewable support scheme, then the more polluting technologies are supported, since the price of the CO_2 credit declines, that is, heavily polluting companies will become more competitive. Thus, for instance, gas fired power plants will face reduced competitiveness compared to coal based plants, resulting in increased coal based power generation and higher emissions.

Johnstone (2003), on the other hand, argues that in specific cases it makes sense to introduce an excise tax on top of an existing emission trading system. These may include the instances when the marginal abatement cost curves are highly uncertain, the tax is imposed on non-compliance, or the windfall profit is intended to be decreased.

When set a renewable target, it has to be decided that the target is in relative or absolute term. Amundsen-Mortensen (2001) prove through an analytical model that if in case of green certificates percentage targets are set instead of absolute values then the higher target of green certificates does not necessarily imply higher renewable generation. The explanation is that due to the higher renewable target, which increases the price of green certificates, final consumer prices of electricity can increase, resulting in lower consumption which may also bring renewable energy generation down (or at least keep it from increasing) on a longer time frame. Choosing a similar method of analysis Will (2010) arrives at the same conclusion.

Widerberg (2011) describes the interaction of an international emission trading scheme and a domestic/international green certificate system. He proves through microeconomic relations that in case of a green certificate system an increasing renewable target leads to decreasing levels of conventional power plant production. Meanwhile, when the price of carbon-dioxide credits rise the carbon emissions of non-renewable power plants decline. In this case, however, not only the production of conventional power plants decreases, the output of renewable producers may also decline. This is the result of the decreasing electricity consumption due to higher prices, which, in case of a fixed volume of green credits also reduces the absolute level of production. This is in line with the result of Amundsen-Mortensen (2001).

IV.2. Review of literatures using economic models

In the followings those literatures are shown, which use economic models to simulate the interactions of the instruments.

Capros et al. (2008) based on their study written for the European Commission, running different scenarios on the so called PRIMES model - a general equilibrium model of the energy sector - examine GHG emissions, total expenditure on energy by final consumers, the ratio of renewables within energy use, and how these are distributed in specific member states of the EU. The general equilibrium model maximises the sum of consumer surplus and producer surplus, using carbon-dioxide emission and renewable targets as constraints. The authors took a detailed look at 11 scenarios in total, the results of which are summarised in Table 9.

Table 9 Scenarios defined by Capros et al. (2008) and the modelling results

Scenario	GHG reduction compared to the 1990 emission level, %	Ratio of renewables compared to total gross energy consumption, %	Total cost of compliance, billion EUR
Baseline	-1.5	12.7	-
Reaching the 20-20-20 targets without renewable trading	-20	20	111.2
Reaching the 20-20-20 targets without renewable trading, assisted by the CDM mechanism	-14.8	20	93.2
Reaching the 20-20-20 targets with renewable trading within the EU	-20	20	94.1
Reaching the 20-20-20 targets with renewable trading, assisted by the CDM mechanism	-15.2	20	70.1
Cost efficient	-20	20	90.8
Cost efficient with CDM mechanism	-16.8	20	75.2
High oil and gas price; baseline	-7.1	14.9	275.5
Cost efficient with high prices	-20	20	59.8
Only GHG reduction	-20	15.9	78.9
Only renewable target	-9.3	20	29.1

Source: Capros et al. (2008)

Based on the results of Capros et al. (2008) the cost of attaining the targets can be substantially reduced through renewable trading among member states (from € 111.2 billion to € 94.1 billion), and the CDM mechanism also mitigates the total cost of compliance. Furthermore, high energy prices alone are not enough to reach the renewable and GHG targets.

One of the most important questions is what the effect of introducing a renewable support scheme on the electricity price when an emission trading system is in force. Several authors analyse this problem. A short description of their methodology and main findings are summarized in the following.

Abrell-Weigt (2008) applies a general equilibrium model to understand how the German electricity market would be impacted by the introduction of an emission trading system with a 20% carbon-dioxide reduction target. They supplement this with either a green certificate system including a 20% renewable share target or with a differentiated feed-in tariff system supporting renewables. The authors rely on the 2004 input-output table of German economic sectors that includes 71 sectors and their products. Modelling results suggest that the introduction of emission trading increases the price of electricity. If, however, this scheme is supplemented with renewable support, then through the support the final consumer price of electricity declines, but compared to the scenario without any regulation prices are still a little higher, while the price of carbon-dioxide credits substantially declines. The authors did not discover any significant difference between the impacts of the two renewable support systems.

Using the MARKAL model Unger – Ahlgren (2005) examine the impacts of introducing a green certificate and/or an emission trading system in the Scandinavian countries. The MARKAL models the demand and supply side of the whole energy market - but focusing especially on the district heating and electricity markets - with a number of constraints, maximising the sum of the consumer and producer surplus, assuming perfect competition. In case of the electricity sector six demand points are modelled, from which the annual average electricity prices, and the price of the green certificates and carbon-dioxide credits can be determined. The simulation results of the model show that the larger the renewable target, the more the wholesale price of electricity declines. The shift in the retail price, however, is not so clear. Except for a specific target range, the retail price generally increases, although the extent of this increase stays below 25% even with a 50% target. A key conclusion of the authors based on the modelling results is that while a certain level of carbon-dioxide abatement is attainable even purely through a green certificate system, the social cost of this option is notably higher than if an emission trading scheme was introduced.

Tsao et al. (2011) look at the Californian market to inspect the impact of simultaneously introducing a green certificate and an emission trading system. They use a simplified electricity market model simulating perfect competition to quantify the results. During modelling the authors distinguished three power plant types (coal, renewable and gas), the marginal cost of each of which was characterised by a linear relationship. These three types of power plants are capable of satisfying the residual demand, which is equal to the total demand minus net import and the production of hydro power plants. Apparently, the last two factors are exogenous within the model. The results demonstrate that the final consumer prices increase for every emission reduction or renewable target. The two regulatory instruments, however, partly erode the effect of the other regulatory instrument: the higher the renewable target, the more the price of the carbon-dioxide credit declines and vice versa.

De Jonghe et al. (2009) model the electricity markets of the Benelux countries, France and Germany. As part of the simulation the authors distinguish two technologies: conventional and renewable producers. The supply curve for both technologies can be described with a linear relationship, and these relations are different for each country. The demand curve can also be characterised with a linear function. Through the modelling exercise the authors establish that regardless of the renewable target the price of retail electricity always rises. They also examine the interaction between the emission trading instrument and renewable support: how the price of these two types of credits change under different targets. An important conclusion is that there can be a large number of situations in which one of the regulatory instruments become completely inefficient (that is, the price of the green certificate / carbon-dioxide credit falls to zero).

Linares et al. (2007) analyse the interaction of different regulatory instruments in the Spanish market using a dynamic, oligopolistic model that they had developed themselves. During modelling the 2005-2020 period is simulated, distinguishing among almost 20 different technologies, each with their own unique costs. Based on the results of the simulation retail electricity prices are lowest in the absence of any regulation. The authors also reveal that in case of the joint application of renewable and emission targets, the most efficient solution requires the use of both instruments (emission trading and renewable support), since according to their calculations this results in lower final consumer prices.

Hindsberger et al. (2003) use an electricity market sectoral model called Balmorel to examine the interaction of green certificates and emission trading. The model covers the Baltic and Nordic countries, assuming perfect competition in both production and allocation of cross-border capacities. The model distinguishes 10 different technologies, the short run marginal costs of which differ by technology, the year of construction and the country. In total four reference hours were defined for each modelled year, and the annual average price, the composition of the production and the carbon-dioxide emission can be calculated by assigning an appropriate weight to each of these hours. Based on the results of the simulation the authors conclude that the higher the renewable or emission abatement target, the higher the retail price paid by consumers, that is, the decline of the wholesale price prompted by the renewables cannot balance the additional expenditure of consumers in relation to the green certificates.

Bird et al. (2011) analyse the electricity sector of the United States with the use of a sectoral model. The ReEDS minimises system costs while also satisfying physical requirements (consumption, sufficient levels of reserve capacity etc.). Optimisation takes place on a long time horizon: the model works with 23 biannual periods. The authors apply the model to look at the consequences of introducing emission trading and a green certificate system separately and in combination. In total 12 scenarios have been analysed, and the composition of the fuel mix was disclosed for two threshold years. Importantly, energy efficiency measures were found to lower the price of carbon-dioxide credits and the price of green certificates is substantially reduced by the introduction of carbon-dioxide trading. Finally, the authors conclude that an average carbon-dioxide emission reduction target or a green certificate system does not result in a significant increase of electricity prices.

Traber-Kemfert (2009) inspect how the price of electricity and the price emission credits would change if a renewable feed-in tariff system was introduced on top of the 2006 baseline of the German system. During the research the so called EMELIE EUR-25 model was applied, which models the European electricity market supplemented with the whole ETS sector, therefore the price of the credit is endogenous for modelling. The model assumes static Cournot quantitative competition, distinguishing 12 technologies in total. It assumes that domestic internal congestion is not present, trading limits appear through cross-border capacities. The modelling results for Germany suggest that as a result of the substitution effect final consumer prices of electricity (the sum of renewable support and lower wholesale prices) substantially increase, and this can only partly be balanced by the lower wholesale price of electricity due to the lower price of carbon-dioxide credits (conventional power plants are crowded out by renewables, lowering the demand for carbon-dioxide credits). In contrast, the price of electricity decreases in all other European countries, mainly thanks to the lower price of carbon credits.

Palmer et al. (2010) use an equilibrium model called NEMS developed to simulate the energy markets of the United States, to select the instruments with which a given carbon-dioxide reduction target is achievable at the lowest cost. Based on the modelling results renewable support schemes are much more expensive in achieving a given level of carbon-dioxide emission reduction than emission trading or a carbon-dioxide tax. The authors reckon that in case of a carbon-dioxide tax renewable support can generate additional emission reduction, while when a minimal price is set for the carbon-dioxide credit, then the chances for this price to take place increase.

Through a modelling exercise Sensfuss et al. (2007) examines how renewable support impacts the wholesale and retail price of electricity. The PowerAce simultaneously models the hourly electricity market and the reserve market of Germany. As part of the exercise through the calculation of the marginal costs of the different technologies the authors determine the supply curve for Germany, while the demand curve is constructed from past data. The results suggest that renewable support leads to substantially lower wholesale prices and retail prices also decline. The introduction of emission trading, on the other hand, definitely increases the prices paid by consumers (or at least it does not decrease them).

Table 10 Review of the literature with modelling results

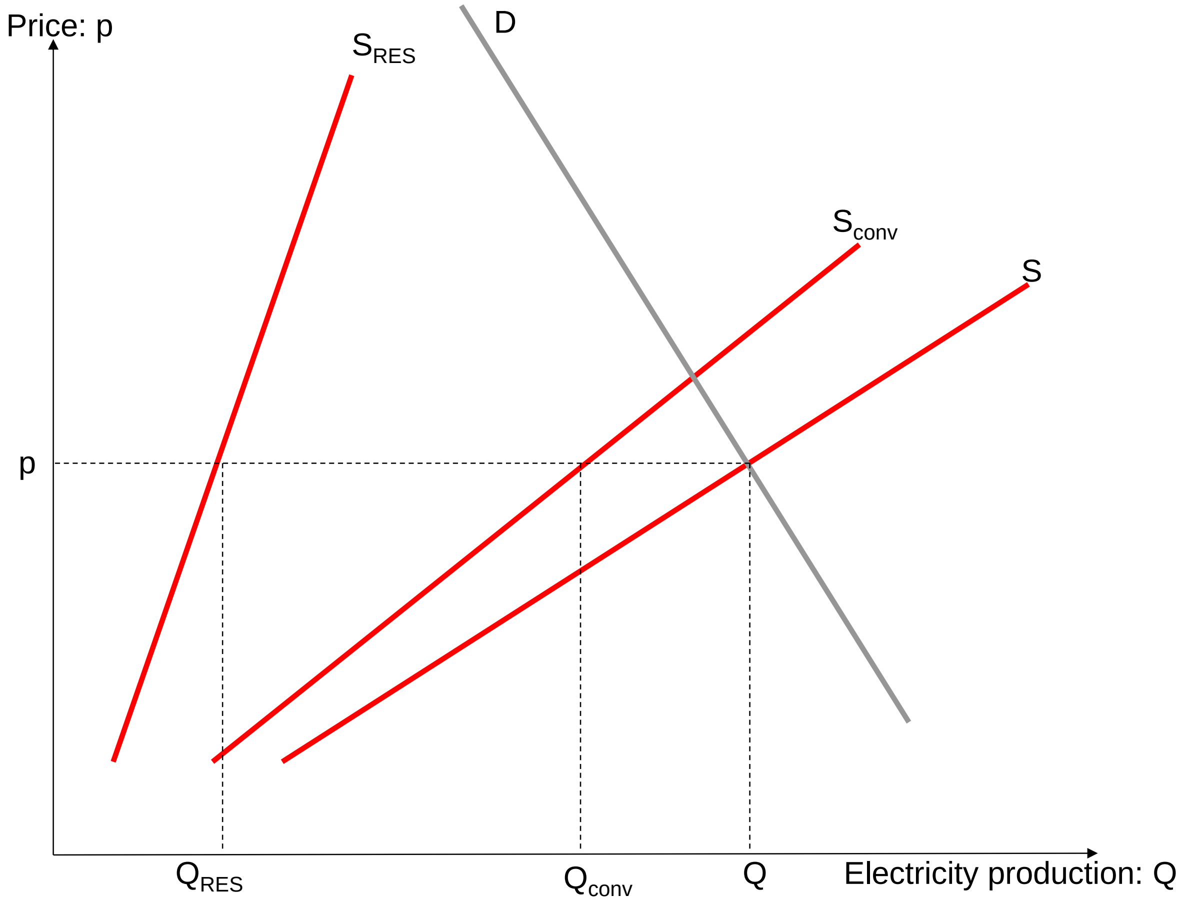
Author	Modell used	Covered region	What is analyzed	Main findings
Capros et. al (2008)	PRIMES - general equilibrium model	EU27	What is the most efficient way to meet the 20-20-20 targets	1.: Efficient, if the CO2 emisison reduction outside of the EU can be taken into account to meet the target 2.: Compliance cost decreases, if it is possible to trade with RES-E within the EU. 3.: High energy prices without any environemntal tool can not lead to meet energy efficiency target.
Abrell-Weigt (2008)	General equilibrium model	German electricity market	Introducing RES-E support scheme to an operating emisison trading system	1.: CO2 price decrease significantly 2.: Retail prices also decrease, but it is higher compared to the reference scenario when no regualtions is applied
Unger – Ahlgren (2005)	MARKAL - energy sector model	Scandinavian countries	Introducing an emission trading system and/or a green certificate regime	1: Although the emission reduction target can be meet only with green certificate system, but the compliance cost is much higher, compared introducing emisison trading system as well. 2: Retail price may decrease, but this is negligible, but typically - especially in high RES-E target - incerase significantly.
Tsao et al. (2011)	Electricity market model	California	Introducing emission trading system and green certificate regime	1.: In every emission reduction target and RES-E target the retail prices increase. 2.: The two environmental instruments weaken the effects of the other ones.
De Jonghe et al. (2009)	Electricity market model	Benelux, Germany and France	Introducing emission trading system and green certificate regime	1.: In every RES-E targets introducing a green certificate regime increase the retail prices. 2.: There are severeal situation when one of the instruments are become insufficient.
Linares et al. (2007)	Oligopol, electricity market model	Spain	Introducing emission trading system and/or green certificate regime	1.: Regualtion without any instruments lead to the lowest retail prices. 2.: If RES-E and emisison reducion targets also exists, then itis efficient to use both of the instruments.
Hindsberger et al. (2003)	Balmorel, electricity market model	Baltic countries	Introducing emission trading system and/or green certificate regime	1.: Higher the RES-E targets, and the emission reduction targets, higher the retails prices are.
Bird et al. (2011)	ReEDS, electricity market model	USA	Introducing emission trading system and/or green certificate regime	1.: Supporting energy efficient investments lower the price of CO2. 2.: Emission trading scheme decrease significantly the price of green certificate prices.
Traber – Kemfert (2009)	Electricity market model	German electricity market	Introducing emission trading system and feed-in support scheme	1.: In Germany the retail price increase significantly, while in the rest of the modelled countries retail prices decreases, partly due to the lower CO2 price.
Palmer et al. (2010)	NEMS, általános egyensúlyi modell	USA	Quantifying the cost of decreasing CO2 emision with RES-E support scheme, with emission trading scheme or with CO2 tax	1.: RES-E support scheme can meet emission reduction targets with a mucm higher cost than applying emisison trading scheme or a CO2 tax.
Sensfuss et al. (2008)	PowerAce, electricity market model	German electricity market	Introducing emission trading system and/or green certificate regime	1. RES-E support decrease the wholesale prices. 2. Introducing emission trading system increase the retail prices.

Apparently, the majority of literature models the interaction of green certificates and the emission trading system. There is an almost complete absence of modelling efforts that would look at the interaction of other, more generally used regulatory instruments (excise tax, measures on energy efficiency).

V. THE IMPACTS OF GIVEN REGULATORY INSTRUMENTS

Each regulatory instrument has different impacts on the price of electricity, and through this the generation of fossil fuel based and renewable power plants, carbon-dioxide emissions, and investments into energy efficiency.

Figure 22 The demand and supply curves of electricity without regulatory intervention



Looking to the situation when non the of instruments are in force, then two groups can be distinguished on the supply side: renewable producers and conventional producers[9].The long run supply curve of renewable producers is illustrated by the S_{RES} curve, while S_{conv} represents conventional producers. By horizontally adding the two curves we arrive at the supply curve of the electricity sector, indicated by S in Figure 22, while D stands for the demand curve of electricity.

The equilibrium quantity (Q) and price (P) are at the intersection of the demand and supply curves. The figure also conveys the electricity production of renewable generators (Q_{RES}) and conventional power plants (Q_{conv}). Within the analysis we always assume that the production

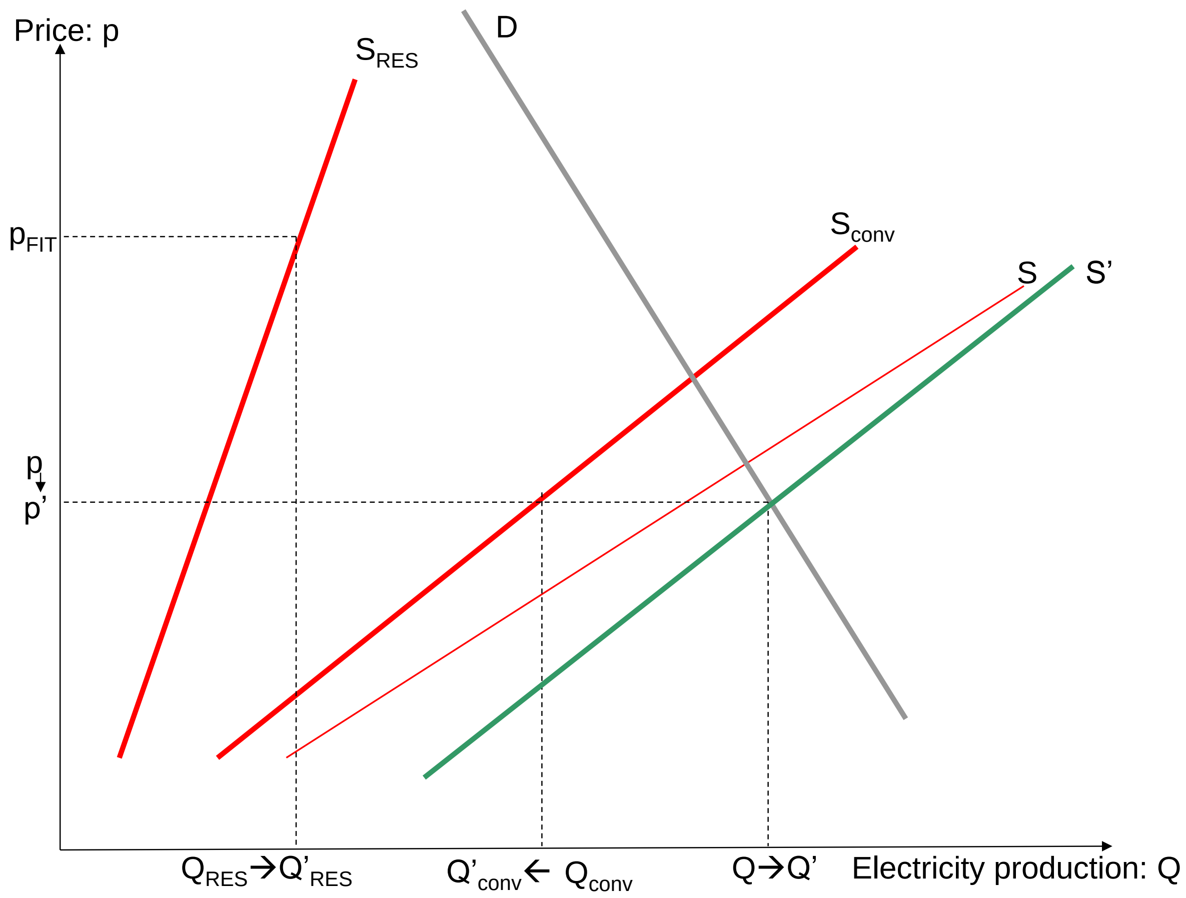
[9] We assume that nuclear power plants also belong to conventional plants. This, however, is not relevant for the subsequent analysis.

of renewables does not involve carbon-dioxide emissions, while the unit emission of conventional power plants is the same on all sections of the supply curve.

V.1. THE IMPACT OF SUPPORTING RENEWABLE ENERGY SOURCES ON THE ELECTRICITY MARKET

Earlier we showed that two main instruments are available to support renewable electricity generation: one of these is the volume based support regime, under which the regulator sets the level of renewable electricity generation for the period in question. This is the green certificate system. The other potential method of support is the price support, that is, the renewable producers can sell the generated electricity at regulated fixed price (or in case of a premium, at a partly fixed price). Renewable production grows in both cases. Let's assume that the desired volume is Q'_{RES} in Figure 23. The regulator has two options to attain this volume. It can set the intended volume of renewable electricity generation and introduce a green certificate market. The volume based target and the supply curve of renewables will indirectly also determine the market price of green electricity. The other option is fixing the price (p_{FIT}), which, based on the supply curve, will also result in production of Q'_{RES}.

Figure 23 The demand and supply curves of electricity in case of a renewable support regime with external financing[10]

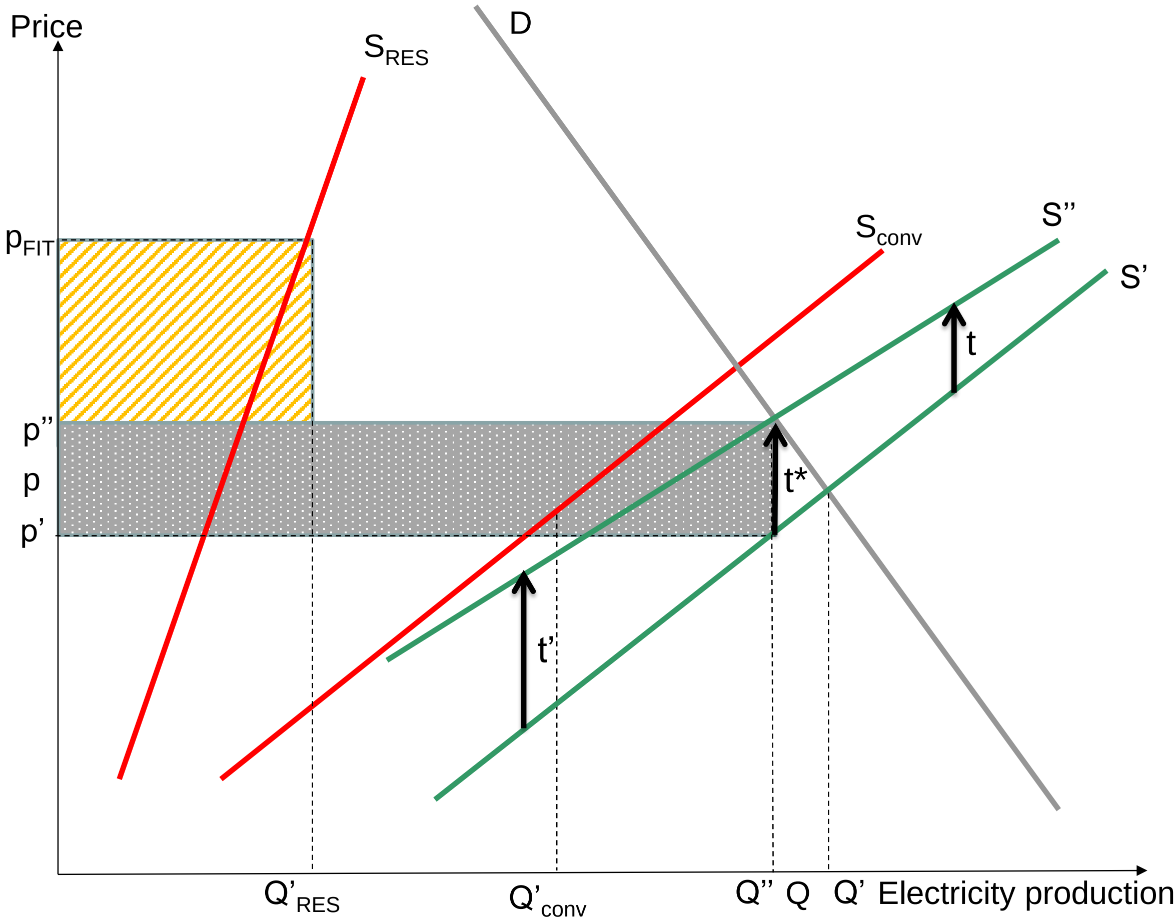


The quantity of renewable production increases to Q'_{RES} as a result of renewable support, independently of market price. Therefore we get the supply curve of the electricity sector (S') by horizontally adding Q'_{RES} to the supply curve of conventional power plants. The new wholesale equilibrium price is thus p', while the demanded quantity is Q'. Thereby electricity consumption increases compared to the original equilibrium. Since the production of conventional power plants declined, carbon-dioxide emissions also go down. Investments into energy efficiency, on the other hand, are negatively impacted, since due to the lower wholesale price of electricity the return on energy efficiency investments also decreases.

It is important to note that the above thought process excludes the demand of renewables for support, the size of which in Figure 23 equals the price difference between p_{FIT} and p' multiplied by renewable production (Q'_{RES}). Therefore we indirectly assumed that renewables are financed from outside the sector, through the central budget, for instance. In most countries that apply renewable support, predominantly electricity consumers generate the sources supporting the renewables. It is therefore important to inspect the case involving intra-sectoral financing.

[10] In case of perfect information the green certificate market and the feed-in tariff lead to the same result.

Figure 24 The demand and supply curves of electricity in case of a renewable support regime, financed within the electricity sector

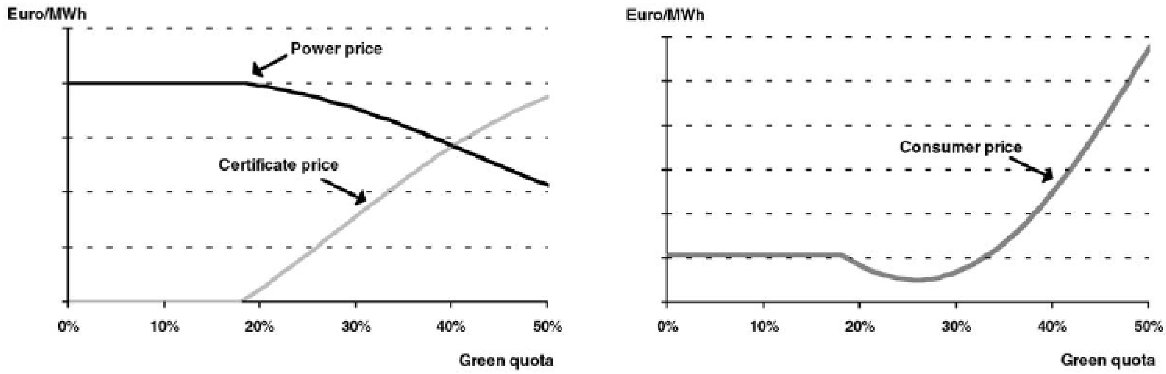


Source: Mezősi (2014)

In the case without renewable support there is an equilibrium price of p and quantity of Q. If financing needs to take place within the sector then the supply curve shifts upward, since the supply curve also has to be supplemented with the tariff constituent financing the renewables. Importantly, the supply curve does not shift perfectly parallel, and its position cannot be entirely precisely determined. This is because the demand for renewable support also depends on the resulting competitive market price (p'), which, however, is also influenced by the extent to which the supply curve has to shift in order for tariff revenues to cover the necessary support requirement. On the other hand the lower the consumption, the higher the tax rate will be, as indicated in the figure (t'>t*>t). The resulting equilibrium price in this case is p'', while the resulting equilibrium quantity is Q'', and the unit renewable tariff is t*. Distinguishing the retail and the wholesale prices, nevertheless, is important. The ensuing wholesale price will be p' in this case, and if we add the renewable tariff (t*) on top of this, we arrive at the retail price of electricity (p''=p'+t*). Since the resulting retail price in this case surpasses the initial price (p), there is an incentive for energy efficiency investments to take place. In Figure 24 figure we introduced a case in which the ensuing retail price is higher than the initial price (p’’>p), this, however, is not necessary.

In their theoretical article Jensen-Skytte (2002) analyse how, in case of a green certificate system, the renewable target affects the wholesale price of electricity, and the retail price of final consumers. As Figure 25 describes, beyond a specific renewable target the wholesale price already declines, but at the same time the price of the green certificate rises. The retail price, which also includes the cost of renewable support, declines for a little bit, but starts to increase at a higher renewable target. The underlying reason is that the decline of the wholesale price in this range is so steep that it is only partly balanced by the support need of renewables, but on the whole the retail price still declines.

Figure 25 The price of the green certificate and the wholesale and retail electricity price at given renewable ratios



Source: Jensen-Skytte (2002), p. 434.

It is possible that the retail price decrease, which Skytte (2006) illustrate with the following way. Let the equilibrium price of electricity be 22 €/MWh without a renewable regulation. Afterwards a green certificate system is introduced, requiring all consumers to purchase 10% of their consumption from renewable based generation. Let the cost of renewables be 30 €/MWh. As the production of renewable power plants displaces the more expensive non-renewable producers, the market price of electricity declines to 18 €/MWh. The price of the green certificate in this case is 30 €/MWh minus 18 €/MWh, which is 12 €/MWh. The retail price is equal to the price of electricity plus the price of the green certificate multiplied with the ratio of green certificates. Since consumers need to purchase 10% of their consumption from renewable sources, the cost of renewable support distributed over their total consumption is 12 €/MWh*10%, that is, 1.2 €/MWh. Therefore, as a result, the initial electricity price of 22 €/MWh declines to 18 €/MWh + 1.2 €/MWh, which is 19.2 €/MWh.

As already described, De Jonghe et al. (2009) arrive to a modelling result according to which regardless of the actual green certificate target, the retail price will increase.

In summary, the introduction of renewable support can trigger the following impacts:

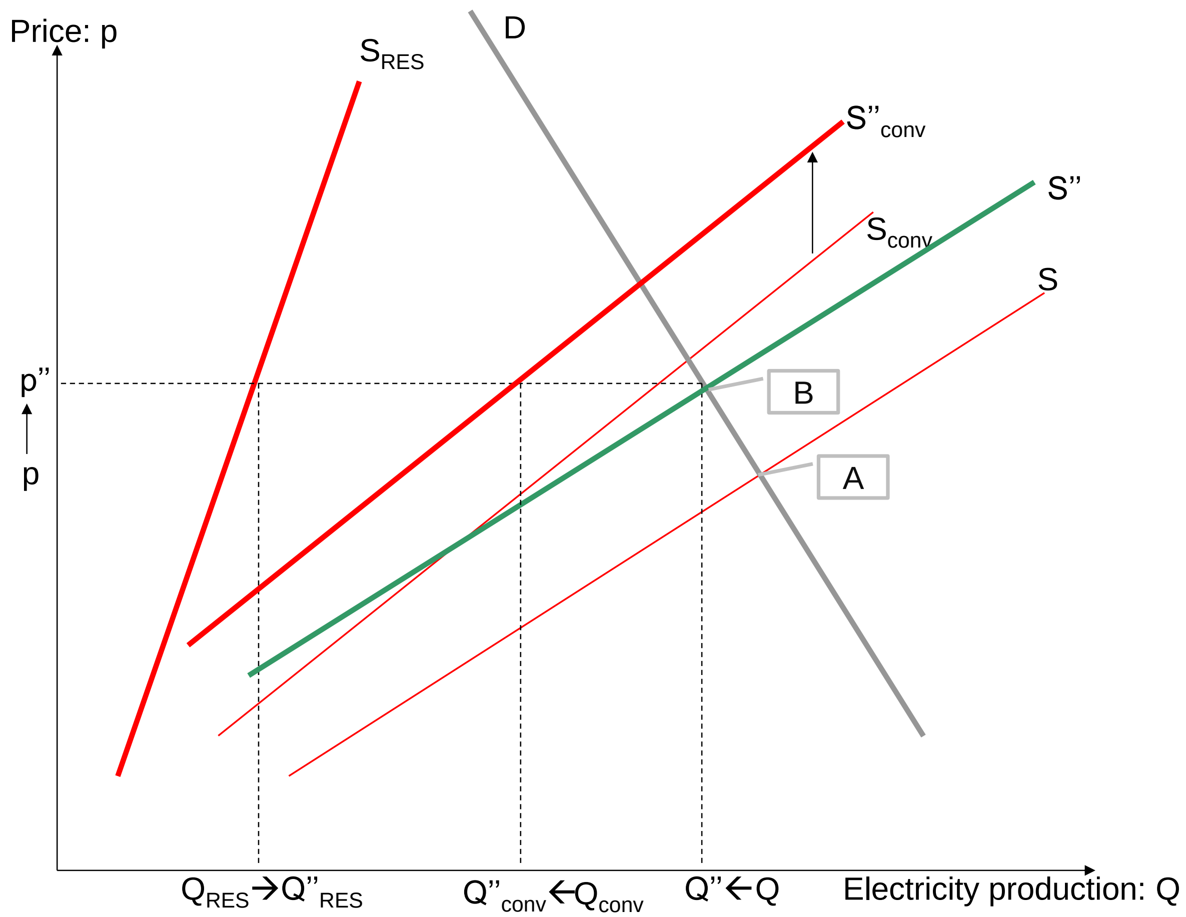
- renewable based electricity generation increases
- the wholesale price declines
- the retail price may decrease as well as increase
- electricity consumption may decrease as well as increase
- the production of conventional power plants very likely declines
- carbon-dioxide emissions very likely decline
- the level of energy efficiency investments may decrease as well as increase

Any renewable support regime may generate three impacts: based on the so called direct impact renewable based electricity generation can displace some of the production of traditional power plants, as a result of which the wholesale price of electricity declines (De Miera et al., 2008). As a result of the decrease of conventional power plant production the demand for carbon-dioxide credits declines (if there is carbon-dioxide trading), that is, their price falls, as a consequence of which the marginal cost of traditional power plants also declines. Therefore, ultimately, the wholesale price of electricity decreases. This is what the authors called indirect impact. Finally, the need for renewable support increases the retail price. The authors inspected the Spanish wind power plant subsidy scheme that was in effect between 2004 and 2006 and found that the direct impact alone counteracts the increase of the retail price due to the subsidies provided to wind power plants. In other words, due to the introduction of the renewable support scheme not only wholesale prices, but retail prices also declined.

V.2. THE IMPACT OF THE FUEL EXCISE TAX ON THE ELECTRICITY MARKET

The excise tax on the fuel use of fossil fuel based power plants changes the supply curve of conventional power plants. As a little simplification we assume that the level of the tax is the same for all units of electricity, that is, the supply curve shifts parallelly upwards (Figure 26).

Figure 26 The demand and supply curve of electricity with an excise tax imposed on the fuel use of conventional power plants



As a result of the shift of the supply curve of conventional power plants (S_{conv}→S''_{conv}) the supply curve of the electricity sector also changes: the initial S curve shifts and there is a new supply curve of S''. The supply curve of renewables does not change as a result of the tax. For the new equilibrium (B) the equilibrium price unmistakably grows ($p<p''$), while the equilibrium quantity declines ($Q>Q''$). Due to higher electricity prices renewable generators increase their production in the long run ($Q_{RES}<Q_{RES}''$), while the output of conventional power plants decreases ($Q_{conv}>Q''_{conv}$), consequently, carbon-dioxide emissions also decline. As a result of higher wholesale prices energy efficiency investments offer higher returns, therefore the level of these investments rises.

V.3. THE IMPACT OF THE CARBON-DIOXIDE TRADING SYSTEM ON THE ELECTRICITY MARKET

The impacts of the carbon-dioxide trading system are similar to those of the excise tax on fuel use. As the supply curve of conventional power plants shifts, the supply curve of the electricity sector also shifts upwards. Since the demand curve does not change, the equilibrium wholesale price of electricity increases, thereby reducing electricity consumption.

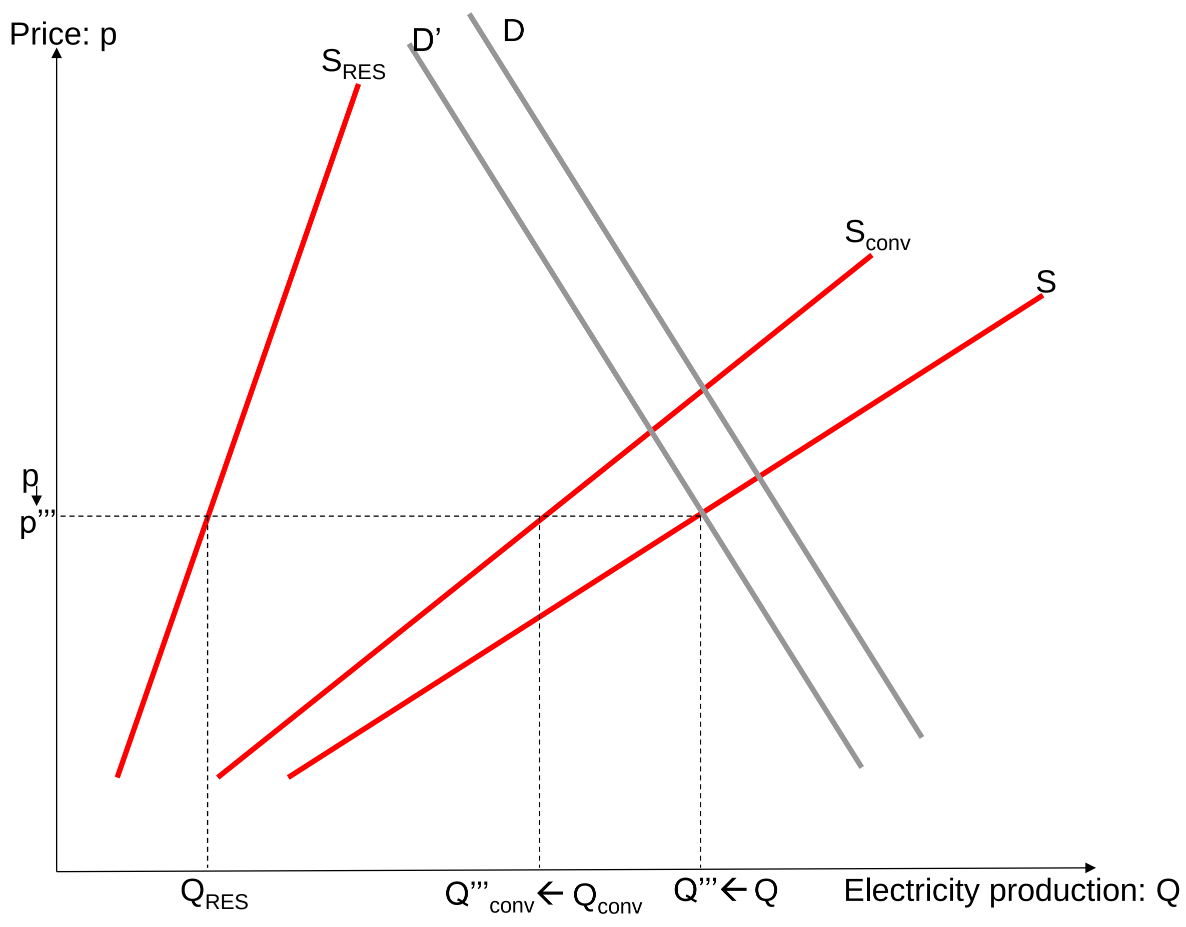
Due to the higher price renewable producers become more competitive, therefore they increase their production in the long run, while conventional power plants reduce their output.

When looking at the emission trading system it is important to emphasize that the method of allocation, that is, whether credits are handed out for free or in exchange for a payment, does not alter the supply curve, thus it does not affect the final equilibrium price (see Lesi-Pál, 2004).

V.4. The impact of supporting energy efficiency investments on the electricity market

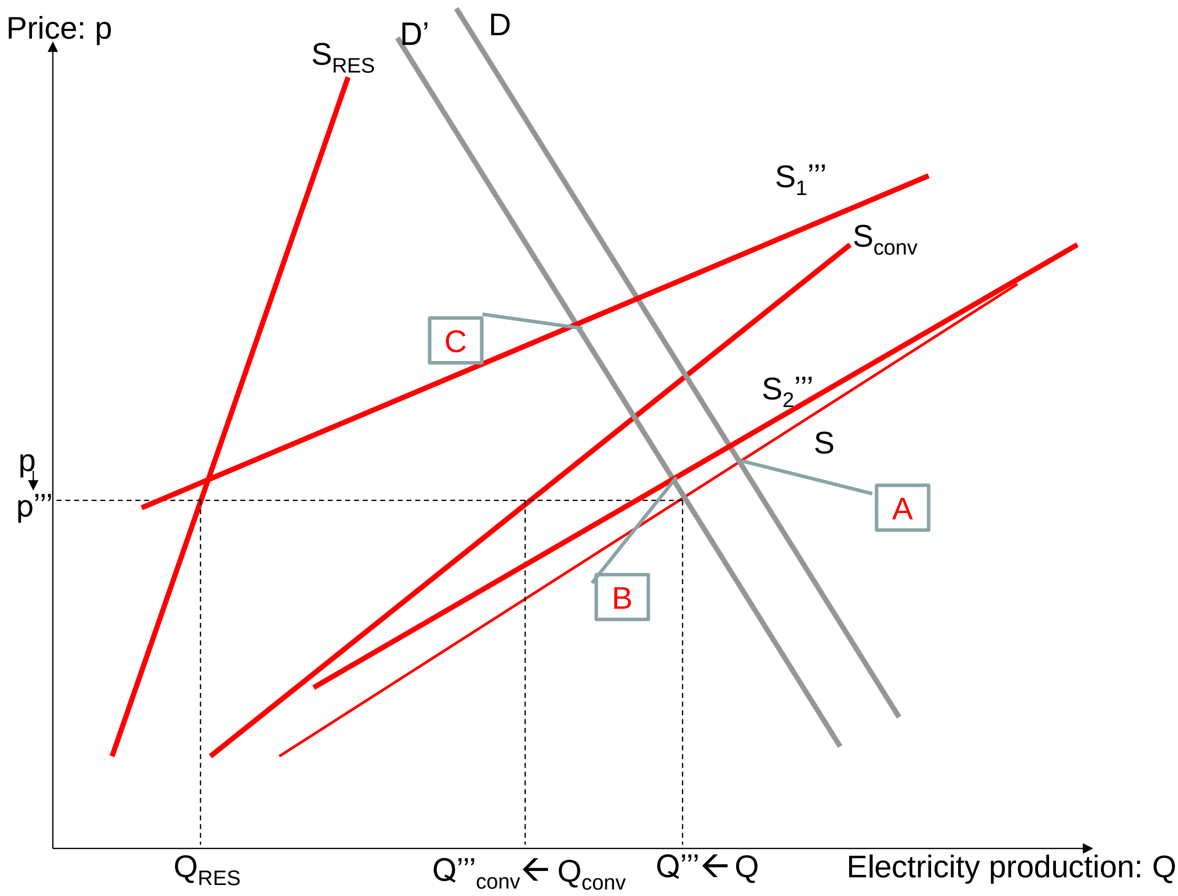
In case of energy efficiency investments the demand curve shifts to the left, while the supply curves are unchanged as long as financing of the energy efficiency investments takes place outside of the sector (Figure 27).

Figure 27 The demand and supply curve of electricity in case of energy efficiency investments, when financed from outside of the electricity sector



As a result of the shift of the demand curve the equilibrium quantity decreases to Q''', and the equilibrium wholesale price slides to p'''. Due to the support of renewables and the lower electricity price in the long run renewable based electricity generation also falls, similarly to the production of fossil fuel based power plants. This also entails lower carbon-dioxide emissions. It is, nevertheless, also important to inspect the situation in which financing takes place within the sector.

Figure 28 The demand and supply curve of electricity in case of energy efficiency investments, when financing takes place within the electricity sector



If a lot of energy efficiency investments are executed, which has a high financing requirement, then the supply curve notably shifts. Let's assume that the financing needs can be met when the supply curve is shifted to S_1'''. [11] In this case the retail price substantially grows and electricity consumption declines (Figure 28). Due to the high price electricity generation may decline at both renewable and conventional power plants, therefore carbon-dioxide emissions also decrease. If, however, the level of financing is modest, then the supply curve only shifts to S_2'''. Now the retail price declines compared to energy efficiency investments, while the consumed quantity also decreases. Due to the decline of consumption renewable production also shrinks, similarly to conventional generation, which implies lower carbon-dioxide emissions.

Sorrell et al. (2009) arrive to the same conclusion for white certificates as well. As a result of lower electricity consumption the wholesale price of electricity declines, reducing

[11] Similarly to the case of renewable support, the supply curve does not shift parallelly in this case either.

conventional power plant production. The direction to which retail prices change, however, is less clear. The authors emphasize that additionality is an important question when white certificates are introduced, that is, only those investments should qualify for white certificates which would not take place otherwise. This is one reason why white certificates operate entirely differently than green certificates. The price of white certificates depends on the target, the price elasticity of demand and supply, the current level of energy efficiency, whether the demand-supply curves are non-linear, and the regulator's decision on additionality.

V.5. SUMMARISING THE IMPACTS OF EACH REGULATORY INSTRUMENT

Previously we described how the four regulatory instruments that we consider as most important influence electricity consumption, price, the production of renewable and conventional power plants, the level of energy efficiency investments and carbon-dioxide emissions. Table 11 pulls together these impacts.

Table 11 The main impacts of each regulatory instrument

	Financed from outside of the electricity sector/revenues are not returned to the electricity sector				Financed from inside of the electricity sector/revenues are returned to the electricity sector			
	RES-E support	Excise tax imposed on fuel	Emission trading system	Support of energy efficiency investments	RES-E support	Excise tax imposed on fuel	Emission trading system	Support of energy efficiency investments
RES-E production	Increase	Increase	Increase	Decrease	Increase	Increase	Increase	Decrease
Electricity production from conventional power plants	Decrease	Decrease	Decrease	Decrease	Very likely decline	Very likely decline	Very likely decline	Decrease
Total consumption	Increase	Decrease	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well	Decrease
Wholesale price	Decrease	Increase	Increase	Decrease	Decrease	Increase	Increase	Decrease
Retail price	Decrease	Increase	Increase	Decrease	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well
CO2 emission	Decrease	Decrease	Decrease	Decrease	Very likely decline	Very likely decline	Very likely decline	Decrease
Energy efficient investments	Decrease	Increase	Increase	Increase	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well	Increase

VI. REVIEW OF THE METHOD

In previous chapters we provided a detailed description of the regulatory instruments that can be used to treat the market failures present in electricity markets. For each instrument we provided an in-depth assessment of the impacts of its introduction, then we depicted the interaction of these instruments relying partly on the literature, and partly on our own research results.

In the following the interactions of the four analysed instruments are shown. After this, we demonstrate the European Electricity Market Model, which is an economic model simulating the European electricity market. With the help of this model, we can analyse the interactions of the four instruments. We provide a detailed description of the operation of this model, its input data and its limitations.

VI.1. THE INTERACTION OF THE EXAMINED FOUR REGULATORY INSTRUMENTS

Partly based on literature, and partly building on our own results we summarise in Table 12 how the four instruments that we inspected impact those factors that are important from the perspective of our analysis. These include the following:

- long run production of renewable power plants
- long run production of conventional power plants
- total electricity consumption
- wholesale electricity price
- retail electricity price
- carbon-dioxide emissions
- energy efficiency investments
- price of emission credit
- demand for renewable support / price of tradable certificate
- demand for support to investments into energy efficiency.

We examined all the possible regulatory portfolio combinations that can be created from the four instruments of our analysis. It is essential to keep in mind that the goal of these regulatory instruments is the mitigation of market failures within the electricity sector. As we already described, the market failures in the focus of our analysis are the following: i) environmental externalities generated by conventional power plants; ii) insufficient level of investments into energy efficiency; iii) the negative externalities of carbon-dioxide emissions. The targets set by the EU are also related to addressing these market failures: higher share of renewables, primary energy savings, and GHG reduction. In Table 12 we used green colour to indicate those cells for which the regulatory instrument portfolio is clearly capable of reaching the given target (at least on a theoretical level), yellow stands for uncertainty in this respect, and adverse impacts compared to the targets are indicated by red.

Evidently, there is only one regulatory mix that cannot get closer to reaching the given target, when solely energy efficiency investments are supported by the regulator, as in the long run this hinders the spreading of renewable power plants. All the other combinations, however, can help to achieve the targets, but there are seven instrument mixes when the impact of them are ambiguous. This is why it is important to use modelling to examine if these targets are indeed achievable, and if yes, at what cost.

Table 12 The impacts of given regulatory instrument combinations

Regulatory mix		RES-E production	Production of conventional power plants	Total consumption	Wholesale price	Retail price	CO2 emission	Energy efficiency investments
Only emission trading system		Increase	Decrease	Decrease	Increase	Increase	Decrease	Increase
Without emission trading system	RES-E support scheme	Increase	Very likely decline	May increase and decrease as well	Decrease	May increase and decrease as well	Very likely decrease	May increase and decrease as well
	Excise tax	Increase	Decrease	Decrease	Increase	Increase	Decrease	Increase
	Supporting energy efficiency investements	Decrease	Decrease	Decrease	Decrease	May increase and decrease as well	Decrease	Increase
	Excise tax + RES-E support scheme	Increase	Decrease	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well	Decrease	May increase and decrease as well
	Excise tax + Supporting energy efficiency investments	May increase and decrease as well	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	Increase
	RES-E support scheme + Supporting energy efficiency investements	Increase	Decrease	Decrease	Decrease	May increase and decrease as well	Decrease	Increase
	RES-E support scheme + supporting energy efficiency investements + excise tax	Increase	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	Increase
With emission trading system	RES-E support scheme	Increase	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	May increase and decrease as well
	Excise tax	Increase	Decrease	Decrease	Increase	Increase	Decrease	Increase
	Supporting energy efficiency investments	May increase and decrease as well	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	Increase
	Excise tax + RES-E support scheme	Increase	Decrease	May increase and decrease as well	Decrease	May increase and decrease as well	Decrease	May increase and decrease as well
	Excise tax + Supporting energy efficiency investments	May increase and decrease as well	Decrease	May increase and decrease as well	May increase and decrease as well	May increase and decrease as well	Decrease	Increase
	RES-E support scheme + Supporting energy efficiency investements	Increase	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	Increase
	RES-E support scheme + supporting energy efficiency investements + excise tax	Increase	Decrease	Decrease	May increase and decrease as well	May increase and decrease as well	Decrease	Increase

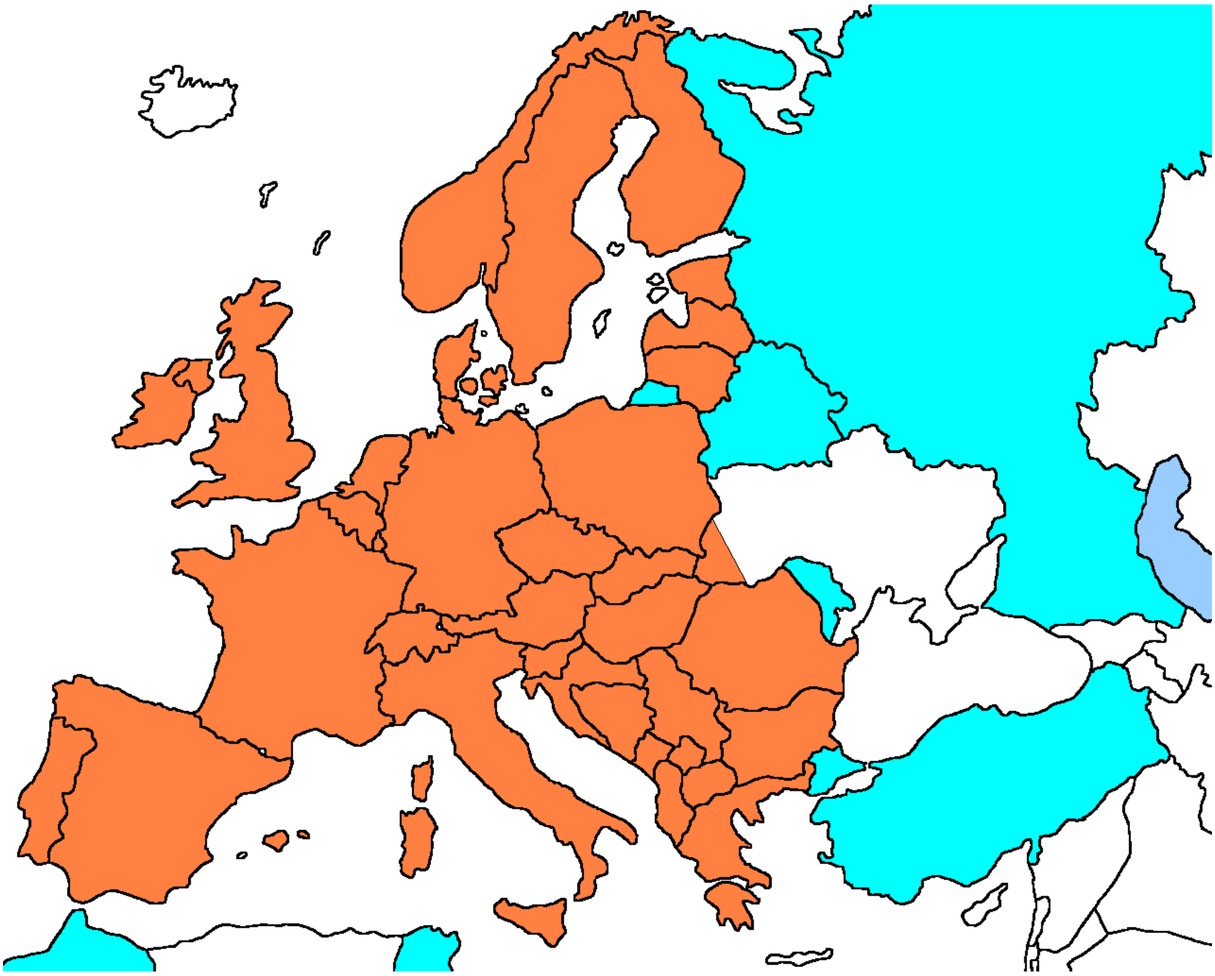
VI.2. DESCRIPTION OF THE EUROPEAN ELECTRICITY MARKET MODEL

The European Electricity Market Model (EEMM) simulates the wholesale electricity markets of 36 European countries, assuming perfect competitive market conditions. The model is introduced using the following pieces of literature: REKK (2011a); REKK (2011b), REKK (2011c), Mezősi-Szabó (2012).

VI.2.1. The general introduction of EEMM

The EEMM simulates the electricity markets of 36 countries. In countries with orange colour prices stem from the equilibrium of demand and supply, while in countries with light green colour prices are treated by the model as given, that is, they are exogenously set (Figure 29).

Figure 29 Countries within the EEMM



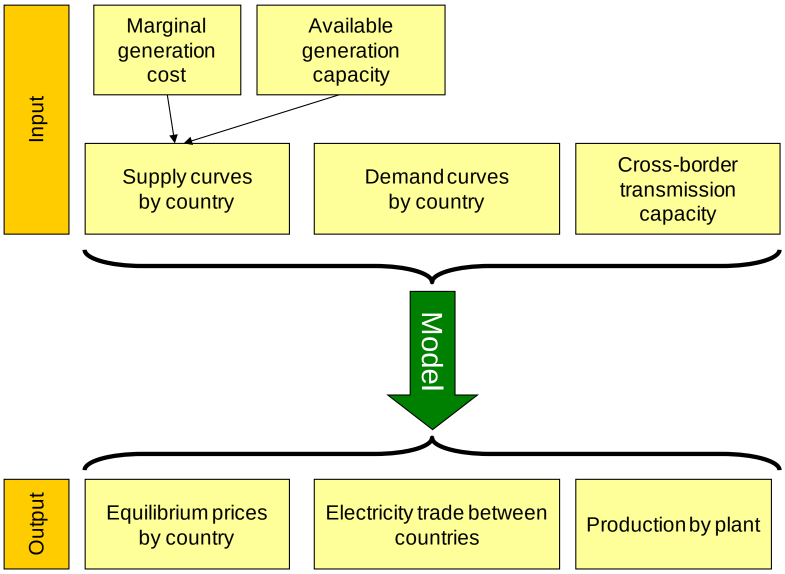
The EEMM distinguishes three types of market participants: the producer, the consumer and the trader. Perfect competition is assumed for each of these, that is, market participants are price takers.

The short run marginal cost can be calculated for each power plant. Production is constrained by capacity, equal to the installed capacity of each power plant unit. Within the electricity sector we distinguish 12 different technologies: biomass fired power plants, coal fired plants, lignite fired plants, geothermal plans, heavy fuel oil fired plants, light fuel oil fired plants, hydropower plants, wind power plants, solar power plants, nuclear plants, natural gas fired plants and tidal power plants. The model makes use of only the short run variable costs: fuel cost, variable operating cost, including the excise tax, and carbon-dioxide costs (in case they exist). Consumers in the model are aggregated as a category, the slope of the demand curve is the same for all countries.

Within the model a country appears as a node, that is, there are not any network constraints within the country, only between countries. The cross border capacities linking the countries are constrained, approximated with available capacities in the model. Traders make the connection between the producer and consumer side of the market by exporting electricity to more expensive countries and importing electricity from less expensive ones.

When modelling hourly markets are simulated, and these simulations are independent from each other, that is, ramp-up costs are excluded. Within the model the equilibrium for a given hour (with respect to quantities and prices) is reached simultaneously, at the same time by the producer and transmission segments. Figure 30 describes the operation of the model.

Figure 30 The operation of the model



Source: REKK (2011c)

By determining the short run marginal cost and available capacity for each power plant we can construct the supply curve for each country, in other words, the merit order curve. Considering the constraints of cross border capacities and the demand curves characterising each country, we arrive at the input parameters of the model. The model applies this data to maximise European welfare, which is the sum of producer and consumer surpluses. As a result of model computations we get the hourly equilibrium price for each country, the hourly commercial transfers between the countries, and the production of each power plant unit. The technical specifications and key input data of the model are summarised in the annex.

VI.2.2. The development of the EEMM and its IT background

The first version of the EEMM model was developed by András Kiss in the Regional Centre for Energy Policy Research. This first version was released in 2006, simulating the electricity markets of seven Central and Eastern European countries (Kiss et al., 2006). Until 2011 the model went through minor improvements, carried out partly by András Kiss, the inventor of the model, and partly by other colleagues of REKK including myself. At this time a significant modification took place as the model was enhanced to cover Europe, simulating the electricity markets of 36 European countries as opposed to the previous version with 15 countries. In addition, a number of modules of the model were also further developed, substantially improving the reliability of the tool. These amendments included the complete overhaul of demand side representation, and the way renewable and combined power plants were handled by the model. I was in charge of all these model developments. It should be noted that the fundamental equations and the optimisation algorithm of the model have never been changed. Table 13 reviews the changes of the main parts of the model through the three phases of model development: the initial model version, the interim model developments until 2011, and the changes related to the 2011 developments.

Table 13 The development of the electricity market model

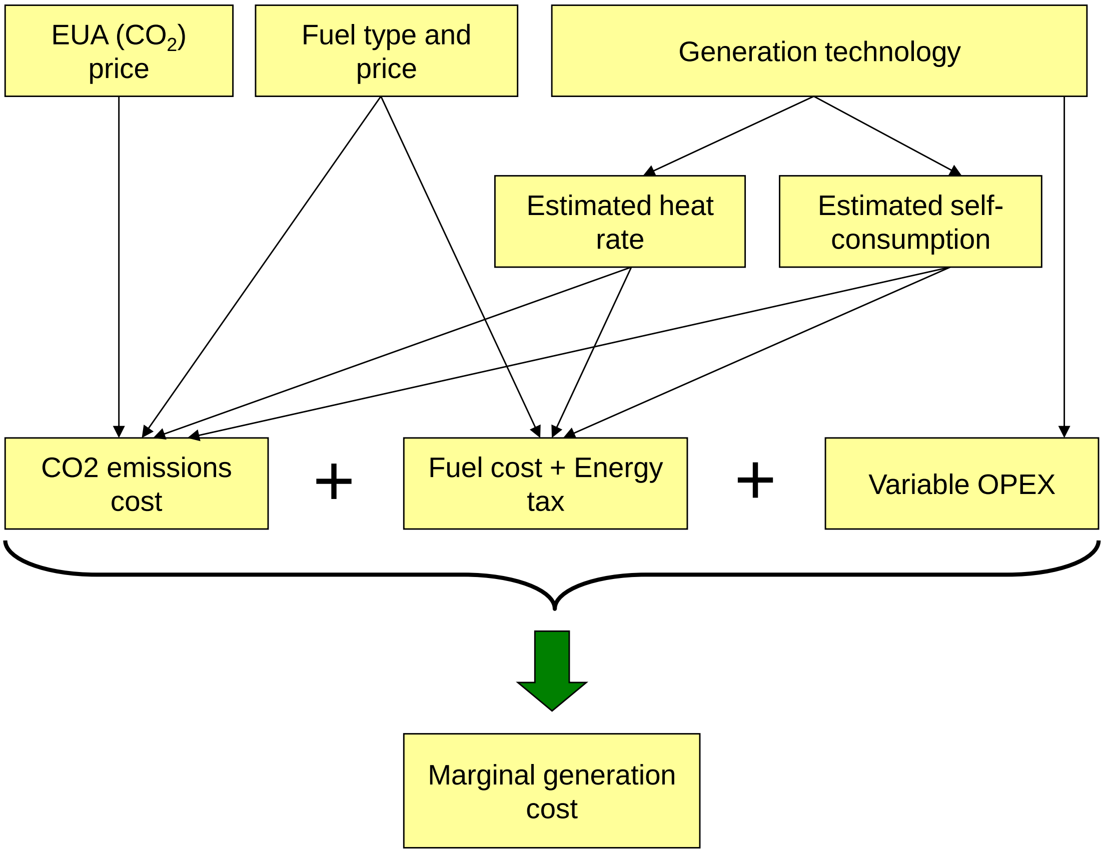
	Initial model	CSEEM	EEMM
Period	2006	2006-2011	2011-
Number of modelled countries	7	15	36
Number of power plants	few hundred	~1000	~5000
Number of cross border sections	20	38	84
Number of modelled periods (hours)	10	24	90
Combined power plants	Not distinguished from the rest of the power plants	Capacity utilisation is differentiated by the season	Capacity utilisation is also differentiated by the month and within the day
Renewable power plants	Average utilisation for all hours and countries (except for hydro power plants)		Capacity utilisation differentiated between countries and periods

Inputs and results are handled by the model in an Excel environment, while the equilibrium state is computed in the MATLAB software using the PATH solver.

VI.2.3. The supply side of the model

To be able to estimate short run marginal costs, first we have to determine the fuel cost, the supplemental cost associated with the use of carbon-dioxide credits, the excise tax and the variable operating cost (OPEX) related to the generation of a unit of electricity. Figure 31 illustrates how the short run marginal cost of specific power plant units can be calculated.

Figure 31 The method to estimate the marginal cost of electricity generation



Source: REKK (2011c)

The given technology and the year of construction together determine the efficiency, self-consumption and also the operating cost of the inspected power plant unit. If we know the type and price of the consumed fuel, then applying the efficiency factor and adjusting for self-consumption we can arrive at the fuel cost of the power plant, using the price of the carbon-dioxide credit we can calculate the carbon-dioxide cost, and even the excise tax payment based on the excise tax rate. Adding the variable operating cost (variable OPEX) we obtain the short run marginal cost of the given power plant unit.

It should be noted that modelling quantifies only the short run costs, it does not examine if the operation of the inspected power plant unit is reasonable in the long run, that is, if fixed costs are covered.

VI.2.3.1. Renewable based power plants

In previous versions of the model the renewable power plants of a given country were assumed to produce all of their expected output as baseload power. This proved to be an oversimplification, therefore substantial was introduced changes in this feature in order to answer the hypothesis and research questions. For each renewable resource we made estimates of the expected installed capacities. In case of wind and solar power plants we assume that whenever the wind blows or the sun shines, they generate electricity, that is, their short term marginal cost is zero, therefore their availability in any hour is the same as their annual average capacity utilisation. An additional assumption for solar power plants is that they work only during daytime hours. Average utilisation rates, however, notably differ across countries. We established availability factors for each of the countries based on EEA (2009) and JRC (2012).

Considerable modifications were needed also for the hydro power plants. While previously in every modelled country hydropower plants operated at the average annual rate of capacity utilisation for each reference hour, in the current model version the average availability of the hydro power plants is notably different for each season. The average rate of utilisation is lower during the rain deprived summer season, and higher during the winter. Hydro power utilisation also substantially differs across the countries. The average seasonal utilisation rate has been estimated based on past monthly production data for each country. Similarly to wind and solar power plants, we assumed zero marginal cost for hydro power plants as well.

VI.2.3.2. Combined power plant production

We consider combined power plants, which produce heat and electricity at the same time, to be heat driven, that is, their production is driven not by the price of electricity, but the demand for heat. Based on past observations we assumed the average capacity utilisation of these power plants to be 45%, but this figure widely varies seasonally and within the day. In addition to their availability, it is also important to decide whether a given power plant unit is considered as a combined power plant from the perspective of modelling. We repeated this exercise for each power plant, and compared our results with the aggregated, national data published by Eurostat (EEA, 2012).

VI.2.4. The demand side

Normally we simulate the short term market represented by a selected hour. We typically aim to model an annual period, and not a single hour, therefore on the demand side it is necessary to settle on a given number of reference hours through which annual average prices are approximated. In the original model version 10 demand hours were established, and this number grew to 24 later on. The hourly values were calculated after having aggregated the hourly electricity consumption of the complete modelled region. Then the regional load duration curve as divided to 24 equal parts, which translated into the electricity consumption of the hour in question. Since the number of countries considerably increased as a result of model development, demand side representation also had to be reviewed. After an in-depth analysis we decided on 90 reference hours in total. Too many reference hours would have substantially lengthened the time need of simulation, while too few reference hours would have notably reduced the reliability of modelling.

All in all, 90 reference hours were established with the following algorithm. Three groups were distinguished based on the day of the week, five groups were set up based on the month of the year, and six groups to reflect the hour within the day. The combinations of these factors (3*5*6) resulted in the 90 reference groups. Table 14-Table 16 show which scenarios were assigned to the different cases.

Table 14 Demand groups based on the day of the week

Monday	0
Tuesday	0
Wednesday	0
Thursday	0
Friday	0
Saturday	1
Sunday	2

Table 15 Demand groups based on the month

	The first 16 days	The second part of the month
January	0	1
February	0	0
March	0	0
April	2	2
May	2	2
June	3	3
July	4	4
August	3	3
September	2	2
October	2	0
November	0	0
December	1	0

Table 16 Demand groups based on the hour within the day

0	0
1	0
2	0
3	1
4	1
5	2
6	2
7	3
8	3
9	3
10	3
11	3
12	3
13	3
14	3
15	3
16	3
17	4
18	4
19	4
20	5
21	5
22	5
23	5

Once we have created reference groups and assigned each hour to one of these groups, we determine the average 2010 electricity consumption of the given reference group for each country. We run the model with these electricity consumption figures 90 times for each year. As we know the number of hours that belong to each group, we apply these numbers as weights to the 90 reference hours, and arrive at the annual baseload price, production, export-import positions and other important outputs.

As part of the forecast we also need to predict how the electricity consumption of the reference hours changes in each of the countries in each of the analysed years. When determining future consumption we consider the relationship between past GDP and electricity consumption figures separately for each country. Based on this relation and the GDP forecast of the IMF (2013) we establish the expected annual electricity consumption. Furthermore, we assume that each point of demand changes with the same absolute value, that is, the load duration diagram estimated from the reference hours shifts parallelly.

VI.2.5. Network representation

As we already indicated, the EEMM assumes that each country is a node, in other words, network constraints do not exist within any of the countries. Cross border capacities, on the other hand, may impose a serious limitation to the trading of electricity. Scarcity is expressed through the so called net transfer capacity (NTC), announced by system operators for each border section. Importantly, the model simulates commercial flows, which may substantially differ from the actual physical flows. Current NTC values were determined based on the ENTSO-E (2012), while in case of new cross border capacities our calculations are based on the realisation of the project plans contained in the ten year network development plan published by the ENTSO-E (ENTSO-E TYNDP, 2012).

VII. RESEARCH QUESTIONS AND HYPOTHESES

VII.1. HYPOTHESIS 1

In the dissertation we apply empirical analysis to inspect the relationship between different regulatory instruments. Such an analysis becomes feasible when a transparent price emerges in the market created by the regulatory instrument: that is, when a white or green certificate market operates in the country in question, but carbon-dioxide credits can also be analysed with this method. Within the dissertation we seek to find the answer to two sub-hypotheses:

H_{11}: The price of carbon-dioxide credits and green certificates substantially decreased as a result of publishing the draft Energy Efficiency Directive and the text of the final Directive.

Within the dissertation we employ a tool called event study to examine how the price of the different credits reacted to the publication of the draft Energy Efficiency Directive and then the adoption of the final version of the Energy Efficiency Directive.

$H_{12:}$ A sudden and lasting decline of the price of carbon-dioxide credits substantially reduces the market price of green certificates.

As also depicted by Figure 11 the price of carbon-dioxide credits notably oscillated for the observed period, covering almost a decade. The most significant price change took place in May 2006, when the price of the credits suddenly halved in just a few days. As part of the dissertation we inspect whether this large price drop also triggered changes of the same magnitude in the operating green certificate markets. The applied method is event study again.

VII.2. RESEARCH QUESTION 1

RQ_1:The quantitative analysis of the following question: under those regulatory instrument combinations for which the direction of impact on specific variables (RES-E generation, carbon-dioxide emission, investments into energy efficiency) cannot be unambiguously identified in a theoretically sound way, how do these variables actually change if we increase renewable support, the support provided to energy efficiency investments or the rate of the excise tax, or reduce the number of carbon-dioxide credits.

Altogether we identified seven regulatory instrument combinations (see Table 12) in case of which theoretical demonstration is not sufficient to reveal the direction in which the three most critical variables (renewable generation, energy efficiency investments and carbon-dioxide emissions) move. We rely on the competitive market model simulating the European electricity market to provide a quantitative answer to this question. During the analysis we start from a hypothetical case without any regulation in place: there is no Europe-wide carbon-dioxide trading, none of the EU countries support renewable generation or energy efficiency investments, and member states do not impose an excise tax on fuel use. Then we gradually tighten the level of regulatory instruments: for example, we increase the rate of the excise tax or reduce the amount of carbon-dioxide that is allowed to be emitted, and so forth. The regulatory instruments are uniformly applied to all member states: we assume a uniform excise tax, the same support to renewable generation, or identical support to energy efficiency investments for all analysed countries.

VII.3. HYPOTHESIS 2

H_2: Any combination of the four regulatory instruments (excise tax, renewable support, emission trading, support to energy efficiency investments) that we inspect is sufficient to reach the 20-20-20 target set by the EU for 2020, except when the only available instrument is the support to energy efficiency investments.

We test this hypothesis based on the methodology applied for research question 1, that is, we start with a European market where none of the four inspected regulatory instruments are applied. Then we gradually introduce different levels of each regulatory instrument. Similarly to the previous research question, the instruments are introduced uniformly across the countries.

VII.4. RESEARCH QUESTION 2

RQ_2: Which regulatory instrument combinations that satisfy the 20-20-20 targets of the European Union are favourable from the perspective of Hungary.

Under this research question we make use of modelling to determine which one of the regulatory instrument combinations that also satisfy the 20-20-20 targets set by the EU is the most attractive for Hungary.

VIII. RESEARCH RESULTS: THE EMPIRICAL ANALYSIS OF THE INTERACTION OF THE REGULATORY INSTRUMENTS

We carry out the empirical analysis of the interaction of selected regulatory instruments through two hypotheses. In both cases we analyse European data, using as detailed data as possible.

VIII.1. THE ANALYSIS OF THE H_{11} HYPOTHESIS

H_{11}: The price of carbon-dioxide credits and green certificates substantially decreased as a result of publishing the draft Energy Efficiency Directive and the text of the final Directive.

Since in the case of European green certificate markets daily trading data is not published, typically only monthly data is available, and the daily liquidity of these markets is also quite restricted, we can only inspect the changes of the price of emission credits.

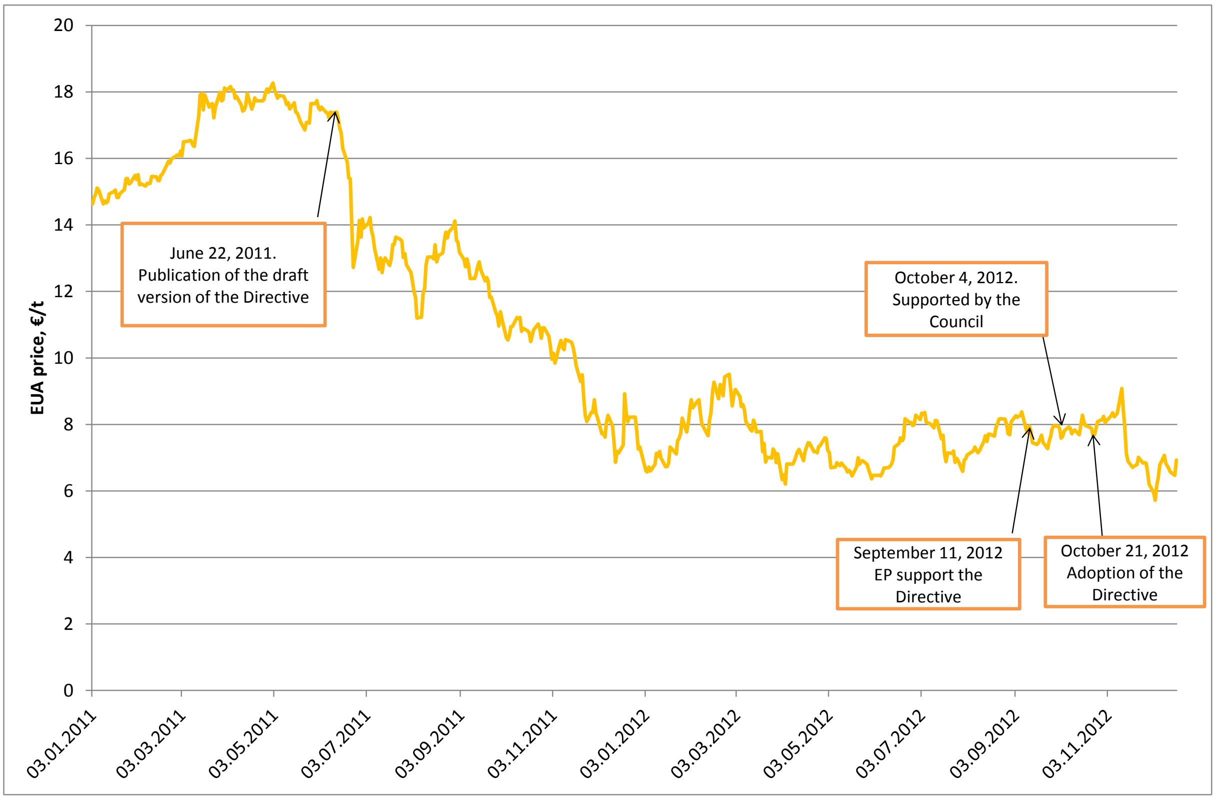
As part of the theoretical examination of the interaction of regulatory instruments we proved that an increase of energy efficiency investments reduces the price of carbon-dioxide credits. This is due to lower electricity consumption and production as a result of improved energy efficiency, which also results in lower carbon-dioxide emissions, which, through the decline of demand, limits the price of carbon-dioxide credits.

In order to be able to answer the hypothesis articulated above, it is important to describe the path leading to the adoption of the Energy Efficiency Directive (DG Energy, 2013).

- On 22 June 2011 the European Commission published its recommendation on how the 20-20-20 targets set by the EU can be achieved in the field of energy efficiency.
- On 11 September 2012 the European Parliament supported the draft of the new Energy Efficiency Directive, which, however, specified less ambitious plans than the Commission proposal from the previous year.
- The draft Directive was also supported by the Council decision passed on 4 October 2012.
- On 25 October 2012 the EU adopted Directive 2012/27/EU on Energy Efficiency.

Figure 32 illustrates how the price of the European carbon-dioxide credit changed on these days. As shown, the price of the EUA notably fell after the recommendation of the European Commission was published, and the price did not even bounce afterwards. In relation to the Energy Efficiency Directive additional price changes of similar magnitude cannot be observed.

Figure 32 The price of the EUA during 2011-2012, €/t



Source: EEX (2012)

The daily returns on the analysed days are worth inspecting – see Table 17. As shown, as a result of the recommendation of the European Commission the price of the EUA fell more than 10% in a day. The price decline did not stall the following day either, declining another 9%, the cumulative price decrease of the credit reaching 19.1% for the two days. Considering the slight correction of the following day the total price change of the three days came to be minus 13%. Similar changes were not recorded for all the other observed days. In all these cases price changes were limited to 5%, with a mixed direction of the changes.

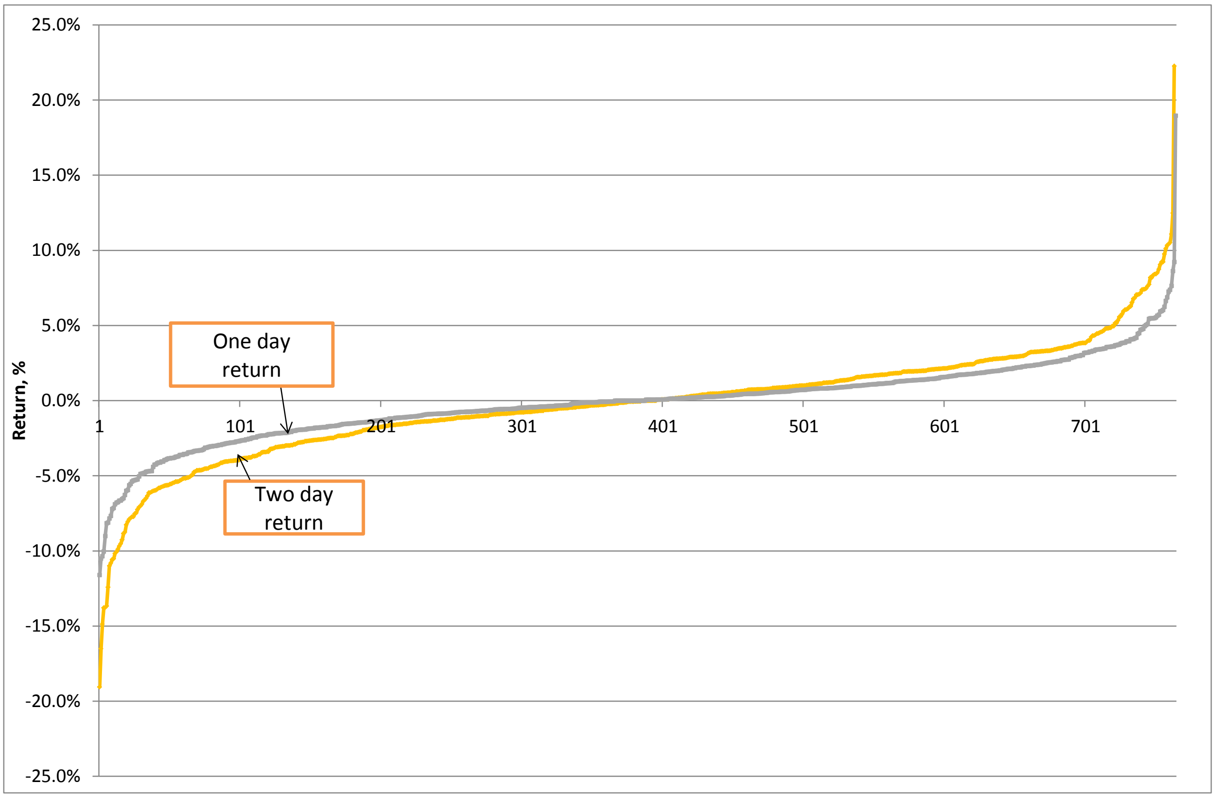
Table 17 One, two and three day returns following the inspected days

	Return		
	One day	Two days	Three days
22.06.2011	-10.0%	-19.1%	-13.0%
11.09.2012	2.5%	0.8%	-3.9%
04.10.2012	2.2%	3.6%	3.2%
23.10.2012	-2.7%	-2.4%	0.1%

Source: Own calculation based on EEX (2012)

The relation of these returns and the average price oscillation of the EUA should also be analysed. For the period of 1 January 2010 and 18 December 2012 we inspected the daily closing prices of the EUA and the one- and two-day returns calculated from these prices. The largest price drop for the EUA took place on 2 April 2011, with the decline of the price of the carbon-dioxide credit almost reaching 11.6% in a single day. The fourth and fifth largest price drop, on the other hand, took place on the two days following 22 June 2011. Thus the negative record for two day price return falls into this period. The returns of all the other days that we inspected are not really outstanding (Figure 33).

Figure 33 The distribution of one and two day returns of the price of EUA, 1 January 2010 to 18 December 2012



Source: Own calculation based on EEX (2012)

Next we outline a statistical tool, the so called event study with which it becomes possible to determine if a given event had an impact which would have substantially changed prices.

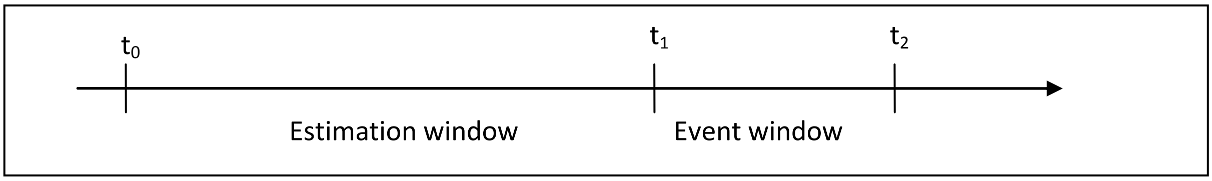
VIII.1.1. The methodology of the event study

Based on their efficiency Fama (1970) divides markets into three groups: markets of weak, semi-strong and strong efficiency. A market is in a weak state of efficiency when past information has been fully integrated into prices. A market should be viewed as having semi-strong efficiency when all publicly available information is incorporated into market prices, while in case of a market with strong efficiency all public and non-public information is already reflected by prices. Based on the results of Mezősi (2008a) the efficiency of the European carbon-dioxide market can be considered as at least semi-strong. Thus, whenever new and substantial information appears it is quickly processed by market participants and incorporated in credit prices. This offers an opportunity to answer our research hypothesis, namely, whether the announcements and other published information in connection with the

Energy Efficiency Directive had a substantial impact on the price of carbon-dioxide credits. One of the methods applicable for such an investigation is the so called event study.

During the event study we analyse if the returns (or other statistical attributes) of a given period are significantly different from the returns and standard deviation of the reference period.

Figure 34 The two periods of the event study



Source: MacKinley (1997), pp: 20

As a first step of the event study we need to create a so called estimation window, in which we measure the daily returns and standard deviation of the price. At t_1 time an event takes place, and we are interested to know how that event impacts the price. Applying statistical methods we examine if the returns within the event window are significantly different from those of the estimation window. If we experience a significant difference then we can claim that a new piece of information that was previously not reflected by prices has just been incorporated into the price. If, on the other hand, we do not find a statistically valid difference, then we can safely assert that the event did not include new information (Brown-Warner, 1985).

Event studies have several model types, covered in detail by Bedő (2007). Of these, we apply the average return model.

In case of the average return method we compute the so called abnormal return within the event window. This return is the difference between the average return from the event window and the average return from the estimation window. The following formula is used for the calculation:

$$CAR = \frac{\sum_{t_1}^{t_2} (r_t - r_{av})}{N} = \frac{\sum_{t_1}^{t_2} (AR_t)}{N}, \text{ where}$$

- CAR: cumulated abnormal return
- r_t: return on day t
- r_{av}: the average of the returns in the estimation window
- N: the length of the event window ($N=t_2-t_1$)

According to the null hypothesis the expected value of the cumulated abnormal return is zero. This is inspected with the t-test. The statistical value of t is the following:

$$\theta = \frac{CAR}{s}$$, where

$$s = \sqrt{\frac{\sum_{t_0}^{t_1} AR_t^{\ 2}}{T-1}}$$, where T is the length of the estimation window ($T=t_1-t_0$).

If the value of t is larger than the critical value of the test then we reject the null hypothesis, in other words, in this case an event with a critical impact on prices has taken place.

VIII.1.2. Application of the event study to the inspected hypothesis

Previously we described the model that we apply as part of the event study. In addition, we need to make a decision on two more important factors: how long should the estimation period - that is, the reference period from which the average return and the standard deviation is calculated - be. The other factor is the length of the event window. Since the literature does not have a clear stance on either of these questions, we make the calculations with three different lengths for both windows: we apply 50, 100 and 150 days as the length of the estimation window, and we analyse one, two and three day intervals following the inspected event in case of the estimation window. Table 18 includes the values of p under the above described conditions.

Table 18 The value of p for different lengths of the estimation window and the event window

	Length of the estimation window								
	50			100			150		
	Length of the event window			Length of the event window			Length of the event window		
	1	2	3	1	2	3	1	2	3
22.06.2011	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%
11.09.2012	17.4%	42.7%	35.4%	18.9%	45.3%	33.4%	18.0%	43.9%	34.4%
04.10.2012	20.8%	27.2%	38.7%	19.9%	26.2%	37.8%	17.5%	23.6%	35.1%
23.10.2012	11.7%	30.5%	49.2%	10.8%	29.1%	47.8%	11.7%	30.7%	49.5%

Apparently, when inspecting 22 June 2011, we reject the null hypothesis for all lengths of both windows, that is, we can declare that a new piece of information with a substantial impact on prices was published on this day. For all the other inspected periods none of the combinations of the event window and the estimation window provide a basis to reject the null hypothesis at a significance of at least 10%, that is, no event with a substantial price driving impact took place.

Based on the above analysis we can arrive at the following conclusions:

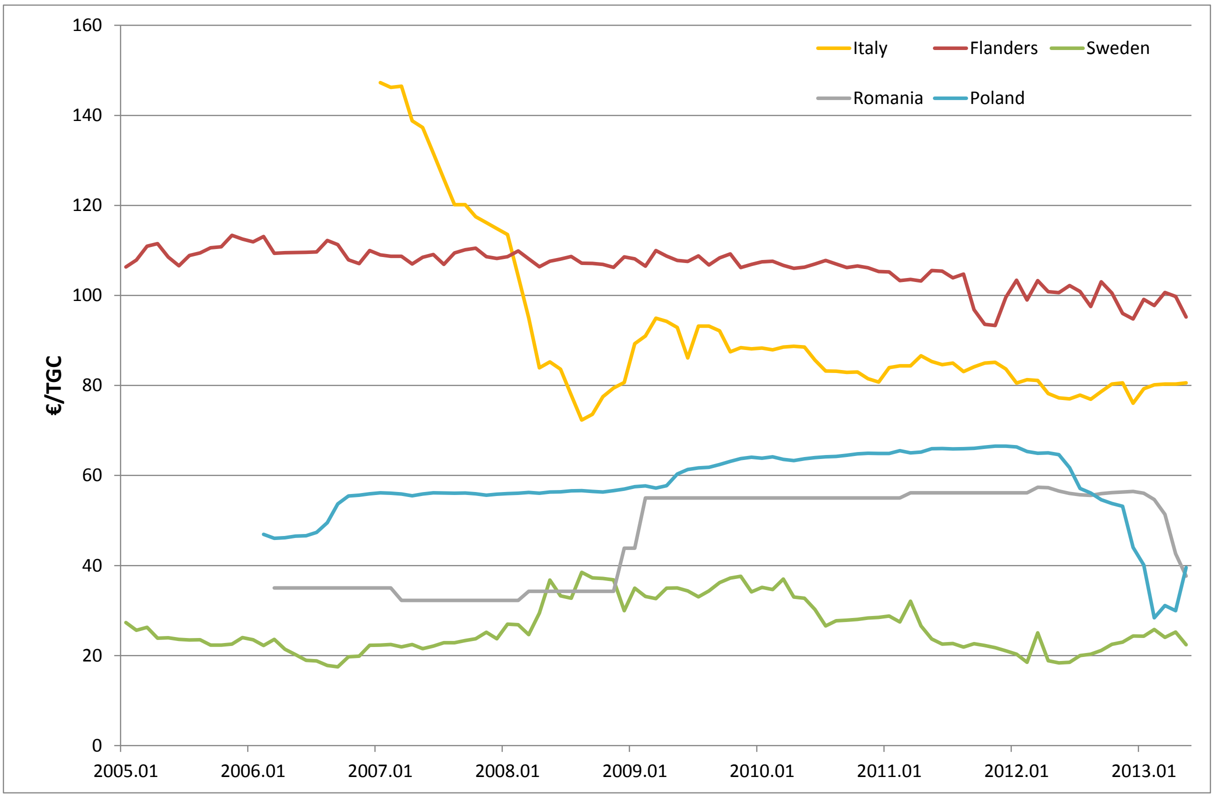
- The Commission proposal on energy efficiency, announced on 22 June 2011, has a substantial impact on the price of carbon-dioxide credits.
- Based on the above statement our hypothesis, according to which the draft Energy Efficiency Directive substantially affected the price of the carbon-dioxide credit, can be declared as valid, but we reject the hypothesis according to which carbon-dioxide prices notably changed when the Energy Efficiency Directive was finally adopted.
- As a result, there is a significant impact between the two regulated areas (energy efficiency regulation and trading of carbon-dioxide credits), the direction of which is the same as we had expected.

VIII.2. EXAMINATION OF THE H_{12} HYPOTHESIS

$H_{12:}$ A sudden and lasting decline of the price of carbon-dioxide credits substantially reduces the market price of green certificates.

As described before, in Europe green certificates are the dominant form of renewable support in only five countries: in Italy, Poland, the Flanders region of Belgium, Sweden and Romania. In these countries green certificates can be traded on exchanges and through some sort of a central platform. In Italy (GME, 2013), Romania (OPCOM, 2013) and Poland (POLPX, 2013) the energy exchange publishes price information, in Flanders the regulator (VREG, 2013), while in Sweden the organisation that keeps records on green certificates (CESAR, 2013) publishes publicly available, transparent prices. In Italy and Poland a weekly price is published, while for the rest of the countries monthly data is released. Prices, however, are not really volatile, thus we do not lose information if we rely on monthly data. Each price data has been exchanged to Euro on the 2013 average exchange rate. Figure 35 reviews the green certificates of the five markets.

Figure 35 The price of green certificates in the five inspected countries, €/green certificate, 2005-2013



Source: GME (2013), OPCOM (2013), POLPX (2013), VREG (2013) and CESAR (2013)

In Poland and Romania the price of green certificates has been observed to be stable through relatively long periods, even as long as a year. The reason behind this is that the support scheme in both countries caps the price of green certificates. Since until 2013 the targets had not been achieved, the maximum price emerged. Significant price changes cannot be observed for Belgian green certificates either. There are only two green certificate markets in Europe with considerable price shifts. In 2007-2008 in Italy prices fell notably as the Italian green certificate market was still a new, less liquid market at this time. From 2009, however, the price of this product stayed within a relatively narrow range. Thus the only tradable green certificate market with more pronounced price movements without a minimal or maximal regulated price in effect is the Swedish market. Therefore next we analyse the interaction between the price of the Swedish green certificate and the price of the European carbon-dioxide credit.

During the exercise we analyse the impact that the events determining the price of the EUA deliver on the Swedish green certificate market. Notably, since monthly data is published in the Swedish market, deep statistical analysis is not an option. Before the analysis, let us describe the interaction between the prices of the two products that should take place on a theoretical basis.

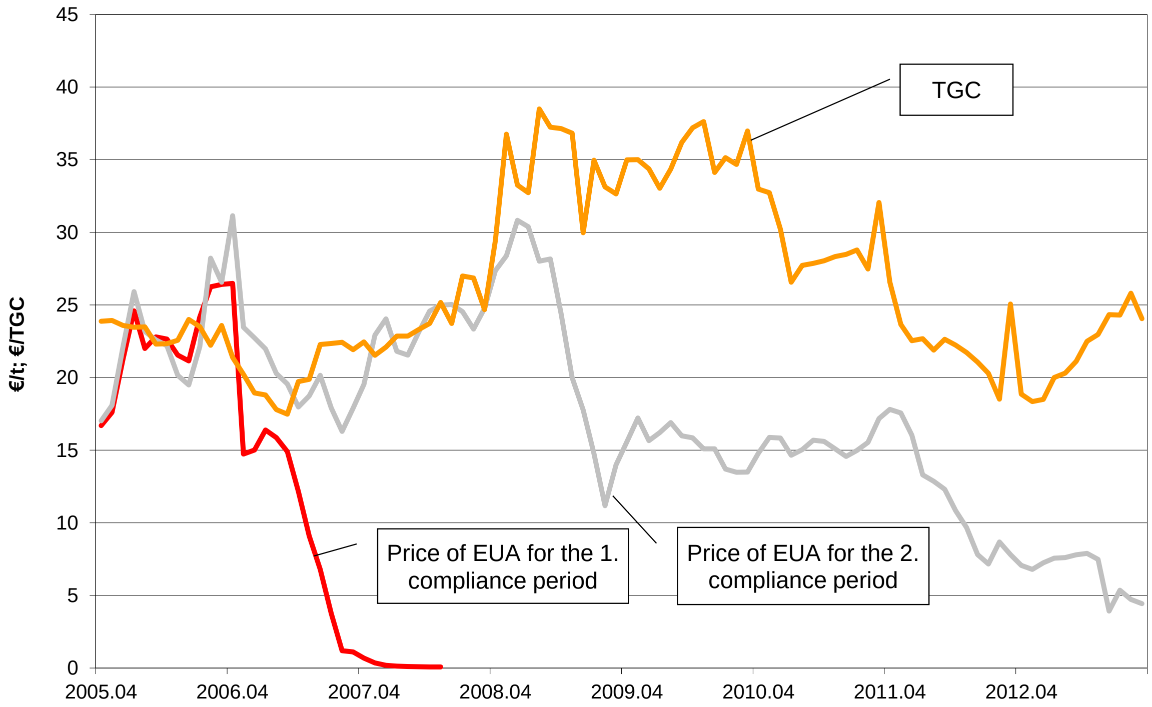
Let's assume that an event takes place with an impact on the price of the EUA only. This may be a regulatory change on the supply side or a piece of information affecting only this market.

If the price of carbon-dioxide credits declines as a result of this event, then the marginal cost of fossil fuel based power plants also decreases, lowering the price of electricity. The supply curve of renewables, however, is not affected, demand and supply characteristics in the green certificate market are unchanged[12]. The quantity of generated renewable based electricity does not change[13], therefore the total revenue of renewable producers is also unaffected. Since, however, the price of electricity declines, the price of green certificates needs to rise in order to maintain the revenue level of renewable generators, that is, for the equilibrium position in the renewable market to remain unchanged. Thus, if the price of the EUA[14] declines, then the price of green certificates has to increase.

Let's inspect if the above theoretical conclusion can be confirmed through historical prices. Figure 36 includes the price of carbon-dioxide credits for the first and second compliance periods, and also the price of the Swedish green certificate. The negative relation is not really apparent. During the period with the largest price change of the EUA (April to June 2006) the price of the tradable green certificate also drops, thus the observed relation is exactly the opposite to what we expected.

[12] As an important condition, no minimal or maximal price should be set for green certificates, or at least such a requirement should not be in force.
[13] If the renewable target is set as a ratio of electricity consumption then this statement is not fully valid. As a result of the declining wholesale price of electricity the consumption of electricity rises, increasing the demand for green certificates. Since, however, the demand curve in the electricity market is rather inelastic in the short run, this impact is not really strong.
[14] Assuming that the price development of the EUA is only determined by electricity producing facilities.

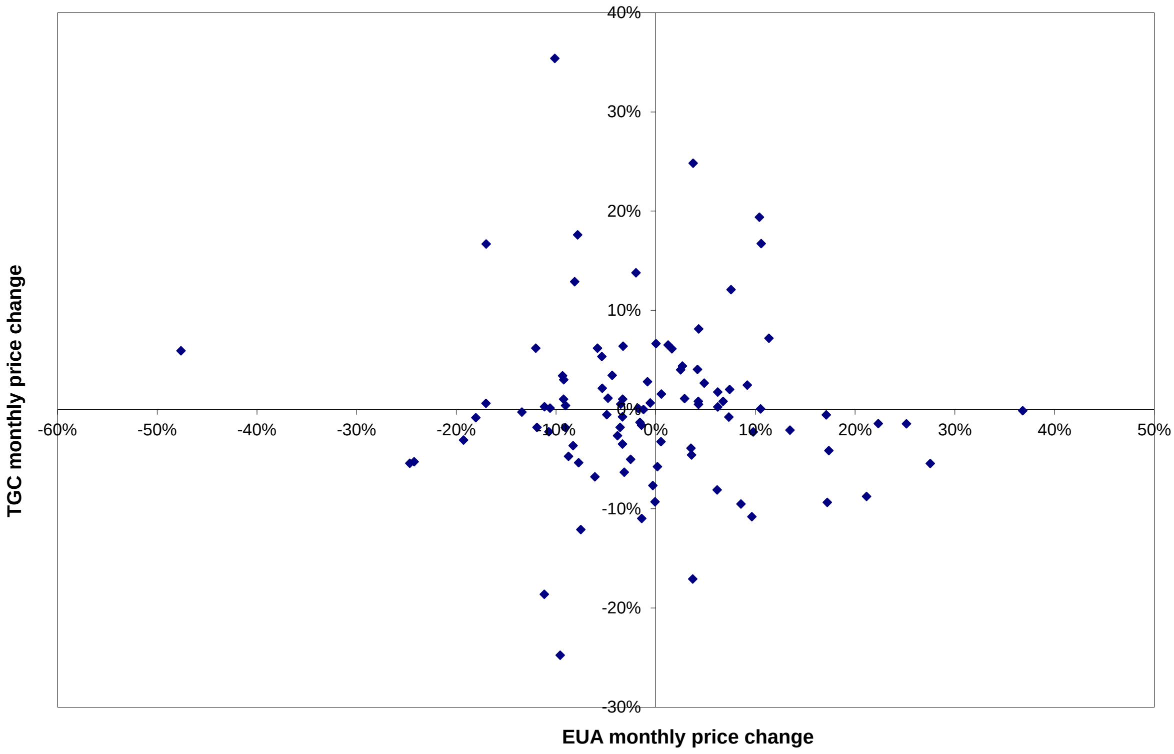
Figure 36 The price of the first and second period EUA and the Swedish green certificate between April 2005 and April 2013



Source: CESAR (2013), EEX (2012), ICE (2012)

Furthermore, we examined monthly prices changes with the expectation of a negative correlation. This, however, is not supported by the results. Figure 37 shows the monthly price change of the EUA as a function of the monthly price change of the green certificate. In case of a negative relation, the depicted dots should fall around a negatively sloping line. This, however, is not visible. Therefore we can conclude that the two products are not negatively correlated.

Figure 37 The monthly price change of the EUA and the green certificate



In summary, theoretically the price of the EUA and the price of the tradable green certificate should be negatively correlated. We inspected the tradable green certificate markets of Europe, and only the Swedish market was found to be suitable for the desired analysis. Based on monthly data we can neither prove, nor reject the hypothesis on the negative correlation between the price of the green certificate and the EUA.

IX. MODEL BASED ANALYSIS OF THE INTERACTION OF REGULATORY INSTRUMENTS

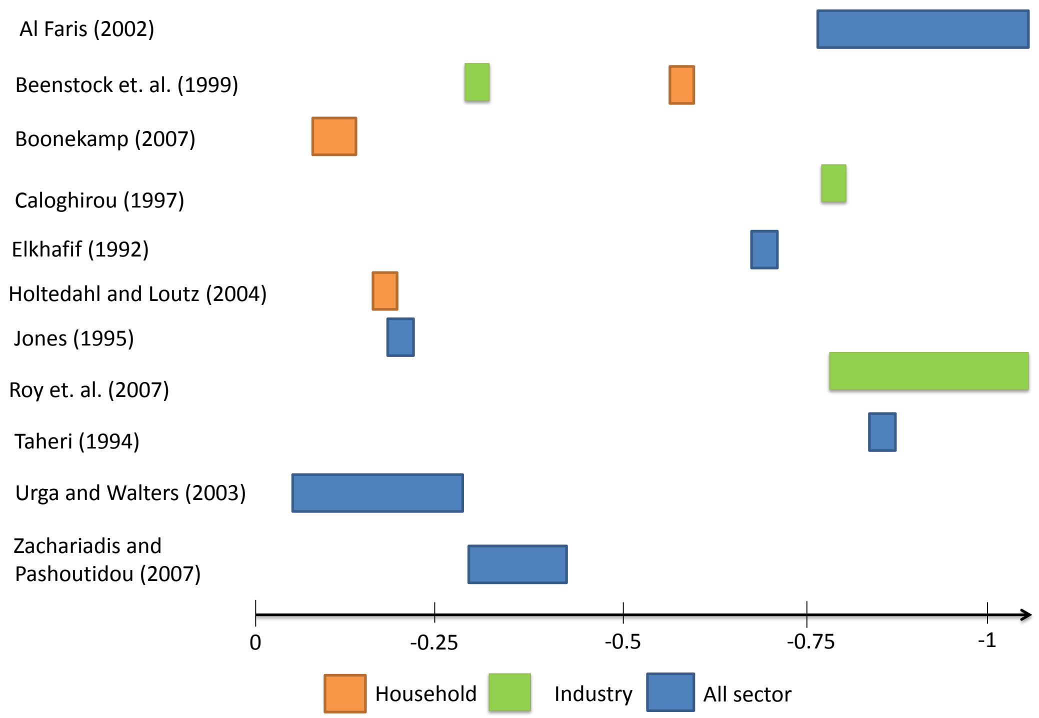
We analyse the interaction of selected regulatory instruments also through modelling. During the simulation we utilise the previously described EEMM model, which, however, had to be further developed to some extent in order to be able to address the formerly articulated hypotheses and research questions. We supplement the model with four components in total: we install a long run price elasticity factor; investments into renewable electricity producing capacities used to be an exogenous variable of the model, we turn this into an endogenous attribute; moreover, we depict the impact of investments into energy efficiency on electricity consumption, that is, how much consumption can be reduced this way. Finally, we provide a detailed analysis of the relation between the price of the carbon-dioxide credit and its emissions.

IX.1. DEVELOPMENT OF THE EEMM MODEL

IX.1.1. Determining the price elasticity of demand for electricity

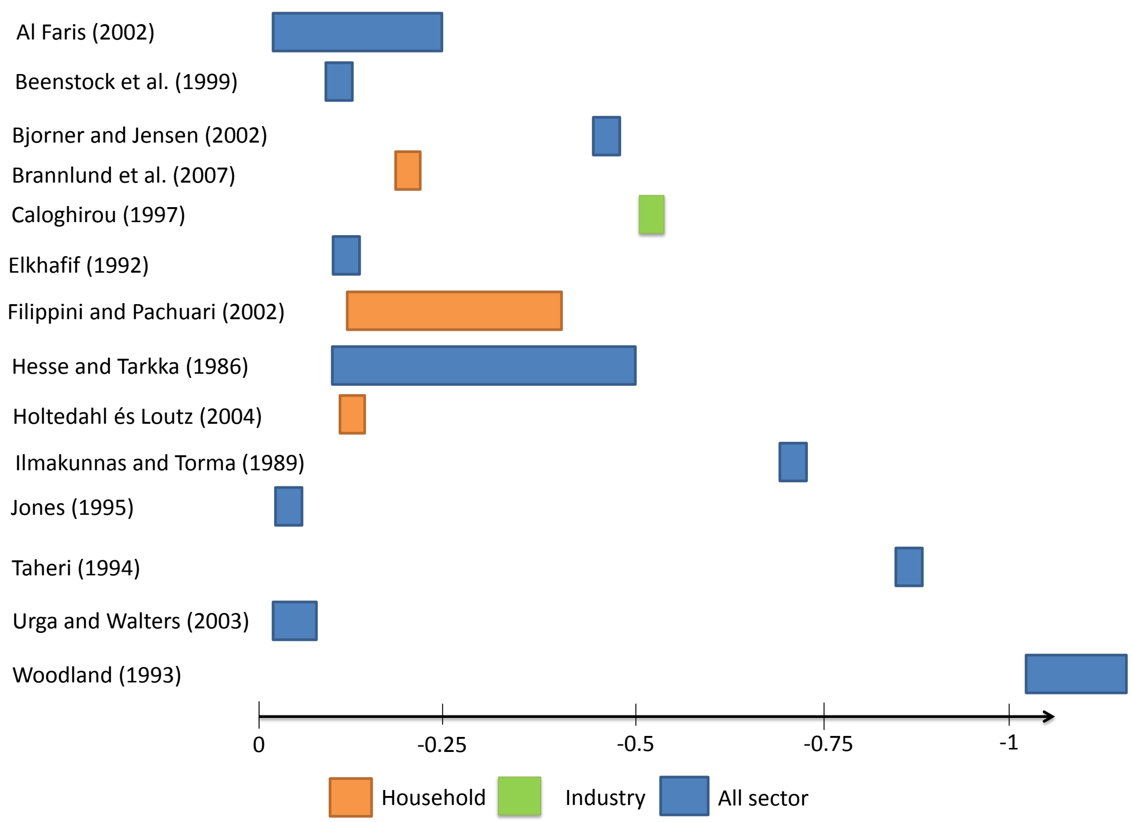
One of the most critical questions during modelling is the value of the price elasticity coefficient. Most studies with a detailed analysis of the price elasticity factor within the electricity market agree on two issues. First, the price elasticity of electricity consumption can be considered as inelastic both in the short and long run. Second, the shorter the time frame, the lower the price elasticity coefficient. Actual values, however, greatly differ. In his study Lijesen (2007) summarised the results of several pieces of research, as recapped by Figure 38 and Figure 39.

Figure 38 The value of long term (> 1 year) price elasticity of electricity consumption based on different studies



Source: Own editing based on Lijesen (2007)

Figure 39 The value of short term (< 1 year) price elasticity of electricity consumption based on different studies



Source: Own editing based on Lijesen (2007)

When modelling the electricity market we run simulations of hourly markets, from which we can derive the annual data by appropriately weighing the results. In case of hourly markets we apply low price elasticity coefficients. Based on our literature review a value of -0.2 is used. On a longer time horizon, nevertheless, a higher figure should be applied, after consulting the literature we use a value of -0.5. Importantly, the above pieces of data from the literature are relevant to the total cost of electricity. As part of our exercise, however, only wholesale prices are modelled (plus the unit cost of renewable support), while about half of the final electricity cost is made up by the energy fee. Since network use fees and other cost items are mostly constant through time (or they only increase with the rate of inflation), therefore for the purpose of modelling we use a price elasticity coefficient of -0.1 in the short run and -0.25 in the long run for the wholesale price of electricity (actually, wholesale prices supplemented with the demand for renewable support).

During modelling short run price elasticity figures are applied for the hourly simulation. This is only relevant for wholesale prices, while longer term price elasticity is incorporated into the model with the following method.

As a first step we run the model for two consecutive years at the reference level of consumption. The change of the resulting baseload electricity price, the need for the unit support of renewables, and the value of longer term price elasticity together show the difference between the predicted reference consumption and the price elasticity adjusted consumption of electricity. As a formula, the electricity consumption of the country in question for a selected year can be calculated as follows:

$$Q_t = Q_t^{REF} \times \left(\frac{P_{t-1} - P_{2013}}{P_{t-1}} \times \varepsilon \right)$$, where

- Q_t is the electricity consumption in year t
- Q^{REF} is the forecasted reference electricity consumption
- P_t is the wholesale price applicable for a given country in year t, including the need for renewable support
- ε is the value of the coefficient of long term price elasticity

IX.1.2. Handling wind and solar power plants within the electricity market model

Within the current electricity market model present and expected future installed capacities need to be determined separately for each country and technology. Availability for given demand periods substantially differs by technology and country. Multiplying the availability factor characterising a given country and technology with the installed capacity results in the electricity produced in a given hour. In case of future installed capacities the electricity market model assumes that they will match the figures of the National Renewable Energy Action Plans (NREAP). This assumption, however, prevents us from examining the impact of renewable support on different factors, therefore this unit of the electricity market model requires substantial development so that it could become a proper tool to answer the research questions and hypotheses.

The majority of renewable power plants that have been newly built for the last few years are wind and solar based plants. According to the data of EWEA (2013) between 2000 and 2012 in Europe wind power plant capacity grew by 97 GW, while photovoltaic capacities increased by 69 GW. Biomass based and hydro generating capacities both grew by 4 GW. This data confirms the recent dominance of wind and solar plants among renewables. The picture depicted by the National Renewable Energy Action Plans is similar. Based on the submitted NREAPs between 2010 and 2020 55% of new renewable capacities would be wind power plant (129 GW) and 28% would be solar power plant (65 GW), while the remaining new, renewable based capacity primarily consists of biomass fired plants (9%) and hydro plants (7%) (ECN, 2011). Since for the last few years a substantial decline of the average cost has taken place specifically in the case of wind and solar power plants, we determine the supply curves of these two technologies for each year and country. For the rest of the technologies installed capacities continue to be viewed as exogenous, accepting the values from within the NREAPs. The supply curve of solar and biomass based power plants is determined through the following steps:

- the current average cost of production for the two technologies
- forecasted future average costs
- quantification of system integration costs.

IX.1.2.1. Calculation of the current average cost of production

To determine the average costs we use the LCOE (Levelized Cost of Energy) formula widely utilised in literature. The result indicates the minimum average electricity sales price at which the operation of the power plant makes economic sense. The value of this indicator can be calculated with the following formula:

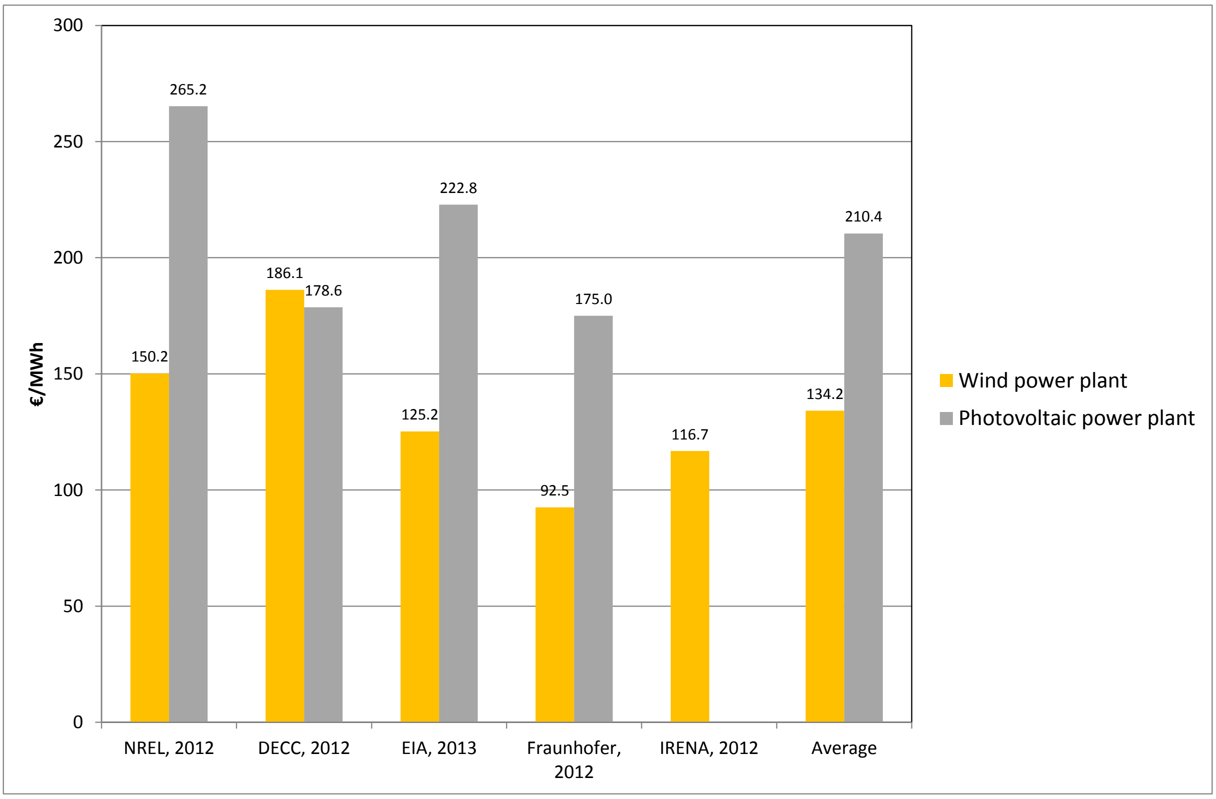
$$LCOE = \frac{\sum_{t=1}^{n} \frac{INV_t + FUEL_t + OM_t}{(1+r_t)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r_t)^t}}, \text{ where}$$

- n is the full lifetime of the project
- INV_t is the investment cost in year t
- $FUEL_t$ is the fuel cost in year t

- OM_t is the total operating cost without fuel costs in year t
- r_t is the discount rate for year t
- E_t is the quantity of electricity produced in year t

A number of studies have disclosed estimates for the average cost of wind based and photovoltaic power plants, of which we described the results of four studies. In order to make these pieces of literature comparable we exchanged all costs to Euro and applied average annual domestic capacity utilisation rates (18.3% for wind power plants and 12.6% for solar plants) to calculate the results. The discount rate has been assumed to be 10%. The LCOE values calculated with these assumptions for the different studies are described by Figure 40.

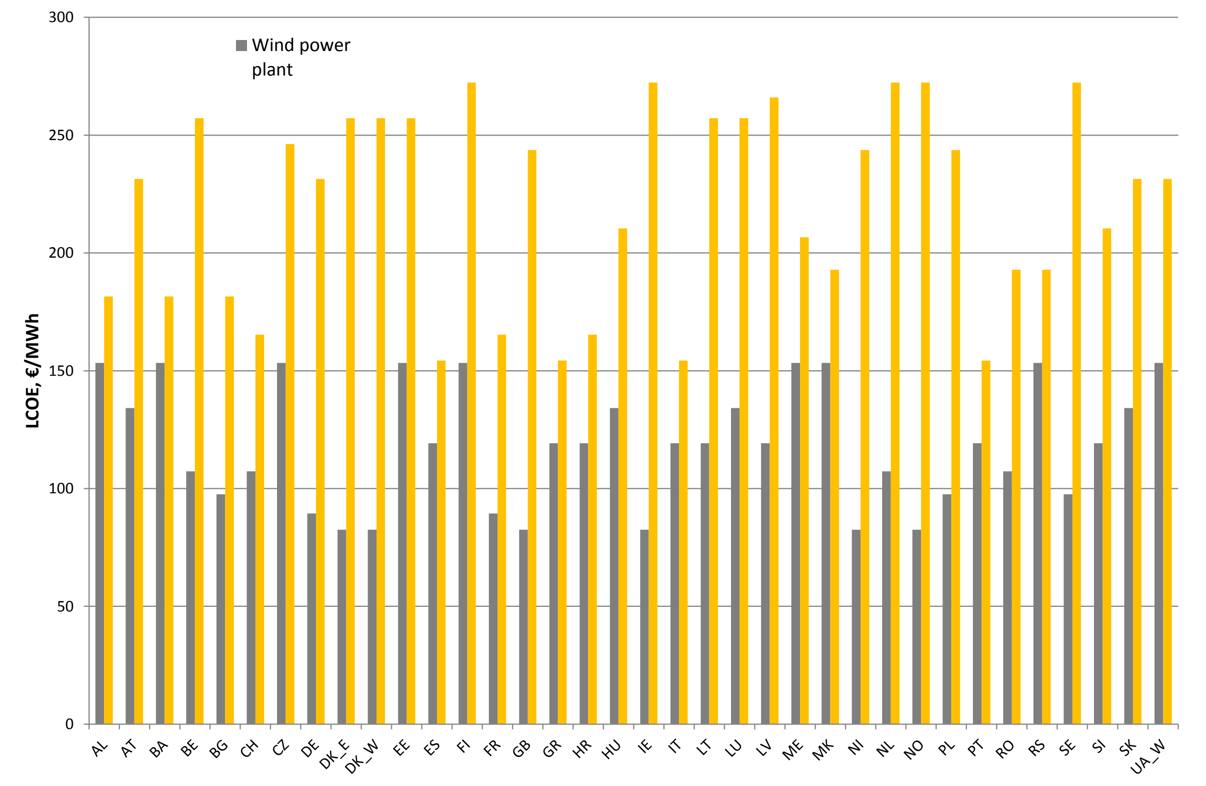
Figure 40 The LCOE values of wind power plants and photovoltaic plants based on different studies and adopted to domestic conditions, €/MWh



Source: Own calculation based on NREL (2012), DECC (2012), EIA (2013), Fraunhofer (2012a), IRENA (2012)

As shown by Figure 40, the LCOE value fluctuates in a wide range for both technologies. If we take the simple arithmetic average of the five quoted studies, then wind power plants break even at an average sales price of 134.2 €/MWh, while this figure is 210 €/MWh for photovoltaic plants. Since we use different annual capacity utilisation rates in each country, naturally the LCOE values also differ, as illustrated by Figure 41.

Figure 41 The LCOE values of solar and wind power plants in the modelled countries, 2013, €/MWh

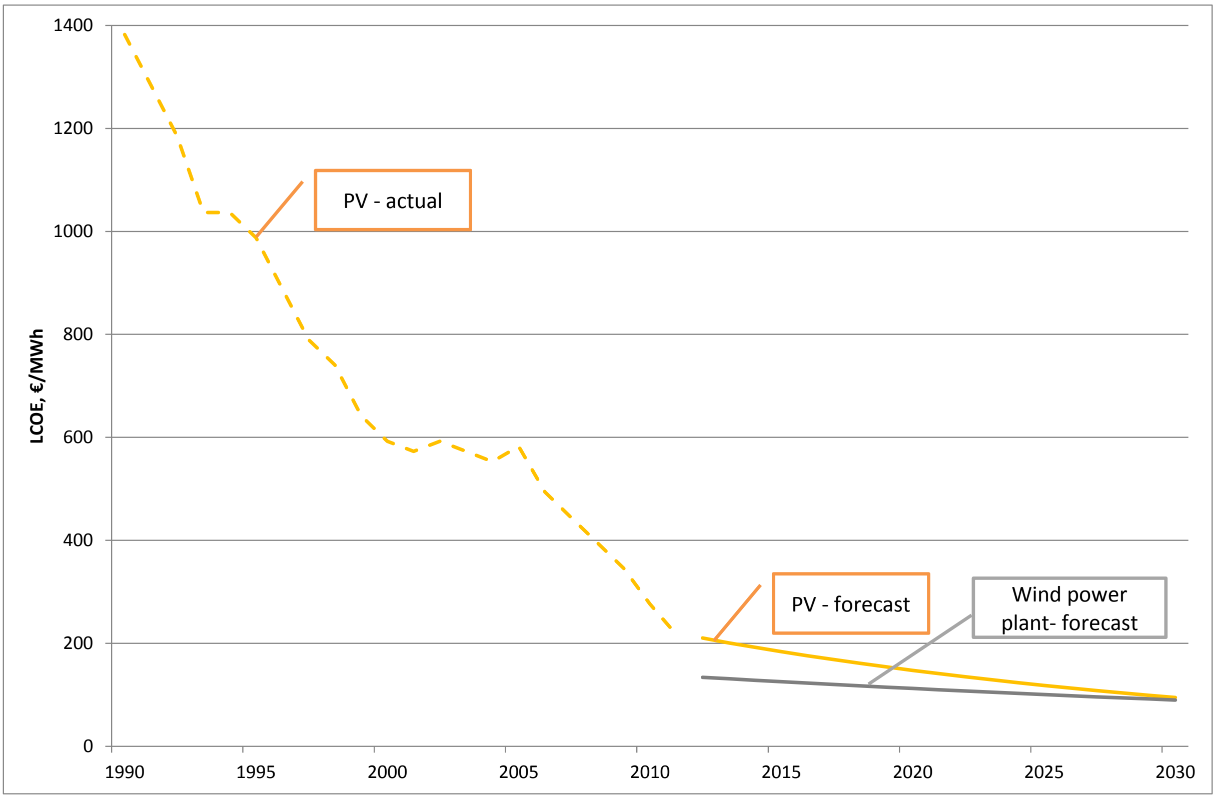


IX.1.2.2. Development of future average costs

Within the model it is not enough to quantify the current costs, we also need to determine the expected average cost of operating, for example, a photovoltaic or wind power investment constructed in, say, 2018. Since a substantial price decline has taken place for both technologies for the last few years and decade, a detailed scrutiny of this topic is absolutely essential.

DECC (2012) and Fraunhofer (2012a) have made a forecast on the expected 2030 average cost of these technologies. There is not any major difference between the two studies, therefore we apply the simple average of their values, shown by Figure 42. Moreover, we also indicated the average cost path of photovoltaic power plants since 1990. Apparently, we can witness a dramatic price drop, but both of the quoted studies (despite both having based its analysis on fresh data) expects this trend to discontinue with the rate of decline substantially slowing in the case of photovoltaic power plants.

Figure 42 The LCOE values of the solar and wind power plants in the past and their expected future values at the utilisation rates relevant for Hungary, 1990-2030, at 2012 real prices



Source: Fraunhofer (2012a), Fraunhofer (2012b) and DECC (2012)

IX.1.2.3. The system integration cost of weather dependent renewable producers

In order to determine the supply curve of renewables for a specific year, we also need to consider their system integration costs. Holtinnen et al. (2009) divide these costs into three groups: network costs, system adequacy or profile cost, and the cost of balancing. Even though based on the current regulation some of these costs do not register directly with the producers, during modelling we assume that that's where they are accounted. The reason behind the assumption is that the regulation is best if the cost is paid by the participant with/by whom the cost occurs/is generated.

Several studies have been conducted to estimate the system integration costs of weather dependent producers, of these we rely on two comprehensive publications (Holtinnen et al., 2011; Hirth, 2012) that collected earlier studies and compared them to draw conclusions.

IX.1.2.3.1 Profile costs

Profile costs can be further subdivided into two components: costs caused by increasing flexibility, and costs associated with lower capacity utilisation. Electricity consumption is burdened with substantial fluctuations from one hour to the next. Several studies (e.g. Nicolosi, 2011) noted that the larger the share of intermittent producers, the higher the swings caused by the so called residual consumption (actual consumption minus intermittent production) between the hours. The larger and quicker the performance change required by the system, the higher the associated costs will be.

In addition, increasing renewable production displaces some of the production of conventional power plants, leading to lower capacity utilisation. Low utilisation, on the other hand, may substantially increase the average cost of production for affected plants. This may result in both a higher wholesale price of electricity, and an increased cost of regulatory reserves.

IX.1.2.3.2 The cost of balancing

The electricity production of intermittent producers cannot be perfectly predicted due to the stochastic nature of the speed of wind and solar radiation. Therefore the larger the share of wind and solar based generation, the higher the difference between actual and scheduled production may be. This, on the one hand, requires more regulatory reserves, and on the other hand, the quantity of necessary balancing energy may also rise, boosting the total cost of balancing and regulation.

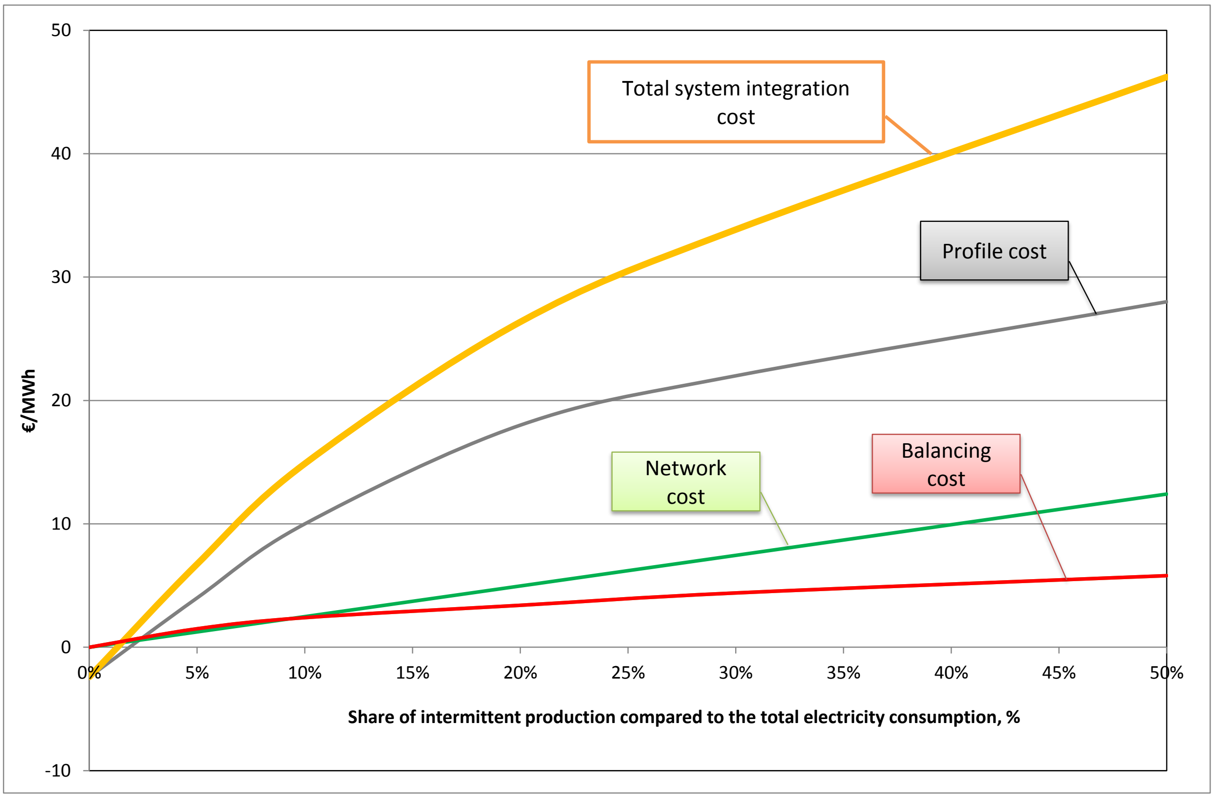
IX.1.2.3.3 Network related costs

Network related costs belong to the type of system integration costs that are most difficult to predict. Since estimating these costs is rather complicated, only a few scientific articles have been published on this topic.

IX.1.2.3.4 The quantification of system integration costs

Figure 43 depicts the composition of system integration costs. Evidently, profile costs make up the biggest portion, approaching 30 €/MWh at a 50% renewable share. A little less than half of this is the cost needed for network upgrade, while balancing costs stay below 6 €/MWh.

Figure 43 The system integration costs of intermittent production, €/MWh



Source: Own editing based on Hirth (2012) and Holtinnen et al. (2009)

IX.1.2.4. Integrating the two renewable technologies into the electricity market model

Previously we described the methodology to determine the average cost of the two inspected technologies. These average costs are supplied to the electricity market model as input variables. If in a given country and year this average value is lower than either the support price applied during model calculations, or in the absence of support the wholesale price modelled for the previous year (baseload price in case of wind power, and peak electricity price for solar energy) then the given power plant type is constructed, while in the opposite case it isn't. In other words, the newly built generating capacity is always determined based on the simulation results of the previous year (or the support price). It should be noted that the supply curve of new capacities is not horizontal, we face an increasing average cost curve (due to system integration costs). During modelling we apply an annual capacity constraint. We assume that in a given year new renewable production cannot exceed 5% of the total national consumption (for each technology separately). Moreover, the upper limit for a given type of weather dependent production is one-half of the total country-wide consumption.

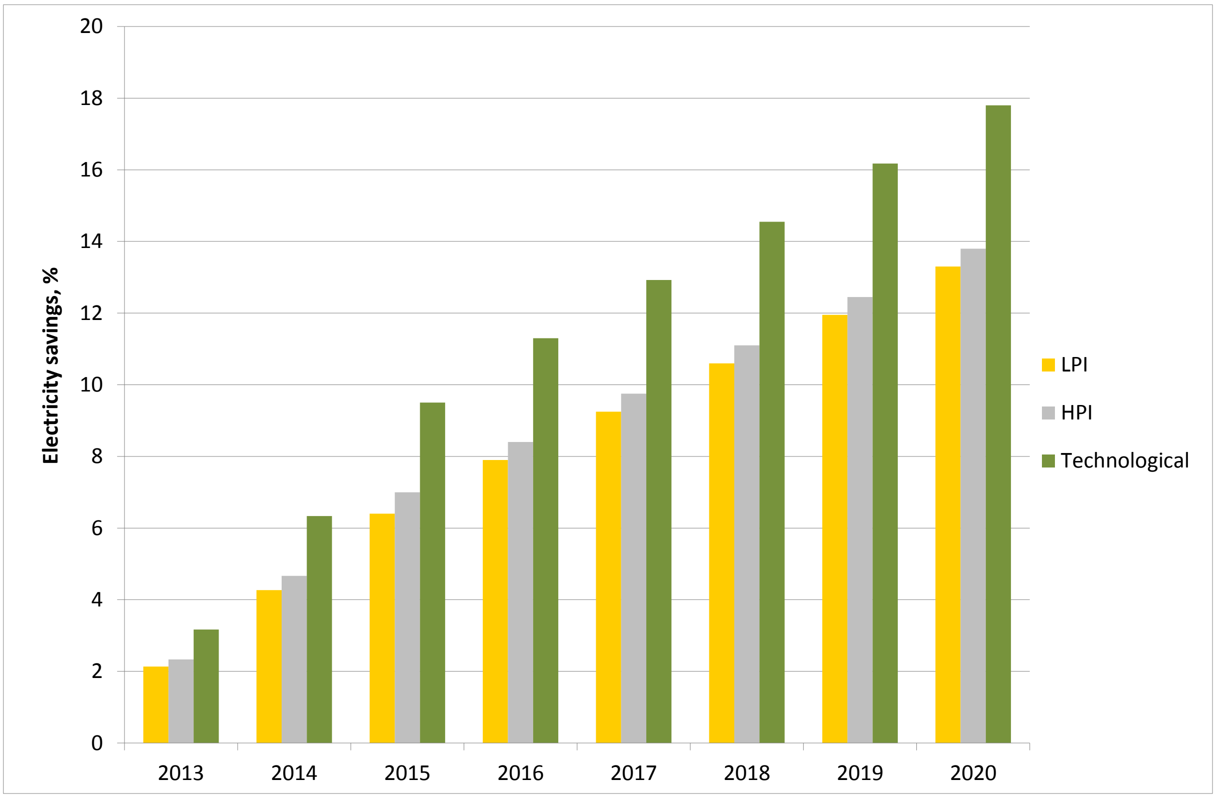
IX.1.3. Potential for energy efficiency investments

In order to be able to analyse the impact of energy efficiency investments on the inspected variables (penetration of renewables, carbon-dioxide emissions, electricity consumption), it is necessary to determine the potential for energy efficiency improvements for the electricity sector of each country. The potential calculation is based on a detailed Fraunhofer (2008) study, commissioned by the European Commission. This study calculates the energy efficiency potential in the four most relevant sectors (households, transport, industry and the tertiary sector) in each country of the European Union applying the same methodology. Under each sector additional sub-sectors were also set up. As an example, during the analysis the total electricity consumption of all refrigerators in each country was estimated, providing the basis for the calculation of the energy efficiency saving potential. The quoted study defined three types of potentials: the so called economic potential with low-policy intensity (LPI), the economic potential with high-policy intensity (HPI), and the technological potential. In the first case the energy savings of only those investments were included which are profitable even at the typically applied discount rate (8-15% real discount rate, depending on the sector). In case of the economic potential with high-policy intensity only those investments are assumed to take place that are profitable even at the social discount rate (3% real discount rate). Finally, the technological potential case it was presumed that all energy efficiency investments would take place without regard to profitability.

Importantly, the potential applies to a given year. There are two reasons for why this potential changes through time. First, the price of the best available technology may decline and new technologies may also appear. Second, there is the so called BAU path, which in itself contains an improvement of energy efficiency.

The authors of the study established the energy efficiency potentials both as a percentage and as an absolute value. Since this analysis had been prepared before the economic crisis, it assumes a robust growth of consumption. Thus we think it makes sense for us to use the percentage values in comparison to the electricity consumption that we estimate. Figure 44 reviews the percentage figures for the three different potentials for the case of Hungary. Importantly, the potentials reviewed here apply only to the consumption of electricity, but not to other types of fuels. We apply the same percentage values from the quoted study for all modelled countries.

Figure 44 Electricity savings achievable through energy efficiency investments in Hungary, %



Source: Own editing based on Fraunhofer (2009)

IX.1.4. Making the price of carbon-dioxide endogenous

Under the current status of the electricity market model the quantity of carbon-dioxide credits is not internal to the model, the price of the carbon-dioxide credit is a modelling input. In order to be able to forecast the impact of lowering/increasing the number of credits the model needs to be developed, making it capable of using the quantity of credits as an input, instead of the price of the credits.

Based on annual verified emission data from the period of 2005-2012, electricity and heat generating installations make up 71-73% of the total emissions of obliged installations, while the rest is up to the industrial sectors with large, point-source emissions (EEA, 2013). As already mentioned, the supply of credits is determined by the European Commission by capping the annual number of credits available for allocation, while demand is driven by the marginal CO_2 emission abatement cost curve of the obliged installations.

ETS emissions can be subdivided to three main segments: the emissions of industrial sectors, heat producers and electricity producers. The installations of the industrial sector can be further split into two sub-segments: installations which were subject to the ETS already during the 2008-2012 period, and newly added installations. For the first category we assumed that their 2013 emission is equal to the average of the 2008-2012 years, while with regard to the emission of the newly added installations we applied the estimates of the

Commission (EU, 2012). Our assumption for the BAU path - that is, the case without carbon-dioxide trading - of both segments has been that sectoral emissions change in parallel with the average real GDP of the European economy.

In the case of district heating we analysed the EU27 data on heat generation for the period of 2003-2011 (Eurostat, 2013). We quantified the carbon-dioxide emission of this sector based on the fuel use and the unit carbon-dioxide emission factors. Moreover, we assumed that the carbon-dioxide emission of district heating companies does not change through the inspected period (Table 19).

Table 19 Planned EUA allocation and the carbon-dioxide emission of specific sectors under the BAU scenario, million tons

	Planed allocated EUA	BAU emission of industrial sector already were subject to the CO2 regulation	BAU emission of newly added industrial installations	BAU emission of the total industrial segment	CO2 emission of district heating installations
2013	2 039	512	113	625	145
2014	2 004	516	114	630	145
2015	1 968	524	116	640	145
2016	1 933	535	118	653	145
2017	1 897	546	121	667	145
2018	1 862	558	123	681	145
2019	1 826	567	125	692	145
2020	1 791	577	127	704	145

Source: Own calculation based on EU (2012), Eurostat (2013), IMF (2013)

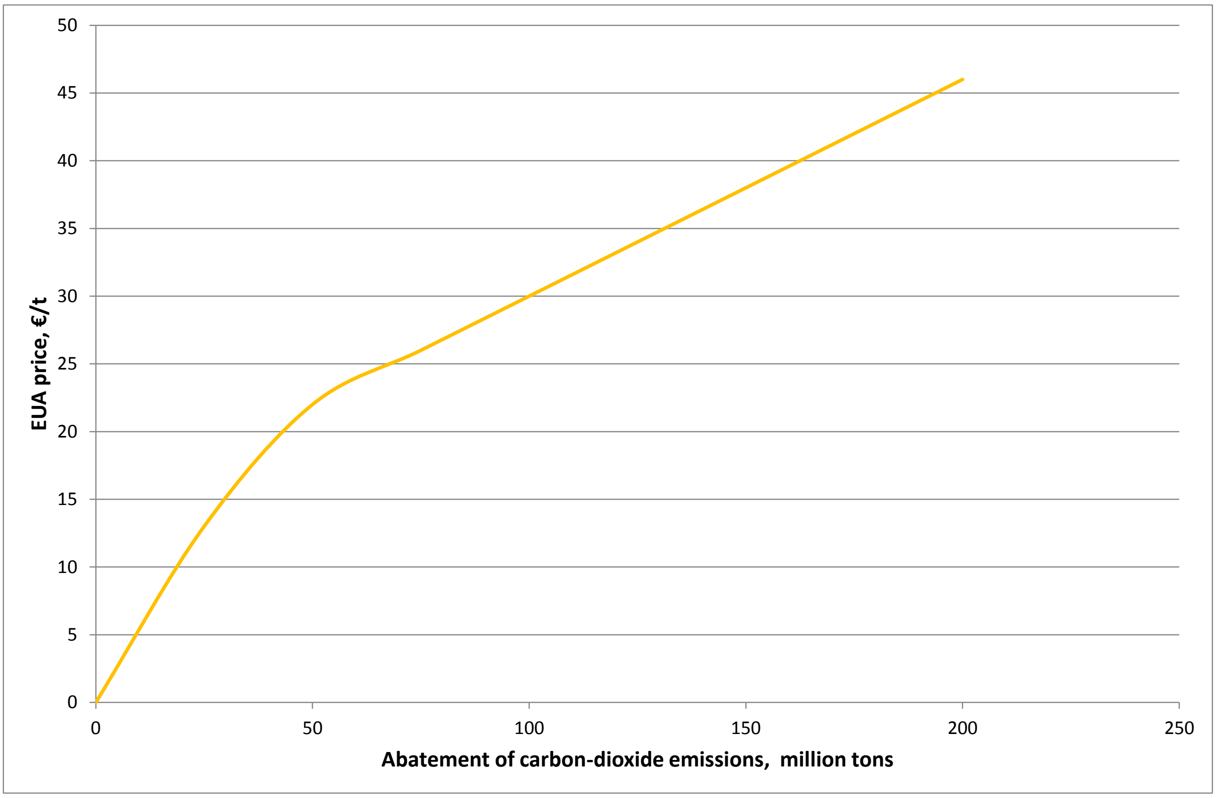
The European electricity market model makes it possible for us to estimate the CO_2 emission abatement cost curve of the electricity sector. We may distinguish three basic types of emission reduction in this sector:

- technology based abatement (e.g. carbon capture and storage - CCS, integrated gasification combined cycle - IGCC, etc.)
- efficiency improvement in selected power plants
- fuel switch.

From a technological perspective the first option is still immature, its widespread application is unlikely before 2020. Besides, this option could practically behave as a price cap, that is, these investments would start to proliferate at a given level of CO_2 price. The impact of the second alternative is of limited scale, and these power plant developments are motivated by the prospect of carbon-dioxide emission reduction only to a minor degree. The principal option for abatement is the third one, fuel switch. This solution does not imply the fuel switch within a given power plant, rather, there is a shift of production among power plants using different fuels, e.g. coal fired plants generate more/less electricity, while the production of gas fired plants moves in the opposite direction.

Since our model only simulates the emissions of the electricity sector, we need to make an assumption on the carbon-dioxide emission abatement cost curve of the industrial sector as well. Trotignon (2012) used a model called Zephyr to estimate the abatement cost curve of the industrial sector, as shown by Figure 45.

Figure 45 The marginal abatement cost curve of carbon-dioxide emissions in the industrial sector



Source: Trotignon (2012)

During modelling therefore we consider the BAU emissions of the industrial sector as well as the carbon-dioxide emissions of district heating as exogenous. Now we would like to know the carbon-dioxide credit price at which the planned quantity of allocation equals actual emissions: this will be the equilibrium price of carbon-dioxide credits. Notably, the price of the EUA is influenced by both the emissions of the electricity sector and the carbon-dioxide emission abatement of the industrial sector.

IX.2. Analysis of the first research question KK_1

RQ_1: The quantitative analysis of the following question: under those regulatory instrument combinations for which the direction of impact on specific variables (RES-E production, carbon-dioxide emission, investments into energy efficiency) cannot be unambiguously identified in a theoretically sound way, how do these variables actually change if we increase renewable support, the support provided to energy efficiency investments, the rate of the excise tax, or reduce the number of carbon-dioxide credits.

Altogether we identified seven regulatory instrument combinations (see Table 12) in case of which theoretical demonstration is not sufficient to reveal the direction in which the three most critical variables - renewable generation, energy efficiency investments and carbon-dioxide emissions - move. We rely on the competitive market model simulating the European electricity market to provide a quantitative answer to this question.

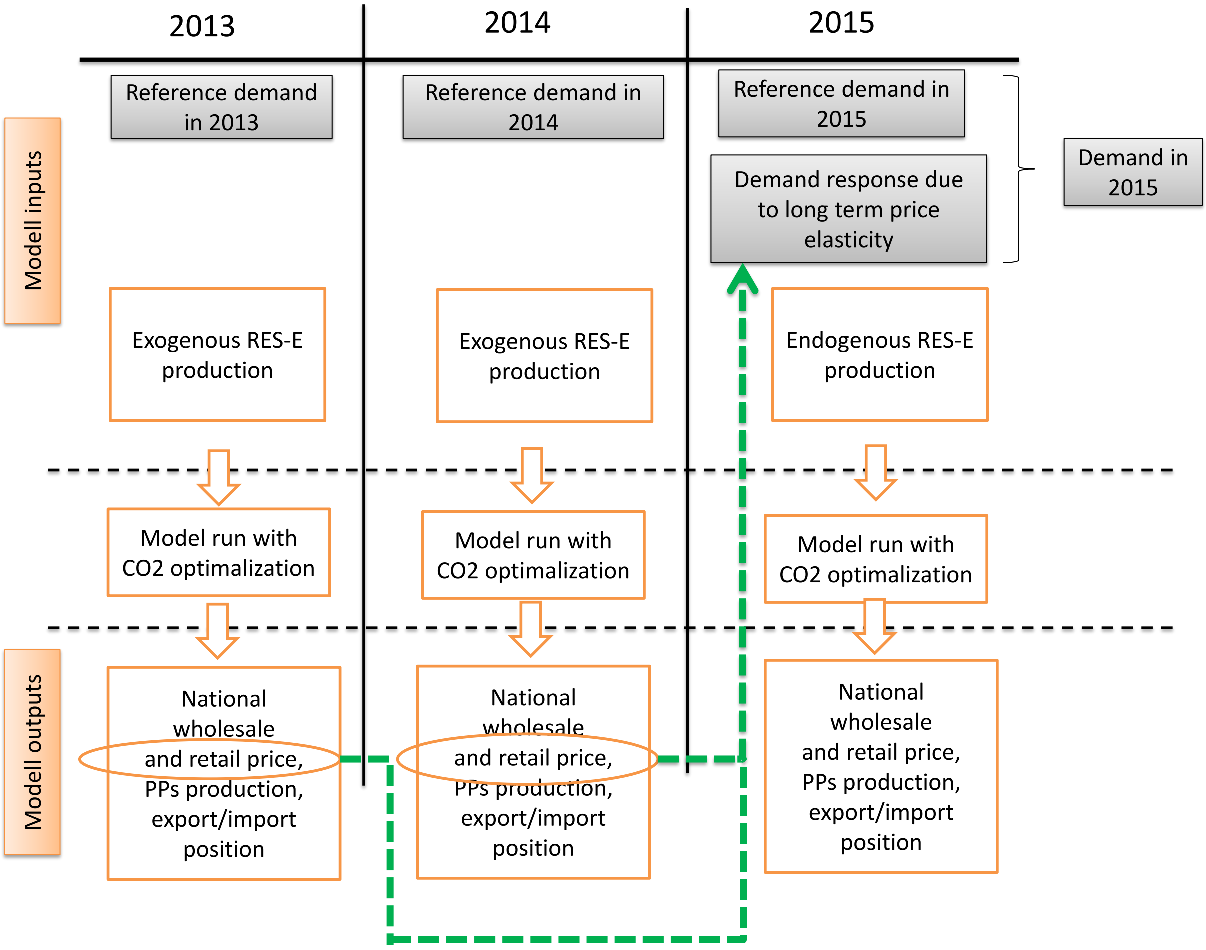
During the analysis we start from a hypothetical case without any regulation in place: there is no Europe-wide carbon-dioxide trading, none of the modelled countries support renewable generation or energy efficiency investments, and they do not impose an excise tax on fuel use. We will refer to this as the reference case.

Compared to the reference case we gradually tighten the regulatory instruments: for example, we increase the rate of the excise tax or reduce the amount of carbon-dioxide that is allowed to be emitted, and so forth. We look at combinations of instruments in the case of which the direction of the impact on the three most important factors (renewable generation, carbon-dioxide emissions, investments into energy efficiency) is not clear.

When working with this research question, the group of examined countries is not limited to the member states of the European Union, we consider the results for all the 36 modelled countries. Furthermore, the regulatory instruments are uniformly applied to all modelled countries: we assume a uniform excise tax, the same support to renewable generation, and identical support to energy efficiency investments for all analysed countries.

For all regulatory instrument combinations we run the model for three years: 2013, 2014 and 2015. Figure 46 shows why it is necessary to simulate the electricity market for all three years when analysing any of these cases.

Figure 46 A schematic representation of modelling the research question



The three simulation years notably differ from each other. In the first year, 2013, renewable production is considered by the model as fully exogenous. We assume that the newly built power plant capacity is the same as the new capacity planned for 2013 in the National Renewable Energy Action Plan. Subsequently, the model - among others - quantifies for each country the wholesale and retail prices of electricity, production by power plant types and net electricity export, while respecting the carbon-dioxide emission limits.[15] During the 2014 model run intermittent producers (wind and solar power plants) are already handled as endogenous, while for the rest of the renewable resources we continue to apply the capacity figures of the National Action plans. If we examine a regulatory instrument mix for which renewable support is available, then the newly built renewable capacity in a given country for the selected type of resource is such that their average cost equals the support price. In the absence of renewable support the wholesale price from the previous year is used. The 2014 retail price equals the sum of the 2014 wholesale price and the unit cost of renewable support. Wind and solar capacities for 2015 are determined through a similar method.

[15] When analysing this research question, emission trading was extended to all modelled countries.

While in both 2013 and 2014 we use our own estimate on the consumption of each country, for 2015 there is a slightly changed situation. In this instance we depart from the reference consumption again, but we amend this for each country with the change in consumption based on long term price elasticity. For this calculation we make use of the change of the retail price between 2013 and 2014, thus also taking into account demand response as part of the simulation.

While addressing the research question we only analyse 2015 values and we aggregate the outputs in order to make the analysis and the drawing of conclusions easier. We sum the electricity consumption, the electricity generation of different types of power plants, and the national carbon-dioxide emissions, while we calculate the weighted average of wholesale and retail prices, where we apply the 2015 consumption ratios of the given country as weights.

Next we describe in detail the conclusions that can be drawn from modelling results for the seven inspected regulatory instrument combinations.

IX.2.1. Renewable support without an emission trading system

As a result of renewable support the ratio of renewables increases. We assume that renewable plants produce electricity at a very low marginal cost (moreover, in case of some support mechanisms the produced electricity is not even sold to the competitive market), thus with the penetration of renewables the wholesale price declines. Supporting renewables with intra-sectoral financing increases the retail price of electricity. Without modelling, however, it is impossible to declare which impact is stronger: the decline of the wholesale price or the level of the unit support of renewables. Since the change of the retail price is uncertain in comparison to the case without renewable support, the impact on energy efficiency investments is also obscure. In addition, even total consumption may increase due to a possible decline of the retail price.

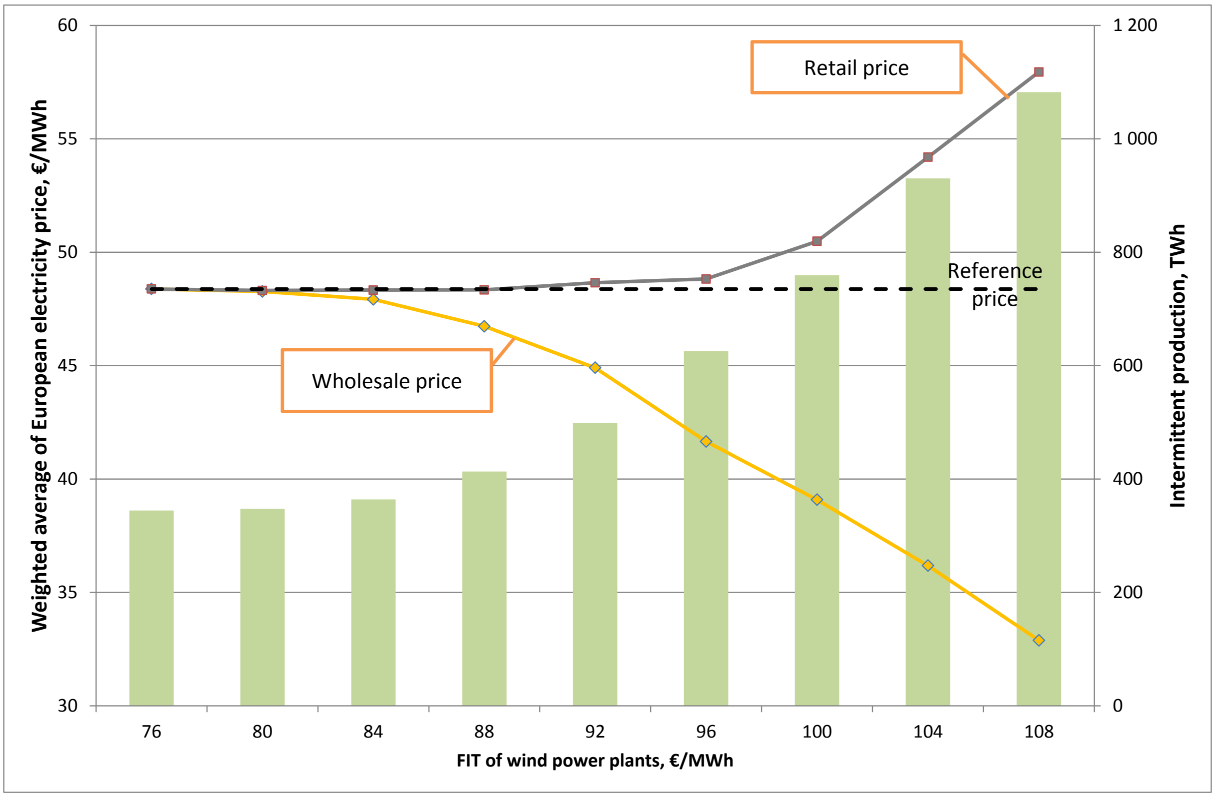
The key outputs of modelling are shown by Figure 47. The horizontal axis represents the feed-in tariff[16] of the electricity produced with the two types of weather dependent power plants (wind and photovoltaic). We assume that the photovoltaic feed-in tariff is 1.7 times the feed-in tariff of wind based generation. This value is the same as the ratio of the current average LCOE values of the two technologies. As an example, 136 €/MWh of photovoltaic feed-in tariff belongs to the 80 €/MWh feed-in tariff of wind power plants.

If the level of renewable support increases, then up to a certain point the retail price does not move, while the wholesale price keeps decreasing in parallel with the change in renewable production. Above a wind power plant support level of 88 €/MWh (=150 €/MWh of photovoltaic purchase price) the wholesale price notably declines. Above 100 €/MWh of wind

[16] In case of a green certificate the sum of the wholesale price and the price of the tradable green certificate.

power feed-in tariff, retail prices start to steeply rise. Since the volume of electricity consumption is a function of the retail price, we can state that as renewable support starts to increase consumption stands still for a while, and incentives for investments into energy efficiency are also unchanged, but after a specific level consumption declines, but the profitability of investments targeting energy efficiency increases. Carbon-dioxide emissions gradually, monotonously decrease as support expands: while in the reference case the combined emission of the electricity sector and the industrial sectors subject to ETS is 2.2 billion tons, this figure drops to 1.8 billion tons at the highest inspected level of renewable support.

Figure 47 The retail and wholesale price of electricity, and renewable production at different level of renewable support



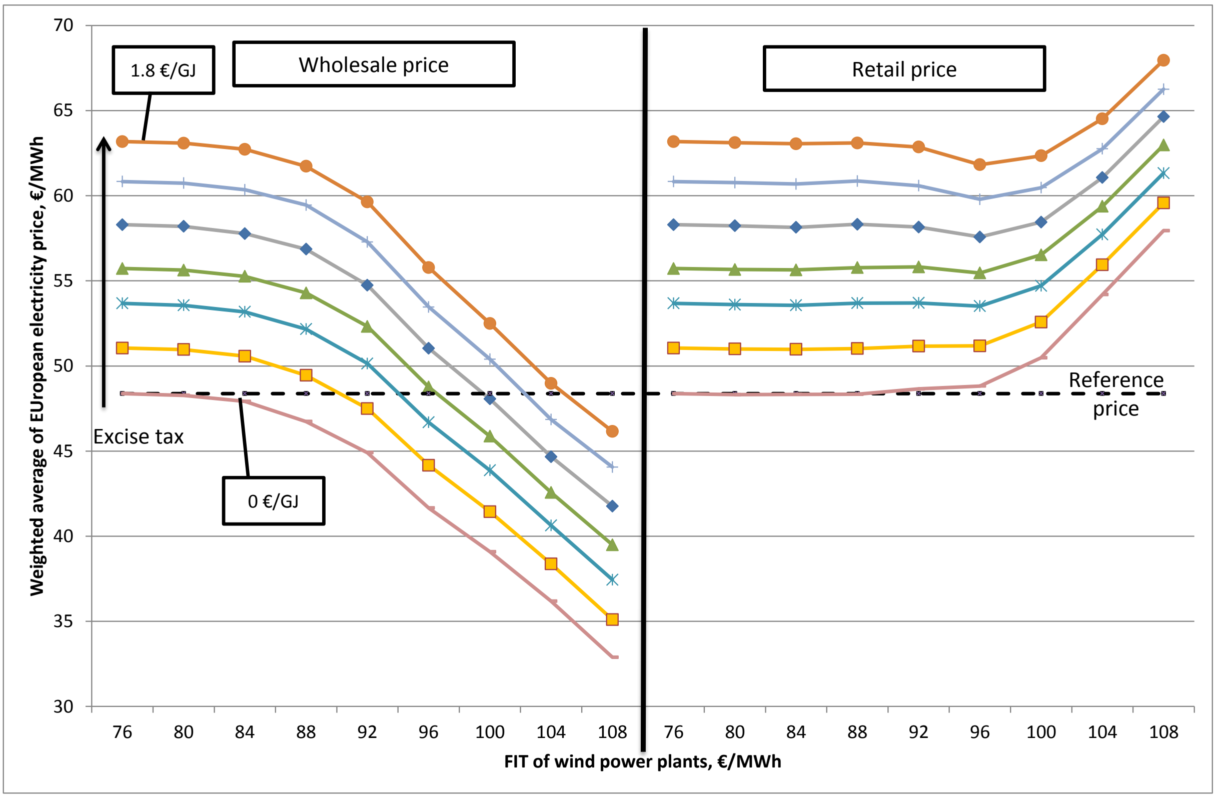
IX.2.2. Common application of renewable support and an excise tax, without an emission trading regime

As described before as the level of renewable support rises, the wholesale price declines, and above a specific support level the retail price increases. In contrast, the excise tax increases the marginal cost of fossil fuel based power plants, which in turn boosts wholesale prices (and retail prices as well), thus we encounter two opposing impacts.

In case of the excise tax we assumed that its level is the same for all countries and all fossil fuels. In Figure 48 we indicated the change of wholesale and retail prices at different levels of renewable support and different levels of the excise tax. We increased the level of the excise tax by increments of 0.3 €/GJ, thus the results are illustrated for tax levels falling between 0 and 1.8 €/GJ. This latter value increases the marginal cost of fossil fuel based power plants by 15-30 €/MWh.

As the modelling results show, renewable support cannot reduce retail prices even on its own, therefore obviously it cannot do this in a regulatory instrument mix supplemented with an excise tax either. The wholesale price, nevertheless, can substantially decline compared to a state of the world without any regulatory instrument. Furthermore, the higher the excise tax and the level of renewable support, the lower carbon-dioxide emissions will be, thus for all combinations of excise taxes and renewable support levels carbon-dioxide emissions will be lower than under the reference case.

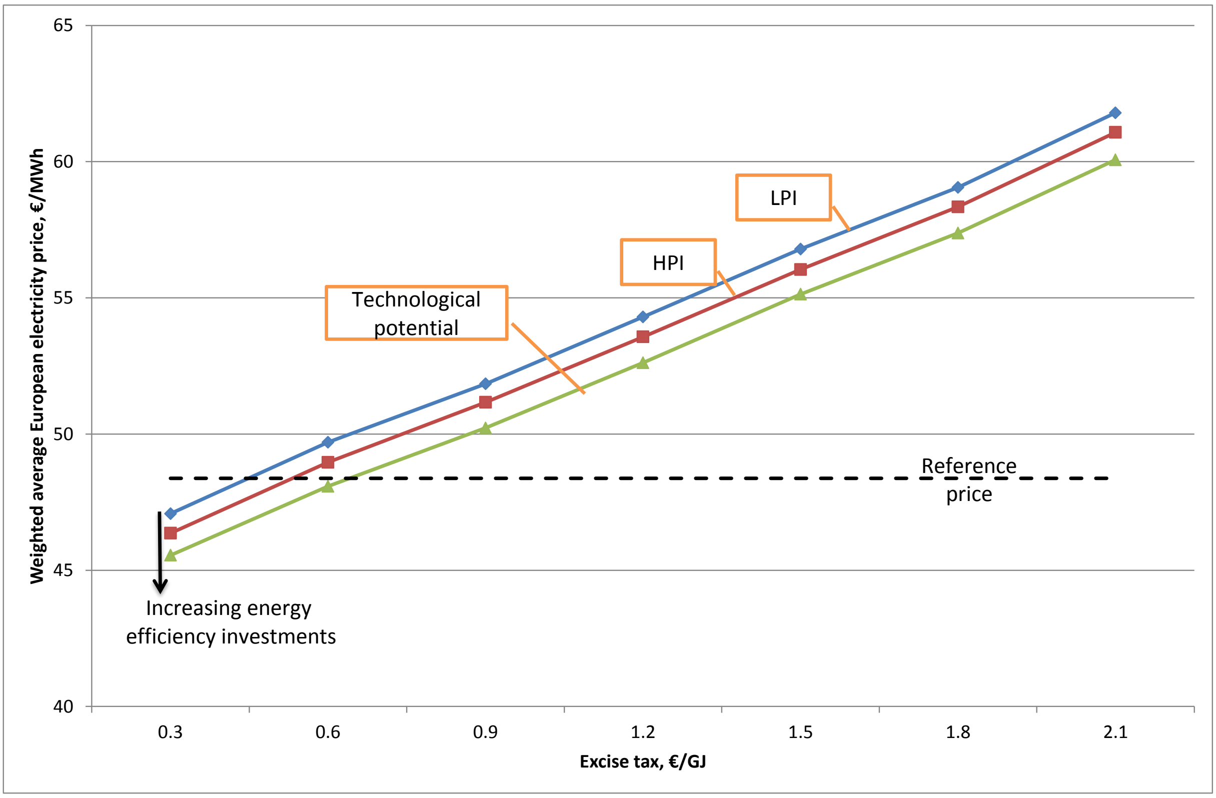
Figure 48 The retail and wholesale price of electricity at different renewable support levels and excise tax rates



IX.2.3. Excise tax and support to energy efficiency investments without an emission trading system

The excise tax increases the marginal cost, that is, the merit order curve shifts upward, while energy efficiency investments affect the demand curve, shifting it to the left. Since demand shrinks, but the supply curve shifts upward, the steepness of the two curves becomes important in determining the impact on wholesale electricity prices. Since the direction in which wholesale prices move is not obvious, the impact on promoting the construction of renewable capacities is not straightforward either.

Figure 51 Wholesale prices with an excise tax and with support to energy efficiency investments



**HPI: economic potential with high-policy intensity; LPI: economic potential with low-policy intensity*

Figure 51 illustrates that based on the result of modelling the price of electricity increases together with the excise tax, while the price of electricity declines due to investments into energy efficiency. In other words, the lower the excise tax and the higher energy savings, the cheaper the wholesale price will be. In case of a 0.6 €/GJ excise tax imposed on fossil fuels, energy efficiency improvements cannot any more counterbalance the rise of the marginal cost of production. Above this level the resulting wholesale price will be higher than in the reference case which lacks both support to energy efficiency investments and excise taxes. The lower price of electricity without a renewable support regime leads to a lower (or at least not higher) penetration of renewables, thus a high excise tax favours the penetration of renewables.

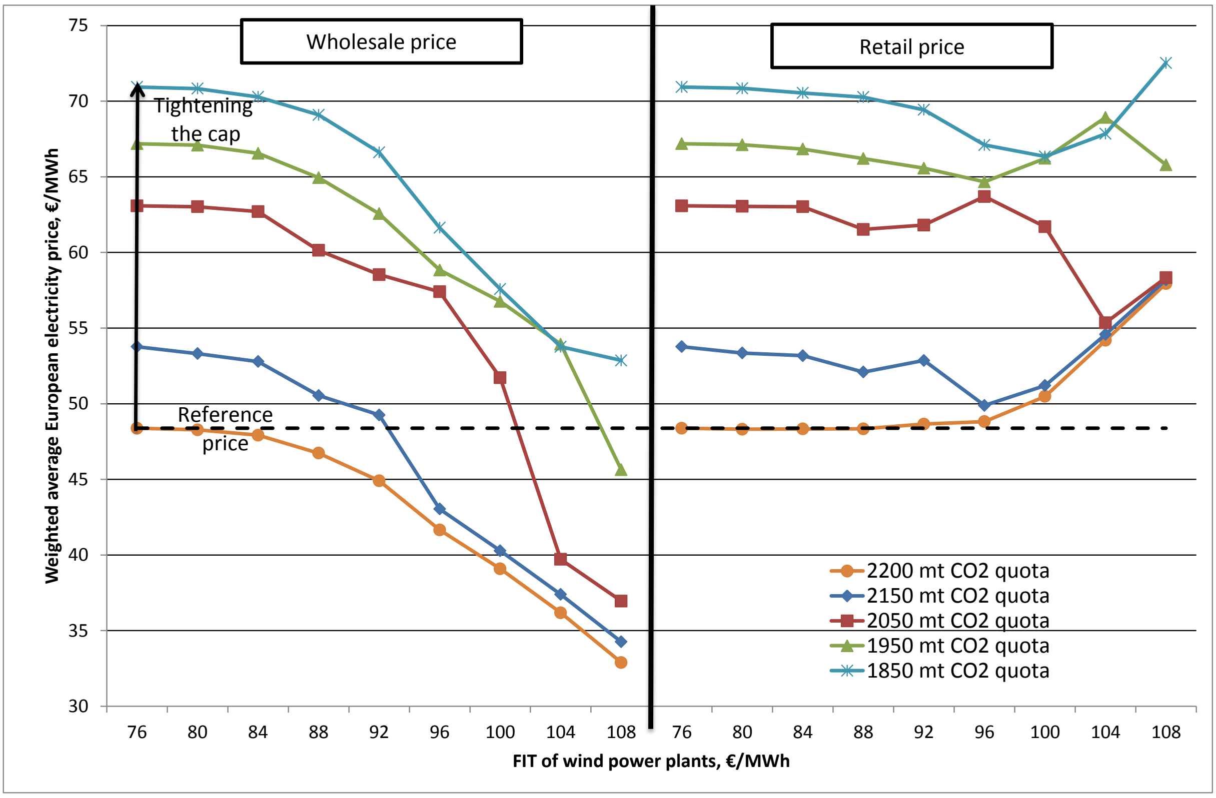
As a result of the examined energy efficiency investments consumption always declines, that is, the increased consumption due to a lower price of electricity cannot counterbalance this effect. This also leads to the decline of carbon-dioxide emissions, since the demand for electricity produced in fossil fuel fired power plants will decrease.

IX.2.4. Renewable support coupled with emission trading

The introduction of the emission trading system increases the marginal cost of production at fossil fuel fired power plants: the tighter the emission cap, the higher the marginal cost will be. Support to renewables displaces fossil based generation, reducing the wholesale price, but having an ambiguous impact on retail prices on its own. Therefore the direction in which the two regulatory instruments impact wholesale electricity prices is opposite.

In Figure 49 the weighted European wholesale and retail prices at different emission caps and renewable support levels are depicted. The lowest running (orange) line represents the case without emission trading. Under this case the carbon-dioxide emissions of the electricity sector and the industrial sector together amount to 2.2 billion tons.

Figure 49 The wholesale and retail prices at different levels of renewable support and emission caps



Apparently, the higher the renewable support and the tighter the cap, the lower the wholesale price will be, which, in some instances, may be even lower than under the reference case. Even though a similar relation can be observed for retail prices as well, there is one difference: the absence of an emission cap - support level combination at which the retail price would be lower than in the reference case.

Not all of the above illustrated scenarios can be characterised by clear trends. This is explained by the complexity of the impacts: when renewable production is on the rise, it alone displaces the most expensive fossil fuel based power generation, thus the wholesale price declines. At the same time, as a result of the displaced production the price of carbon-dioxide credits declines, further reducing the wholesale price of electricity. The declining wholesale price, in turn, increases the unit support of renewables at a given support level, thus contributing to the rise of the retail price.

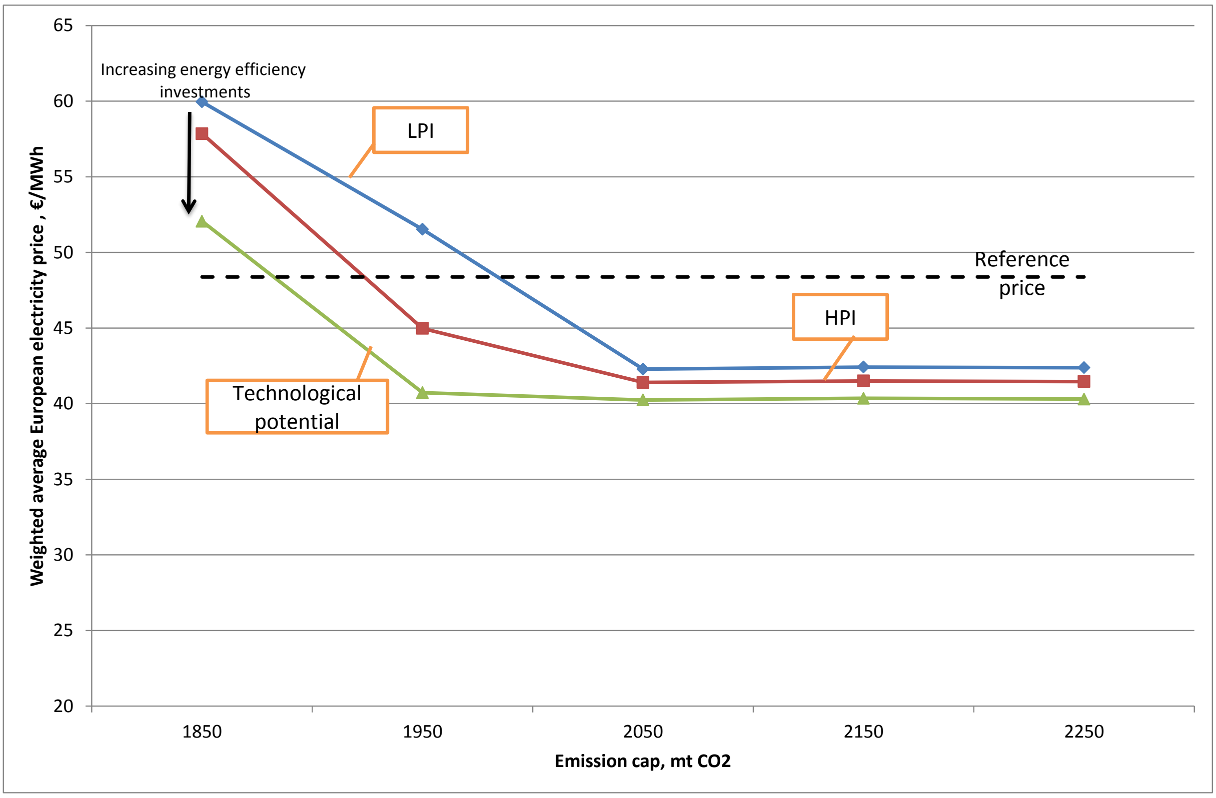
IX.2.5. Support to ene rgy efficiency investments along an emission trading system

As already described, the introduction of emission trading adds to the marginal cost of fossil fuel fired power plants, resulting in higher electricity prices. Energy efficiency investments, on the other hand, deliver exactly the opposite impact. As the demand curve shifts to the left, the resulting equilibrium price decreases.

The combination of emission trading and support to investments on energy efficiency operates precisely like the instrument pair made up of an excise tax and support to energy efficiency investments: in case of a high number of carbon-dioxide credits (=less tight cap) and abundant investment support to energy efficiency the resulting electricity price may be lower than under the reference case.

Similarly to the excise tax - energy efficiency investment instrument combination the consumption of electricity declines and the level of carbon-dioxide emissions stays at or below the number of allocated emission credits. The penetration of renewable resources depends on the wholesale price: if it is lower than in the reference case, then the penetration of these resources is adversely impacted, otherwise it promotes the construction of new renewable energy based electricity generating capacities (Figure 50).

Figure 50 Wholesale prices at different levels of emission credits and energy efficiency investments



**HPI: economic potential with high-policy intensity; LPI: economic potential with low-policy intensity*

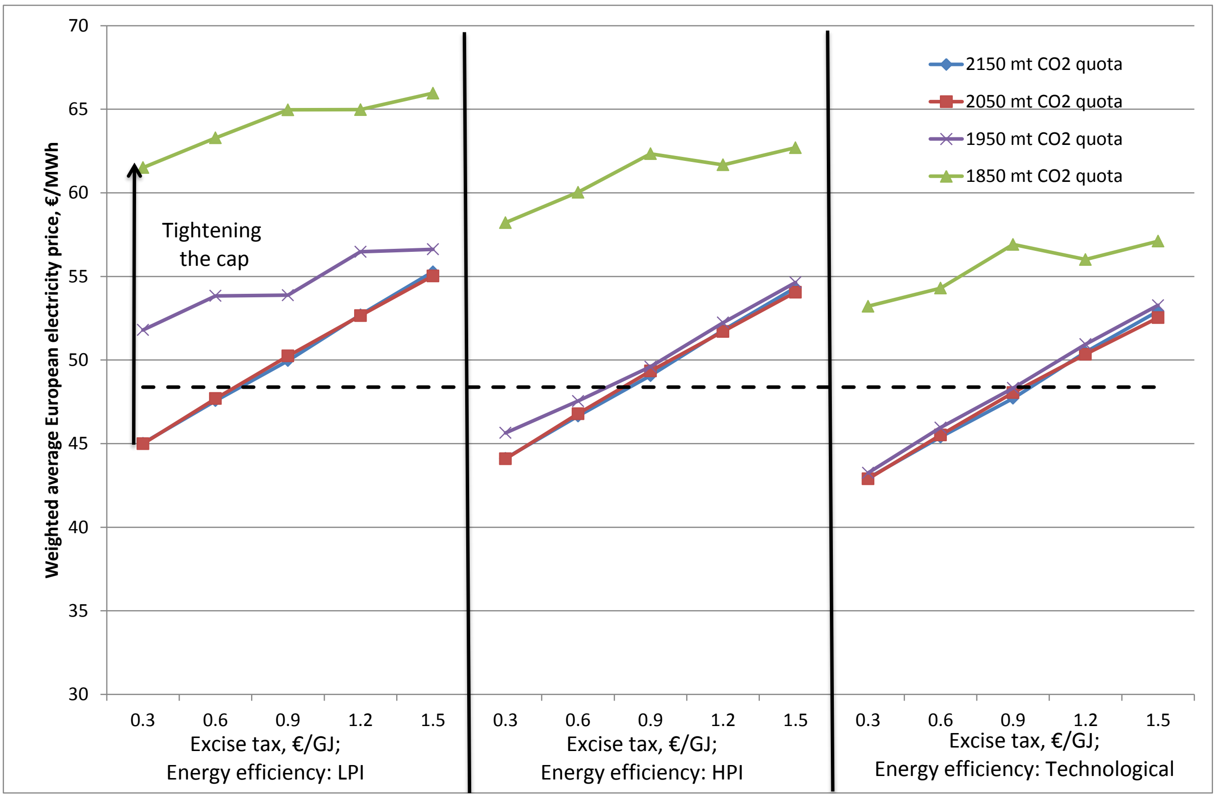
IX.2.6. Support to energy efficiency investments, together with an excise tax and an emission trading system

The excise tax and the emission trading system deliver their impacts similarly: the introduction of both regulatory instruments increases the marginal cost of fossil fuel fired power plants, therefore the supply curve shifts upward. Two instruments, however, impact gas and coal fired plants differently.

During modelling we assumed a uniform excise tax for all fuel types. Since, however, gas based power plants are more efficient than coal fired ones, the rise of marginal costs is more moderate for installations using gas. Emission trading provides an even more pronounced competitive advantage for gas fired plants, since their specific carbon-dioxide emission is lower not only because of their higher efficiency, but natural gas also has a much lower emission factor than coal.

Figure 51 describes the results of the simulation. Two conclusions can certainly be drawn: first, the emerging electricity price will be lower than under the reference scenario only in case of a particularly high level of energy efficiency investments, a low excise tax and a high level of emission credits. Second, electricity consumption as well as carbon-dioxide emissions are always lower than under the scenario without regulation.

Figure 51 Wholesale prices at different levels of emission credits, excise taxes and energy efficiency investments



IX.2.7. Renewable support together with an excise tax and an emission trading system

As we have already shown in the previous section, the excise tax and emission trading both increase the marginal cost of fossil fuel based power plants, but they impact gas based and coal based power plants differently. Renewable support, on the other hand, reduces the wholesale price, but - as noted before - it may boost the retail price.

Modelling results show that in case of a high level of renewable support and a low excise tax, and also if the number of credits is not too tight, the wholesale price is lower than the reference price. As expected, a higher excise tax and a tighter emission cap raise the wholesale price, while increasing the level of renewable support reduces it. Retail prices, meanwhile, exceed the reference price under every instrument mix (Figure 52, Figure 53).

Figure 52 Wholesale prices at different levels of emission credits, excise tax and renewable support

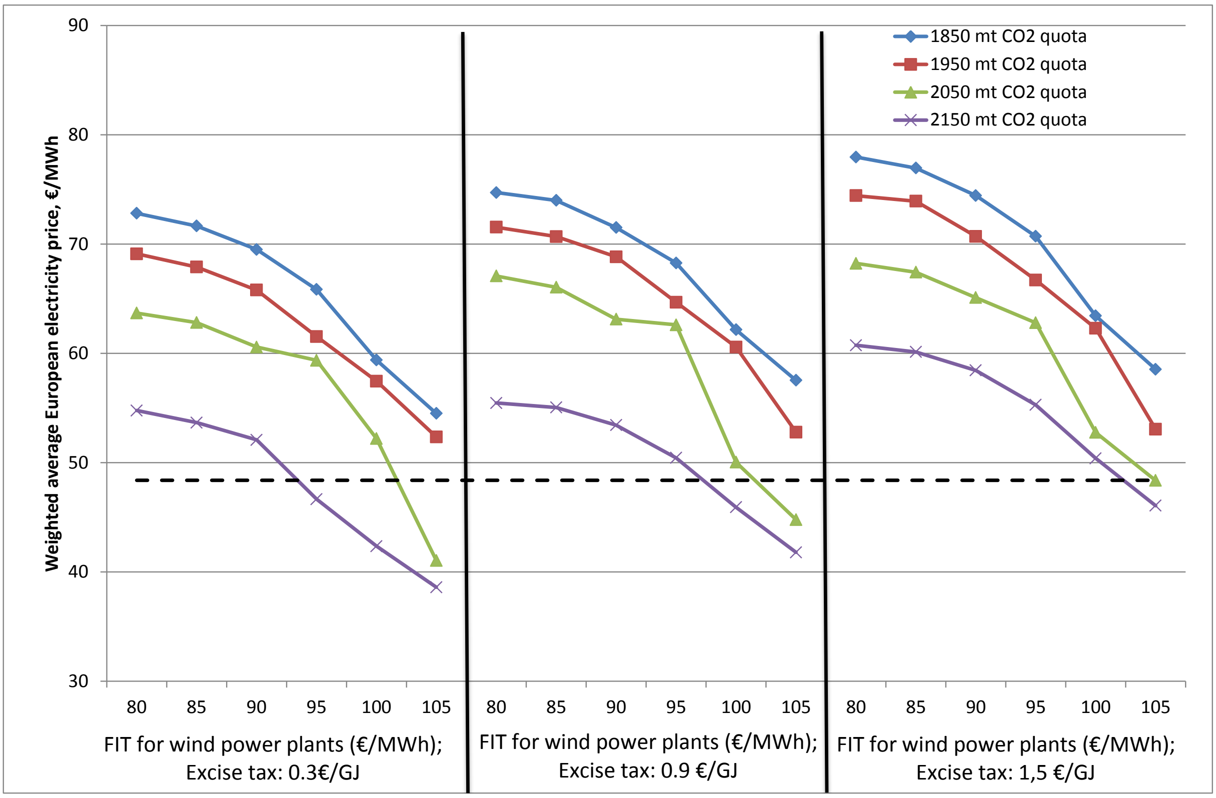
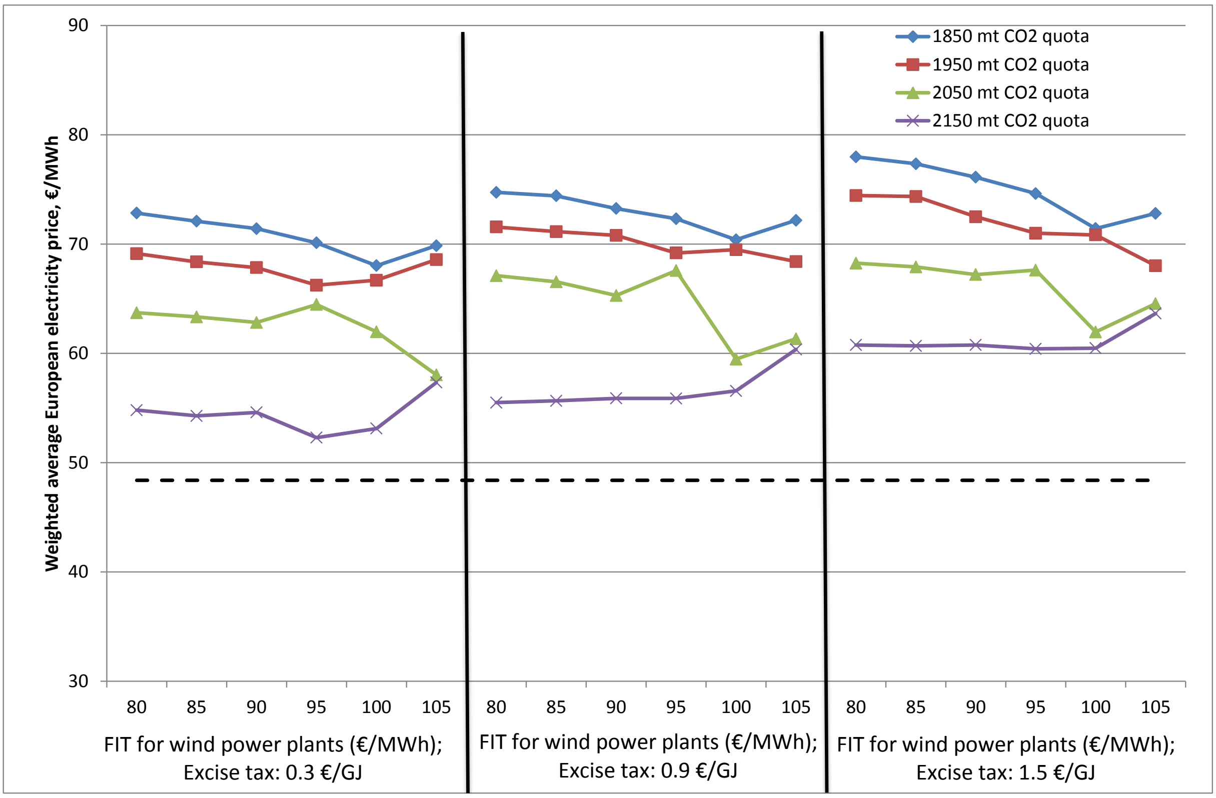


Figure 53 Retail prices at different levels of emission credits, excise tax and renewable support



IX.2.8. Sensitivity analysis

In order to make the results more robust and more reliable, sensitivity analysis of the most important factors needs to be carried out. We conduct a partial sensitivity analysis for three factors altogether:

- The value of long term price elasticity: As a base case we assumed the long term price elasticity to be 0.25. During the sensitivity analysis we test a value of 0.1.
- The price of coal: For the partial sensitivity analysis we assume that the price of both coal and lignite is 50% more expensive than under the baseline.
- The price of natural gas: In this case we assumed that the price of natural gas is 50% cheaper than in the base case

IX.2.8.1. Long term price elasticity

We carried out the above model calculations with a long run price elasticity coefficient that is lower than the one in the base case. Below, nevertheless, we describe only those scenarios that substantially differ from the baseline.

- In case of an instrument combination consisting of an excise tax and support for energy efficiency investment the resulting price can be lower than in the reference scenario both in case of a higher excise tax and a lower support for energy efficiency investment.

- If renewable support and emission trading are applied together, then as a result of the lower long term price elasticity the wholesale price may be lower than in the reference scenario even in case of a lower level of renewable support or a tighter carbon-dioxide credit cap. Nonetheless, even at this level of price elasticity there isn't any renewable support - emission cap combination under which the retail price would be lower than in the reference case.

- Under an energy efficiency investment - emission trading mix price elasticity turns into a rather important factor and the simulated results under this instrument combination are quite sensitive to this factor. In case of a much tighter cap or lower level of energy efficiency investment the resulting electricity price will be lower than in the reference case.

- We arrive at a similar result if the previous instrument combination is supplemented with an excise tax as well.

In conclusion we can declare that as a result of the lower price elasticity coefficient under the examined instrument mixes there is an increased probability for electricity prices to be lower than in the reference case.

IX.2.8.2. The price of coal

We have also carried out all the calculations with regard to the price of coal. In sum, we find that results are much less sensitive to this input data than to long term price elasticity. We observe the following main changes:

- In case support to energy efficiency investments and emission trading is applied together, a higher coal price coupled with a lower number of emission credits, or less extensive measures on energy efficiency already result in lower electricity prices than under the reference case (without any regulation).

- In case of an excise tax, a high level of renewable support and emission trading the price of electricity will stay below the price of the reference case when a high price of coal is coupled with a tighter emission cap or a lower excise tax.

IX.2.8.3. The price of natural gas

During the partial sensitivity analysis we reduced the price of natural gas by 50% compared to the base case. At such a low gas price gas fired and coal fired power plants switch their position in the merit order. As a result, carbon-dioxide emissions significantly drop even without the application of any regulatory instrument. Since simulations were run for the same emission cap that belongs to the reference natural gas price, in the cases involving an emission trading policy the resulting credit price is rather low. In sum, the following changes can be observed:

- In case of an excise tax and the application of renewable support, the wholesale price will be lower than the reference price if the level of the excise tax is lower and the renewable support is higher.
- Under any excise tax and energy efficiency investment combination the resulting price is higher than under the scenario without regulation.
- Under this instrument combination the price of electricity will be higher than under the case without regulation only if the emission cap is clearly low and the level of energy efficiency investments is also modest.

IX.2.9. Summary of the RQ1 analysis

Table 20 provides a summary of our main modelling results.

Table 20 Modelling results pertaining to RQ1

Analysed instruments mix	RES-E production	Production of conventional power plants	Total consumption	Wholesale price	Retail price	Carbon-dioxide emission	Energy efficiency investments
RES-E support without emission trading	Increase	Decrease	In medium support level a bit higher compared to the reference, otherwise no significant difference can be seen	Decrease	Until medium support level stagnate, than increase	Decrease	Until medium support level stagnate, than increase
Excise tax and RES-E support without emission trading	Increase	Decrease	Decrease	In low excise tax and in high support level decrease, otherwise increase	Increase	Decrease	Increase
Excise tax and support of energy efficiency investments without emission trading	Increase	Decrease	Decrease	In very low excise tax and high energy efficiency investments decrease, but usually increase	In very low excise tax and high energy efficiency investments the price is smaller than in the reference	Decrease	Increase
RES-E support with emission trading	Increase	Decrease	Decrease	In high RES-E support levela and in high quoata amount decrease, otherwise increase	Increase	Decrease	Increase
Support of energy efficiency investments with emission trading	Increase	Decrease	Decrease	In high energy efficiency investments subsidy and high level of quota amount decrease, but usually increase	In high energy efficiency investments subsidy and high level of quota amount decrease, but usually increase	Decrease	Increase
Excise tax and support of energy efficiency investments with emission trading	Increase	Decrease	Decrease	In low excise tax, high level of quota amount and high level of RES-E support decrease	Increase	Decrease	Increase
Excise tax and support of energy efficiency investments with emission trading	Increase	Decrease	Decrease	Increase	Increase	Decrease	Increase

In order for results to be reliable, we carried out a partial sensitivity analysis for three factors. While - as it has been described before - the generated modelling results are slightly changed, our conclusions in relation to research question RQ_1 do not need to be revised, thus our results can be viewed as robust.

IX.3. EXAMINATION OF THE H2 HYPOTHESIS

H_2: Any combination of the four regulatory instruments (excise tax, renewable support, emission trading, support to energy efficiency investments) that we inspect is sufficient to reach the 20-20-20 target set by the EU for 2020, except when the only available instrument is the support to energy efficiency investments.

When testing the hypothesis we follow the same path as for research question 1, that is, first we depart from a European market where we disregard the application of the four inspected regulatory instruments. Then we gradually introduce different levels of the regulatory instruments, but in a uniform manner in each member state.

Importantly, in case of the 20-20-20 targets we only examine the accomplishment of the ultimate goals, whether a member state fulfils its own particular, obligatory goals derived from the Europe wide 20-20-20 targets, is not part of the analysis.

IX.3.1. Definition of the 20-20-20 targets for 2020

In 2009 the EU adopted the new Climate and Energy Package targeting by 2020 a 20% reduction of GHG emissions, 20% lower primary energy use and a 20% share for renewable energy use. Subdividing these goals for the electricity generating sector, however, is not entirely straightforward. Let's inspect each of the three areas separately.

IX.3.1.1. Renewable target

Based on the targets of the EU in 2020 energy generated from renewable energy sources should make up at least 20% of the final energy use. The EU Directives do not identify a separate renewable sub-target for the electricity sector, but the National Renewable Energy Action Plans (NREAPs) assign indirect targets to the electricity sector as well, thereby it becomes possible to quantify the 20% EU renewable target falling on electricity producers. Based on these documents in 2020 the total electricity consumption of the EU27 may reach 3535 TWh, of which 1199 TWh is predicted to be renewable production, equal to a 34% renewable share within the electricity sector in 2020 (Beurskens et al., 2011). During the inspection of the hypothesis we consider the percentage target as the guiding principle.

IX.3.1.2. Reducing primary energy use

By 2020 the EU would like to reduce its primary energy use by 20% compared to the so called baseline scenario. The calculations of DG Energy (2011) predict a baseline figure of about 1842 Mtoe by 2020, based on which the targeted energy use should be 1474 Mtoe. Mainly as a result of the economic crisis, however, the BAU path considerably changed. According to the calculations of the Commission, without additional measures the current primary energy use pathway may reach 1678 Mtoe by 2020. Thus, in order to attain the 2020 targets, 204 Mtoe (1678-1474) of primary energy use needs to be saved. With regard to the targets, the Commission did not set specific figures for the individual sectors. Nevertheless, in order to be able to answer the research question, we need to make an assumption on the energy savings of the electricity sector necessary for the fulfilment of the primary energy use reduction target.

According to the Fraunhofer (2009) study the technological potential of energy efficiency investments within the EU27 with respect to 2020 is 310.8 Mtoe, of which 109.1 Mtoe is available within the electricity sector. In order to attain the target, however, "merely" 204 Mtoe energy needs to be saved by the end of the decade, thus we also made the target of the electricity sector proportional to this figure. The calculation shows that in case of the electricity sector 71.6 Mtoe (204.2 / 310.8 * 109.1), that is, 3000 PJ of primary energy needs to be saved. If we exchange this to electricity output with the conversion factors (40% average gross efficiency) used by Fraunhofer (2009), then we get 333 TWh as the result. Table 21 depicts the steps of the calculation.

Table 21 "Translating" the primary energy reduction target to the electricity sector

BAU path	1842 Mtoe
Target 20 % by 2020	1842 Mtoe *0.8=1473.6 Mtoe
The expected Primer energy consumption in 2020 according to the present path	1678 Mtoe
Furher necessary primer energy reduction	204.4 Mtoe
Primer energy reduction potential in 2020 in all sectors	310.8 Mtoe
Primer energy reduction potential in 2020 in the electricity sector	109.1 Mtoe
Necessary primer energy reduction in the electricity sector	(204.4Mtoe/310.8Mtoe)*109.1Mtoe
Necessary primer energy reduction in the electricity sector	3000 PJ
Assumed gross efficiency rate	40%
Necessary reduction related to the electricity output	3000*0.4/3.6=333 TWh

IX.3.1.3. GHG reduction

According to the 20-20-20 targets the EU wishes to reduce its GHG emissions by 20% compared to the 1990 baseline year, equivalent to a 14% reduction compared to 2005. In order to attain this target separate sub-goals were created for the ETS and the non-ETS sectors. Within the non-ETS sectors the Commission expects a 10% reduction, within the ETS sectors a 21% reduction compared to 2005. The calculations of the Commission show that this is sufficient to reach the 2020 target. The 2013 allowance allocation of the ETS sector is equal to the average emission level of the 2008-2012 period, to be decreased by 1.74% annually afterwards (EU, 2012). The corresponding number of allowances to be allocated has already been described in Table 16.

IX.3.2. The modelling process

With the H_2 hypothesis we follow the same method as with the analysis of RQ_1, namely, we run the model for every year between 2013 and 2020. The annual simulations, however, are not independent of the results of the preceding year, since the simulation results of the previous years also impact the consumption of the current year through the long term price elasticity. Consequently, prices can "oscillate" through the inspected time period. Let's assume that the price for 2016 happens to be 100 €/MWh, while in the previous years it was only 80 €/MWh. In this situation the 2017 consumption will decrease compared to the reference case thanks to the declining consumption associated with the elasticity of price. The lower consumption, however, may lead to a lower equilibrium price, declining to 90 €/MWh, for instance. Under this condition, nevertheless, the 2018 consumption will be higher than under the reference case, therefore the price of electricity is likely to rise again. In order to eliminate this impact, during the analysis of the hypothesis we work with the simple average of the 2019 and 2020 values of each of the analysed factors.

IX.3.3. The case without regulatory instruments

Under the scenario without regulatory instruments the consumption weighted average price of European electricity is 47.5 €/MWh for 2019-2020. This is approximately 6-8 €/MWh above current levels. Total electricity consumption in the countries of the European Union is 3399 TWh, of which 333 TWh needs to be saved by 2020 in accord with the energy efficiency targets. Renewable electricity generation makes up 30.68% of total consumption, that is, in sum 1042 TWh of energy is produced by renewable based power plants. This is 3.2 percentage points below the targeted level of 34%. The third target pronounced by the EU is for carbon-dioxide emissions not to exceed 1915 million tons on average during 2014-2020. Under the baseline scenario the total emission of the ETS sectors is 2124 million tons. Evidently, the introduction of one or more regulatory instruments is definitely needed in order to be able to reach the 20-20-20 targets set by the EU.

IX.3.4. Introduction of one type of regulatory instrument

Next we make use of modelling to see if the introduction of a sole regulatory instrument can be sufficient to reach the targets set by the EU. For each regulatory instrument we were looking for the regulated level (number of allocated allowances; level of renewable support; level of excise tax; and the intensity of investments into energy efficiency) at which the targets become attainable. Table 22 shows the most important modelling results at these regulated levels.

Table 22 The most important modelling results for 2019-2020 on average in case one type of regulatory instrument is introduced at a level that is sufficient for the accomplishment of the 20-20-20 targets

Instrument	No instrument	Emission trading	RES-E support	Excise tax	Support of energy efficiency investmets
Level of instrument	-	Total allocated quoata: 1560 Mt	FIT for wind power plants: 114 €/MWh; FIT foe PV: 193 €/MWh	Uniform excise tax: 2,4 €/GJ	Those energy efficient investments realized, which return between social and economin discont rate
Weighted average of European wholesale price, €/MWh	34.6	0.0	0.0	0.0	0.0
Weighted average of European retail price, €/MWh	77.2	0.0	0.0	0.0	0.0
European total consumption, TWh	3 012	0	0	0	0
European coal-based power production, TWh	229	0	0	0	0
European total gas-based power production, TWh	221	0	0	0	0
European total RES-E production, TWh	1 973	0	0	0	0
RES-E share, %	65.5%	0.0%	0.0%	0.0%	0.0%
Carbon-dioxide emission	1 171	0	0	0	0
CO2 quota price, €/t	0.0	0.0	0.0	0.0	0.0

If only an emission trading system is applied, with 1560 million tons of carbon-dioxide allowances allocated (the same figure is 1915 million tons under the current regulation) then the 20-20-20 targets can be attained. Under this scenario as a result of a tightening supply of credits the price of carbon-dioxide approaches 30 Euros a ton. Due to the high credit price the weighted average wholesale price in Europe increases by almost 15 Euros per MWh in comparison with the baseline. The high carbon-dioxide price, nevertheless, reduces the competitiveness of coal fired power plants, thus their production level falls by almost one-half, balanced partly by the additional production of gas fired plants, and partly by the declining consumption driven by the higher prices. The production of renewable power plants barely increases, but since renewable targets were set as a percentage, an unchanged level of renewable production is already sufficient to reach the renewable target due to the decline of consumption.

In case there is only renewable support, all three targets can be attained with a feed-in tariff (or the sum of the price of green certificates and the wholesale price) of 114 €/MWh for wind power plants, and 193 €/MWh for solar power plants. As a result of the support renewable based electricity generation substantially increases, exceeding 2120 TWh for 2019-2020 on average, supplying almost 70% of the total consumption. Consequently, conventional power plants are crowded out, bringing about the dramatic fall of carbon-dioxide emissions, reducing them to almost half of the targeted figure. Since renewable resources are typically available at zero marginal cost, wholesale prices also notably decline. At the same time, due to the renewable support the retail price rises to almost 80 €/MWh, curbing consumption. Whether under these conditions the European electricity sector can operate as a real competitive market remains to be seen, since two-third of the production is supplied by power plants operating in a separate, protected market.

The excise tax operates through a mechanism similar to that of the emission trading system. As a result of the increased production cost of the fossil fuel based power plants the price of electricity also increases, reducing demand. In order for the 20-20-20 targets to be achievable solely through the introduction of the excise tax, according to our calculations an excise tax of 2.4 €/GJ needs to be imposed on fossil fuels. This is over ten times the current rate. The penetration of renewables does not change compared to the reference case, but the renewable target is still met due to a declining demand.

Finally, if only energy efficiency support is utilised, then due to the investments into energy efficiency electricity use declines, reducing fossil fuel based electricity production. This also fulfils the carbon-dioxide emission reduction target. Even though new capacities based on renewable energy sources are not created compared to the reference case, the renewable target becomes achievable as a result of the declining consumption.

Evidently, all four regulatory instruments can be applied on a level at which the 20-20-20 targets of the EU are met. These, nevertheless, may create distorted markets and satisfy only the specific targets, but in the long run their contribution to a sustainable electricity market is rather dubious. If only a renewable regulation is introduced then wholesale prices will be so low and the ratio of renewables so high that the security of supply becomes questionable. In all the other cases the renewable target is met only because consumption declines, while new, renewable based generating capacities are not created.

IX.3.5. The simultaneous application of two regulatory instruments

Next we show how the EU targets can be met with the combination of two regulatory instruments.

IX.3.5.1. Excise tax and renewable support

Table 23 includes those excise tax - renewable support combinations for which all three targets are fulfilled. Clearly, the "bottleneck" under each case is reaching the energy efficiency target. If the excise tax increases then a lower renewable support level is already sufficient. At the same time, the retail price declines but the wholesale price rises. Even though - as a result of lower support - renewable based production declines, at an excise tax of 2 €/GJ the renewable ratio still exceeds 60%. Carbon-dioxide emissions are significantly lower than the targeted level under all cases.

If the two instruments are applied at the same time, then the results are less excessive: we can count on a higher wholesale price and a lower retail price, while substantial new renewable capacities will be created.

Table 23 Key modelling results at different combinations of excise tax rates and feed-in tariffs for renewables, meeting the 20-20-20 targets

Excise tax, €/GJ	0	1	2	3
FIT for wind power plants, €/MWh	114	112	109	94
FIT for PV plants, €/MWh	194	191	186	160
Weighted average European wholesale price, €/M	19.5	24.8	31.7	50.2
Weighted average European retail price, €/MWh	85.1	80.5	75.1	68.0
RES-E production, TWh	2 120	2 061	1 976	1 582
RES-E share, %	69.1%	67.2%	64.4%	51.6%
Electricity consumption, TWh	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 200	1 208	1 223	1 433

IX.3.5.2. Excise tax and support to energy efficiency investments

If only those energy efficiency investments are implemented that are profitable at a high discount rate (low policy impact scenario) then this in itself is not sufficient to achieve the energy efficiency and renewable targets, while the carbon-dioxide target is met thanks to the decline in fossil fuel based generation. If, however, this instrument is supplemented with a relatively modest excise tax of only 0.13 €/GJ, then all three targets are met. The higher excise tax rate slightly increases the wholesale price of electricity, leading to lower consumption, reducing fossil fuel based production and thus also lowering carbon-dioxide emissions.

IX.3.5.3. Renewable support and energy efficiency investment support

In case investments that are profitable at a high discount rate are implemented (LPI), a relatively modest support to wind power (90 €/MWh) and solar power (153 €/MWh) is enough to meet all three goals. Under the combination of these two instruments wholesale prices decline to 31.5 €/MWh, while the retail price increases to 49.2 €/MWh. The ratio of renewables under these regulatory conditions reaches 48%, while carbon-dioxide emissions decline to 842 million tons, less than half of the target.

IX.3.5.4. Emission trading and renewable support

In case of the common implementation of an emission trading system and a renewable support regime a relatively tight emission cap needs to be applied in order for this instrument to become effective. If 1.4 billion tons of carbon-dioxide allowances are allocated then either a very high or a very low feed-in tariff is required to be able to meet all three targets. This result may be surprising at first sight, but there is an explanation for it: the penetration of renewables substantially reduces carbon-dioxide emissions, thus the price of carbon-dioxide credits gets closer and closer to zero. In interim cases (modest renewable support), however, the retail price does not rise high enough to generate ample savings of electricity consumption (Table 24).

Table 24 Key modelling results along different emission credit levels and renewable feed-in tariffs that meet the 20-20-20 targets

Amount of allocated CO2 quota, mt	1500	1400	1300	1440
FIT for wind power plants, €/MWh	113	112	104	80
FIT for PV plants, €/MWh	192	190	177	136
Weighted average European wholesale price, €/MWh	20.3	21.0	36.1	58.5
Weighted average European retail price, €/MWh	79.5	75.3	70.7	62.7
RES-E production, TWh	2 093	2 060	1 827	1 213
RES-E share, %	68.3%	67.2%	59.6%	39.6%
Electricity consumption, TWh	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 204	1 219	1 294	1 488

IX.3.5.5. Emission trading and excise tax

Emission trading and the excise tax operate on like principles, thus these two instruments can substitute each other. Table 25 reviews those modelling results at which the 20-20-20 targets are met. As we shift toward a lower excise tax (and lower number of credits) carbon-dioxide emissions rise, just like the price of electricity. However, applying a moderate excise tax rate we arrive at lower electricity prices compared to the case with an emission trading system only.

Table 25 Key modelling results along different excise tax rates and emission credit levels that meet the 20-20-20 targets

Excise tax, €/GJ	2.36	1.26	0.32	0.00
Amount of allocated CO2 quota, mt	3 000	1 700	1 600	1 560
Weighted average European wholesale price, €/MWh	63.2	62.0	61.6	61.9
Weighted average European retail price, €/MWh	63.2	62.0	61.6	61.9
RES-E production, TWh	1 043	1 043	1 043	1 044
RES-E share, %	34.0%	34.0%	34.0%	34.1%
Electricity consumption, TWh	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 769	1 716	1 631	1 603

IX.3.5.6. Emission trading and support to energy efficiency investments

In case of energy efficiency investments implemented at a high discount rate (LPI) the 20-20-20 targets can be kept even if carbon-dioxide allowance allocations are relatively generous. Modelling results show that if 1.87 billion tons of carbon-dioxide credits are allocated as an annual average figure for the period 2013-2020, all three targets become achievable. The resulting wholesale price in this case is 42.8 €/MWh. Renewable penetration, nevertheless, does not change compared to the case without regulatory instruments, therefore the renewable target can be reached only because of the lower consumption.

IX.3.6. The simultaneous application of three regulatory instruments

IX.3.6.1. The simultaneous application of renewable support, the excise tax and energy efficiency investment

In case all energy efficiency investments that are profitable at a high discount rate are implemented (LPI), moreover, we apply a 1 €/GJ excise tax on fossil fuel use, and support wind and solar power plants with feed-in tariffs of 80 and 136 €/MWh, then all three targets become attainable. Under these conditions the wholesale price is at around 43.5 €/MWh, while the retail price is about 48.4 €/MWh. Renewable production grows by about 15% compared to the case without regulation, therefore the share of renewables exceeds 40%. Carbon-dioxide emissions are equal to about 1650 million tons, that is, over 250 million tons less than the target. We list the most important modelling results in Table 26, furthermore, we describe the modelling results in case one of the three instruments is scrapped. We can see that in case three instruments are used the results are much less volatile: renewable generation also grows in absolute terms, but not as much as if only one instrument was utilised in addition to renewable support. Likewise, electricity prices are not too excessive either.

Table 26 Key modelling results in case two or three regulatory instruments (renewable support; excise tax and support to energy efficiency investments) are applied satisfying the 20-20-20 targets

	Three instruments	Two instruments			
FIT for wind power plants, €/MWh	80	90	112	100	No regulation
FIT for PV plants, €/MWh	136	153	191	170	No regulation
Excise tax, €/GJ	1.0	No	1.0	2.6	0.1
Support on energy efficiency investments	LPI	LPI	No regulation	No regulation	LPI
Weighted average European wholesale price, €/MWh	43.5	31.5	24.8	44.6	43.0
Weighted average European retail price, €/MWh	48.4	49.2	80.5	69.4	43.0
RES-E production, TWh	1 198	1 475	2 061	1 696	1 042
RES-E share, %	40.3%	48.1%	67.2%	55.3%	34.0%
Electricity consumption, TWh	2 972	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 651	1 619	1 208	1 403	1 866

IX.3.6.2. Common application of a carbon-dioxide trading system, an excise tax and energy efficiency investments

If we cap the number of allocated emission credits at 1.8 billion tons of carbon-dioxide on average during 2013-2020, impose a 0.5 €/GJ excise tax on the fuel use of fossil fuel based power plants, and the energy efficiency investments that are profitable at a high discount rate are implemented, then all three EU targets can be attained. In this case the penetration of renewables does not increase in absolute terms, but as a result of declining electricity consumption the share of renewables grows. Both the retail and the wholesale price stays at around 46 €/MWh. If energy efficiency investments were not implemented, then the targets would be possible to meet only at higher electricity prices (Table 27).

Table 27 Key modelling results in case two or three regulatory instruments (emission trading; excise tax and support to energy efficiency investments) are applied satisfying the 20-20-20 targets

	Three instruments	Two instruments			
Amount of allocated CO2 quota, mt	1800	No regulation	1868	1700	1600
Excise tax, €/GJ	0.5	0.1	No regulation	1.3	0.3
Support to energy efficiency investments	LPI	LPI	LPI	No regulation	No regulation
Weighted average European wholesale price, €/MWh	46.1	43.0	42.8	62.0	61.6
Weighted average European retail price, €/MWh	46.1	43.0	42.8	62.0	61.6
RES-E production, TWh	1 042	1 042	1 042	1 043	1 043
RES-E share, %	35.2%	34.0%	34.0%	34.0%	34.0%
Electricity consumption, TWh	2 961	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 768	1 866	1 861	1 716	1 631

IX.3.6.3. Common application of a carbon-dioxide trading system, renewable support and energy efficiency investments

If we replace the excise tax with renewable support, then the penetration of renewables increases, as a result of which retail prices slightly rise, but the wholesale price declines. Under these conditions the emission trading system becomes ineffective, that is, the price of carbon-dioxide credits drops to almost zero (Table 28).

Table 28 Key modelling results in case two or three regulatory instruments (emission trading; renewable support and support to energy efficiency investments) are applied satisfying the 20-20-20 targets

	Three instruments	Two instruments		
FIT for wind power plants, €/MWh	90	90	No regulation	114
FIT for PV plants, €/MWh	153	153		194
Amount of allocated CO2 quota, mt	1 800	No regulation	1 868	1 800
Support of energy efficiency investments	LPI	LPI	LPI	No regulation
Weighted average European wholesale price, €/MWh	31.3	31.5	42.8	19.5
Weighted average European retail price, €/MWh	49.1	49.2	42.8	85.0
RES-E production, TWh	1 479	1 475	1 042	2 119
RES-E share, %	48.3%	48.1%	34.0%	69.1%
Electricity consumption, TWh	3 061	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 614	1 619	1 861	1 200

IX.3.6.4. Common application of a carbon-dioxide trading system, renewable support and excise tax

If we apply an excise tax of 2 €/GJ, renewable support of 103, and 175 €/MWh, and introduce an emission trading system with a cap of 1.5 billion tons, then the retail price exceeds 70 €/MWh, while the wholesale price falls below 40 €/MWh. As a result of the renewable support scheme the ratio of renewables approaches 60% (Table 29).

Table 29 Key modelling results in case two or three regulatory instruments (emission trading; renewable support and excise tax) are applied satisfying the 20-20-20 targets

	Three instruments	Two instruments		
FIT for wind power plants, €/MWh	103	109	No regulation	104
FIT for PV plants, €/MWh	175	186		177
Amount of allocated CO2 quota, mt	1 500	No regulation	1 700	1 300
Excise tax, €/GJ	2.0	2.0	1.3	No regulation
Weighted average European wholesale price, €/MWh	38.4	31.7	62.0	36.1
Weighted average European retail price, €/MWh	70.3	75.1	62.0	70.7
RES-E production, TWh	1 795	1 976	1 043	1 827
RES-E share, %	58.5%	0.6	0.3	0.6
Electricity consumption, TWh	3 066	3 066	3 066	3 066
Carbon-dioxide emission, mt	1 351	1 223	1 716	1 294

IX.3.7. The simultaneous application of all four regulatory instruments

Finally we examined a scenario involving all four regulatory instruments, with 80 and 136 €/MWh of wind and solar feed-in tariff, an excise tax of 0.5 €/GJ, emission trading with 1.8 billion tons of allocated credits, and assuming that all energy efficiency investments that are profitable at a high discount rate are implemented (LPI). Under these conditions the weighted average European wholesale price turns out to be 40.3 €/MWh, while the retail price is 45.5 €/MWh. Thanks to the renewable support more renewable capacities are created than under the reference case. Due to lower electricity consumption and as a result of renewable support the share of renewables increases to 40% (Table 30).

Table 30 Key modelling results in case three or four regulatory instruments are applied satisfying the 20-20-20 targets

	Four instruments	Three instruments			
Support on energy efficiency investments	LPI	No regulation	LPI	LPI	LPI
FIT for wind power plants, €/MWh	80	103	90	80	No regulation
FIT for PV plants, €/MWh	136	175	153	136	
Amount of allocated CO2 quota, mt	1800	1500	1800	No regulation	1800
Excise tax, €/GJ	0.5	2	No regulation	1	0.5
Weighted average European wholesale price, €/MWh	40.3	38.4	31.3	43.5	46.1
Weighted average European retail price, €/MWh	45.5	70.3	49.1	48.4	46.1
RES-E production, TWh	1 204	1 795	1 479	1 198	1 042
RES-E share, %	40.0%	58.5%	48.3%	40.3%	35.2%
Electricity consumption, TWh	3 014	3 066	3 061	2 972	2 961
Carbon-dioxide emission, mt	1 686	1 351	1 614	1 651	1 768

The difference between the application of four and only three regulatory instruments is worth examining. If we omit support to energy efficiency investments then a higher excise tax, a tighter emission cap and increased renewable support is needed to meet all three EU targets. As a result, additional renewable capacities are created, approaching a renewable ratio of 60%, while carbon-dioxide emissions also decline. The retail price, however, exceeds 70 €/MWh, while the wholesale price is lower than under the scenario with four instruments.

Without the application of an excise tax renewable support needs to be boosted in order to be able to reach the targets. This results in increased renewable production, which reduces the wholesale price, while at the same time increases the retail price. In the absence of a carbon-dioxide trading system the rate of the excise tax has to be increased, leading to very similar results as the application of the four regulatory instruments.

Finally, in the absence of a renewable support regime similar levels of the excise tax, the carbon-dioxide cap and the support to energy efficiency investments make it possible to reach the targets. In this case, however, there are no newly created renewable capacities compared to the reference case without regulation. Both the wholesale and the retail prices exceed the prices under the scenarios with four regulatory instruments.

IX.3.8. Sensitivity analysis

Similarly to the analysis of research question RQ_1 we carry out a partial sensitivity analysis as part of testing hypothesis H_2 as well, in order to investigate the robustness of the results. Again, we inspect three factors.

- The value of long term price elasticity: As a base case we assumed the long term price elasticity to be 0.25. During the sensitivity analysis we test a value of 0.1.
- The price of coal: For the partial sensitivity analysis we assume that the price of both coal and lignite is 50% more expensive than under the baseline.

- The price of natural gas: In this case we assumed that the price of natural gas is 50% cheaper than in the base case.

Next we undertake the three partial sensitivity analyses. For each variable we compare only the results of the cases without regulation and with a single piece of regulation. In other words, we do not publish the cases in which two or more regulatory instruments are applied together. This is satisfactory since the results of the sensitivity analysis can already be properly analysed with the application of just one regulatory instrument.

IX.3.8.1. The value of the elasticity of price

When we apply a price elasticity of 0.1 instead of the 0.25 value of the baseline case, then under the reference case without any regulatory instrument the results do not change - as we expected. In contrast, when emission trading is introduced, the cap must be much tighter in order for the 20-20-20 targets to be attainable. In the reference case the targets can be met with 1560 million tons of carbon-dioxide credits, this figure drops to 1.2 billion tons in case the lower price elasticity is used. As a result the price of carbon-dioxide increases, contributing to higher electricity prices. It is necessary to apply a tighter cap because consumption responds to the price increase to a lower extent, that is, a steeper price increase is required in order for consumption to notably decline.

Applying only a renewable support scheme the targets are not achievable within a reasonable support range. Let's inspect what happens when only a renewable support system is introduced while the long term price elasticity is so low. As already observed for the reference case, higher support reduces the wholesale price, while the retail price rises. In the base case the retail price has a more critical role than the wholesale price as the value of the long run elasticity of price is higher than the short run elasticity. During the partial sensitivity analysis, however, the value of these two coefficients are the same, therefore both prices (retail and wholesale) are equally important. Therefore, if renewable support increases, then the wholesale price declines, but the retail price rises. While the two price changes are not completely symmetrical, a slightly higher change of the retail price cannot trigger a large enough decline in consumption to make the energy efficiency goal within the 20-20-20 targets achievable. Obviously, there must be a high enough support level at which the wholesale price doesn't decline, while the retail price continues to rise, thus reducing consumption. Essentially, the target can be met with this instrument, but the level of support is unreasonably high, indeed so high that renewable production does not any more increase, only a windfall profit is provided to renewable producers.

In order for the 20-20-20 targets to be achievable purely through the introduction of the excise tax, a tax rate of 4.0 €/GJ is needed, higher than in the baseline. This works exactly like the tighter cap under emission trading: the production costs of fossil fuel based power plants increase, which in turn boosts the price of electricity, reducing consumption. Since, however, price elasticity is lower, a large price increase is needed, that is, a higher tax rate has to be applied.

Finally, in case energy efficiency investments are supported, the value of long run price elasticity does not influence the results.

IX.3.8.2. The price of natural gas

If none of the regulatory instruments are introduced, then in case of a lower natural gas price the price of electricity will also be lower. Since natural gas fired power plants will be more competitive, the production of coal based power plants declines, their lost production being replaced by natural gas fired plants. As a result, carbon-dioxide emissions also decrease.

If only an emission trading system is applied, then the cap has to be much tighter. In this case the price of carbon-dioxide credits almost doubles compared to the baseline. Despite this, the price of electricity becomes lower than in the base case. This is explained by the lower natural gas price.

Much lower renewable support is needed to reach the targets if we assume a lower price for natural gas. The lower support restrains the penetration of renewables (compared to the baseline), which, however, results in a lower increase of the retail price.

If only an excise tax is applied, then a higher tax rate is necessary to attain the goals, but its level does not reach 3 €/GJ. The resulting price, nevertheless, will still be lower than under the baseline, and carbon-dioxide emission also decline as coal based power plants are eclipsed.

Finally, in case of energy efficiency investments the renewable target cannot be reached even if the full technological potential is considered. Based on the above we can accept the hypothesis, since only through energy efficiency investments the 20-20-20 targets cannot be met.

IX.3.8.3. The price of coal

In the case without regulation the higher coal price results in higher electricity prices, which reduces the consumption of electricity, while the declining production of coal fired power plants cuts carbon-dioxide emissions.

If only emission trading is introduced then a tighter cap needs to be applied in order to be able to reach all three targets. This is because since in case of the 2013 and 2014 simulations we assumed the higher coal price, in order for the price elasticity driven decrease of consumption to be equal to the target, the price of electricity has to increase even more, since in case of price elasticity it is the percentage change that matters and not the absolute level of change.

In case of a higher coal price using only a renewable support scheme a slightly higher support level is required to reach the targets. The higher renewable support augments the penetration of renewables, as a result of which the retail price also increases, while carbon-dioxide emissions decline.

Using only an excise tax, compared to the reference case the excise tax rate on the fossil fuel use of power plants needs to be raised by about 0.5 €/GJ. As a result of the higher tax rate the price of electricity increases, while the ratio of renewables does not change.

Finally, applying only energy efficiency investment support has a moderate impact: due to the higher price of coal the wholesale price will also be higher compared to the base case.

IX.3.8.4. Summary of the partial sensitivity analysis

We have introduced the results of the three partial sensitivity analyses, and summarised them in Table 31. To conclude, the inspected hypothesis is significantly affected only by the gas price: if a low gas price is assumed, then the renewable target within the 20-20-20 bundle cannot be reached only through energy efficiency investment support. In this case essentially we accept the full statement of the hypothesis. While the results notably changed in some of the other cases, these did not influence the answer to the hypothesis.

Table 31 Summary of the results of the sensitivity analysis

		No instruments applied	Emission trading	RES-E support	Excise tax	Suport on energy efficiency investments
Reference case		-	1560 Mt	114 €/MWh, and 193 €/MWh	2.4 €/GJ	Between LPI and HPI
Price elasticity	Level of regulation	-	1200 Mt	In realistic FIT price can not meet the energy efficiency target	4.0 €/GJ	Between LPI and HPI
	Note	Same result	Quota price increased by two times -> higher equilibrium price -> Both RES-E production, and RES-E share increase; same consumption		Higher price; natural gas-fired power production increase, while the production of coal-based power plants decrease; same consumption and RES-E share	Nearly the same result
Natural gas price	Level of regulation	-	1250 Mt	97 €/MWh, and 164 €/MWh	2,8 €/GJ	Even in technological potential RES-E target can not meet
	Note	Lower price -> higher consumption; significant smaller coal-based power generation -> smaller CO2 emission	Significant higher - 50 €/t - CO2 quota price; Despite this the equilibrium price is lower	Lower FIT prices -> lower RES-E production > lower retail price; higher CO2 emission	Lower the price; same consumption; lower CO2 emission	
Coal price	Level of regulation	-	1260 Mt	120 €/MWh, and 204 €/MWh	2,9 €/GJ	Between LPI and HPI
	Note	Higher price -> lower consumption; significant smaller coal-based power generation; smaller CO2 emission	Higher quota price -> higher price; same RES-E share and production	Higher FIT prices -> higher RES-E production -> higher retail price; lower CO2 emission	Higher price; samr RES-E production and share	Higher wholesale price -> lower consumption -> lower CO2 emission

IX.3.9. Summary of the H_2 hypothesis

Previously we inspected if the H_2 hypothesis can be accepted or rejected. This is how the H_2 hypothesis was defined:

Any combination of the four regulatory instruments (excise tax, renewable support, emission trading, support to energy efficiency investments) that we inspect is sufficient to reach the 20-20-20 target set by the EU for 2020, except when the only available instrument is the support to energy efficiency investments.

Model simulations have shown that the 20-20-20 targets of the EU can be reached for all regulatory instrument combinations. Thus, we reject the H_2 hypothesis, since the targets can also be attained with energy efficiency investment support on its own.

The application of quantitative modelling offered a number of important lessons:

- One of the most important conclusions is that the higher the number of utilised regulatory instruments, the less extreme will the values of the most important variables be. Even though the three targets set by the EU can be accomplished through any combination, the application of 3-4 regulatory instruments is advisable, as the prices, the electricity-mix or the carbon-dioxide emissions will change less dramatically compared to the case without any regulation. If, for example, only renewable support is applied then the wholesale price of electricity can be especially low, which can then transform the operation of the European electricity market, while the retail price paid by consumers may get close to 100 €/MWh.
- The renewable target is frequently reached because it has been set as a percentage value and not as an absolute figure. If renewable support is not utilised then the volume of renewable energy does not change in a meaningful way compared to the case without regulations. Importantly, however, during the analysis when we looked at the impact of a given regulatory instrument, we only considered a range within which the targets are already accomplished. Thus we did not inspect the impact of a very tight emission cap, or a high level of excise tax on renewable resources.
- The excise tax and emission trading are almost perfect substitutes of each other, therefore for administrative reasons it is advisable to use only one of them. There is not any significant difference between the two instruments, since they both target fuel use, that is, they reward the improvement of the efficiency factor (lower tax payment per unit of energy output). There is only one slight difference: carbon-dioxide trading burdens coal fired plants more than the excise tax.

IX.4. ANALYSIS OF RESEARCH QUESTIONS RQ_2

RQ_2: Which regulatory instrument combinations that satisfy the 20-20-20 targets of the European Union are favourable from the perspective of Hungary.

Previously we looked at the regulatory instrument combinations that are capable of reaching the 20-20-20 targets set by the EU. With research question RQ_2 we seek to calculate the electricity prices and electricity mixes resulting from these combinations in Hungary and to identify which one of these are favourable for our country.

When analysing the hitherto outlined research question, we cannot create indicators that would clearly determine which regulatory instrument combination is the most advantageous.

Thus, during the analysis of RQ_2 we start from the principles outlined in the Energy Strategy (2012) adopted by the Parliament. The Energy Strategy defines the following main principles, in no particular order.

- Reducing energy dependency, which, in the case of the electricity sector is equivalent to a lower net import ratio.
- Increasing ratio of renewables: the National Renewable Energy Action Plan (NREAP) of Hungary determined the ratio of renewable sources within the electricity sector. The ratio of renewable generation compared to total electricity consumption has to reach 10.9% by 2020. The Energy Strategy designated this figure as the target to be attained.
- Affordable electricity prices, that is, the lowest possible retail electricity price.
- A diversified power plant portfolio, consisting of nuclear energy as well as renewable energy, along with coal and natural gas based electricity production.

These are the factors based on which it becomes possible to evaluate which instrument combination may be the most advantageous to Hungary, that is, which combination suits the Energy Strategy most adequately. In Figure 54 and Figure 55 we indicated the Hungarian electricity mix for the 15 different regulatory instrument combinations, and the corresponding retail and wholesale prices of the domestic market.

Figure 54 The electricity mix of Hungary under those regulatory instrument combinations that satisfy the all-European 20-20-20 targets

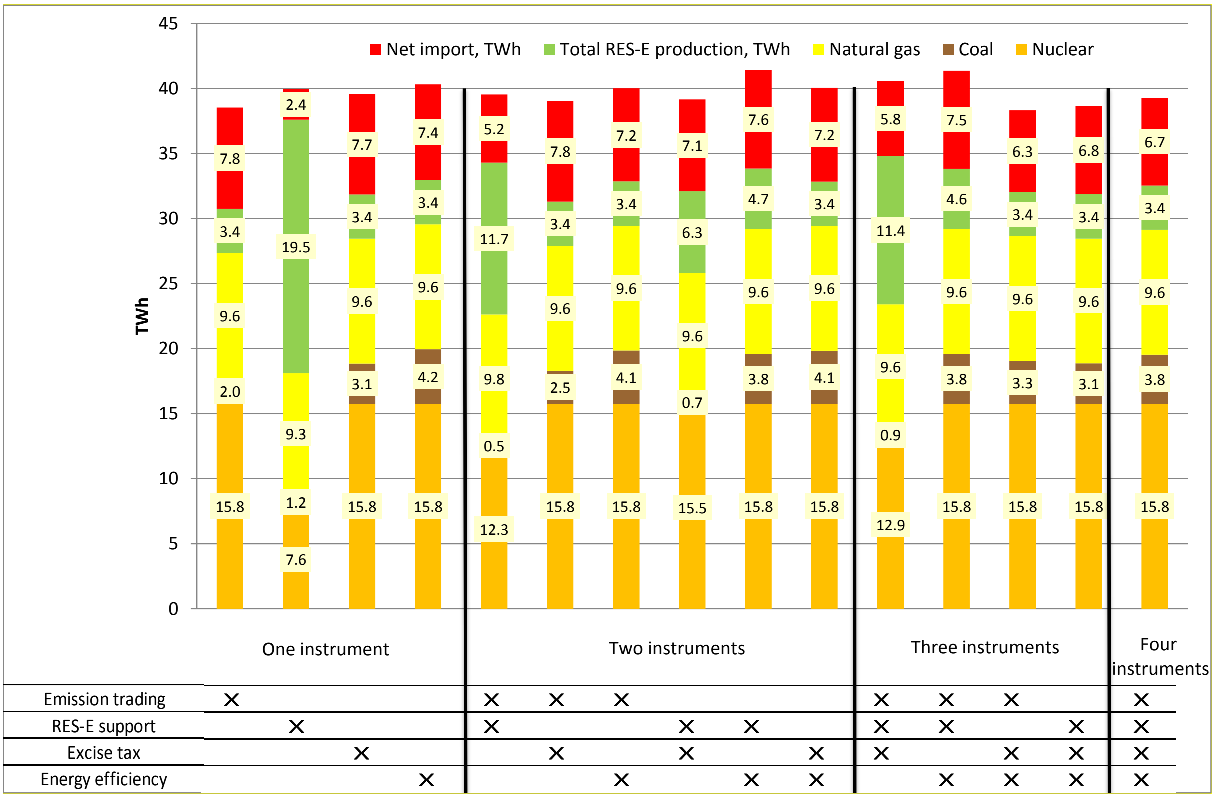
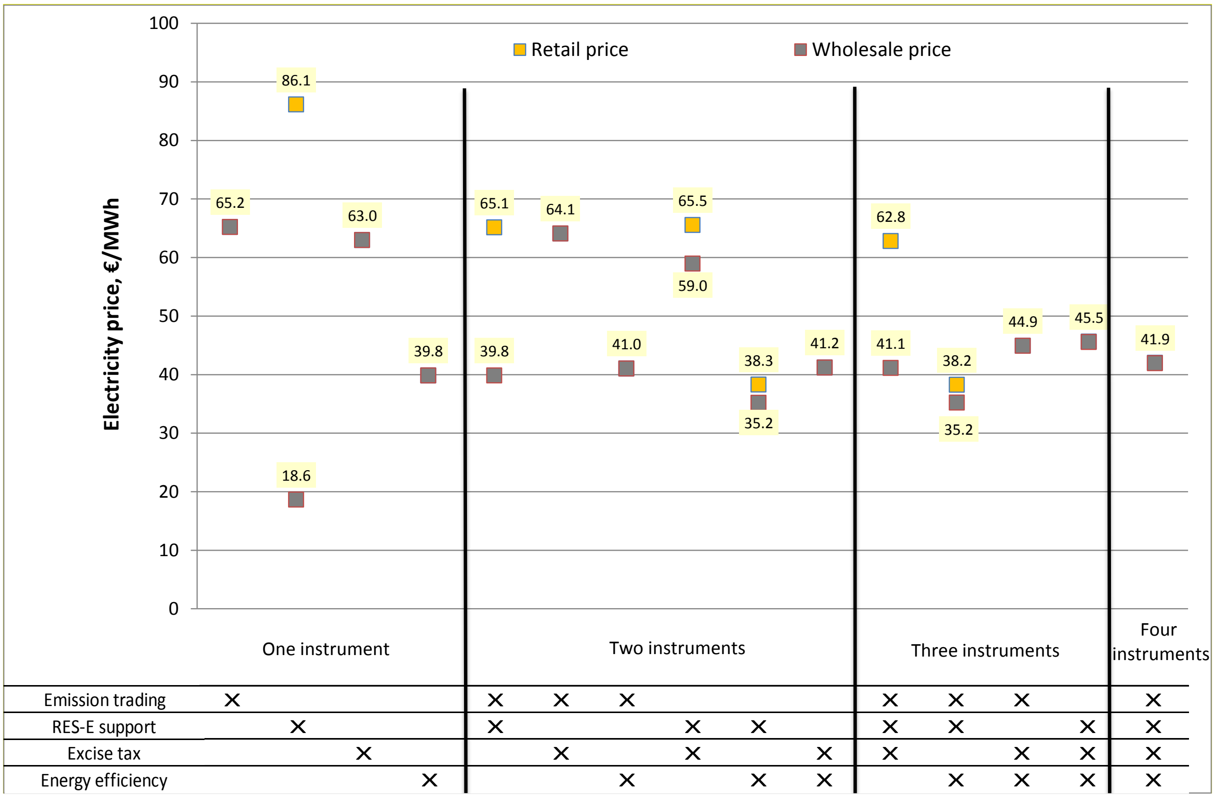


Figure 55 Electricity prices in Hungary under those regulatory instrument combinations that satisfy the all-European 20-20-20 targets



Based on the data of the figures we examined the extent to which the given instrument combination is in harmony with the principles contained in the Energy Strategy. In addition to the ratio of renewable energy use the Energy Strategy does not spell out specific figures, thus for the rest of the principles we applied the following algorithm to decide if the results suit the Energy Strategy. We calculated the simple arithmetic average of the results of the 15 regulatory instruments, to compare the given instrument combination. If for the given instrument combination the value of this factor exceeds the average then in case of coal fired and nuclear production the principles of the Energy Strategy are met, while for electricity consumption, retail price and net import they are not.

In Table 32 we used green colour to indicate the cases that are in harmony with the Energy Strategy, and red to indicate those that aren't. As shown, there are not any instrument combinations that would suit the Energy Strategy for all six result variables. The instrument combination that satisfies the highest number of conditions is the one including emission trading, excise tax as well as support to energy efficiency investments. We should note that in this case additional renewable capacities are not built in Hungary either compared to the reference case without regulation. There are altogether four cases in which four out of the six result variables suit the principles of the Energy Strategy. These include the case in which all four regulatory instruments are used with the exception of emission trading, and also the case in which renewable support is supplemented only with energy efficiency investment support or emission trading. For the last two cases the renewable ratio set by the NREAP (and the Energy Strategy) are also met.

Table 32 Summary of the impacts on specific factors under each of the regulatory instrument combinations

	One instrument				Two instruments						Three instruments				Four instruments
Emission trading	X				X	X	X				X	X	X		X
RES-E support		X			X			X	X		X	X		X	X
Excise tax			X			X		X		X	X		X	X	X
Energy efficiency investments				X			X		X	X		X	X	X	X
RES-E share	low	high	low	low	high	low	low	high	high	low	high	high	low	low	low
Electricity price	high	high	high	low	high	high	low	high	low	low	high	low	low	low	low
Coal-based power production	low	low	high	high	low	low	high	low	high	high	low	high	high	high	high
Electricity consumption	low	high	low	high	low	low	high	low	high	high	high	high	low	low	low
Net import	high	low	high	high	low	high	high	high	high	high	low	high	low	high	high
Nuclear based power generation	high	high	low	high	high	low	high	high	high	high	high	low	high	high	high

Similarly to hypothesis H_2, we carried out the sensitivity analysis of the three most important factors for this case as well. For the three partial sensitivity analyses and the reference scenario the Table 33 reviews how many of the six most important factor impacts are in harmony with the Energy Strategy. We can see that from all the scenarios (base case and three sensitivity analyses) the results are best in line with the principles of the Energy Strategy when three or four regulatory instruments are applied. There is one exception from this observation, when we apply all regulatory instruments together except for the support to energy efficiency investments. Therefore we can claim that the sensitivity analysis does not modify our conclusions, thus our results can be viewed as robust.

Table 33 The number of factors that are in harmony with the Energy Strategy out of the six most important factors in case of given regulatory instrument combinations and various sensitivity analyses

	One instrument				Two instruments						Three instruments				Four instruments
Emission trading	X				X	X	X				X	X	X		X
RES-E support		X			X			X	X		X	X		X	X
Excise tax			X			X		X		X	X		X	X	X
Energy efficiency investments				X			X		X	X		X	X	X	X
Reference case	2	3	2	3	4	1	3	3	4	3	3	3	5	4	4
Low price elasticity	3	3	3	3	2	3	4	3	3	5	3	6	5	3	6
Low gas price	3	3	2	3	3	2	3	3	3	3	3	3	3	3	4
High coal price	2	2	3	3	3	2	3	3	4	3	2	4	5	4	4

X. SUMMARY OF THE FINDINGS AND RESULTS OF THE DISSERTATION

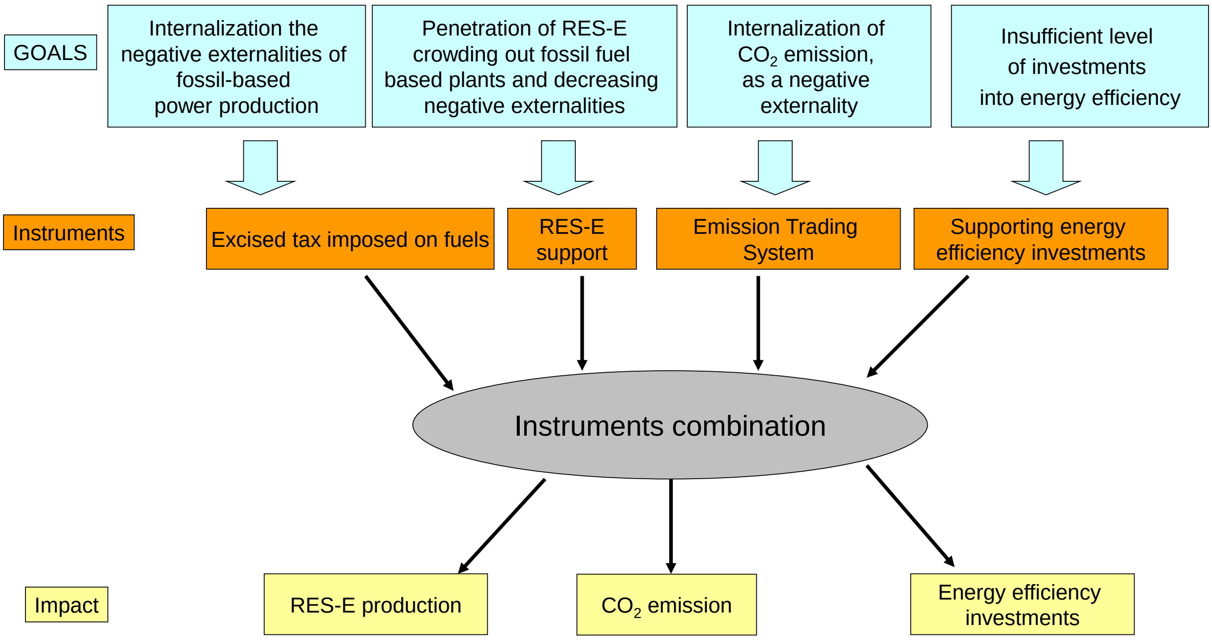
There are a number of market failures within the electricity sector, of which we introduced two in detail in our dissertation: environmental externalities and market failures related to energy efficiency investments. A number of regulatory instruments are available to manage these market failures. These include the excise tax imposed on more polluting technologies, support to cleaner technologies, the introduction of emission trading or some support to investments into energy efficiency. These instruments, nevertheless, deliver their impacts through similar mechanisms, thus they directly or indirectly influence each other through the price of electricity. The main theme of the dissertation is the analysis of this interaction.

We examined the interaction of regulatory instruments in four steps:

- Theoretical, microeconomic approach
- Literature review
- Analysis of empirical, European data
- Modelling of the European electricity sector

During the examination of the **theoretical, microeconomic** approach we analysed the impact of all the instrument combinations created from the four regulatory instruments on the three most important factors, which reflect the degree of the market failures. These three most important factors are the volume of renewable electricity production, carbon-dioxide emissions, and the level of energy efficiency investments.

Figure 56 The targets, the applied instruments and the factors through which the targets can be measured



One of the conclusions of the analysis is that in seven of the 15 combinations the applied instruments deliver a clearly positive impact on the previously listed factors, thus the level of both market failures declines. In seven other cases a definite stand cannot be taken with regard to the direction of impact on the three main factors. Finally, in one case, when only energy efficiency investments are applied, the impact on the penetration of renewable energy sources is negative.

For the **literature review** the inspected literature has been split into two. In one group the interaction of regulatory instruments has been inspected from a theoretical perspective, while in the other group the tool of modelling is used to answer the analysed question. Part of the model-based literature makes use of general equilibrium models, while the other part employs sectoral models assuming perfect competition. We can identify only a few pieces of literature that use oligopolistic models to analyse the interaction of regulatory instruments. The literature review has shown that most literature typically analyse the interaction of the green certificate and the emission trading system. During my research I have not seen any articles that would have used modelling to examine the interaction of at least three or four regulatory instruments

During the **empirical analysis** we looked at two questions. In the first instance we utilised statistical methods to prove that there is a relation between the Energy Efficiency Directive proposal and the price of carbon-dioxide credits. When the Draft Directive of the European Commission was published, the price of carbon-dioxide credits notably fell. This rhymes to what we expected from a theoretical perspective. Furthermore, we also inspected the relations between the European carbon-dioxide credits and the price of tradable green certificates. A relatively liquid, European tradable green certificate market without an effective price cap is necessary to analyse this question. As we pointed out in the dissertation, only the Swedish market seemed appropriate. Based on the analysis of monthly data, however, we were neither able to prove, nor reject the hypothesis that there is a negative relation between the tradable green certificate and the price of the EUA.

Finally, we also examine the interaction of regulatory instruments with **modelling**. The European Electricity Market Model simulates the wholesale electricity markets of 36 European countries assuming perfectly competitive market conditions. Having implemented a number of upgrades on the Electricity Market Model we gained an opportunity to explore the interactions in more depth. In the dissertation we identify seven regulatory instrument combinations for which – from a theoretical point of view - we could not unambiguously identify the impacts on the three factors in the focus of our analysis. We also use modelling to answer this question.

During our research we focused on the instrument combinations through which the 20-20-20 targets of the EU can be achieved, and the advantages/disadvantages of simultaneously using more regulatory instruments. One of the most important results is that the higher the number of simultaneously applied regulatory instruments, the less extreme will the values of the most important variables be. Although the three EU targets can be achieved under any combination, it is still advisable to use 3 or 4 regulatory instruments. As a result the prices, the electricity mix or the carbon-dioxide emission change less dramatically compared to a case without any regulation. If, for example, we only use renewable support, then the wholesale price of electricity may be quite low, which may rearrange the operation of the European electricity market. In addition, the retail prices paid by consumers may increase above 100 €/MWh.

We pointed out that the renewable target of the EU is often achieved because it has been set as a percentage and not as an absolute value. If a renewable support instrument is not applied then the quantity of generated renewable energy does not change significantly compared to the case without regulation. Nevertheless, it should be noted that during the analysis we inspected the impact of the level of given regulatory instruments only in a range within which the targets are already met.

We also pointed out that the excise tax and emission trading are almost perfect substitutes of each other, thus due to administrative reasons it is advisable to use only one of them. There is not really a notable difference between the two instruments, since they both apply to fuel use, that is, they reward the improvement of efficiency (resulting in less tax per unit of energy output). As a minor difference, carbon-dioxide trading burdens coal fired power plants more than the excise tax.

Lastly, we employed modelling to determine which one of the regulatory instrument combinations that satisfy the all-European 20-20-20 targets is the best for Hungary. During the analysis of the research question we kept the principles contained in the National Energy Strategy in mind. We showed that there is not any instrument combination at which all the six examined factors (renewable ratio; price of electricity; coal based generation; electricity consumption; net import and nuclear production) would change in line with the Energy Strategy. Most criteria are satisfied by the instrument mix under which emission trading, an excise tax and energy efficiency investment support are applied together. We should note that in this case additional renewable capacities are not created compared to the reference case without regulation in Hungary either. There are altogether four cases in which four out of the six result variables comply with the principles of the Energy Strategy.

In summary, the following recommendations can be made as a result of the dissertation:

- It is advisable to use three regulatory instruments to reach the European targets, as a result of which the market failures of the electricity market can be reduced. The recommended regulatory instruments include renewable support and energy efficiency investment support, supplemented with either emission trading or an excise tax.

Within the dissertation we also provided quantitative evidence that these last two regulatory instruments are practically substitutes of each other.

- In case of renewables it is more reasonable to set absolute targets, since otherwise energy efficiency or energy saving measures may also lead to the fulfilment of the targets without creating new renewable capacities.
- During the analyses we only inspect the electricity sector. Although sectoral models have a lot of advantages, but further investigations are needed with economic model covered the whole energy sector.

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XII. ANNEX A: THE TECHNICAL SPECIFICATION OF THE EEMM AND A SUMMARY OF ITS INPUT PARAMETERS

XII.1.1. The technical specification of the model[17]

As already mentioned, the EEMM simulates the hourly electricity market, and these model runs are independent of each other, thus indirectly assuming that the ramp-up costs of power plants are zero. The model assumes a perfectly competitive market, both for production and export/import trades. The equilibrium state is determined by maximising the welfare of the complete modelled region. The welfare is calculated with the following formula:

$$W = \sum_{m=1}^{M} TCS_m - TC$$

Marks: countries: m=1,..,M; consumption: Q; power plant unit: p; power plant production: q; variable cost: c; export-import flow: t; power plant capacity constraint: C; capacity constraint at the borders: N; W: complete welfare; TCS: Total consumer surplus; TC: Cost of electricity production, D: demand; A and B: constants determining the demand curve

Welfare, therefore, is composed of two parts. First, the area below the demand curve, equal to the gross consumer surplus. In case of the demand curve we assumed a linear negative slope. The other item that determines the welfare is the sum of variable type costs needed for the production of electricity. As formulae, we can express these two items as follows:

$$TCS_m = \int_0^{Q_m} D_m^{-1}(Q)dQ = A_m Q_m - \frac{B_m}{2} \times Q_m^2$$

$$TC = \sum_{p=1}^{P} c_p q_p$$

Maximising welfare takes place along three main criteria. First, the production of a given power plant unit cannot exceed its capacity, and it has to be equal to or higher than zero. Second, cross-border transfers cannot exceed the capacity constraints of the given border section. Finally, electricity consumption in a country has to be equal to the sum of the total production of domestic power plants and the balance of export-import transfers. In case of the last condition the value of δ in the second part is 1 when country A exports to country B, and –1 in the opposite case.

$$0 \le q_p \le C_p$$

$$\overleftarrow{N}_i \le t_i \le \overrightarrow{N}_i$$

[17] The description of the model specification is based on Kiss (2008).

$$Q_m = \sum_p q_p + \sum_i \delta_{i,m} \times t_i$$

Equilibrium takes place when total welfare is maximised, expressed by the following formula.

$$W = \sum_{m=1}^{M} \left[A_m \times \left(\sum_p q_p + \sum_i \delta_{i,m} \times t_i \right) - \frac{B_m}{2} \times \left(\sum_p q_p + \sum_i \delta_{i,m} \times t_i \right)^2 \right] - \sum_{p=1}^{P} c_p q_p \xrightarrow{q_p, t_i} \max$$

XII.2. ASSUMPTIONS ON THE MAIN INPUT DATA

XII.2.1. Installed capacities

One of the most important parameters of the supply side is the installed capacity of the power plants. The EEMM works with power plants on the unit level, and there are close to 5000 power plant units in the model. Importantly, renewable capacities are typically aggregated by countries and technologies, since we assume zero marginal cost for renewables. For individual power plants the following essential information is contained by the model: installed capacity, year of construction, technology and main fuel type. Table 34 provides a summary of the installed capacities of power plants in operation in 2012, broken down by countries and technologies.

Table 34 Installed capacity of power plants in operation in 2012 by countries and technologies, MW

AL	0	0	0	1 451	0	0	0	135	0	**1 586**
AT	1 483	5 394	0	13 653	1 378	0	0	278	0	**22 186**
BA	1 765	0	0	2 146	0	0	0	0	0	**3 911**
BE	1 490	8 568	5 934	1 259	1 375	1 500	813	280	0	**21 219**
BG	4 737	336	2 000	3 705	684	133	0	0	0	**11 595**
CH	0	505	3 265	13 680	50	71	363	73	0	**18 007**
CZ	10 561	968	3 912	2 158	0	2 000	0	20	0	**19 619**
DE	52 375	28 712	12 696	12 699	31 308	24 700	6 384	2 635	0	**171 508**
DK_E	2 070	1 520	0	0	1 087	0	126	664	0	**5 467**
DK_W	3 087	1 704	0	2	3 075	6	403	0	0	**8 276**
EE	1 917	190	0	4	269	0	75	0	0	**2 455**
ES	12 159	29 570	7 641	22 541	22 796	4 350	190	11 222	0	**110 468**
FI	4 405	2 600	2 696	2 525	288	0	3 377	513	0	**16 404**
FR	7 942	9 803	63 130	29 399	7 564	2 500	1 223	10 447	0	**132 008**
GB	28 474	32 851	10 170	7 217	8 445	0	1 051	5 951	0	**94 159**
GR	5 115	6 636	0	3 930	1 749	550	0	633	0	**18 613**
HR	330	999	398	2 167	180	0	0	786	0	**4 860**
HU	1 124	4 703	2 000	44	329	0	149	0	0	**8 349**
IE	1 165	4 109	0	533	1 738	0	156	1 190	0	**8 891**
IT	11 008	57 108	0	21 739	8 144	11 537	517	8 696	695	**119 443**
LT	0	2 977	0	1 026	225	0	45	160	0	**4 433**
LU	0	489	0	1 133	45	29	9	0	0	**1 705**
LV	32	614	0	1 560	68	0	0	0	0	**2 274**
ME	210	0	0	676	0	0	0	0	0	**886**
MK	818	280	0	571	0	0	0	210	0	**1 879**
NI	520	1 688	0	4	0	0	13	180	0	**2 405**
NL	4 224	22 933	512	37	2 391	88	1 145	0	0	**31 330**
NO	0	1 330	0	30 163	703	0	0	0	0	**32 196**
PL	30 409	165	0	2 391	2 497	0	0	464	0	**35 926**
PT	1 884	4 481	0	5 812	4 525	130	0	2 214	0	**19 046**
RO	4 595	2 884	1 400	6 329	1 905	0	0	1 654	0	**18 767**
RS	5 231	0	0	2 905	0	0	0	0	0	**8 135**
SE	812	1 183	9 385	16 351	3 745	0	3 460	2 621	0	**37 556**
SI	915	143	348	1 101	0	0	0	291	0	**2 798**
SK	1 232	1 704	2 024	2 478	3	500	0	264	0	**8 205**
UA_W	2 500	0	0	27	0	0	0	0	0	**2 527**
Total	**204 588**	**237 146**	**127 511**	**213 415**	**106 566**	**48 094**	**19 498**	**51 580**	**695**	**1 009 092**

XII.2.2. New investments

In order to gain a realistic picture of the European electricity market until 2020, we need to make an estimate of the expected new investments as well. Since the model is not dynamic, that is, it is not the model that calculates if a new investment is profitable, the model takes this factor as an input. We estimate new future investments based on two publications: Platts Energy in East Europe and Platts Power in Europe.

XII.2.3. Power plant closure

When compiling the power plant database we also collected information on the expected closure date of the given power plant unit. When such data was not available, we assumed that nuclear power plants have a lifetime of 50 years, while coal and biomass fired plants operate for 55 years, combined cycle gas turbines for 30 years, and open cycle gas turbines for 40 years.

XII.2.4. Calculating the marginal cost of given power plant units

As it has already been shown, the marginal cost of given power plants depends on the applied technology, the fuel cost, other costs (carbon-dioxide cost, excise tax, and variable type operating costs). The applied technology and the year of construction determine the gross efficiency and self-consumption of the power plant unit in question.

XII.2.4.1. Determining capacity availability and rate of efficiency

Table 35 and Table 36 provide a summary of the rate of efficiency and self-consumption that we apply for different technologies depending on the year of construction.

Table 35 Gross rate of efficiency

Year of commissioning	Gross efficiency		
	Gas and oil steam turbine	Coal and biomass power plant	CCGT
1960	37%	35%	-
1970	39%	37%	-
1980	41%	39%	-
1990	43%	41%	50%
2000	45%	43%	55%
2010	47%	45%	57%
2020	49%	47%	59%

Source: KEMA (2005)

Table 36 Self consumption and the assumed availability of capacity

Type of power plant	Self-consumption	Availability
Gas and oil steam turbine	5%	90%
Coal and biomass power plant	13%	85%
CCGT	5%	90%
Gethermal and tide-and-wave power plant	-	85%

Source: Own calculation based on VEZESTÉK (2011)

When analysing the past data of nuclear power plants we found that their capacity utilisation also differs by the season. This is because typically each unit has to undergo a two week - one month long maintenance every year, during which they are out of production. Based on expert estimates we applied a marginal cost of 10 €/MWh for these plants, but this value has little practical relevance, since their short run marginal cost is so low that they rarely drive the price.

In Table 37 we summarised the average capacity availability of wind power plants, solar plants, hydro power plants and nuclear power plants.

Table 37 The availability of solar power plants, wind power plants, hydro power plants and nuclear power plants in given countries, %

	Yearly average utilization rate, %			
	Wind power plant	Solar power plant	Hydro power plant	Nuclear power plant
AL	16.0%	14.6%	30.1%	
AT	18.3%	11.4%	35.9%	
BA	16.0%	14.6%	30.1%	
BE	22.8%	10.3%	13.3%	89.5%
BG	25.1%	14.6%	14.3%	83.0%
CH	22.8%	16.0%	30.9%	91.2%
CZ	16.0%	10.7%	14.6%	81.3%
DE	27.4%	11.4%	25.2%	79.3%
DK_E	29.7%	10.3%	29.1%	
DK_W	29.7%	10.3%	29.1%	
EE	16.0%	10.3%	20.2%	
ES	20.5%	17.1%	19.3%	83.4%
FI	16.0%	9.7%	45.3%	92.9%
FR	27.4%	16.0%	25.0%	74.3%
GB	29.7%	10.8%	44.5%	67.7%
GR	20.5%	17.1%	17.1%	
HR	20.5%	16.0%	31.9%	92.3%
HU	18.3%	12.6%	47.8%	90.0%
IE	29.7%	9.7%	44.5%	
IT	20.5%	17.1%	25.5%	
LT	20.5%	10.3%	22.7%	
LU	18.3%	10.3%	10.7%	
LV	20.5%	9.9%	26.7%	
ME	16.0%	12.8%	32.6%	
MK	16.0%	13.7%	31.6%	
NI	29.7%	10.8%	44.5%	
NL	22.8%	9.7%	30.7%	92.6%
NO	29.7%	9.7%	47.3%	
PL	25.1%	10.8%	14.0%	
PT	20.5%	17.1%	24.9%	
RO	22.8%	13.7%	28.7%	93.9%
RS	16.0%	13.7%	42.0%	
SE	25.1%	9.7%	46.5%	70.3%
SI	20.5%	12.6%	44.3%	92.3%
SK	18.3%	11.4%	21.2%	82.3%
UA_W	16.0%	11.4%	58.0%	

Source: ENTSO-E (2013), JRC (2012), EEA (2009)

XII.2.4.2. Fuel costs

The following fuels are distinguished by the model:

- coal

- brown coal and lignite
- biomass
- light and heavy fuel oil
- natural gas.

In case of coal, biomass, brown coal and lignite we assume that fuel costs are the same for all countries. We set both the current and predicted future price of coal based on EIU (2013). Transparent prices for lignite do not exist, but we assumed that the price of both lignite and brown coal are equal to 70% of the price of coal.

Under its present version the model assigns zero marginal cost to biomass fired power plants, since these power plants normally do not supply the competitive market, but sell the produced electricity through some sort of renewable support scheme. This feature, however, needs to be amended, therefore within the dissertation we also make estimates for the marginal cost of these power plants.

The prices for different fuel oils depend very much on the price of crude oil. Using historical data the correlation between the price of crude oil and the two types of fuel oil can be estimated with regression models. The price of these products therefore can be estimated based on the regression as well as the forecasted price of crude oil obtained from EIA (2013).

For the price of natural gas we generated two estimates: the Western-European spot price and the oil-indexed price. The spot prices are based on the EIU (2013) estimates, while the oil-indexed price of natural gas can be derived from the Hungarian gas price formula. In case of Eastern European countries the price of natural gas applicable to electricity generating power plants is gained from a mix of the oil-indexed and the spot price. Our assumption for the region covering the period until 2015 is 55% ratio for spot gas and 45% for oil-indexed gas, adjusting to 70%-30% after 2015. A 10% supplement is also added to gas prices to account for the costs of system use.

Table 38 provides a summary of the prices used for different fuels.

Table 38 Estimates for the price of different sources of energy

	Crude oil price, \$2011/barrel	Price of hard coal, €2011/GJ	Price of brown coal and lignite, €2011/GJ	West-European gas price, €2011/GJ	Oil-indexed gas price, €2011/GJ	Spot gas ration in East-European countries, %	East-European gas price, €2011/GJ	Heavy fuel oil price, €2011/GJ	Light fuel oil price, €2011/GJ
2013	96.81	2.74	1.92	8.61	10.57	55%	9.49	9.35	9.85
2014	97.00	2.98	2.08	8.38	10.60	55%	9.38	9.37	9.87
2015	95.91	3.24	2.27	8.44	10.47	70%	9.05	9.26	9.74
2016	97.00	3.27	2.29	8.04	10.60	70%	8.81	9.37	9.87
2017	99.08	3.30	2.31	7.87	10.84	70%	8.76	9.60	10.10
2018	101.20	3.34	2.33	8.00	11.09	70%	8.93	9.82	10.34
2019	103.36	3.37	2.36	8.05	11.34	70%	9.03	10.06	10.58
2020	105.57	3.40	2.38	8.09	11.59	70%	9.14	10.29	10.83

XII.2.4.3. Estimation of other variable costs

Power plants face three more types of cost items that are variable in their nature:

- carbon-dioxide costs
- excise tax
- variable operating cost.

In case of the carbon-dioxide cost the current version of the model handles the price of carbon-dioxide as an input variable, and estimates it separately. At the same time, as already mentioned, during the analysis of the research questions and hypotheses of the dissertation we also need to examine the impact of a tighter cap on the price of carbon credits, thus the carbon-dioxide cost is an outcome of modelling. Furthermore, we assume that the credits need to be accounted for only in those countries that are subject to ETS.

The excise tax differs by fuel types as well as countries, the various excise tax levels have already been described. At the same time, in the thesis the excise tax is an input variable, as articulated under the research questions and hypotheses.

The level of the variable type operating cost depends on the technology and the year of construction for the given power plant unit, varying between 3 and 7 €/MWh.

XII.2.5. Exogenous countries

While 36 European countries are simulated, there are five more countries in the model (Belarus, Morocco, Moldova, Russia and Turkey) with which the modelled countries trade electricity. We do not model the demand-supply characteristics of these exogenous countries and neither do we examine the respective prices. We assume that the commercial electricity transfers observed for 2011 will also apply for the future.

XIII. THE AUTHOR'S OWN PUBLICATIONS ON THE TOPIC

Articles in referred journals in Hungarian

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- Mezősi, A. (2014): Drága-e a megújuló? A hazai megújuló villamosenergia-termelés hatása a villamosenergia-árára, Vezetéstudomány, megjelenés alatt, p. 22. („Is the renewable energy expensive? – Impact of the Hungarian renewable based power generation on electricity price")

Other articles in Hungarian:

- Mezősi, A. – Szabó, L. – Kaderják, P. (2011): Hőpiaci energiafelhasználás és szén-dioxid-kibocsátás becslése 2030-ig, Magyar Energetika, 2011/6, pp. 24-27. („Projectons of heat usage and carbon-dioxide emission by 2030")
- Mezősi, A. (2008): Az Európai Szennyezési Jogpiac első időszak adatainak elemzése, különös tekintettel a villamosenergia-szektorra, Energiagazdálkodás, 5. szám, pp.18-25. („Analysing data of the first period of the European Emission Trading System, especially in the electricity sector")

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- Kiss A. - Mezősi A. - Pál G. - Szolnoki P. - Tóth A. (2008): ‚*A szivattyús energiatározás kérdésének közgazdasági elemzése.* Műhelytanulmány (working paper), Regionális Energiagazdasági Kutatóközpont, Budapest, p.51. („The economic analyses of state pump storage facility investments in Hungary")
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