Telling stories or solving problems?

The 20-20-20 package and the efficiency of EU Climate Change Policies

Dissertation

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"Der Staat schützt auch in Verantwortung für die künftigen Generationen die natürlichen Lebensgrundlagen." Grundgesetz, Artikel 20a

Table of Contents

List of Figures

List of Tables

List of Abbreviations

A	Abatement
BDEW	Bundesverband der Deutschen Energie und Wasserwirtschaft (Federal Association of the German Energy and Water Industries)
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)
BSA	Burden-Sharing Agreement
°C	Degree Celsius
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
DEA	Data Envelope Analysis
DM	Decreto Ministeriale (Ministerial Decree)
E	Emission
EC	European Community
EEA	European Environment Agency
E_{eg}	Global Radiation
EEG	Erneuerbare Energien Gesetz (renewable energy sources act)
EFTA	European Free Trade Association
EKC	Environmental Kuznets Curve
EPO	European Patent Office
EU	European Union
EU-ETS	European Union Emissions Trading Scheme
FD	First Differences
FE	Fixed Effects
FIT	Feed-In Tariff
GC	Generation Cost
GDP	Gross Domestic Product
GHG	Green House Gas
GSE	Gestore dei Servizi Energetici (publicly-owned company which promotes and supports renewable energy sources RES in Italy)
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation

K	Capacity Load Factor
K_C	Capacity Converter Correction Factor
K_G	Capacity Generator Correction Factor; module efficiency
K_L	Capacity General Losses Correction Factor
K_T	Capacity Temperature Correction Factor
kWh	Kilowatt-hour
MAC	Marginal Abatement Cost Curve
MC	Marginal Cost
MPP	Maximum Power Point
NAP	National Allocation Plan
OECD	Organisation for Economic Co-operation and Development
P	Price
P_{CE}	Price for Conventional Energy
P_{GE}	Price for Green Energy
PS	Producer Surplus
PV	Photovoltaic
R&D	Research and Development
RE	Random Effects
REFIT	Renewable Energy Feed-In Tariff
RES	Renewable Energy Sources
STC	Standard Test Conditions
TEHG	Treibhausgas-Emissionshandelsgesetz (GHG Emission Trading Act)
TEU	Treaty on European Union
T_I	Temperature surplus due to installation
T_S	Surrounding Temperature
UNFCCC	United Nations Framework on Climate Change
US	United States (of America)
W	Watt
Y_F	Final Yield in kilowatt

1. EU climate change policies - Introduction

This thesis contributes to the discussion on climate change policies by analysing the performance of different instruments integrated in the European Union (EU) framework for climate protection with a focus on renewable energy sources (RES), energy efficiency and particularly carbon savings. The emission of greenhouse gas (GHG) is the main factor contributing to global warming and these gases remain in the atmosphere for decades.[1]

Neither the use of RES nor the reduction of GHG can be influenced directly. EU member states have to set the legal framework that creates an eco-friendly economy, which allows investments in RES and provides incentives to markets to reduce emissions.

In general, there are two main strategies for increasing the share of RES of total energy production: firstly, polices that promote investments in RES like direct subsidies for private investors or indirect feed-in tariffs that guarantee the return on investment after a certain period of time; secondly, a quota system, which change the production conditions for energy suppliers, as they are obligated to include a set share of RES in the production mix.

The reduction of GHG is even harder to influence with policy measures because of the broad range of different sources of pollution with very heterogeneous polluters from private vehicles, through small and medium enterprises with local production, to heavy industries like iron and steel production where energy inputs are one of the biggest input factors. While private and small emitters are not covered directly by GHG saving policies, heavy industries and the electricity production sector are: green policies try to force the perpetrators to bear the costs of air pollution (polluter-pays principle). Emissions are limited through a cap on the allowable emission volume. Emitters have to buy allowance certificates in a (single) European market, the EU emission trading scheme (EU-ETS) for carbon emissions. Private emitters are important as well. Their contribution to total emission should not be underestimated. Policies address this issue with programmes to change individual behaviour through education or attempt to influence it indirectly through higher energy prices or more stringent compliance standards.

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[1] See Jacobson (1998) for the general physics and correlation of different green house gases to each other, the influence of carbon emissions on global warming and the implication in the long run.

For a long time, research analysis as well as policy makers concentrated on economic efficiency of climate protection policies. A popular policy approach to control environmental damages is a cap-and-trade programme: often initiated for different kinds of pollution or the use of natural resources like fish, to limit the pollution or the intensity of use of a certain good. It is currently accepted that a certain level of pollution is inevitable to produce goods, that individuals have the need to use a common good like the air, and thus system participators on the demand side should receive permits to emit and compensate the injured parties. If accepting the compensation, they can be considered indirectly by suppliers due to accepting not only the use of a good, but also being aggrieved of e.g. worsened environmental conditions. The trade of permits is an effective instrument to price environmental damage on the market. In perfectly competitive markets the economically optimisation is reached, the cap set by the policy maker will be achieved - i.e., in such a scenario the allowed level of total pollution for the whole economy will be used completely as it is cost efficient. Further pollution savings will not occur.[2] Surprisingly, such policies do not take into account the social costs of pollution in the long run and do not try to optimise the ecological output, e.g. the minimisation of the usage of a specific output or emissions.

The current scientific discussion has reached a consensus on the economic efficiency of climate change policies: The resulting optimum can be beneficial in the short run. In the long run, however, Schumpeter's theory of growth (1942) generally describes the core element of capitalism as “creative destruction”: Growth and development are uncoupled from each other and through innovations economies succeed in growing sustainably without increasing the use of resources. With the implementation of RES capacities and the switch towards green energies, economies are moving towards a world without the use of fossil fuels. Climate policies should not prevent the innovation process, but can help to accelerate it. For the present, Stern (2006) underlines the importance of growth through innovations instead of burning fuel and describes climate change more drastically as “the greatest example of a market failure we have ever seen” (p.1). Pollution accumulates in the atmosphere causing global warming and changes in the ecosystem lead to externalities like

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[2] In a scenario, where the marginal costs of pollution is lower than the market price of emission allowances for all emitters, the total emission volume will be lower than the set cap. This indicates that the cap was not ambitious enough or set under wrong estimates, see chapter 2.

floods, dry periods, and rising sea level: polluters do not pay for these environmental costs.

For the global system, the focus on ecological or social rather than private optimisation seems to be justified on the basis of warnings by scientist, which predict that climate change is going to be out of control, if immediate action is not taken. The beginning of the twenty-first century is important to reposition the world‘s system towards a low carbon economy. A business as usual strategy would lead to irreversible consequences. Through global forecasts of warming, the question is no longer whether the average temperature will rise, but to what extent. The IPCC (2007) listed predicted consequences of climate change. Empirical analysis shows high confidences of sea level rise and consistent warming, with higher precipitation in some areas while others are affected by droughts. Extreme weather events are going to be more intense. Several scenarios calculate effects that will mainly affect the poorest of the poor. By 2020, Africa is projected to experience a 50% reduction in soil fertility, as well as increasing costs of coastal protection against flooding, and water scarcity for a higher share of the population.

Developed countries will be less affected. Warming can also bring benefits for example through less need for heating or higher productivity in the agriculture sector. On the other hand, especially in the long run, weather-related extremes will arise more often in Europe and floods and droughts are likely to induce high costs. The scarcity of water in southern Europe can shift tourism and production capacities away from the poorer south. Demographical stagnation and migration movements can destabilise the political construction of a united Europe (see Stern 2006). The IPCC (2007) underlines Stern's statements and adds to the discussion the loss of biodiversity, and a "medium confidence of some aspects of human health, such as heat-related mortality in Europe, changes in infectious disease vectors in some areas" (IPCC, 2007, p. 3, summary for policy makers).

Anyone, in particular policy makers, who takes seriously the above scenarios, is urged to design climate change policies more actively. It is not clear why the Copenhagen Accord specified a 2°C target as the maximum accepted global warming scenario. Why not taking instead another, more restrictive one. A lower target might be conceivable, and is called for by environmental experts and scientists. Moreover, the head of the United Nations Framework Convention on Climate Change (UNFCCC), Cristina Figueres, postulates the need for a new discussion about a 1.5°C target instead of the previous benchmarks of 2°C.[3] Still, meeting the 2°C target requires emission reductions in the short run, otherwise the percentage reductions required in the future would be on an unachievable level with the permanent risk of failing to prevent warming and facing unexpected, abrupt changes in ecosystems even if the temperature increases only marginally. As emphasised by Steffen (2001, p. 55), “The decade between now and 2020 is critical”. It seems, that the 2°C target is the tolerable limit to "allow" industrialisation, while beyond this the damage to ecosystems and human beings as a result of climate change will increase rapidly, as summarised in a literature review by Jaeger and Jaeger (2011).

In principle, the European Union has recognised the need for action. In international negotiations about climate protection plans, the EU acts with a dual strategy. Its own climate protection programmes are implemented without preconditions. More stringent EU policies are promised to cooperating partners if agreements on

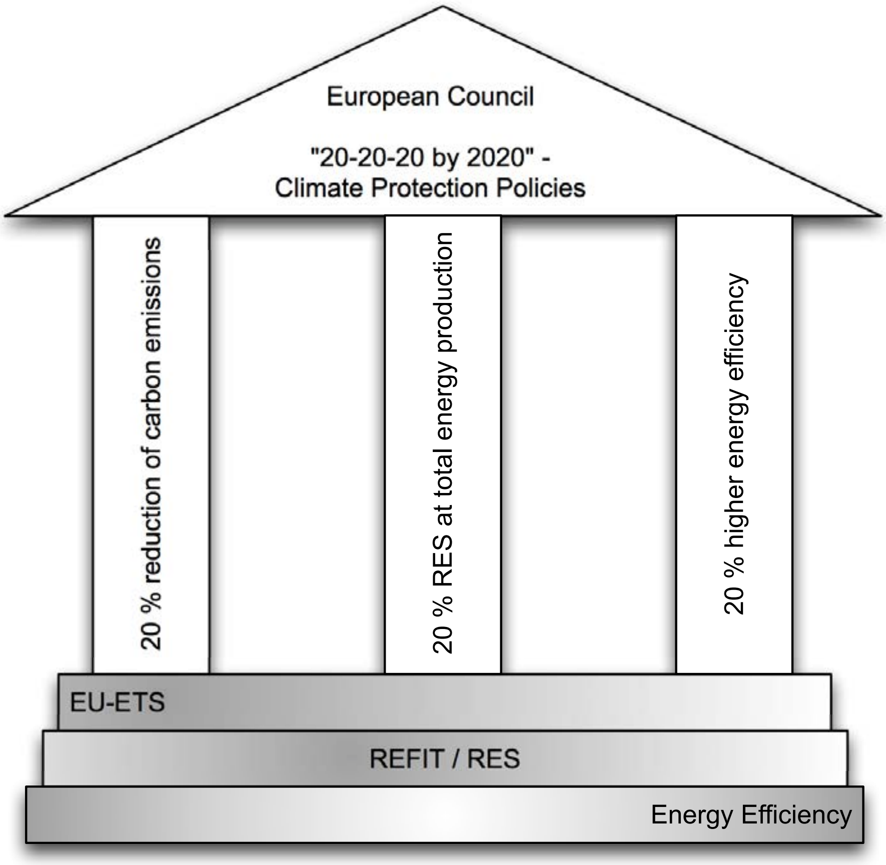

Figure 1: *European climate change policies, own illustration.*

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[3] Conference speach, Carbon Expo 2011, Barcelona, see http://www.guardian.co.uk/environment/2011/jun/01/christiana-figueres-climate-2c-rise (last review: 07.08.2011).

international cooperation will be implemented, with ambitious goals especially for other developed countries like the US or Canada, and emerging partners like China, Mexico or India. Through these proposals Europe recognises the responsibility of developed countries as the main source of GHG emissions, but less developed countries will not be discharged from their responsibilities, as can be seen in the Copenhagen Accord (UNFCCC, 2009)[4] for instance, which was mainly influenced by the EU member countries.

As climate policies are enforced through the Treaty on European Union (TEU), a uniform law for all member states, the confederation as a global player with diverse single members is a powerful unit to push climate change strategies and is influencing the world community through unilateral acting. Because of the diversity of the EU‘s member states, the region is an interesting economic area to assess environmental policies and thereby to focus on economic and ecological optimisation of policies and to calculate the outputs and impacts.

The main instrument for the EU climate change protection plans relies on the 20-20-20 by 2020 targets[5]. This roadmap, adopted in 2008, is the result of years of continuing work for a joint programme for Europe-wide application of a common framework of climate change policies. The positive developments from the past are the guideline for further tightening of the environmental policies for European member states, enterprises and citizens. A unified market for pollution permits, the European Union Emissions Trading Scheme (EU-ETS), is the main instrument to reduce the emissions of GHG. Within the framework of carbon saving policies, the EU members have different obligations. The burden-sharing agreement takes care about that fact, that different countries face different (economic) conditions.

Further components are the ecological targets to reduce energy input and raise the efficiency of energy use, as well as a higher share of renewable energies in total energy production. Instruments that bring Pareto-efficient and cost-minimising solutions are often inadequate replacements high-instruments of environmental protection. All three elements, as shown in Figure 1, presumably affect the achievement of each other: if one is affected by new regulations or will be redesigned, the conditions of all the three will change. The graph illustrates for the

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[4] The exact formulation of the accord was highly influenced by the European Union.

[5] 20-20-20 by 2020 - Europe's climate change opportunity, 23.01.2008, COM(2008) 30 final, European Communities, Brussels.

three core elements the strength of the side effects on the other two elements, where a dark colour indicates a high influence and vice versa. The examples will be given below. For the following thesis, there are given three examples, each one from one of the three (1-3 as in the following) elements as postulated in assignments and decrees based on the 20-20-20 by 2020 targets: cap-and-trade systems (EU-ETS) for (1) emission reductions, solar investments for the share of (2) RES capacities, and pressure of policies on (3) energy efficiency. While for (1) the most important policy measure is chosen, (2) give an example of how effective RES promotion can be and whether the measures seem to be effective, and (3) is a proof that energy efficiency can be influenced directly by policy makers.

Main and side effects of the European climate change policies will be discussed in three chapters along three main arguments. Through the propositions, popular but non-proven assertions are formulated to consider them true or false along three chapters and a closing, summarising conclusion:

> *Proposition 1:*
> *If shocks foil emission reduction plans, the policy maker has to ensure the achievement of national climate protection plans.*

Of what use would be the best plan to reduce carbon emissions if the calculations of future economic and technological developments fail due to drastic changes in recent developments?
Such a shock occurs firstly when production is decreasing, e.g. growth declines in the economy, and total economy wide emissions fall below the level of calculated emissions in a business as usual scenario with steady growth; or secondly when the innovation process of economies is faster than expected and leads e.g. to new zero emission power plant capacities and reduces the need for emission savings in other industries or other emitters. The shock changes the costs of environmental policies not just for the individual emitter but for the general public as well. The consequence for the ecological success can be that shocks may prevent the implementation of a technology, which would have the potential to generate an even larger amount of e.g. emission reductions. The question arises further, how to thus maximise ecological success.

Reduction plans in the (EU-)ETS set a cap for economies or sectors, where the allowed emissions are the upper limit of total emissions of all participators. Financial incentives can help to increase investments in RES capacities. If both mentioned policies are applied simultaneously, the results may lead to a partial failure of emission reductions for the specific cap quantity if a part of the production is substituting carbon emissions while emitted pollution is increasing someplace else, e.g. Hogrefe et al. (2007). The issue of resetting the cap on carbon emissions arises sharply in the aftermath of a faster increase in new RES capacities that far exceeded policy makers' estimated scenarios.

One has to consider the costs and the benefits of climate protection policies. In this context, efficiency is a term that can be justified both economically and ecologically. The most efficient energy policy will be achieved if measures are inexpensive to implement and the results of the reduction of environmental damage are ecologically significant: Within a cap-and-trade system, participators are searching for their individual optimum. For the single emitter, the individual marginal abatement cost curves (MAC)[6] is important for every market participator to decide whether to reduce their emissions or to buy emission permits.

The literature often emphasises joint MACs to minimise the costs of environmental policies "in" the system. An aggregated MAC of all single emitters shows the system costs minimisation and the cost curve of all emitters. This approach reduces the costs of the environmental policy instrument of trading the emission permits and the target is met under cost-minimising conditions. The priorly set cap is chosen by the policy maker with the intention to reduce emissions to a certain level and is based on extrapolated scenarios. Thus, environmental protection costs will be minimised, but not the environmental protection itself. Ecological efficiency has to be in the focus of the analysis, as total social costs seem to be higher than the avoiding costs in the cap-and-trade system: there is a gap of non covered costs. Long run costs are higher if no action is taken or if short run costs (of production) will arise for individual participators in trading schemes. The initial implementation of environmental protection causes costs for the system participants: it is a kind of reallocation of social costs to the emitters. Fiscal income from environmental taxes and other

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[6] A single firm will be a seller of permits as long as the permit price is higher than the individual marginal abatement costs curve (MAC) of emissions. The market price for allowances will be equal to the optimum, which can be realised by the joint MAC for all market participants (Montgomery, 1972); see chapter 2 for a deeper explanation of the concept.

instruments that price emissions can be reallocated and serve as additional governmental budget to be spent on e.g. investments in green energy capacities, projects for sustainabile production, or research and development of RES.

Until now it is unclear if the new policies like RES-promotion schemes, pricing of carbon emissions and trading schemes for emission allowances are positive or negative for the output of economies, and how e.g. cap-and-trade systems are influenced by side effects of shocks through other measures. Shocks, e.g. through economic growth or decline, new technologies or innovations, as well as general changes in production processes and substitution of fuels can thwart even well balanced emission trading schemes: the demand for emission permits will increase or decrease drastically.

If the goal remains to minimise system costs, neither positive nor negative effects can be taken into account changing the targets to optimise the ecological efficiency, which may even be negatively affected through economic shocks. Will support systems to promote new RES capacities only increase emissions somewhere else?

> *Proposition 2:*
> *Green technologies are too expensive: without subsidies*
> *a share of green energies of 20 percent of total energy*
> *production is out of reach.*

The installation costs of RES capacities can be high, but depending on the technologies, conventional and green energies are becoming more and more competitive. An increasing learning curve and technological innovation lead to declining production costs both of green power plants and produced green energy, while high prices for conventional fuels raise prices for conventional energy.

Through fixed feed-in tariffs, different member states of the EU are giving incentives for private investors to invest in green energies. These feed-in tariffs are positively discriminating in favour of certain technologies. One of the most expensive of them, solar energy, counts for the highest guaranteed price per kWh, see e.g. table 1 for Germany. Such a positive discrimination can be justified as an efficient instrument especially in imperfect markets: REFITs, renewable energy feed-in tariffs, lead to a broad implementation of new (ecologically) worthwhile technologies, and welfare losses through the lack of implementation of green technologies will be decreased

	production costs* / REFIT **	external costs*** (GHG)	**total costs**
gas	3.78	2.90	**6.68**
hard coal	3.62	6.30	**9.92**
brown coal	2.97	7.90	**10.87**
photovoltaics	51.79	1.00	**52.79**
wind energy	8.76	0.12	**8.88**
water energy	7.19	0.15	**7.34**
geothermal energy	15.00	0.18	**15.18**

***Table 1: Total costs of electricity production**, in €-Cent per kWh.*
Constant prices for inputs based on technologies with end of life point in the year 2025.
*Own illustration basing of the following sources: *) production costs for conventional power plants (gas, hard / brown coal) based on 25 years amortisation according initial operation in the year 2000 (Dürrschmidt, van Mark, 2006); **) production costs for RES (photovoltaics, wind / water / geothermal energy) based on 2005 average compensation for the 20 year period of fixed feed-in tariff (according Dürrschmidt, Büsgen, 2007); ***) external costs based on 70 EUR/1t CO_2 (Krewitt, Schlomann, 2006).*

(Kalkuhl, Edenhofer, Lessmann, 2012). This is a very important point that will be discussed in the following chapters on different levels.

The (end consumer) prices of electricity from conventional oil and gas, as well as from nuclear power, are still below the price per kilowatt-hour (kWh) for RES as well as below the REFIT. One can recognise easily the cost disadvantage of the RES capacities. The gap closes, however, through continually rising fuel costs on the one hand, and on the other hand decreasing investment costs for renewable energy with simultaneously increasing efficiency.[7]

While some emphasise the cost argument and doubt if the plans are realistic, others highlight the benefits. Power companies in particular are advised to invest in RES, but a 35% share of green energy sources in total energy production, as proposed for example by the German government, seems to be too optimistic, and cannot be realised without additional costs (see Müller, BDEW, in: Deutsche Bundestag, 2011). These arguments do not take into account the social costs of emissions or the positive externalities of RES investments. Jaeger et al. (2011) consider counting the positive job effects, while Krewitt and Schlomann (2006) present evidence about real costs of different energy technologies, see e.g. table 1. It is obvious that RES are not

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[7] Nuclear power is not included in the analysis, since in particular the assessment of external costs is incalculable. Thus, neither the costs of disposal can be valued monetarily, nor can the probability of damage be accurately given. In case of damage, especially the follow-up costs are incalculable.

yet competitive with conventional energy sources, but there is an ongoing trend to reach equal production costs of RES and conventional energies in the near future. If external costs are included, the gap should close much earlier.

It seems to be clear that RES have positive effects, but they cannot be implemented without costs. The price for the green revolution of energy production is high. The calculation of benefits and costs tends to shed light on the optimum strategies to firstly decrease the spending and secondly increase the energy harvest.

Proposition 3:
If emissions are correlated to output and growth,
the Kyoto Protocol obligations and energy saving policies
have no effect on the emission output quantity.

Aimed to fight global warming, the Kyoto Protocol of the UNFCCC is a treaty with binding targets for signatory countries to reduce GHG emissions with the goal to achieve the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system", as proclaimed as the objectives in Article 2, UN Climate Change Convention, UNFCCC (1992).[8]

Various literature sources point out that the Kyoto Protocol will fail due to the fact that the growth of emissions is in direct relation to population and economic growth. According to Ehrlich and Holdren (1971), environmental damages and climate change through GHG are determined through a positive correlation with population size and growth: GDP and population growth determine emissions. In order for the Kyoto Protocol to succeed it is an open question how the policy makers can influence economic-wide emissions. Nordhaus (2010) is in line with the findings of Ehrlich and Holdren (1971), concerning scientific predictors for climate change. However, he stresses that these predictors might be influenced with the right set of policies, if economies were not complex systems with individuals trying to optimise their individual needs and maximise their utility. Tietenberg and Johnstone (2004) regard another approach as best for economies: to analyse first the economic efficiency before signing binding targets for emission reductions.

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[8] On the occasion of the UNFCCC conference, which took place in Kyoto in December 1997, the Kyoto Protocol was passed as a supplementary document for the application and implementation of the UN climate change convention from 1992.

On the other hand, there are positive impacts of policies on the increase of energy efficiency and emissions, e.g. the World Energy Council (2008) mentions the effects of strengthened efforts by almost all OECD nations in the past Kyoto era on the application of environmental policies. Delarue and D’haeseleer, W. (2008) describe fuel switching as a consequence of emission trading with decreasing emission as a result: burning the more expensive gas causes less emissions in comparison to cheaper oil or coal, but carbon emission certificates change the price relation. The mix of energy input factors may change drastically and will influence policies, too. Parry (2003) analyses, that every policy efforts more environmental protection than doing nothing at all: a price for emission initiates the development of energy saving technologies and can reduce the future costs of abatement.

The direction of causality is not clear: not only will GDP growth influence emissions, but emission reductions also have the power to put pressure on growth or even to influence growth positively. The general upgrading process starts when enterprises search for competitive advantages to decrease the costs of production or to innovate in the creation of completely new products. Conversely, if enterprises are forced to innovate and create new appliance standards, e.g. low energy machinery or production units with a more economical use of input factors, these investments for innovations decreed by governmental measures can have positive impacts on economic development.

It has to be demonstrated, that policy can influence emission savings and which are the driving factors of influence. Without proof otherwise, the strong dependency on emissions and GDP growth has to be accepted.

The synthesis of the three propositions mentioned above: Economists have to choose between private or social maximisation, or microeconomic system optimisation or macroeconomic supranational policies. As climate protection policies are a global issue, one should think big and point out every single policy as a part of the whole. System participants may have higher costs through regulations and standards on the on hand, but on the other hand, as they are acting in a global environment, benefits cannot be measured in private earnings alone, but in worldwide gross social product. One has to ask the question how to minimise costs and optimise the use of resources, if it is already broadly accepted that climate protection is the price for our consumption of energy, needed for our high standards of living. The EU's burden-sharing agreement is of importance in this context. It obliges the various countries across the EU to carry their share of the Kyoto Protocol, though only in proportion to their economical feasibility. Thus, countries carry only so much 'burden' as they are able to manage given their economic situation, while more able countries take on more responsibility given their more stable status, with the result, that the individual carbon emission reduction obligation is different for each observed country.

This doctoral thesis analyses the three components of the European Union climate policies, and is structured as follows:

Chapter 1: EU climate change policies - Introduction
Chapter 2: Emission reductions - The no cost emission-saving policy
How can a cap-and-trade systems reduce carbon exhausts?
Methodology: economic modelling of a standard market model for emission trading under the influences of renewable energy feed-in tariffs.
Chapter 3: Renewable Energies - Follow the sun
How can the maximisation of a technological-geographical fit raise the energy harvest of a chosen technology, e.g. solar power plants?
Methodology: thought experiment with an output analysis approach to compare status quo technology and local conditions e.g. of solar radiation and temperature.
Chapter 4: Energy Efficiency - The influences of climate change policies
EU Burden-Sharing Agreement obligations: are climate change negotiations worth the effort and can they influence the energy use with sustainable success?
Methodology: panel data analysis, sample: cross country data from N=25 EU member states over a period of T=13 years.
Chapter 5: Conclusions and recommendations for policy makers

Table 2: Structure of the doctoral thesis.

The European Union started the worlds biggest carbon emission trading scheme. Chapter 2 addresses the question of how to reach higher emission savings without higher costs within the framework of a national allocation plan (NAP) for carbon permits when other policies are implemented simultaneously. If the NAP cannot be adjusted, both instruments seem to neutralise each other.

EU member states have to raise the share of renewable energy sources. Chapter 3 presents a thought experiment as a country comparison for a selected technology:

what if the solar power plant installations undertaken in Germany had been installed in Sicily? The thought experiment illustrates the need for a fit between geographical conditions and technology. Europe-wide balanced policies for RES would lead to a higher amount of installed green energy capacities without higher costs.

Finally, the EU puts pressure on national states to use energy more efficiently. Thus, addressing the European level, chapter 4 proves for the influence of the Kyoto Protocol obligations and the following EU Burden-Sharing Agreement on European policies to increase energy efficiency. Through the more efficient use of electricity additional carbon savings will be realised. But are these savings caused endogenously through economic growth and population, or do policies put (effective) pressure on consumers' electricity consumption?

The conclusions and a short summary of further implications of the different energy policies close the thesis in chapter 5 with recommendations to policy makers and try to give answers to the postulates propositions.

2. Emission reductions - The no-cost emission-saving policy

The EU is putting emphasis on proposing climate saving policies that place Europe as the innovator in reducing emissions and increasing the share of renewable energy sources (RES). However, the application of suitable instruments appears to create problems, with differences between the policy approaches that seek to achieve the objectives. The European Union Emissions Trading Scheme (EU-ETS) and national support regimes such as renewable energy feed-in tariffs (REFIT) in particular are often not well integrated in the national allowances plans (NAP). Whilst the aim of the former is primarily to price carbon emissions, the aim of the latter is to increase the market share of green energy. However, coordination of the two is sometimes lacking.

Firstly, the EU-ETS allows policy makers to set a cap on absolute emissions as a maximum of pollution. As for the whole economy as for the single emitter who is participating in the trading scheme, the emissions have to be covered with emission allowances certificates. The emitter will decide whether to save emissions and sell allowances or to emit and buy certificates. Thus, emissions have a price and can be interpreted as a negative by-product of the output, which should be avoided.

Secondly, the key question is whether increasing RES capacities that are erected by private investors outside the ETS will affect countries‘ NAPs. That part of new RES capacities which is not covered in the ETS can be described as an exogenous shock on one branch: the power utilities. They are affected by less demand for their conventional goods due to the fact that green produced electricity has to be fed-in to the grids and used first. Power utilities are faced with a huge amount of unused allowances certificates. Here, the further question arises of what the consequences are for their business and the end consumer prices of electricity, on the absolute amount of emission savings and econonomy-wide effects of wealth from an ecological point of view.

In the following, the instrument of the REFIT is identified as a particular and effective tool to stimulate new investments. The emissions of CO_2 are capped and calculated under scenarios which take into account growth and (technological) development. They provide a controlled expansion of RES in the energy sector. RES promotions without an upper limit can lead to another scenario in which new RES capacity is added by investors not primarily from within the energy sector. Such a situation,

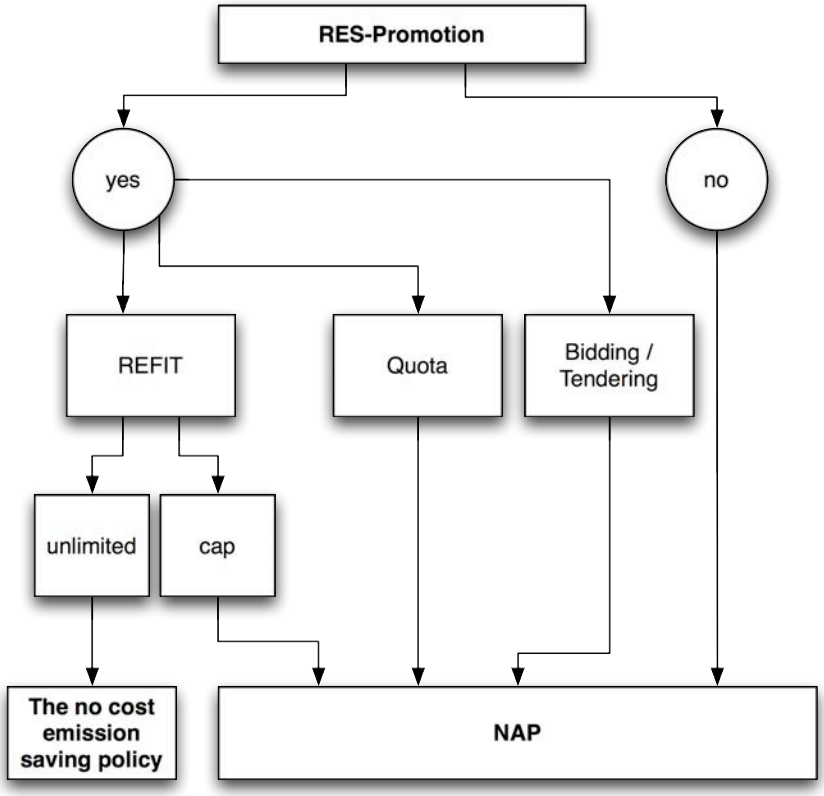

Figure 2: Different RES promotion systems.
Own illustration of the consideration in the national allocation plans (NAP) for CO_2 emissions. Only a REFIT without limitation of the supported quantity opens opportunities for additional emission savings without increasing system costs in comparison to the NAP reduction.

without regulation by policy makers, helps to achieve the national emission target sooner and faster, but reduces the pressure for individual emitters participating in the emissions trading scheme, as described before.

Emitters should reduce emissions where emission saving occurs at its lowest price. The NAP should guarantee carbon savings and take into account an estimated RES capacity. If this capacity is able to grow faster than as estimated by NAP, the demand for carbon permits decreases and a lower permit price follows. The two scenarios with i) caped and ii) unlimited growth of new RES capacities have to be compared and discussed with the goal of finding ways to realise additional savings without incurring higher costs for the individual emitter.

There are many instruments to guarantee the return on investment of green energy plants. These promotions are the basic prerequisite for the private sector to invest in photovoltaics, wind or geothermal energies and other new green energy production technologies, also if the production costs of green energies are above those of conventional energy power plants. Initially, the NAP is calculated under the expected quantity of future new installations of RES. If these estimations are exceeded, the consequences are manifold. Such an exogenous shock could, in particular, include increasing costs of RES support regimes and decreasing prices of emission permits. In the following example, the REFIT costs are borne by end consumers, while the additional carbon savings in the energy sector lead to decreasing emission allowances prices and thus a shift from consumer to producer rent. To a certain degree, market mechanisms lead to decreasing energy prices for the residual demand of conventional energy. Without policy intervention, a faster-growing RES capacity prevents emission savings elsewhere: other sectors profit from decreasing costs of emission permits and are even able to reduce their emission savings by absorbing the free permits that will not be used by the electricity producing sector. This factor could weaken the economic pressure to save emissions. The lack of the policy maker‘s ability to cut the cost of RES promotions once plants are erected compels other possibilities to change the cap on emission allowances to realise the initially conceived quantity and price of permits. These limited policies are referred to as the no-cost emission-saving policy: the environmental maximisation of the quantity of carbon savings if an exogenous shock threats the estimated NAP scenario through measures that restore the original conditions.

This chapter analyses briefly the literature addressing the two instruments EU-ETS and REFIT and shows how, when jointly applied, they can interact with one another. If interaction is possible, what is the potential to reduce emissions at a faster rate without increasing costs in comparison to the primary NAP with a capped RES installation? Are additional carbon savings and the costs of RES installations balanced and if, to what extent? The discussion of legal options in addition to economic efficiencies and the interdependencies of the relevant stakeholders can enable new policies that can help to reach faster the ambitious climate saving goals of the EU.

This chapter is organised as follows: Section 2.1 discusses the fundamentals of the question of interest: If the EU-ETS and national REFITs are jointly applied in one market, will the benefit of carbon savings vary from the single application and to what extent? Sections 2.2 to 2.4 will firstly explain the theoretical conditions of a REFIT, a cap-and-trade market, and the net effects of its application. All the three sections are more theoretical and less empirical and necessary to describe different equilibriums in the short run perspective, e.g. without future technological development. In section 2.5, the question of the interdependencies of the two instruments and the possible contrary effectiveness of both instruments when implemented simultaneously is addressed. Do emission reductions through RES lower the absolute economy-wide demand for carbon permits? Will the demand for allowances decrease or is the market inundated with these free certificates? Section 2.6 will discuss solutions for the allocation problem resulting from new installations and the amount of possible additional, cost free carbon savings. The focus is on Germany as an innovator of REFIT policies. One must refer to the difficulties between economic demand and legal needs, which limit the design of trading schemes. Section 2.7 will conclude the chapter with the results of the theoretical analysis and recommendations for further policies.

2.1 The two instruments policy mix

If scientific scenarios about global warming become true, time is running out and the European Union aims to be a pioneer in climate protection. Ambitious policies agreed in the 20-20-20 by 2020 targets (European Commission, 2008) seek to lower carbon emissions to at least 20% below the level of 1990. Further, the share of renewable energies in total energy production must rise to 20%, and the energy efficiency must increase by up to 20% by 2020. Is the achievement of these goals realistic? Most member states decided to adopt the policy of a joint application of two different instruments. At first sight it seems to be absurd not to concentrate on the strength of one, but to implement a second cost intensive policy measure. Nevertheless, the advantages of such a policy mix exceed those of a single instrument. It appears that this measure can be used to cut emissions radically and to provide new opportunities for the no-cost emission-saving policy, which have not yet been realised.

The instrument chosen to lower carbon emissions is a cap-and-trade market of emission permits. If one seeks to raise the share of green energy in total energy production, the appropriate instruments are support regimes, which aim to increase new installations of zero emission power plants. While the application of an emission trading scheme is a cross-sector incentive aiming to save emissions at the lowest cost point, subsidies for green energies lead to sector-specific and large quantity savings of emissions and thus make a certain amount of conventional production and its permits redundant. The German NAP is calculated based on a scenario with a limited quantity of new green power plant installations. The quantity was defined before the trading period started. Thus, marginal interperiod expansion of green energies about the scale of the NAP scenario imply an external shock on system participants. The beneficial industry, e.g. the power utilities, can sell their redundant pollution permits to other branches with the result of an unchanged quantity of emission reductions in comparison to the NAP but at a lower cost level. Research generally focuses on economic and not ecological efficiency: The lowest costs for the permitted (carbon) emissions are considered to be a Pareto optimisation for the emitters, and not what could be obtained as the highest possible carbon savings for the general public under a specific budget. Thus, the question arises, if both climate protection policy instruments are jointly implemented, what is the combination that would lower absolute emissions across sectors below the cap set in an emission trading scheme? The maxim is to optimise the quantity of emissions savings as welfare optimising point of view and keep the costs on a business as usual level: the permit price remains constant, while the amount of savings increases.

But first and foremost, however, both instruments require a more in-depth elaboration of their theoretical content. It is of a lesser importance to explain the exact design of the EU-ETS and whether participants are faced with scarcity of emission permits and therefore far from a market equilibrium and what kind of markets are involved. The proposition of this chapter does not require proof of a detailed design of support mechanisms, but is proven,rather, the simultaneous application of the two instruments, which, although seemingly contrary to each other, open up avenues to save more emissions at the same cost level for the individual emitter.

The EU is primarily pursuing the instrument of a Europe-wide CO_2 emission trading scheme, the EU-ETS. The EU-ETS develops in phases and covers about 50% of carbon emissions of all participating sectors. Its design consists of three phases of increasing length: Phase I was from 2005-2007, Phase II from 2008-2012 and finally Phase III finally from 2013-2020. Each phase is a closed trading period with a maximum allowed carbon emission quantity and permits cannot be transferred from one period to another. This instrument sets a maximum allowance as the limit for the emission of greenhouse gases and thus fulfils the EU climate targets to meet the Kyoto Protocol and the 20-20-20 by 2020 Commission targets.

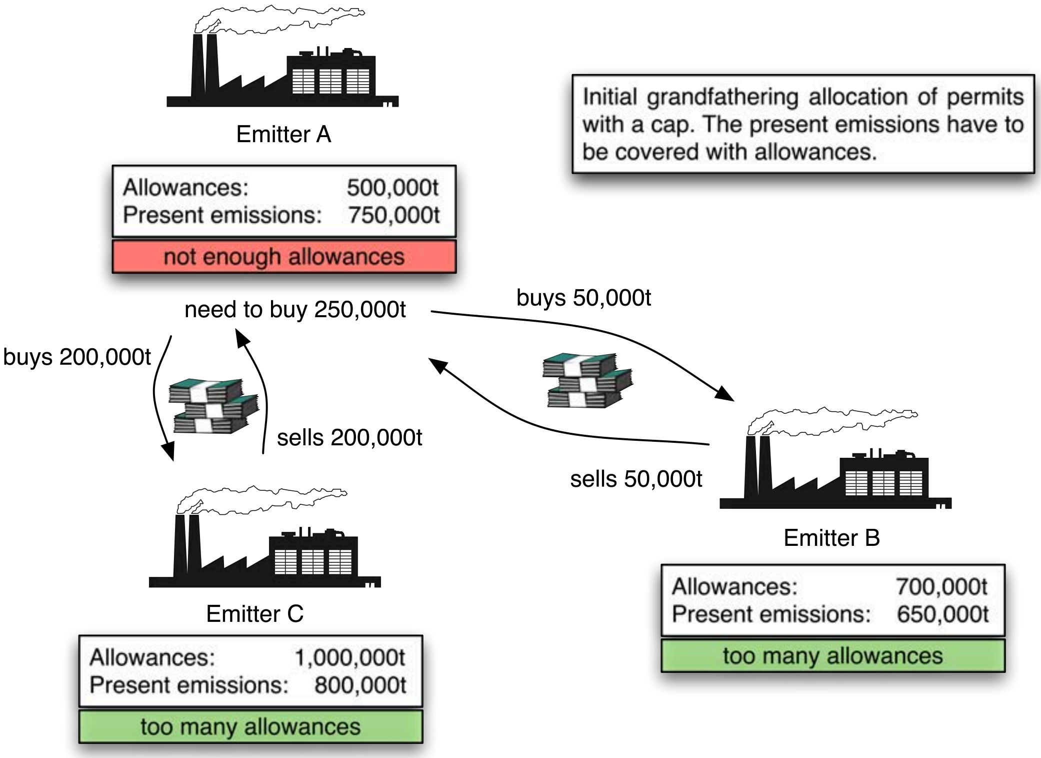

Figure 3: Emission trading scheme, *illustration of the function of an emssion market and its transactions, own illustration.*

Within a phase, allowances can be traded between participating emitters directly or with the help of intermediate stock trading. The trading between different emitters is illustrated in Figure 3. The overall quantity of emitted carbon pollution is subject to a cap. Participating sources receive the historical needed allowances for free or buy them from the government in an initial auctioning process or from other participants. The allocation process as well as the need to hand over enough allowances to cover the emissions of a source is done year by year. While in the Phase I and Phase II the annual allocation is constant, starting with Phase III the emission cap reduces annually.

Phase I and II force EU-member states to organise the allocation process based on their NAP. The NAP is part of the overall carbon-saving obligation. Less savings in the EU-ETS lead to the need to save more emissions in other sectors[9], which has to be accepted by the EU commission. The allocation should be based on a grandfathering process of historical emissions.

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[9] Sectors not covered by the EU-ETS are e.g. road transport, private consumption or the most services branches.

Phase I, from 2005-2007, placed emphasis on the learning-by-doing process. The allocated emission permissions turned out to be too gratuitous with the consequent decision to reduce prices to zero in 2007.

In Phase II, from 2008-2012, the quantity of allowances was reduced and more branches, for example the aviation sector, had to participate. A larger amaount of certificates was auctioned rather than given away complimentary to participants. For the first time, participants could choose to use either one of two instruments, Joint Implementation (JI) or Clean Development Mechanism (CDM) as part of their obligation: measures, all measures to save emissions in less developed countries. These instruments come along with a transfer of technology to develop a more clean production capacity in countries without emission-saving obligations.

Phase III, from 2013-2020, is to be marked by major changes in the design of the EU-ETS with an annual reduction of the cap and an increasing share of certificates that are permitted to be bought through the auctioning process instead of free allocation. The basis for allocation shall no longer be grandfathering, and some more branches will be covered. The power generating industry is anticipated to be the first sector with 100% auctioning.

Through the flexibilities of the EU-ETS system, emission savings should be done where the costs are at the lowest. Participants can also profit from early action. Investments in emission-saving technologies lead to a smaller demand in allowances and thus decreasing costs. One danger of free allocated emission allowances it the issuing of banking certificates that are not sold in the end. While this may be economically incomprehensible, the tendency for human psychology to lead to such behaviour is present.[10]

After Phase I of EU-ETS commenced, the literature discussed in particular if the associated cap on emissions was set at the right level:

In a theoretical system-wide equilibrium, the marginal abatement costs equal the price of allowances, while single emitters face the decision of whether to buy permits or instead save emissions through technical innovations. The market in reality has a price for the good of emission permits, resulting from the supply-demand-function arising from the fact that permits are a finite commodity set exogenously by the policy maker. It remains unclear to what extent social costs are considered: burning fuels

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[10] To prevent banking, some trading systems have implemented special mechanisms, see Godard (2002) or Tietenberg (2003).

cause damages that are often not included in the overall cost account. Finally, it emphasises the need to accept the price as the only economical pressure for individual emitters to save emissions at the location of the pollution source. That is highly important to understand, because "without government intervention, producers would face no cost at all associated with pollution, but only a benefit. (...) Therefore, they would select an infinitely large level of pollution." Bovenberg and Smulders (1995, p. 379). Higher permit prices lead to higher emission savings for the single emitter, because savings become more competitive.

Some authors focus on whether the quantity of allowed permits is set at the right level and on the ecological efficiency, e.g., are the CO_2 savings the maximum that can be derived from the application of technology at the state of the art? Schleich and Betz (2005), as well as Betz and Sato (2006), determine that the initial allocation can already indicate the likelihood of over-allocation or abatement, where the potential savings will not occur if allowances are cheaper than the abatement of emissions through technological measures for the single emitter. The same problem is encountered within the regulation of NAP for emission permits: Ellerman and Buchner (2007) argue that such plans are often less ambitious than technological developments would allow. Thus, the reduction of emissions is not maximised, and the potential of technological feasible savings remains unused.

Feed-In-Tariff I*	Feed-In-Tariff II**	Quota obligation
Austria Bulgaria Cyprus Czech Republic Denmark Estonia Finland France Germany Greece Hungary Ireland Latvia Lithuania Netherlands Luxembourg Portugal Slovakia Slovenia Spain	Belgium Italy Malta United Kingdom	Poland Romania Sweden ——— * *only feed-in tariff or feed-in premium apply* ** *for selected technologies, partly besides other promotions*

Table 3: EU-27 application of RES promotion
Sources: Klein et al. (2010), Ragwitz et al. (2012)

Other authors concentrate on how emission trading schemes can be optimised, focus on the economic efficiency of the costs for the participating emitters, see the comparative analysis of different analyses about diverse trading schemes and their costs for the participants by Tietenberg and Johnstone (2004). While a lot of ETS or similar systems were applied locally, the EU-ETS can be seen as the first large-scale cap-and-trade market, an "experiment" as stated by Kruger and Pizer, (2004), with all the early stage problems such as the orientation of NAPs based on past emissions and growth, as well as the anticipation of growth to future emission scenarios without rigorous cuts: the results are present emissions well below the intended allocation that leads to permission prices at zero or only a little above zero, which was proved positively by Schleich, Betz and Rogge (2007). Not contrary to this point, but supplementary, Alberola, Chevallier and Chèze (2008) analyse the policy intentions and criticise the often missing political volition: pressure forces emitters to accept bigger emission cuts. If the pressure is low, this can lead to higher economic costs: ETS participants anticipate (low) permit prices and become less innovative in light of the problems associated with the higher costs of the long run perspective. Again, as explained before, the price seems to be the only measure to bring emissions down.

At the same time as implementing the EU-ETS, the EU-27 member countries are encouraged to increase the share of RES through national incentives. There is no common set of policies, but best practice shows the domination of one specific instrument (see table 3). The implementation of new technologies often arises through national decrees that guarantee a fixed renewable energy feed-in tariff (REFIT)[11] for every produced kilowatt-hour (kWh) of energy. The newly installed capacity is (almost) free of CO_2 emissions. Electricity suppliers are obliged to primarily feed in electricity produced from any renewable energy plants in their service territories. This commitment helps the affected enterprises from the power generation sector to reduce total emissions without what would otherwise be necessary spending on permits. Through selling allowances, other sectors can be affected as well, as the supply of permits will arise.

If the additional RES capacities are changing significantly the market conditions, the permit market should be reorganised and adjusted under the uncertainty of the future

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[11] Besides REFIT, there is a shift toward the instrument of "*Feed-In premium*": the general structure is identical to a REFIT, but a fixed amount is paid on top of the average spot market price per kWh. Producers of green energies are obligated to sell energy through contracts or spot markets.

realised amount of new RES capacities. Some similarities can be found in the literature about the overlapping effects of ETS and the [ETS-] system aside from emission taxes. Not all industries are covered by the EU-ETS, thus taxes can be an instrument to force emission reductions in non-EU-ETS sectors. Eichner and Pethig (2010) refer to the unclear effects of different and overlapping instruments, namely ETS and (sector specific) taxes. The authors seek to quantify the economic and ecological efficiency and determine the risk of a *dry-up* of permit markets through taxes. The new installation of CO_2 neutral capacities in one sector appears to cause similar *dry-up* effects and RES installations may reduce the efficiency of the EU-ETS.

2.2 Introducing RES promotions

The REFIT is a price-driven instrument and shall stimulate private investments and is generator based: every single investor decides on his individual project and its return on investment. Other price driven strategies are tax credits, low interest rates or softloans, and they are investment focused; quantity-driven instruments include tendering or bidding schemes or tradable certificates (see Haas et al. 2011a).

REFITs are the most successful instruments and tend to have the lowest additional costs for final customers: "thus, a well-designed (dynamic) FIT system provided a certain deployment of RES in the shortest time and at lowest costs for society" (Haas et al. 2011b, p. 1033). Bovenberg and Smulders (1995) suggest that "the government should pay for the development of new technology and freely provide the knowledge to firms", and in particular in the generally assumed situation of perfect competition, thus for "new pollution-augmenting technology (...) no quasi-rent would be left to pay for (...). Hence, pollution-augmenting technological innovation would not be rewarded and thus no research would be undertaken" (p.379), polluting technology would have no future in the market, green technologies would have advantages. Without a REFIT, the spread of RES investments through private investors would be much smaller and the learning curve and associated increase of efficiency rates and decreasing marginal costs of (green) electricity would not be as intense as observed under such a promotion regime. Obviously, other instruments besides the REFIT, like quotas or obligations, seem to have economic disadvantages and are not broadly applied. For the application in EU-27 see table 3. Thus, they will not be considered in detail below, and are therefore neglected in this chapter.

The general design of REFITs is relatively simple and consistently applied in the EU member states: under a REFIT investors will be paid a fixed tariff for the produced energy over a specified duration, typically 20 years. The local grid operator is obliged to feed in the green-produced electricity primarily. The REFIT rates are differentiated: for example on the basis of technology, geographical conditions or the capacity of the plant. The important condition for the REFIT design is to guarantee a cost-effective operation for the investor of the power plant. The REFIT rate for newly installed plants is subject to a regular decrease. That is important to put pressure on the technology manufacturing industry to decrease their prices. The decrease in the REFIT compensation can be legitimated through shrinking costs caused by higher

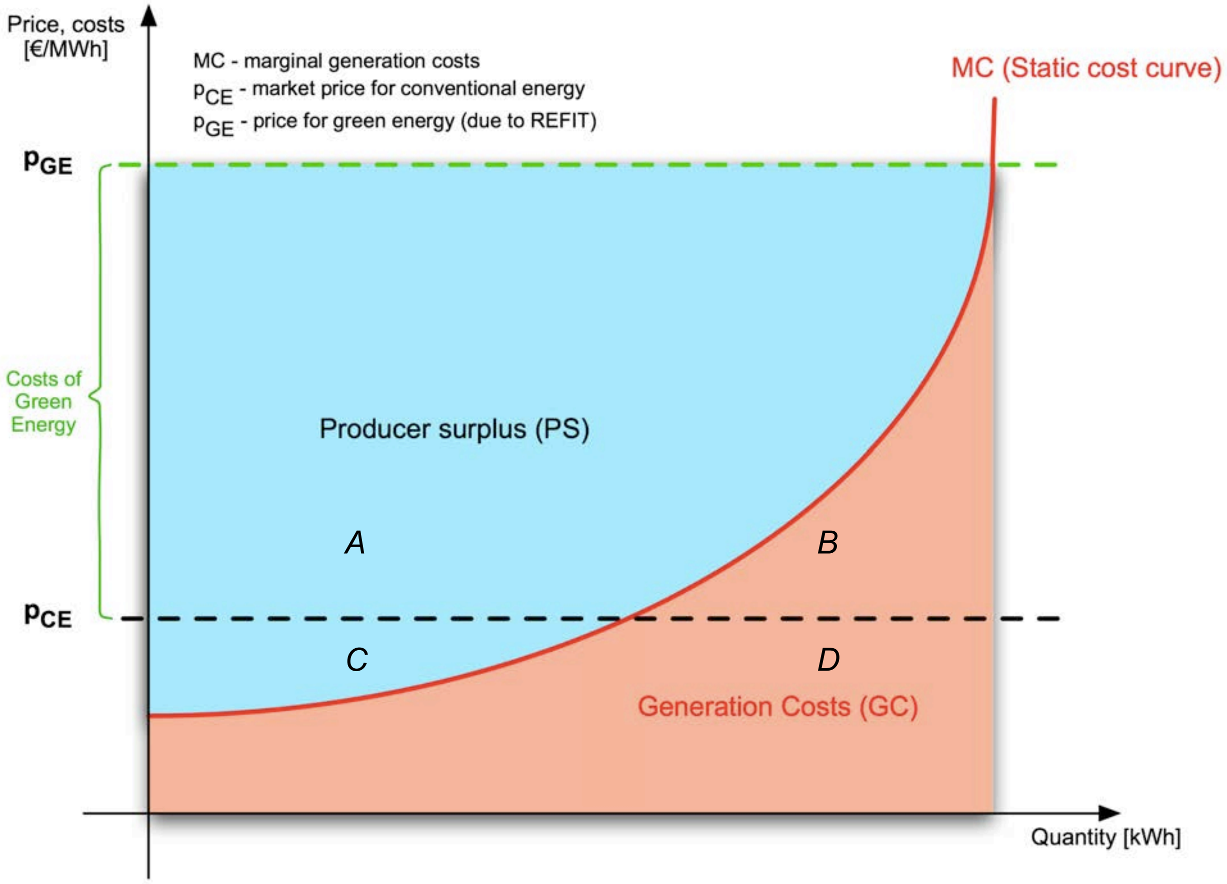

Figure 4: Cost of energy produced due to REFIT tariffs, *where producer surplus* $PS = Q \cdot P_{GE} - C(Q)$ *with quantity Q, price for green energy* P_{GE} *and total production costs C(Q); own illustration according Haas, 2011a.*

technological efficiency (learning curve) and cost effects in the manufacturing process (economies of scale).

REFITs typically apply with different rates and/or for selected technologies like e.g. the German Renewable Energy Sources Act (EEG, Erneuerbare Energien Gesetz) stipulates that the following sources will receive a guaranteed funding per kWh: solar energies (photovoltaics, solar thermic): 31.9 - 43.0 cent, hydropower: 3.5 -12.7 cent, biogas: 6.0 - 14.3 cent, geothermal: 14.5 -27.0 cent.[12]

According to Haas (2011a), the "additional costs for consumers (policy costs) have to be paid finally by electricity customers" (p.2188) and contain the producer surplus plus generation costs minus revenues from the electricity market (minus avoided external costs).

The resulting additional costs are expenditures for the electricity customers above the standard or conventional energy price, and thus the profit for the RES power plant owners, as shown in Figure 4. The figure illustrates the economy-wide costs of RES: the quantity is determined by the aggregate of all energies, green and conventional, that meet the energy demand. Green energies receive a REFIT which is equal to the price of green energies (P_{GE}) on the market, but much higher than the price for conventional energy (P_{CE}). The additional costs result of the diagram areas A and B, the higher profits for RES suppliers (A) and the higher generation costs for less efficient RES sources (B) compared to an equilibrium without the REFIT. The investor or producer surplus is based on the generation costs (GC) of the RES and is an individual figure, thus equal to the areas A (REFIT) and C (non-REFIT equilibrium profit). The RES must be feed in first. The costs of RES can be above the P_{CE}, which would in free markets determine the P_{GE}, too, as both would compete. Here, the REFIT is guaranteed and causes $P_{GE} > P_{CE}$. The economic costs of green energies are the gap between P_{CE} and P_{GE} if analysing the sales price, multiplied with the quantity of RES, and for the sum. The fixed REFIT is coming along with a redistribution effect to an increase in the producer rent: for all generators covered by the REFIT, the generation cost is not the benchmark for the payment but the feed-in tariff.

The local grid operators pool the difference between the rate paid and revenues from the electricity. A national clearance system divides the costs evenly between all national network operators. Thus, regardless of regional differences in the generation

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[12] References year: 2008, fixed feed-in tariff for 20 years.

of electricity from renewable energy sources, all energy utilities carry the same REFIT payment per kWh. Final consumers will be charged the retail prices due to price calculations of the electricity sector.

A detailed overview of the various national RES promotion policies cannot be given here and is not relevant to explain the effect, which is not depending basically on the exact amount of the REFIT. The general conditions under which the EU members support new RES installations are considered to vary too widely for a true comparison to be possible, e.g. time duration and amount of the REFIT payment, or the selected technologies. Another very important distinction is the capacity capping of the REFIT payment. While some national governments set an annual maximum for new supported installations, others do without. In case of a cap, there should be a negative effect on investment confidence through growing uncertainty over wether a new plant will be supported through the REFIT scheme or not. The cap on REFIT payments guarantees the achievement of the NAP-calculated RES capacity but shatters the investors' confidence if the standing of the new plant is uncertain with regard to its ability to gain REFIT payment.

The theoretical analysis in this chapter is about the issue of the general integration of RES promotion into an ETS with the chances of additional CO_2-savings. An important characteristic of a REFIT is the priority feed-in of RES into the grid. The consequences are far-reaching as it shifts the mix of the residual load required to be produced by conventional energy sources. Energy utilities will switch off the most expensive power plants, under the conditions of transport of electricity to ensure the delivery of the base load in the grid.

The REFIT stimulates RES investments. The REFIT, the investment guarantee for the RES, is paid by all consumers through a levy on all energy sources whether they are conventional or green. It has two effects on the demand: firstly on energy capacities and secondly on the quantity of demanded certificates. Through the statutorily stipulated priority feed-in of RES, the *merit-order effect*[13] occurs, see Figure 4: for the spot markets pricing in the short run (intraday or within a short period) power plants will be ranked according to their marginal costs of production. Those with the lowest cost will be ordered first to fill the gap of the current residual

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[13] The merit-order effect can be observed only if one or more goods (e.g. energy sources) are positively discriminated. As for German electricity from RES, in general it has to be immediately fed into the grid. Here the effect is most often described theoretically and in absolute figures, see Sensfuß and Ragwitz (2007) and further analysis of the authors published by the BMU.

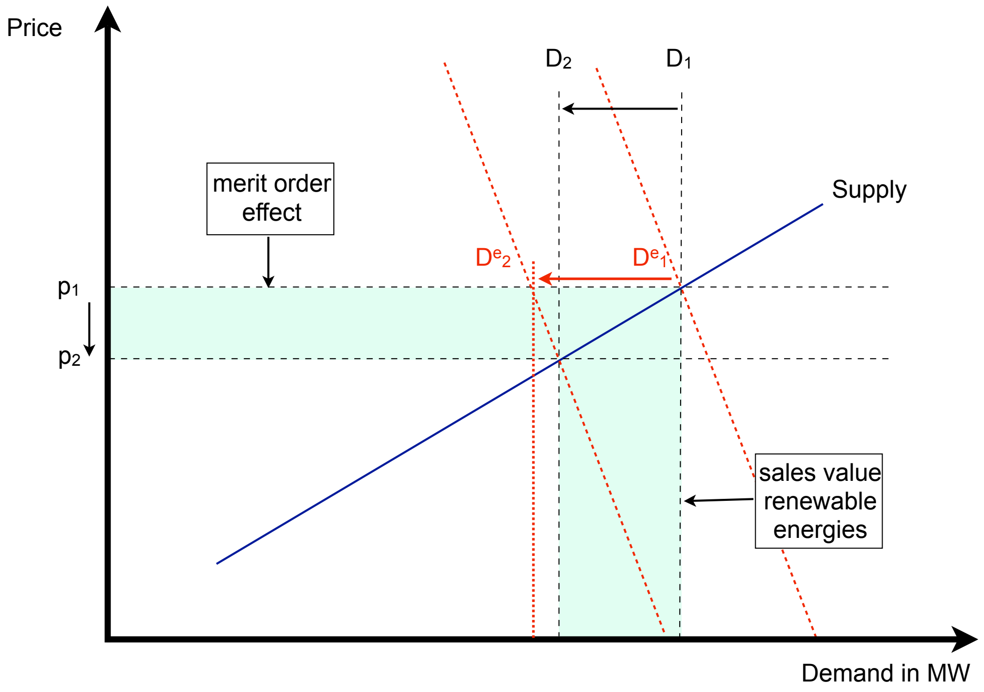

***Figure 5: Merit-order effect**, own illustration.*

between RES feed-in energy and power demand. Depending on the demand quantity, the last considered power plant determines the price for all suppliers. Power plants with higher production costs than the spot price are shut down. Hence, the demanded quantity for conventionally produced energy is reduced from D_1 to D_2. This comes along with a price decrease from p_1 to p_2 and is the cost shrinking component on (consumer) electricity prices, as shown in Figure 5. The supply is determined by an inelastic[14] short run demand of electricity. Even for the assumption of elastic demand, the conclusions do not change fundamentally - compare the elastic demand of D^e_1 to D^e_2 with D_1 to D_2 in Figure 4. In the illustration, the geometrical distance between the two demand functions shows how much energy from RES is provided.

The mechanism of replacement has been proven by Weigt, Ellermann and Delarue (2013). The authors describe the injection of REFIT stimulated RES investments in the market as such: "RE injections displace whatever is on the relevant margin with a zero-CO_2-emitting source." (p. S158). The replaced sources are nearly always less efficient plants with high carbon emission.

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[14] See Morthorst (2003), or Sensfuß, Ragwitz, Genoese (2008) for empirical analyses of German energy markets. Branch (1993) described a very low elasticity of US markets, Holtedahl and Joutz (2004) analysed Taiwan‘s demand of household energy as price inelastic.

With inelastic demand (D_1 and D_2), the price decrease from p_1 to p_2. For the same decrease in price, with elastic demand, a larger quantity of RES produced energy is needed. For further analysis cf. Sensfuß and Ragwitz (2007). The decreasing energy prices redistribute a part of the producers rent to the consumer rent with the condition that the REFIT payments themselves are only paid by end consumers. Thus, heavy industrial consumers have a real decreasing effect on prices, while for end consumers it is a zero-sum game. The effect of the shift from producer to consumer rent is difficult to specify exactly: Wissen and Nicolosi (2008) describe the effect of a change in the generator mix for the residual load, influenced by diverse factors, one of which is the RES capacity. They argue that the production cost may decrease with an positive effect on the producer rent.

For Germany, the value of the merit-order effect is calculated to be higher than the annual costs for the consumer through the REFIT levy, hence the cost effect is positive, see Sensfuß and Ragwitz (2007), and Sensfuß, Ragwitz and Genoese (2008). For the merit-order effect and for the substituted energy sources, see Bickel, Kelm and Edler (2009). If so, one should agree to reallocate the cost of carbon emissions to the consumer. REFIT payments do not stand for carbon costs, but the installed capacities reduce the pollution due to a reduced need for conventional energy consumption. Thus, the REFIT payments are decentralised carbon savings made exogenously, without additional costs as long as they do not exceed the cost savings caused by the merit-order effect. For further analysis, the REFIT payments and merit-order effect will be counted equal with resulting costs of zero.

2.3 The theoretical framework of a trading scheme

The implementation of a cap-and-trade system creates a market for the good "emission allowances" under certain regulations. Pollution allowances become a good: modern economies are based on industrial production and as a negative consequence, the environment is polluted and damaged by by-products of manufacturing processes. The emitter is using the air as a good for private purposes, while the costs of pollution, cleaning mechanisms and the reduction of environmental impacts are public.

Production has to pollute, otherwise there would be no output. Regulation is an issue due to the missing price of the environmental impact of production and the resulting social costs of its pollution. Pollution implies for the free usage of public goods, e.g. air, water, forests, natural resources, or land. The missing price for these goods and the non-compensation for the ecological negative outcome of production can be classified as a market failure.

The idea of an ETS is to charge polluters for their emission quantity and reward the injured parties. The question of interest is, how to price carbon emissions? During the production process, when burning fuels, the exhaust gas will be emitted at the place of the manufacture. But the ecological impact often does not appear at the same time and place. If a fisherman cannot fish any more because the water close to a production unit is polluted to the extent that all fish die, the injured party is identified easily. The fisher should have the right to negotiate with the polluter about how much pollution will be and has to be accepted, and the price of compensation for the abandoned fishing. For example, direct costs are easy to name but it is much harder to identify who is affected by pollution and when. The emitter can pay for pollution directly. Moreover, it is difficult to measure the damage to nature and the consequences over time. If the emitter has not paid during the fuel burning process, it will be rather hard to identify who is responsible and to what extent for environmental damages a long time afterwards and estimate the costs. A price for the social costs of greenhouse gases is hard to set. It is much easier to establish a system that prices the emissions directly at the source, i.e. where the emitter pollutes the air. Thus, pollution and its ecological impacts are internalised.

Emission allowances are a market-based instrument that prices air pollution. The allowances become an additional input factor influencing production processes and the prices of goods. Other measures such as carbon taxes are an option, but not market based and thus less cost effective (see e.g. Parry, 2003). Only markets force emitters to compete for the emission permits or save emissions if prices for allowances are higher than the cost of savings. A cap on allowable emissions is set that determines the absolute quantity of pollution for all emitters, e.g. in one economy. The demand for permits makes them a scarce commodity and every permitter has to decide to make-it or buy-it: if one does not emit there is no need for allowances. The alternatives are holding permits or avoiding emissions. Single emitters will decide according to cost minimising conditions. The advantage for the whole economy is the avoidance of emissions and the meeting of the target set as the emission cap, assuming a least cost solution.

The scientific discourse about the best solution for cost compensation of pollution has a long standing:

Pigou (1912) described the only private use of air and the general public as the victim of air pollution, where the state should be willing to undertake corrective actions, otherwise no compensation would occur.

Coase (1960) first addressed the debate on a compensation for ecological damages payable by the emitter to the injured individual as a reciprocity process: Both parties should thus find the price for the damage through private negotiations under the condition of perfect information. Due to the asymmetric allocation of information the problem cannot be ideally resolved, as it should be. He gave the example of a cattle-raiser whose herd stray onto the cropland of the neighbouring farmer. The use of one of both is the damage of the other. Thus, both should accept a solution where meat and crop will share the property rights of the land. Depending on the individual marginal cost curves, independent from the initial assignment, the allocation should be pareto efficient where the marginal costs of both parties are equivalent. The example can be easily transferred to the public good air, where the polluter has a use of air, while the damage of pollution causes a negative use.

Crocker (1966) proposed to link emission allowances to the ownership of land. The allowance for air pollution refers generally to the own land, heavy pollution will result in a tax or other compensation for damages: the use of air produces a positive output (e.g. goods) at one place that causes damages at another place (e.g. *waldsterben* - forest dieback, or health problems and higher mortality rates from cancer and other diseases). Both parties should have a (financial) incentive to allow a specific amount of pollution on one side and avoid emissions on the other side.

Dales (1968) added that the policy maker must fix the maximum quantity of emissions allowed with an exact description of where and when the emission is allowed, while the price of every single permit must be found in a classical market scheme in relation to the number of allowances demanded.

The explanation of the market of a cap-and-trade system requires simplification. In the following, a classical market shall be assumed under the conditions of perfect competition and perfect information.

The one side of the market covers the private emitters: All emitting sources have to participate in the market. The pollution of air allows emitters to produce goods and services. Without any regulations, emitters will produce at the maximum capacity that returns positive earnings. By introducing market regulations such as a cap on permitted emissions, each single emitter is price taker and can decide to reduce its production with the consequence of a reduced output of carbon emissions and a loss of profit, or let the production remain on the same level as before and pay for the superfluous emissions not covered by the cap.

On the other side of the market, the general public grants permissions to the private emitters to pollute the air corresponding to the price of the damage that occurs through pollution.

The cap-and-trade market can be described as to being comprised of two submarkets: in one submarket, or the demand side of the cap-and-trade system, participants compete for emission allowances, emission savings will occur where they are cost-efficient corresponding to the aggregated marginal abatement cost curve. The other submarket, or the supply side, is dictated by the policy maker: the estimation of the damage costs through pollution determines the quantity of pollution allowances and thus the equilibrium price regarding the supply side's aggregated marginal emission cost curve. The social optimum than is realised at the point where both curves intersect.

In reality, it is not clearly explained how markets for emission allowances work. Empirical studies show evidence of (partly) normal market conditions for some periods, while others are characterised by uncertainty about real consumption of permits *ex ante*, the influence of weather and other *forces majeures*, market participants, limited trading periods, and the artificial implementation of markets for permits as a new good. All factors can lead to over-accumulation and banking of certificates on individual level, while the effect on markets are not affecting prices or efficiency, moreover, volatility seems to be less, cf. Ellerman and Buchner (2007), Wagner (2007).

The following model will first generalise the emission permits market in this section, and discuss the efficient set of a cap. In the further two sections the interdependencies of RES and the EU-ETS will be discussed, focussing on one single branch, namely power production as one of the biggest groups of air pollution through GHG emissions.

If the use of the air becomes a good, the individual profit of the emitter is the corresponding benefit of the emission less the cost. The aggregated use is the private profit of emitters, while the environmental damage costs are to be born by the general public. The welfare-maximising condition is the point where marginal use of emission equals marginal damage. This Pareto efficient situation indeed turns to be hardly obtained.

It is difficult to implement the optimal cap due to missing information about real costs of emissions. Each single emitter knows his individual marginal cost and use curves. The estimation of the damage costs is much more difficult due to lack of information, the time horizon and the global impact. While the benefits of emissions can be measured for the emitter as his profit, the damage remains abstract. Baumol and Oates (1988) describe the problem as the responsibility of the policy maker to set the emission cap regarding its information, scientific analysis and economic forecast, but in any case as an arbitrary choice. This choice might be a Pareto optimum, but more probably the set is too strict or to generous, emitters face a not-optimal situation for abatement. The set standard should be achieved cost-effectively. The authors summarise this so called standards approach as a system of "efficiency without optimality" (p.159).

Böringer et al. (2006) describe the standards approach for the national EU-ETS markets. The following analysis adopts the considerations and shows that any individual emitter must reduce its profit-maximising quantity of emissions by a specific avoidance. The amount of emission savings depends on the individual marginal abatement cost curve in relation to the aggregated market cost curve. The emitter choose between two options, emitting or avoiding of emissions, and takes into consideration the market prices for his decision. The aggregated market cost minimisation solution is efficient for the given set.[15]

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[15] The authors are analysing the cost efficiency of separating carbon markets, while the basic assumptions are similar to the approach of an efficient cap-and-trade system.

Without restrictions, in the absence of any regulations, the total emission E_0 is equivalent to the sum of the individual profit maximising CO_2 emissions E^{max} of N emitters, namely pollution sources:

$$E_0 = \sum_{n=1}^{N} E_n^{max} \tag{1}$$

Under the unrestricted use of the air, the polluters realise the production quantities that maximise their private earnings, while the damage through pollution is the negative environmental impact and thus causes undefined costs for the general public.

The overall welfare comprises of the private profits of the polluters, who can realise earnings through the selling of the production of goods and services, reduced by the social costs of air pollution and environmental damage. It is difficult to calculate the net benefit of pollution. The net use of pollution is the resulting GDP and the strength of the economy. The net damage is the sum of the diverse impacts of the environment that are already occurring, such as a weakened, less healthy workforce and those that shall occur in the future, such as negative growth perspectives if a shortage of natural resources will occur due to environmental conditions.

Within an emission trading scheme, here the EU-ETS, the policy maker limits the total allowed emission quantity and limits not only pollution, but private profits. It is the responsibility of political leaders to balance net use and net damage to guarantee a welfare maximisation for the general public and its net use of pollution. It underlines the major policy challenge of implementing instruments to control emissions under the conditions of economic-ecological needs. The cap-and-trade system is just one component in the environmental policies framework. It can illustrate well the difficulties of examining the correct functions of the net use and the net damage and where to set the pollution cap, for the further analysis of the resulting net effect of a cap, see chapter 2.4.

The set cap $\overline{E}$ determines the allowed quantity of emissions and is equal, or below, the emissions level of the profit maximising quantity, thus system participants have to reduce their system wide maximum demanded emissions E_0 by the sum of the abatements A_n of all N emitters to satisfy $\overline{E}$, the cap set by the policy maker. This is ideally at the point where the marginal costs of emission saving are equal the marginal costs of damage through caused emissions:

The most common scenario is the shortage of emission allowances in comparison to a policy without restriction. The cap $\overline{E}$ forces emitters to reduce partly their profit maximisation emissions E_n^{max} by the abatement A_n:

$$\overline{E} = \sum_{n=1}^{N} (E_n^{max} - A_n) \tag{2}$$

The single emitter can individually choose between avoiding emissions or buying permits under market conditions for the remaining emissions depending on their marginal costs for the additional reduction in one unit of pollution, the individual marginal cost curve (MAC)[16]. The aggregated MAC is the sum of all emitters' individual curves and determines the system wide emission saving. This aggregation is highly important in the further analysis when discussing the right set of the cap. Here, it is assumed that the system-wide cost minimisation leads to emission savings, which are realised at the lowest cost point. Emission rights flow to where emission savings are cost intensive and emitters will buy allowances from participants who abate pollution. MACs are an often-used approach to "communicate findings on the technological structure and the economics of CO_2 emissions reduction", (Kesicki, 2013). They can show the potential for carbon abatement though with the flaw that they are unable to explain in detail technological changes or interactions of influence factors on abatement costs. Nevertheless, for the following theoretical discussions, the aggregated MAC simplifies steady conditions for emitters: price and quantity effects will not be influenced by other factors like technological change or global increase or decrease on demand.

Each single emitter produces under its individual marginal cost curve.The aggregated cost curve for all emitters and its first order conditions explain the system wide saving potential. Emitters are price takers, the short run MAC is steady, e.g. technological change will not influence the cost function. The shortage of emission allowances determines through the set cap the autarkic price. If the autarkic price is lower than one emitters individual abatement costs, the emitter is willing to buy emission permits from the market; conversely if the autarkic price is higher than the emitters abatement costs, he will save pollutions and sell the corresponding abatement quantity into the market, see Ellermann, Decaux (1998). The MAC curve gives the

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[16] Parry (2003) describes the primary costs as the triangle that span under the MAC curve "equal to forgone benefits from fossil fuel production net of reduced production costs" (p.388). The result is the sum of emission abatement or reduction in emission output.

same information for the marginal use of emission and the marginal abatement costs, depending if the point on the MAC is above or below the autarkic price.

The decision about abatement or pollution comes along with its cost function. It is composed of the sum of the remaining emissions for all emitters N after their individual abatement $(E_n^{max} - A_n)$, and the sum of emission pollution $(E_n^{max} - E_n)$. Both, the emission saving or pollution, have the same price p. The emitter pays the price of the permit that the avoider sells.

The abatement cost curve is characterised by progressively increasing cost, thus it is assumed that $C' > 0$ and $C'' > 0$, cf. Böhringer et al. (2006).

System participants emit will reduce their profit maximising emissions E_0 by the sum of their individual emission reduction A_n, the emissions E_n remain. For those remaining emissions, emitters have to buy emission permits. The abatement A_n has the identical price p and results through the technical costs of emission savings and the loss of production. The compliance cost of the set cap thus is

$$C = \sum_{n=1}^{N} E_n p + \sum_{n=1}^{N} A_n p \tag{3}$$

The abatement A_n is equal to the profit maximising emissions E_n^{max} minus the present permissions E_n. Individual emitters control their emissions according to the emission costs p. Depending on the decision about the emission amount of the cap, the abatement costs follow as a result of the abatement quantity A_n and the abatement costs.

Under the assumption of the abatement as the sum of the maximum demanded emission quantity reduced by the emission reduction, the single emitter choose his individual saving strategy as a price taker: $A_n = E_n^{max} - E_n$.

The associated first-order condition for the aggregated cost curve shows that the marginal emission costs are equal the price p across all system participants:

$$\frac{\partial C}{\partial E_n} = p \tag{4}$$

Giving up one unit of production is saving the cost of one emission permit p, the costs are equivalent to the abatement costs p. The damage will be reduced by one unit of emission, equivalent the equilibrium price $\overline{p}$.

The single emitter will emit, if his utility of emission is higher than the cost of abatement. The marginal abatement cost MAC curve is decreasing by the price, equal the avoidance of one produced unit or its individual emissions. The marginal damage or marginal emission cost curve MEC is increasing by the price of emission. The welfare optimisation is reached, where MEC equals MAC.

The compliance costs result from the necessary permits, multiplied by their price p for the emitted pollution quantity. The obligation to acquire allowances can be substituted by an emission reduction. Realised cost savings by this emission avoidance are equal to redundant fuel costs. The substitution will take place when and where the marginal cost of avoiding one unit of pollution is lower than the price $\overline{p}$ for the emission allowance. The total costs then consist of the avoidance costs and the costs of allowances for the remaining emitted amount $E_n^{max}-A_n$.

In case of realising a larger abatement, the emission amount actually realised by the sum of all E_n, can be less than the set target cap and should be equal to the cap as long as the marginal costs of abatement and the marginal costs of damages are equal:

Every produced unit causes a use, U, and a damage, D; thus while the abatement of a single unit on the one hand decreases the profit of the emitter, but on the other hand reduces the social costs of pollution.

The use, U, is the benefit through emission, e.g. production and earning, reduced by the permit price in relation to the emission quantity.

The damage, D, is a negative use function of emission and the resulting pollution, the compensation equal to the price of permits in relation to the emission quantity, partly reduces the damage.

$$U = \sum_{n=1}^{N} U_n(E_n) - \sum_{n=1}^{N} E_n p \tag{5}$$

$$D = \sum_{n=1}^{N} -U_n(E_n) + \sum_{n=1}^{N} E_n p \tag{6}$$

The cost effective optimum is achieved if the marginal costs of emission reduction per unit are equal to the emission price. The emission price itself is depending on the emission demand in the cap and trade system. To evaluate the use and damage costs, it is an exogenous given, constant price.

For the optimisation of use U and minimisation of damage D follows:

$$\frac{\partial U}{\partial E_n} = \frac{\partial U_n}{\partial E_n} - p \tag{7}$$

$$\frac{\partial D}{\partial E_n} = -\frac{\partial U_n}{\partial E_n} + p \tag{8}$$

The associated first-order condition states the emission use is equal to the emission price:

$$\frac{\partial U_n}{\partial E_n} = p \tag{9}$$

Effective cost control and sanctions for the individual failure of participants lead to a system that ensures the exact attainment of the maximum allowed emissions $\overline{E}$, the policy maker chosen cap, equal to the sum of all emitters' E_n^{max}-A_n. Hence further technically possible reductions of pollution will not occur. They are not cost-effective for the individual emitter who is a price taker, because the individual costs for one unit of abatement A are higher than the equilibrium permit price $\overline{p}$.

The advantage of the ETS system is the efficiency of permit trading between system participants, the flow of emission permits to the point where the physical abatement is at the highest cost. Emissions savings are found at the minimum cost point, as described by Baumol and Oates (1971). Hence the initial allocation, i.e. grandfathering according to historical pollution, auctioning in the market or other instruments, is without influence. Permits are "flowing" to the place where emission saving would cause the highest costs. A single firm will be a seller of allowances as long as the permission price p is higher than the individual marginal abatement costs curve (MAC) of emissions: correspondingly the MAC for the whole market determines the absolute emissions - for the aggregated market, the price p for allowances will be equal to the optimum, which can be realised by the joint MAC for all ETS market participants (Montgomery, 1972). Tietenberg (2003) verified the theory by evaluating different applications of diverse ETS. He highlighted the importance of the appropriate implementation of financial sanctions for the case when a participant fails to hold enough permits to cover his emissions output. Thus, if sanctions are high enough and at least equal to the permit price, all participating parties in the ETS meet the binding cap.

2.4 Net effect of a cap

In the framework of an ETS, the policy maker can choose the level of the cap and thus set three different scenarios in motion. The setting of the cap at the appropriate level is thus important for the economic wide emissions. Due to a certain trade-off between the two purposes, namely, cost efficiency (price), and ecological maximisation (savings quantity), it is important to define the initial cap as the measure that determines the achievement of these objectives. Put differently: the net benefit *NB* results of the sum of net use *NU* of pollution for production purposes reduced by the net damage *ND* for the general public.

$$NB = NU - ND \quad (10)$$

Derived for the use of pollution, the optimisation of the net benefit, social use, results as the equilibrium emission price and quantity for which the marginal abatement cost curve is equal the marginal emission cost curve.

$$\frac{\partial NB}{\partial U} = \frac{\partial NU}{\partial U} - \frac{\partial ND}{\partial U} \quad (11)$$

The welfare maximisation for the general public complies for D‘ = U' where the efficient emission level is reached. The emission of each single unit is a decision which influences private use, the damage for the general public, and, in sum whether the general welfare is increasing or decreasing. As long as the use through the usage of air is higher than the environmental damage, the net benefit increases. Referring to the aggregated cost curves, the damage is described by the MEC, the use by the MAC.

Figure 6 shows three different scenarios of setting a cap through the policy maker and the consequences for the emitters. The initial situation is pareto efficient under the condition that the cap is set exactly at the market equilibrium in the intersection of MEC and MAC, which was referred in chapter 2.3.

The cap in scenario 1) shows a cap under conditions of estimated environmental damages equal social use, D‘=U‘, while in scenarios 2) and 3) the cap is influenced by over-allocation or scarcity, which can be interpreted as a change of the supply curve, compare Ellerman and Decaux (1998) for further analysis. For the net analysis, the notation simplifies to e.g. E^{max} for the sum of all single emitters profit

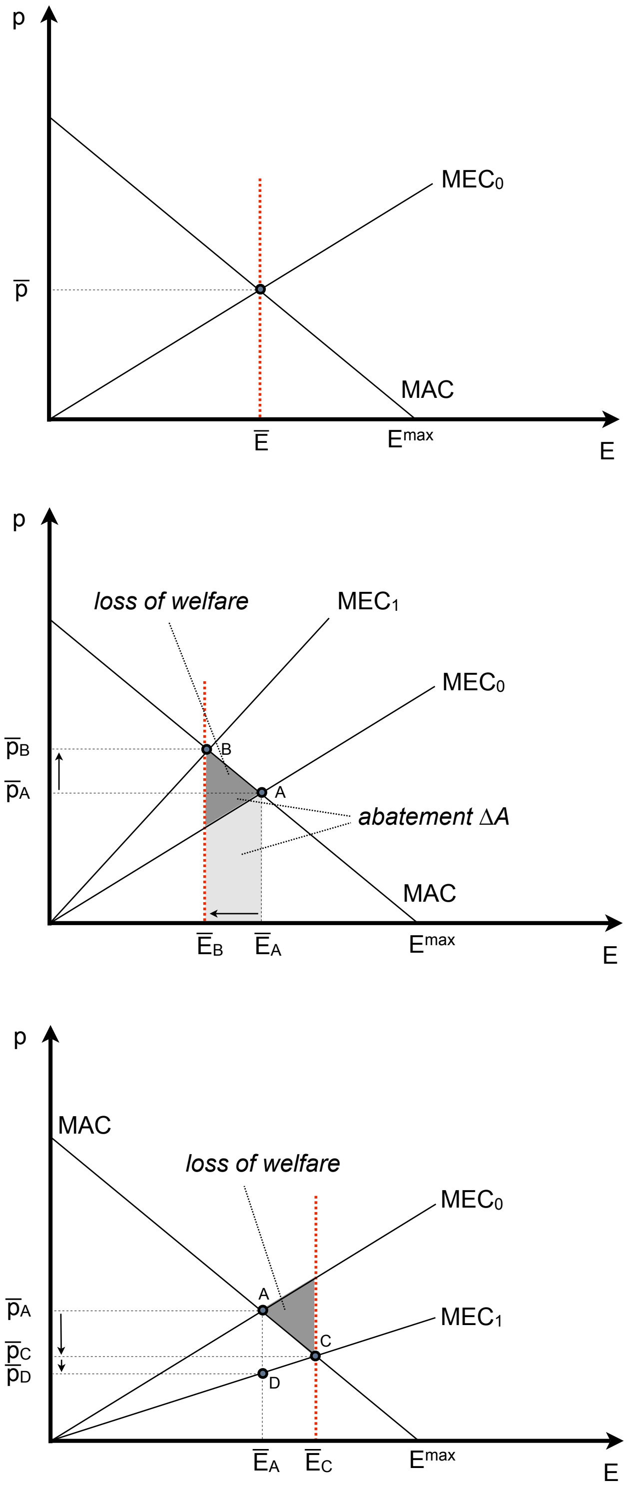

Figure 6: Carbon savings in different scenarios for the allowances cap.
1) Cap with optimal allocation; 2) scarcity in allowances; 3) over allocation of permits. E^{max} illustrate the profit maximising demand for emissions in absence of environmental policies, $\overline{p}$ the cap. MEC as marginal abatement cost curve, MEC as marginal emission cost curve. Own illustration.

maximising emissions, $\overline{p}$ and $\overline{E}$ represents the equilibrium price and emission.

1) The policy maker sets a cap $\overline{E}$ equal to the point where the aggregated marginal abatement cost curve MAC is identical to the marginal emission cost curve MEC demanded emission quantity. The result is a reduction of the emission under the maximum demanded quantity and that the cap is met, but no further reductions will occur.
The cap itself is in the social optimum without forcing further savings, except for the fact that the future increase of emissions will be prevented and the solution is welfare maximising: In comparison to the absence of environmental regulations, this situation is not affected by welfare losses. The price $\overline{p}$ of one permission right is equal to the abatement costs of one unit of emissions. The cost minimising solution of the net benefit equations above is realised if the status quo is maintained regarding demand and technical progress.

2) The real costs of ecological

cost, the intersection of MAC and MEC_0, is represented in the optimum $\overline{E}_{A}$. If the policy maker's estimation on ecological damage per unit is higher than the real costs, the cap is set wrong, according to $\overline{E}_{B}$, and thus below the present level of emissions. The cap forces emitters to save an additional amount of pollution, which is not optimal and results in a loss of use:

Initially, the intersection of the market MAC and the profit maximising emission demand curve is at point A, emissions are above the cap $\overline{E}_{B}$, which has to be achieved. Emitters have to reduce emissions under the present, welfare maximising emissions, represented by point A. The permit price increases to $\overline{p}_{B}$. The emitters face a loss in their rent, the overall welfare is negatively affected, assumed that the initial abatement of pollution was already equal to the former MEC-MAC intersection, where MEC_0 described well the real social costs of pollution. The realised aggregated MEC will turn left from MEC_0 to MEC_1. The compliance of the policy maker‘s set cap basing on a wrong estimate of environmental damage, results in additional costs: The emitter pays a surplus on real social costs what can be interpreted as a penalty tax.

3) An over-allocation, i.e. government supply of a permit quantity above market needs, leads to a decrease of the permit price $\overline{p}$. The MEC curve for emission damages turns right to MEC_1, what can be interpreted like subsidies on pollution or an under estimated damage cost curve. As one scenario, emitters could increase their emissions along the MAC, the price will decrease below the initial price $\overline{p}_{A}$ to $\overline{p}_{C}$, the quantity of emitted pollution will raise to , $\overline{E}_{C} > \overline{E}_{A}$, corresponding to point C. As an alternative, if market participants are remaining emissions on pollution level $\overline{E}_{A}$, total emissions do not change, but the price drops from $\overline{p}_{A}$ to $\overline{p}_{D}$, corresponding to points A and D in Figure 6.3. The emissions remain steady. Polluters will be affected by lower costs of permits, and in the more likely event of expansion of the emission level, welfare losses are realised along the increase of absolute emissions and the linked social costs. Especially in the short run, such a scenario may occur if e.g. production capacity and technologies are not adapted due to restrictions or shortage in labour force or missing demand in additional production output.

For all three scenarios, in the short run, there are no economic reasons to cut emissions under status quo levels in the absence of effective environmental policies.

Thus, if the policy maker implements a cap, which is smaller than the present emissions, he has ecological intentions for future periods and risks welfare losses in the short run, as the resulting MEC of a shorter cap is economically equal to overestimated damage costs. The cut and the decrease of the environmental pollution will, as a consequence, prevent further social costs and can lead to innovation in technologies to decrease (individual) abatement costs with a left shift of the aggregated MEC to solve the net benefit condition D'=U‘.

2.5 Interdependencies between EU-ETS and national feed-in tariffs

The European Union’s ambitious climate protection plan is based on market instruments for emission trading and support regimes seeking to increase the share of total energy production from RES. As demonstrated, the EU-ETS ensures the achievement of a pre-defined cap on carbon emissions. The policy maker sets the amount of the cap. The second measure, a REFIT, helps to increase the share of RES energies and is a kind of financial promotion of research and development. It is cost intensive. The question arises wether REFITs bring further benefits of CO_2 savings or are just cost intensive. What drives the EU to force the joint implementation of these two instruments? Is it simply expensive or is it well thought out with results that can be interpreted as a calculation yielding more than 1+1 = 2?

The first climate protection policy of the EU is the Europe-wide emission trading scheme (EU-ETS) that seeks to reduce carbon emissions by at least 20% below the level of 1990. The first multi-annual trading period, Phase I of the EU-ETS, was based on a grandfathering process where the status quo emission less a compulsory reduction were the benchmark for the initial allocation and setting of the cap. In future periods, the free allocation will be substituted by a certain quota of auctioning, while for the long run perspective the full auctioning will become the standard for allocation. The length of one period of the EU-ETS will be expanded from phase to phase over a few years. The early adoption of energy saving technologies will become more efficient and release redundant certificates for sale on the market.

The EU-ETS was initially designed as a system with three periods. The length of one period grows from Phase I to III, running from three to seven years. Thus, even if the EU continuously evaluates its directives for the trading scheme, (policy) scenarios must consider more parameters under the heading of uncertainty. The period‘s length and the fact that the cap is set before the trading phase starts, brings less flexibility during the single phases if market demand and supply do not develop consistently and in relation to one another. This was already shown for over allocation, i.e. the supply of permits exceeded the demand of the market, which leads to prices near zero; this is however not at all a shortcoming of the general ETS design. Concerning the inter-periodic adjustment of the permit amount, the EU member states have a strong instrument, the annual allocation of allowance rights. In Phase I in particular, but also in Phase II, *grandfathering*, the free allocation of allowances based on historical emissions (see e.g. Ellermann and Buchner (2007) for detailed processes), caused high *windfall profits* in the power sector. When pricing the initial permit prices into retail prices after the trading period has commenced, energy suppliers are overcharging consumers due to the price inelasticity of electricity and the market dominating influence of some suppliers. Power producers often do not feel the need to seriously save emissions as the cost of allowances will be paid by consumers. Lower retail prices would only reduce the producer rent, so cost intensive long run innovations, which reduce short run profits, do not occur, as determined by Betz, Schleich and Rogge (2006), and Schleich, Betz and Rogge (2007), or see Bukold (2015a, 2015b) for similar analysis about price decreases of energy inputs, which are not or only partly passed to consumers. Further, if permit prices decrease, consumers still have to pay the initial price: It can be observed in reality that at least in the short run, energy prices are sticky. Price adjustments, also e.g. in case of decreasing fuel prices, are normally made only every 12-24 months. Parry (2003) underlines that every price of carbon permits > 0 leads to positive welfare effects as emitters reduce their emissions according their MACs.

Banking free permits can result in a shortage of markets and carbon prices can even increase if the market power is strong enough. Auctioning cannot solve the problem of over-allocation and high prices on consumer bills. Hephurn et al. (2006) evaluated the grandfathering process in Phase I and estimated auctioning in Phase II. Auctioning can provide solutions to prevent distortions through banking permits: emitters have to pay for every single pollution allowances, while grandfathered permits must not be paid initially and hence have no negative financial impact when not sold, even though they are unused. Partly or full auctioning instead of grandfathering makes strategic hoarding less attractive and expensive at the same time. High prices and price volatility due to market domination of single players will not occur or will be reduced, if market participants do not have incentives to hold free allocated, unused permits.

Thus, in terms of general theory, the price should regulate emissions and force carbon savings. If the individual MAC is lower than the allowance price, savings are economically worthwhile and saved emission allowances can be sold to the market. High prices of permits signal that an abatement is needed, the price is higher than the market MAC, and individual savings occur where the abatement costs are low. Emitters can buy allowances if their individual abatement costs are above the market price.

It is often not taken into consideration that other factors also play an important role:

(i) high market power of a single player or inefficient markets can distort prices when market participants bank permits. In this scenario, the market will have a shortage of tradable permits, resulting in high prices. There are several possible explanations for this behaviour: Hintermann (2010) analysed empirically Phase I of the EU-ETS, stating that market participants could prefer holding certificates due to uncertain estimates about future needed capacity, when it is better to hedge certificates than paying penalty fees. As a reason for strategic hoarding, Grubb and Neuhoff (2006) see firms faced with the difficulty of predicting the future prices and the firm specific needs of permits. This effect of waiting comes along with a delay of adjustment of prices and investment decisions. For the same uncertainties, Sijm, Neuhoff and Chen (2006) mention a delayed adjustment of prices but note that due to the free allocation market players may be inclined to high prices of certificates, thus leading to an increase in windfall profits;

(ii) the simple correlation between economic growth and certificate prices, where there is a gap between economic growth estimated for the setting of the cap and the real rate of growth (see Alberola, Chevallier and Chèze, 2008).

The setting of an emission cap has important impacts on energy efficiency and emission abatement. If firms have to pay for emissions, they raise their efforts in saving carbon emissions. Innovations in energy saving technologies become a competitive advantage and result in lower production costs. Thus, the permit price has to be higher than the individual MAC if a firm will abate emissions instead of buying certificates from the market. The EU-ETS and the pertinent NAPs of the member states have to implement a certain shortage in the quantity of allowances in order to secure and hold a specific price level - also if exogenous shocks occur. Otherwise, the remaining sources will increase their emissions. The allocated allowances will be used by less sources at lower prices, with the consequence that the percentage reduction of every single emitter will reduce.

The second climate protection policy of the EU is the introduction of national support regimes that are aimed to push the share of RES of total energy production to at least 20% by 2020. Where new capacity expansions of RES lead to a lower demand in required certificates, the price of allowances will fall. Hence, in existing conventional power plants, the realisation of emission savings will occur at a lower cost level. The full technological potential of emission savings through innovations to the production process will not be realised.

Countries have good reasons to implement RES support regimes: decentralised energy production, security of energy supply, innovation and research in RES technologies, steeper learning curves and cost shrinking effects in the future (to name only a few, see, for example, Abrell and Weigt, 2008, or Nicolosi and Fürsch, 2009). Furthermore, set caps are a forecast of future power plant generation - the emissions result from a combination of current emission amounts with expected scenarios regarding the implementation of new technologies. For example, if RES efficiency becomes higher and/or the share of total production is growing faster, the policy maker can set a lower cap. Technological conditions available on the market allow energy utilities to reach the emission target faster and/or more cheaply. This is the focus of the German government, also underlined in different publications of authors like e.g. Klinski (2005), and Wenzel and Nitsch (2008).

The general approach of the market model in section 2.2 with perfect competition has to be discussed and modified, if necessary: through RES, a part of the energy production of the utility sector is not calculated in the NAP, if the new installations are above the expected value. The model and its optimisation problem face new conditions. Are ETS and support regimes two systems interacting or contrary to each other? How are the new RES capacities influencing the endogenous variable?

If the growth of RES capacities is well below expectations, the markets are in a similar situation as shown in Figure 6.2. where the cap is shorter than the demand. Without knowing the exact values, the present emissions are above the cap on allowed emissions and must be reduced. Thus, the pressure through the scarcity of permits increases.

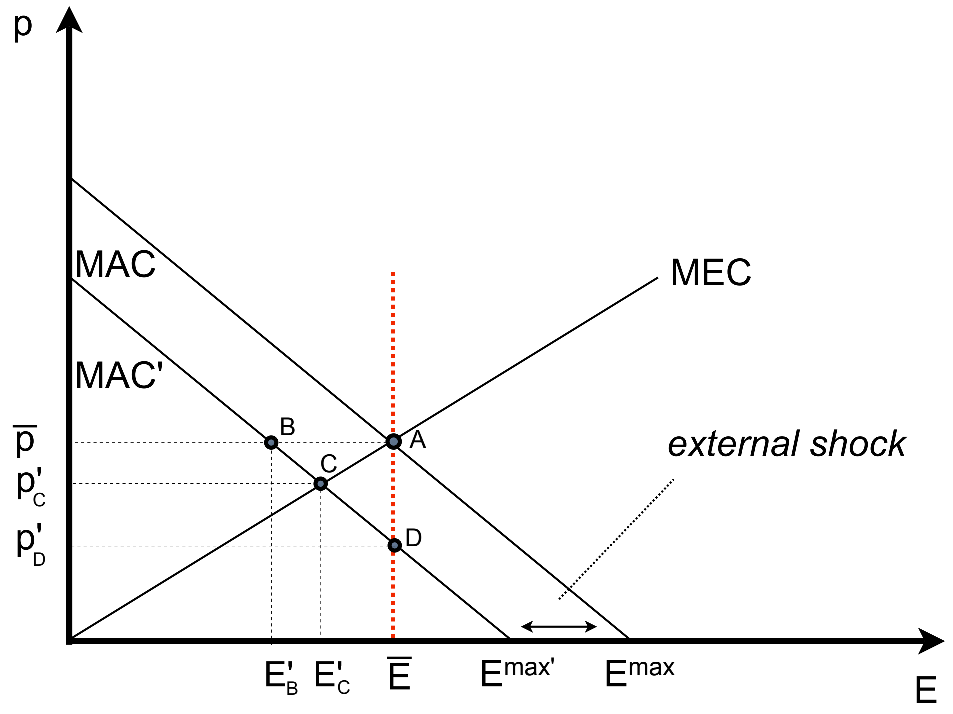

Figure 7: External shock on emission demand, *own illustration.*

The situation changes totally if the amount of new installations exceeds that calculated in the NAP, which can be interpreted as a shock. A huge part of RES installations is an investment from outside the electricity producing branch. The amount of additional produced electricity from green energies not within the investment plans of the utility sector leads to the avoidance of an additional amount of CO_2 that was not planned in the national pollution plans. For the concerned industries, this constitutes an exogenous shock with the same consequences as the exit of a part of the production capacity: a part of their conventionally produced electricity and the linked emissions is redundant. Here, the shock is a new, not planned RES capacity, other examples of such a kind of shock could be a technology innovation process or a decrease of production caused by an economic crisis.

Figure 7 shows the unclear consequences: Most likely, the utilities' MAC shifts left with. Diverse scenarios may occur:

- (A) if other branches can buy unused permits, prices will return to the initial level, the pollution level will remain unchanged. The MAC is returning to the initial level, the emissions meet again the cap with resulting emissions $\overline{E}$ For this trade-off, all branches have to be participating in an ETS under perfect market conditions. Real world ETS often include only selected branches, permits cannot be sold to every other branch or country, and banking of permits occur.

- (B) a very unlikely but not absolutely unrealistic scenario is the presence of market dominating players with very personal interest in high permit prices. If they can dominate the markets, starting from the equilibrium point A, the absolute emissions decrease from $\overline{E}$ to a lower level if the permits are already allocated and the owner, i.e. the utilities, will neither use nor sell them, the permit price p will remain steady, while the absolute emissions of all branches will decrease to E'_B. The scenario in point B seems to be realistic if market players have enough power to influence the market price, e.g. in the electricity sector: utilities price certificate prices into sale prices and the sum is going to be higher than selling the permits on the market for a decreased price, for further analysis see Sijm, Neuhoff, and Chen (2006). In (B), damages are over compensated: MEC and MAC are not in an equilibrium, the total net use is negative.

If the permits flood the market, first the price $\overline{p}$ drops:

- (C) to p'_C and the emissions E'_C in point C will be realised in a new equilibrium of MEC and MAC', but only if the cap will be adjusted on a lower level, C seems to be a realistic scenario;
- (D) seems to be a more realistic scenario. Under the scenario of the left shifted MAC', prices for permits decrease drastically to p'_D and permitters will substitute cost intensive carbon savings with higher pollution exhausts. The emission cap $\overline{E}$ will be realised, the net damage is negative: MAC‘ and MEC are not in an equilibrium and environmental damages will not be totally compensated.

To summarise, the shock of unplanned RES capacities may result in less emissions, remains unclear whether this becomes reality. The new balanced but not completely market confirm equilibrium is depending on the eventually domination of single market players, the fuel switching options of energy suppliers e.g from gas to oil, the shutdown of energy plants in relation to management decisions instead of environmental reasons, and other obstacles of a perfect market.

The analysis of Weigt, Ellermann and Delarue (2013) is one of the few empirical and not only theoretical articles about the interaction of RES-promotion and ETS. The authors give a small comparison of different scenarios with and without a price for carbon with the conclusion that the use of both instruments, REFIT and EU-ETS, save more emissions than the application of only one of both policies, and that the effect increases in direct proportion to the carbon price. Only if having permit markets, carbon gets priced, thus an effect of unplanned RES capacities may result in some additional savings, those by green energies will not be all over absorbed by other emitters that increase their emissions.

The spot market prices analysis of CO_2 certificates by Wagner (2007) asserts that pricing does not necessarily follow the assumptions of perfect market pricing. Reasons seem to be uncertainties about factors such as future environmental policies, but also that the actual emissions *ax ante* are unknown and the market participants do not act completely rational. Sometimes, strong players are identified, which can influence the price, while at other times this effect is not observed. The limitation of the trading periods also results in greater volatility at the end of a period. Other influence factors on prices have been mentioned earlier in this chapter and often appear to be a consequence of uncertain predictions of the future price development and the demand of the single emitters.

Considering free market pricing, the risk of a rebound effect exists. This is the simple mechanism that falling factor prices, here emission permits, and the linked pollution saving at one place lead to more pollution at a different location. Described by Jevons (1866) for the use of carbon fuels, this effect can be easily converted to CO_2 certificates. The excess supply of free allowances through for example CO_2 savings in power plants leads to a decrease of permit prices and an increase in emissions elsewhere. This is expected across all industries, also because some industries will outsource manufacturing processes and the linked emissions offshore. Of course, the set cap is met, but the exogenous RES installations will not result in additional pollution reductions in comparison to the cap.

Here, the question arises what assumptions are a realistic scenario. Two main factors have to be taken into consideration: the decision of the policy maker whether emission reductions are to be solely done through the instrument EU-ETS, or whether the use of the second instrument, REFIT, makes sense. If the policy mix of both instruments is chosen, the question is then how they change the conditions of the system. This discussion prepares for the subsequent section which will clarify how emissions can be further reduced under these new conditions.

Buttermann, Hillebrand and Hillebrand (2009) propose full auctioning in Phase III of EU-ETS for energy utilities. Otherwise, the amount of allocated certificates is sufficiently high for a continuous use of conventional fuels as was used previously in the past. A slight cut in the cap for example can be compensated by a switch from coal to gas. In this scenario, physical switches to new RES capacities are not an option and too expensive.

Fuel switching, the change from one conventional fuel to another with lower emissions per burned unit, is an important issue. If carbon permits have high prices or the cap is significantly cut, the first option for carbon savings is to switch from coal to gas capacities, which both already exist in the power plant mix of energy utilities. A long run switch to RES would cause higher costs in the short run. The advantage of the implementation of a more efficient technology in the energy mix is a disadvantage in the short run and causes higher costs. Delarue, Voorspools and D'haeseleer (2008) investigated scenarios for Phases I and II of the EU-ETS with the obviously result of a correlation between prices and CO_2 savings. Nevertheless, the overall effect appears to be a positive emission reduction and, contrary to this, the prices in the EU-ETS tend to be low (Delarue and D'haseeleer, 2008). In this case, one can propose that the EU-ETS leads to carbon savings in the existing power plant park. The policy strategy might aim only at preventing an unchanged pollution scenario, but not a fundamental change in energy production processes. RES are neither needed nor demanded. Therefore, innovations in new technologies will occur only where conventional fuel efficiency has the potential to increase and results in additional inter-system savings.

This confirms that the political capacity to act is limited. The policy maker should set a relatively small cap if carbon savings are the main intention of the political framework and this decision cannot be adjusted as the cap can only be set once before the period has started. The EU-ETS directives do not allow adjustments during the on-going period. The EU-ETS and the NAP goals will be met by the economy. Thus, a REFIT does not bring any additional carbon savings additional to the EU-ETS. But then, why should such a policy be adopted?

Fischer and Preonas (2010) analyse the two-way influence of ETS and FIT. Lower permit prices can lead to a crowding out of a favourable technology and technology-specific FITs can help diminish disadvantages from, for example, higher costs of green energy production and push RES into the market. The cap for the next period can thus have more ambitious targets.

De Jonghe et al. (2009) focus on welfare maximisation through an ETS, but criticise the fact that, depending on the energy mix, especially in countries with a high share of nuclear power plants, the marginal production costs of energy are very low and prevent the spread of RES, and fuel switching will not occur. Thus a FIT for RES is highly recommended in order to encourage a significant share of RES in the market.

The demand for carbon permits is analogous to the discussed merit-order effect on energy prices, but with a contrary result. High prices for permits lead to savings where burning fuel causes high costs, e.g. where the degree of efficiency is low. A higher expansion of RES increases the amount of allowances available and can counteract this desired effect.

Literature on RES promotion often quantifies only the pure costs of RES support systems, but not the possible substitution effects in the energy mix, or social costs of air pollution. If pollution is free of costs, it prevents carbon savings as explained in the scenarios above. The allowance prices have a huge influence on the make-it-or-buy-it-decision for emission reductions and thus lead to fuel switching to sources with the lowest fuel costs, e.g. for permit prices equal to zero, substitution of natural gas with coal. The contribution of different papers by authors such as Bickel, Kelm and Edler (2009), Wenzel and Nitsch (2008) or Sensfuß and Ragwitz (2007) is important when quantifying the spending on support systems for green energies and estimating fuel switches and emission quantities. The resulting effects on spot prices of electricity and carbon permits are indicators of targeting the future emission cap. Low spending on RES support regimes and low costs of permits show an over-allocation of permits and open up the option to cut the set cap more rigorously.

Ecologically this may result in either additional or reduced CO_2 savings with changes in demand for emission permits. Delarue and D'haeseleer (2008) and Delarue, Voospools and D'haeseleer (2008) explain how short run fuel switches influence carbon emissions under the EU-ETS. If emissions have a price, less competitive but ecologically advantageous sources will become cheaper. The monitoring of Phase I of EU-ETS shows fuel switching from coal to gas that has already led to emission savings not previously realised. It is important to take into account the effects when support regimes for green energies have an impact on allowance prices and the demanded quantities of permits in the market.

Mennel and Sturm (2009) stress the inundation of the market by permits caused by the additional green energies and the negative associated impacts; it is somewhat harder to obtain higher fuel efficiency if emissions have a price equal to zero, or at low levels, as shown above. Wissen and Nicolosi (2008) point out the unclear effects in terms of the implications of the EEG and the German REFIT, which are already included in a defined quantity in the NAP. Without green energy capacities, the import of cheaper nuclear power would have had an influence on electricity prices. The authors do not negate the merit-order effect and mention the importance of increasing prices and the price elasticity of energy demand in the long run.

Besides the issue of permit prices and the usage of permits by the emitters, the named effects on both electricity (merit-order) and permit prices (shock related price increase) have an impact and should lead to lower costs for energy consumption in perfect markets.

However, the German example shows a more complex situation, the exact market conditions are unclear. Due to a (decreasing) tendency to market dominating or influencing players and the low elasticity of electricity, prices are relatively sticky. Calculated permit prices are set pre-periodically, before billing the consumer:

Maubach (2013) describes the German electricity market and its characteristics influenced in a large part of future contracts, which price in the today's prices and / or future expectations, and not all consumers can profit from cost efficient spot market prices. Following this specific finding, it can be argued here that energy utilities cash the profits by themselves, while the permit prices as one part of the end consumer prices remain on high levels, equivalent to a scenario as shown before in point B of Figure 7.

Empirical evidence of the German antitrust authority shows a potential dominance of the four biggest power suppliers and the tendency towards too high prices for private households, which account for approximately 25% of all electricity consumption, while industrial clients are able to profit from decreasing prices (Bundeskartellamt 2011, 2014). The authority describes further a sharp increase in market dominance and a weakened price increase for private consumers. This points towards a tendency for markets to develop into fully competitive markets, also if studies of energy markets of Bukold (2015a, 2015b) analyse the gas and oil price decrease. Energy supplier in neither case pass this decrease on through their prices, or not more than partly.

To what extent market power is and especially was misused to drive prices remains unclear. Sijm, Neuhoff, and Chen (2006) calculate that price adjustments of the power sector with opportunity costs pass-through rates are between 60-100% for the Netherlands and Germany. End consumers pay the calculated permit prices through their bills, even if the (initial) allocation was free of charge. Müsgens (2005) observes energy prices above competitive benchmarks, and "exercise of market power has increased over time" (p. 92). In contrast, Lang (2007) finds less evidence for market power, but even if natural conditions can explain most prices, for some years market power of dominant players is obvious. Further, Hirschhausen, Weigt and Zachmann (2007) describe asymmetrical cost calculations for permit prices in spot markets and as a part of electricity prices. Ellersdorfer et al. (2009) recapitulate other studies and assert, that evidence about market power is not clear, but prices tend to be hard to find due to many uncertainties. End consumer prices can thus be affected by high prices, while on the other hand scenarios with prices below marginal costs are not implausible.

To summarise and conclude here, one can state that 1) the EU-ETS is the measure for the compliance with government regulations on carbon savings at the lowest cost point and thus welfare maximisation is given for the on-going period, whereas 2) a REFIT pushes technological innovation and broaden the possibilities to cut emissions in the future periods of the EU-ETS faster and more cheaply regarding the single emitter's source.

For the market model, the consequences are that, in the case of perfect markets, the change in the demanded quantity of allowances itself and the abatement quantity and its price affect the certificate price. The avoided emissions and the absolute emissions for the specific period will affect the price. The price will still be influenced by the set cap which determines the necessary abatement quantity, but the influences through RES can affect the further demand for emissions and the need for savings.

Support regimes for RES technologies lead to emission savings, which are exogenously made if they exceed the NAP. Conventional capacities can be shut down, and system participants from other branches can buy cheaper certificates up to the allowed system-wide emission quantity that is determined by the cap, which was set for NAP expected emissions. The change in the demanded quantity of allowances itself affects the certificate price.

As shown, newly installed RES capacities enter the market without any direct impact on the system participants. Figure 7 showed that, depending on whether conventional production capacity can be substituted, lead to less efficient use of fuels or free permits will be sold to other sectors:

- in the case of non-substitution and the use of less efficient plants, or selling the certificates to other emitters, exogenously made RES installations lead to a movement on the profit-maximising emission curve. Ultimately the total emissions remain in accordance to the cap.
- in partial or full substitution of fuel burnings through the RES plants, and non-usage of the free permits elsewhere, the total emission decreases below the initial cap with uncertain consequences for the price.

In the literature review and the theoretical market analysis, it was demonstrated, that if both measures, EU-ETS and RES support regimes, are jointly implemented, the ETS cap set by the policy maker will always be achieved. Feed-in tariffs are not contrary, but have an impact on the effective achievement of the emission saving cap. Further reductions through rigorous cuts and a smaller future cap are options for future policies.

2.6 How to reach the zero cost emission policy

As shown before, retail prices of electricity remain at high levels even if permit prices tend to zero. Energy utilities often act in oligopoly markets and can bill consumer prices, including allowance prices of the past, which are, according to the general design of the EU-ETS, often higher than they are in the present. Thus, if allowance prices decrease, energy utilities may gain a part of the welfare effect arising as their own rent. These windfall profits are an imbalance at the expense of the consumer. In absence of the windfall profits, the second option for the utilities is to expand the carbon savings for the same costs as before. Redundant certificates due to the external shock of an expansion of RES installations can be used for the remaining conventional energy production with the option of full switching to less clean sources. If the utility let the energy mix unchanged, not used certificates can be banked with the tendency to influence the market into the direction of high prices. Smaller market participants are price taker and will have the highest private profit if selling the permits on the market.

From a welfare-maximising perspective, it is legitimate to cut the recent windfall profits of (especially) the energy suppliers. The question is how to achieve lower consumer prices, or, in particular if the pricing and single player dominance are not explained adequately, how to force a larger amount of carbon saving, e.g. a smaller emission cap. If single players can dominate the ETS market, it is difficult to place pressure on the energy utilities to decrease (consumer) prices. Is it thus legal to withdraw free, unused certificates from the market or at least to reallocate them to other market participants? Windfall profit problem-solving instruments consist of special taxes or a levy on such profits with the aim of lowering or reallocating windfall profits from private suppliers to the community.

For the system participants, the maximum emission quantity is given exogenously, but as the policy maker orchestrates a further shortage of permits through policy regimes and thus forces additional savings, the cap itself becomes quasi-endogenous (see Tietenberg and Johnstone, 2004). Its economic efficiency is influenced by the emission target and the implementation of technologies within the ETS, and because of the influence of new RES installations triggered by the REFIT. Chosen policies can undermine the achievement of the emission target, and market participants may influence the cap. The technological and economic possibilities to save emissions are determined by endogenous changes through the application of environmental changes as well as climate saving polices. Thus the question arises, what the legal options to withdraw allowances from inside the system are and whether the system conditions change, as they do for example through a REFIT.

Full auctioning is one option. Especially for Germany, Schleich, Betz and Rogge (2007) attesting the advantage of full auctioning to avoid windfall profits, but also support the simplification of the NAPs to lead to more transparency:

The advantages for the community are that the emitter must buy all necessary allowances in periodical auctions or in inter-periodical trades within the market when participants have free permits for sale. As trades can only occur with the government as the initial seller, financial resources will be relocated from the private to the public sector and can fund further research and development of RES or subsidies for new green power plant capacities. If the price increase of allowances does not exceed the value that is still contained in the electricity prices, the costs for the community do not rise, while the rent for energy suppliers shrinks. The social costs of climate change caused by carbon emissions will be internalised. The allowances price is thus market based and not only a theoretical construct. Additionally emitters have no incentive to bank allowances. Further effects are highly positive and will enable policy decisions that can yield in additional carbon savings at almost zero cost: If the exogenously produced RES capacity does not count for the whole economy in comparison to the business-as-usual environment, emitters face constant conditions. The achievement of savings results in the initial MAC and the damage cost curve, where the remaining demanded conventional energy amount has decreased. The general public pays the REFIT and the producers will not be rewarded by the possibility to charge the positive effect of lower carbon prices as their producer rent.

Literature on auctioning generally endorses the practice of withdrawal of a part of the initially planned amount to be auctioned, with the exception of some minor uncertainties regarding the legal feasibility. If one participator loses his right to pollute the air, is this a dispossession of a property or common law?

Posser and Altenschmidt (2005) state that the property law governing allowances cannot be clearly defined. If the government cuts allowances to create a shortage, it is legally questionable and may be contrary to EC treaties on property rights. The energy utility always requires a sufficient amount of allowances in order to operate its production unit, the power plant.

Martini and Gebauer (2007) share these concerns in terms of the protection for reliance on existing laws, where only a grandfathering allocation can address to the issue of property rights, because it is based on the emission experienced in the past. Nevertheless, a certain reduction in the amount of allowances can be realised. It is not discriminating against individuals if it is a global percentage cut.

Tietenberg (2003) argues that the ETS as "the system is to protect the economic value of the resource, not the resource itself" (see p. 403). Therefore, in the American emission trading, the right to emit one unit is not a property right, but remains a collective good. Thus, a future reduction without compensation is possible.

It is important to refer to the EC treaties (96/92/EC and 2003/54/EC) that limit national solo efforts and underlines the importance of European co-ordination when planning to cut emissions under the pre-period implemented level. A single member state like Germany cannot decide to withdraw certificates if not based on a common agreement with the other member states.

Mennel and Sturm (2009) stress the problem of energy efficiency, if an ETS is the single policy to be applied. The policy maker should undertake policies with a certain regulation, where it is relevant to the (ETS-)system: e.g. technology-specific taxes or a shortage of CO_2 permits. Zenke and Schäfer (2005) concentrate on how to revoke redundant certificates from the market if more savings are generated within the sector or exclusively to large proportions of the sector by the subsidised RES. The European Community treaties for property rights protection therefore underline the limitation of such an approach and provide restrictions on a change to the cap once it is set. Magen (2009) criticises the emissions market as a whole, stating that it is "not free" in respect of how it should be for a market good, but this market design opens at least the possibility for the policy maker to change the cap *ex post*, thus when the trading period already started.

To summarise the literature, one can argue that non-utilisation of permits due to reduced production output, like the substitution of conventional energy through RES, should lead to an adjustment of the quantity of allowances. The crowding out of conventional energy producing capacities through the new exogenous green capacity renders permits redundant. At least in the next period, a further shortage in the same proportion is recommended and intra-periodic adjustment must be avoided, especially to guarantee the property rights of permit holders.

Magen (2009) supports this argument stating that the trade of emission rights is not and was never completely free, if for burning fuels in a power plant, (i) a governmental authorisation is required and can be refused, and (ii) once in operation, permits for air pollution are essential for energy production. Thus, the plant operator must own enough permits to demonstrate compliance with the legal restraints coupled to the authorisation. The government on the other hand, should ensure that it maintains enough permits so that all authorised operators can burn fuels for power production as legalised through the governmental authorisation.

The EU-ETS, legally implemented in the German Decree for Emissions Trading (TEHG), is a core environmental regulation like operation authorisations, thus the legislative is legally obligated to protect the collective goods of clean air and the environment. As an implication, through German basic constitutional law, it is obligated to utilise every legal option to cut emissions and thus intensify the protection of the environment.

At least in the long run, the demand for electricity is elastic, thus a higher price has to be preferred from an ecological point of view. The EU itself, as established in the constitution, should strengthen efforts to establish free markets and competition for different types of energies. Currently, REFITs help less competitive energies with high emissions savings to become cheaper than they really are and help to obtain EU-wide free energy markets from different sources (Gunst, 2005). Thus, the EU-ETS alone does not yet have the power to protect the climate. It may however transform into a powerful instrument through the setting of a cap that creates a shortage of permits. Enlarged REFIT investments can help to allow a further emissions cut.

The national levels, due to the EU-ETS design options, are provided with a certain possibility that is not yet exploited in terms of decreasing the quantity of permits. Kruger and Pizer (2004) emphasise the three levels of the ETS: first is the European burden-sharing agreement, followed by the national level and then the emitter level. The last two levels are designed by EU members, and the CDM (Clean Development Mechanism) and JI (joint implementation) activities in particular are instruments to reduce GHG outside the national territory and reduce permit prices. The ratio of both instruments at the level of the whole carbon saving obligations can vary and is set by each member state on its own. On the other hand, the instrument can, but does not necessarily have to be used if other policies, like the REFIT for RES, put pressure on prices, cf. Criqui and Kitous, A. (2003)[17]. Thus, the EU members already have an instrument to regulate their permit quantity reductions at least within a small range.[18]

The German NAP provides an approach for this purpose. For example, if an energy utility shuts down a power plant, it triggers the mandatory duty to withdraw the certificates linked to this specific production capacity. In this case, the new REFIT capacities induce the theoretical shutdown of a percentage of conventional capacities and there should be no reason to not withdraw the certificates as the withdrawal is obligated after a full shutdown.

Determining the right economy-wide quantity of pollution can have a purely rational basis that corresponds to economic factors. Such justification is possible but not advisable, because other (ethical) factors must be considered. The legal options that may propose a reduction policy should be clear and have to be realised within the final set. The ETS is the measure to control carbon emissions through quantification, while the exact amount of the cap on the allowed emissions is a question of scientific and political nature, see Rahmeyer (2008).

As shown in this section, a shortage of allowances created through policy measures will raise the permit prices up to the ex ante anticipated price, which is part of the

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[17] The authors simulated diverse scenarios with and without CDM and calculate a cost-shrinking effect, but neither take into account transaction costs, nor use empirical data to prove the predictions.

[18] If proposing the non-usage of CDM and JI, one has to mention technical consequences. The political intentions of the two instruments will not be evaluated.

consumer bill, without incurring any extra costs for the consumer. For the industry, the cost of abatement will be equal to the expected scenario before the exogenous shock. The policy maker can force additional carbon savings through a further shortage in the quantity of certificates.

2.7 Conclusions

The design of the EU-ETS makes it a strong instrument to control emissions and reduce them to a cap set by the policy maker. Without an over allocation of allowances to market participants, the cap will be attained. The joint implementation of support regimes for RES, such as the REFIT for example, does not change the system's outcome, but can put some pressure or reduce the stress on the linked variables.

The costs of a standards approach ETS system were described in the equations from (4) to (8) as a cost-minimising Lagrange function where participants seek to reduce their individual costs due to their individual MAC. The costs of abatement and the permit price per unit become equal at the optimum.

Depending on the single emitter cost curve in the optimum, for sellers the costs were equivalent to avoiding costs and the saved emission quantity, namely the redundant allowance certificates could be sold to the market, or for buyers the individual costs result in buying permits at the market price. Both buyer and seller, calculated with the same price for emission allowances, choose their individual level of abatement. Thus, most research is focused on the economic efficiency of cost minimisation in order to achieve the cap.

If the cap is considered as exogenously given and system participants are forced to attain the objective, the approach makes sense. Optimisation of the system does not change the amount of carbon savings. If the adjustment of the system conditions can reduce the costs without negative impacts on the environment, the saved financial resources can be spent elsewhere and the total economic burden of the instrument can be limited.

In the context of the ETS debate, the fact is often missed that the trading scheme does not increase the share of RES produced energy in total production when it is the only policy measure applied. Support regimes can increase investment in RES power plants. If newly installed capacities of green energies and their output are growing faster than total energy consumption and faster than expected (meaning covered in NAP) when setting the cap, it can lead to displacement in the structure of permit holders.

Energy utilities are obligated to feed-in RES-produced energy first. This does not lead directly to free emission permits and the total amount of allowances is not affected. Nevertheless, a part of the conventional energy production output is redundant and a minor percentage reduction of carbon emissions is still necessary. If the total cap remains constant, this leads to free certificates. It seems that there is no ecological advantage, but there are cost-shrinking effects for emitters.

Through the substitution of conventionally produced energy, market demand decreases lead to lower prices of allowances and especially "dirty" technologies or other sectors can even (i) raise their absolute emissions or in percentage per unit of output, or (ii) the production output can increase while maintaining the initially planned emission reduction, i.e. the cap. Economically this effect is desirable and leads to the shown cost-shrinking effect or production increase and therefore results in prosperity gains.

The high social costs of air pollution and a possible "role model" of the innovator (here: Germany) to other nations are often not taken into account when evaluating or enhancing the ETS design. But a faster development of RES provides political leeway to cut emissions faster now and in the future.

The emission cap is not at all exogenous, because endogenous factors influence the cap for the next period. The joint implementation of ETS and RES support regimes is a difficult policy.

The recommendations to the policy maker resulting from the analysis in this chapter are as follows:

- The REFIT is part of the EU-ETS parameters, but due to a gap between expectations and real production output of green energies, the RES power plant production places pressure on the well-balanced system. REFIT-supported RES power plants and/or their carbon saving potential should be separated from the EU-ETS and the NAPs.

- When this occurs, conventional power plant capacities become redundant. This is because the new installed capacities are exogenous. The production authorisation for a disused power plant should also be withdrawn in parts if the plant is not completely shut down. The withdrawal of the authorisation should be linked to the withdrawal of emission allowances.
- Full auctioning can also support the enforcement of a shortage of permits. This results in additional emission savings by an intensive use of technological innovations that are above the emission reduction scenario that was anticipated before the period started.
- The cap is exogenous for the system participants, but system conditions can have a strong influence. Thus, the setting of a cap is determined endogenously through, for example, the intensity of the support for RES and the further application, implementation and enhancement.
- A side benefit is the cost-shrinking effect of the technology through the higher demand for RES and the resulting learning curve. If RES technologies become more efficient, a shift of the MAC curve may be the result of technological innovations and lower costs. It remains unclear, if the German the industry can profit from learning effects in global markets.
- Benefits gained by Germany‘s position as a role model and its role as the innovator are yet to be realised. Questions arise and remain open about employment effects and the real estimated economic costs in consideration of social costs and competitive advantages of single players and economies.

The illustrated effects could have an enhancing effect if simultaneous RES support regimes would be accepted not as a cost-intensive instrument separate from the EU-ETS, but as one that optimises the future conditions of the emission trading schemes of the European Union. The targeted support regimes for selected technologies at selected places or regions would lead to cost-minimising use of expenditure, higher outputs and lower costs per unit of produced energy. Here, the quantification of the potential remains open at this point and requires deeper research in the following chapters.

What can be mentioned is the missing pragmatism to calculate the full effects through RES capacities. The non-integration of (exogenous made) RES capacities in the carbon saving obligations of the (conventional) energy sector would be the first step for the future to bring to fruition unrealised intra-system emission reductions with a simple mechanism: at the moment, real market prices are to low to force further emission reductions. When separating green energy capacities not covered by the initial NAP, emission reductions would have been done within the initial framework before the extended RES installations. That part of energy production that is substituted through green energies and the linked carbon emission allowances should be withdrawn, namely the allocation of permits should be decreased. The allowed emission quantity decreases, and the cap now has stronger, more stringent conditions. The permit price for the single emitter would increase up to the initial level that was planned when designing the NAP and the EU-ETS. As a positive effect, the absolute reductions increase with the effect of social cost savings and a positive rent for the whole economy.

It is an unpopular result for EU-ETS participants, especially for the energy sector, as they would lose their economic advantage, while the community and the environment would profit highly from additional carbon savings at zero costs in relation to the original NAP. Ecologically, it would enable an enormous step forward in European climate saving policies.

3. Promotion of renewable energies: Follow the sun

When using natural resources, water, wind and the sun are volatile inputs. Rivers can't be dammed where no rivers flow, wind blows with higher intensities in certain regions and has its seasons, and the sun shines during the day and due to the day length and the intensity of radiation to a greater extent in summer than in winter. Planning the sources for the electricity mix of the future, one has to take into account geographical and physical conditions to maximise the earnings from RES.

Under the mentioned conditions, as a selected example and thought experiment, Germany could have reached obligations set by the Kyoto Protocol earlier if German solar investments had been relocated to where the sun shines almost continuously. If going strictly south from the territory of Germany, Sicily as one of the most southern points in Europe offers additional benefits of emission savings and energy production. Just the sun radiation surplus to the German average should raise the sun power plants earnings by up to 85%. Solar energies do not have the best geographical fit when installed in Germany.

However, in 2008, German solar power plants accounted for 20% of the financial benefits through support mechanisms such as the German REFIT "EEG" for renewable energies, while the share of green energy produced was no more than 4.8%. Although from an economic point of view the promotion system for solar energies seems inefficient nevertheless it is appreciated to be an innovative and powerful instrument and was adopted by many other countries.

This chapter is a thought experiment and an example to underline the need for clear objectives and guidelines in policies that aim to support green energies. It does not aim to be a comparison of diverse European national regulations, but a theoretical calculation of what it would be the additional or extra load of solar power plants as one selected technology. Solar energies receive one fifth of all RES promotions and only accounts for approximately 5% of the renewable energy production. Thus, the focus of the thought experiment is on photovoltaic and its efficiency.

Germany promotes solar energies; however the sun is shinning on a higher intensive level elsewhere. Thus, the thought experiment should not evaluate support mechanisms, but be an argument to support Europe-wide coordinated support systems to enhance the green energy harvest through a better fit of the place (the geological location) and the technology. Because a single European market for emission permits already exists, energy production from RES would be decentralised and thus a significant boost in production capacity could be realised. European countries are far from being independent of fossil fuels. If every region were to produce RES energy from the best fitting technology, it is recommend to use the electricity at the place of production. While the transportation of electricity is characterised by severe losses, the decentralised energy production still seems to be favourable. In the case example of solar power plants, the best-suited regions would be in Spain, Italy or Greece. These countries frequently face scarcity of power supply and the expansion of solar energy usage could help these countries to guarantee supply reliability. It has to be mentioned that also a massive expansion of solar power plants e.g. in Sicily is only a redesign of the electricity mix and will substitute other power plants that produce locally, in particular fossil fuels like coals and gas. The production capacity from solar power plants can be absorbed at the place of its production without the need to transport the electricity to the mainland or even other countries.

To have a reliable calculation, further application of new technologies or innovations, modifications of the legal framework or changes in the financial return on RES investments will not be taken into account. The 2008 levels, legal regulations and data serve as a basis to make visible (dis)advantages of national support regimes of RES in general and selected, positively discriminated technologies. The selected year was on the edge between having Germany as a strong innovator in green energies application and other countries copying the legal framework in order to close the gap.

Firstly, the analysis underlines the importance of renewable energies being financially supported and how and why policy makers can justify subsidies for selected technologies because of social costs of carbon emissions. The second point is that the place, the geographical location of the installation, does in fact matter and physics set the limit: the chosen approach for expected final yield shrinks the additional benefits of the theoretical relocated south solar investments to a lower value than the accepted +85%. In closing, the conclusion provides political recommendations for the design of further subsidies of solar energies in Europe.

3.1 Introduction

Developed countries like those of the European Union and their matured economies in particular must swiftly reduce their CO_2 emissions in large proportions. For member states of the EU, especially the old EU-15[19,20] members, it is not simply a question of meeting the 20% reduction goal in line with the Kyoto Protocol or the 30% reduction in line with the Copenhagen agreements, but one of the negative impact on further growth if they do not act now. The UK government initiated review by Stern (2006) states that the costs of natural extremes and the negative long-term impact on growth will be much higher for countries that do not act immediately. CO_2 and other climate gases cause global warming, the so-called greenhouse effect. "Warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if GHG concentrations were to be stabilised" (IPPC, 2007, p. 48).

An important milestone in European action for climate protection has been passed by the European Council: the 20-20-20 by 2020 targets and subsequent decrees for an obligatory reduction of 20% of CO_2 emissions and a 20% share of renewable energies used in total energy production by the year 2020. Thus the question is not if, but how the aims of the 20-20-20 by 2020 targets can be reached and what political measures are necessary, see EU Commission (2008).

Due to the neutrality of the location of the emissions, the problem in question is how to reduce CO_2 emission best. RES are one piece of the puzzle, photovoltaics are another. Highly effective solar cells use the almost unlimited potential of solar radiance to produce clean energy without any CO_2 emissions, but this approach is cost-intensive. Until today, it has not been possible to produce a kilowatt-hour of solar electricity at the same price as the cheapest conventional energies. The challenge is to decrease the costs of consumption of one unit of green energy on the one hand, and to increase the earnings of the investor on the other hand through cheaper installation costs of new power plants. Further implementation of Europe wide CO_2 certificate markets would allow improved regulation and thus make it easier to intensify the application of certain technologies in areas in which they are most

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[19] Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxembourg, Netherlands, Austria, Portugal, Finland, Sweden and the UK.

[20] Old EU members have stricter reduction goals, new EU members are often facing a partly de-in-dustrialising, thus their economies have other conditions, see chapter 4 for a further analysis.

effective. The varied geographical conditions of different countries result in different needs in terms of energy production and these must be taken into account.

Each member state must reach the European goal and Germany in particular must commit to restructuring the energy mix with the intention of increasing the share of renewable energies through subsidies; this approach must aim not only to produce energy, but also reduce CO_2 emissions, see Klobasa and Ragwitz (2005).

The thought experiment of this chapter estimates the amount of solar power that could theoretically be produced if German private investments resulting from governmental action between 2000 and 2007 were diverted to Italy. The two countries were chosen due to very similar conditions in the legal framework, but very different radiation intensities. Italy copied the German EEG, but some years after the solar promotion regime started in Germany. If going directly south, crossing the Alps, Germans come to Italy and should bring with them their solar power plants. What hinders them from investing south, or conversely, if they did so, what could they earn in addition? The following calculation considers the capacity of photovoltaics that could already be installed today and thus what the theoretical additional harvest of electricity and surplus of CO_2 savings and the additional return on investment could have been in the German-Italian collaboration.

In section 3.2 the theoretical framework of social costs due to environmental damage from carbon emissions is discussed, with a focus on price solutions such as emission taxes. This discourse will help to legitimate and to justify a REFIT and to evaluate the right balance of the amount paid. Only if the system itself can be identified as ecologically and/or economically worthwhile, can one go ahead and talk about adjustments and future designs of promotion regimes. Further, the subsidy system for solar power plants in Germany and Italy, in its function as a kind of environmental Pigou tax, caused by a national clearance system, shall be explained briefly as an example of how promotions of RES work and what the conditions are for new power plants. The comparison of the two selected countries does not encompass the case for all European Union members. The aim is not to compare and to evaluate diverse promotion systems, as this would require need a much broader and deeper analysis. The selected countries serve to answer the theoretical question, if a thought experiment like that done in the following, is realistic or requires further policy adjustments. Furthermore, the comparison of only two countries and one technology will show a fundamental effect on the energy harvest, here, the efficiency of electricity production. If this one example, which is rather small in its outcome, is able to show an increase in electricity production, the coordination of RES promotion all over Europe should result in even higher benefits: If the result of the thought experiment is positive for solar energy, other technologies and support regimes should face similar challenges. Germany promoted solar energy and high investments were done in photovoltaics. Other countries with higher solar radiation act less ambitious. To give an example, France is still continuing nuclear power as the preferred technology, even though it has the Atlantic coast and other areas with a high potential for wind power. There are even more conceivable scenarios as the selected in this chapter. The theoretical question of interest is not to figure the total potential of RES supported investments, but to illustrate that there is a potential and, regarding the example, to what extent. The results will finally bring up further questions and recommendations.

The mechanisms of RES promotion are also important in order to understand how policy makers can justify the high costs associated with promoting solar energy as a privileged technology. The particular intentions of German support regimes for renewable energies are to gain research and development support through market demand. The political objectives are identified as a) to trigger changes in social behaviour (Bartle and Vass, 2007), and b) the optimisation of subsidies (Staiß, Schmidt and Musiol, 2007). Both will be discussed in the following.

Secondly, the question of what would occur if Germany had invested in extra-territorial solar plants will be considered. On one of the biggest and southernmost European islands, Sicily, solar irradiation should promise a surplus in solar harvest of up to 85% in comparison to the German harvest. Why not take advantage of higher irradiation and a higher expected electricity production of solar cells? In 2008 the installed capacity in the whole of Italy was only 2% of that in Germany. Are there any natural or technological obstacles hindering the realisation of Italy’s solar energy potential? To calculate the physically limited solar harvest, modifications of the conventional method for the expected annual yield in Italy will be presented in section 3.3.

Thirdly, the results in section 3.4 summarise the cost and benefit surpluses of the theoretical German solar investments in Sicily and 3.5 makes political recommendations for the design of further solar energy subsidies.

3.2 Linking the social costs of carbon emission to RES support regimes

This chapter is linked to the environmental economic question of the internalisation and minimisation of both the social costs of CO_2 emissions and the higher production costs of generating electricity from renewable energies: what is the best practice to reduce CO_2 exhaust by growing renewable energy investments? Policy makers seek to design support systems that internalise the costs within national markets. The social costs of CO_2 emissions are broadly discussed.

Pigou (1912, 1932) first described the inequality of the private use of air pollution and the social costs: "It is true, and this matter is of growing importance, of resources devoted to the prevention of smoke from factory chimneys: for this smoke in large towns inflicts a heavy uncharged loss on the community in respect of health, of injury to buildings and vegetables, of expenses of washing clothes and cleaning rooms, of expenses for the provision of extra artificial light, and in many other ways." (Pigou, 1912, p. 159) He indicated this circumstance and its economic-ecological consequences as an externality that is not correctly priced into the market. Pigou proposed a tax equal to the ecological damages caused by emissions. He mentioned the pollution generator and the victim, where the state is forced to undertake corrective actions under these circumstances. Market participants will not be able to shirk payment the governmental tax and mitigation will occur where it is most efficient.

The concern over direct emissions as the cause of pollution and damages to the environment is further discussed within the scope of social costs of emissions (Crocker, 1966), negative impacts on prospective growth (Bovenberg and Smulders 1995) and external costs of electricity production and CO_2 in modern economies (Krewitt and Schlomann, 2006). It is important to question even the best political actions and the impact of CO_2 certificates on the channelling and reduction of emissions as a choice of prices (taxes) for emission or quantities (=certificates) (Weitzman, 1974), where environmental taxes should be the price of the damages (Segerson, 1988).

There are different ways in which renewable energies can be supported. One example is the feed-in tariff for renewable energies (REFITs), which is often adopted in combination with a clearance system. This approach leads to private decentralised investments in renewable energies. The general design of a REFIT system guarantees investors a fixed price for every kilowatt-hour produced and access to the national grid: local grid providers must then absorb the energy. A national clearance system allocates the system costs to all consumers of electricity: any REFIT with a clearance is in itself an instrument that internalises the higher costs of renewable energies. That means the environmental costs of power production due to emissions are shifted to the consumers. But, as described by Segerson (1988), due to the surcharge for all consumers, it is similar to an energy tax in terms of the uncertainty of environmental damages. All consumers pay the investment incentives, which can be identified as a kind of Pigou tax: for the consumers, the results are costs in proportion to the absolute waste from their consumption, namely the pollution by the energy production. The consumer paid Pigou tax is equal to the income of the investors. They choose the most profitable technique and their benefit is the REFIT. This is equal to the sum of tax payments.

Feed-in tariffs are adopted in a broad range of countries; within the European Union in 15 of the 27[21] member states, as well as in Switzerland. All REFITs have in common the support of technology without direct subsidies to producers of technical equipment and systems. Large solar farms can profit from REFITs, but often small-sized private power plants are the beneficiaries of a higher tariff. According to the analysis for the EU by Jäger-Waldau (2008), REFITs are highly effective in terms of market stimulation if a positive return on investment is reached in a period of 10 to 12 years and if the private investors have direct access to local grid connectivity. The author notices that his previously described efficiency conditions for market stimulations are fulfilled well by the design of the German REFIT. It appears to be clear, through the legal conditions, that in 2007 80% of the European photovoltaic capacity was installed in Germany.

Produced solar energy is climate-neutral; the production of 1 kWh does not create any greenhouse gas emissions once the plant is in operation. The German Federal Government announced an extension of renewable energies of up to 59% in order to reach the aim of emission savings of 20% as officially announced by Nitsch (2008) on behalf of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Hence, the photovoltaics' contribution to environmental protection targets is more important than the production of energy itself. Without renewable energies, the total German CO_2 emissions would be 15% higher, but as stated by Böhme and Dürschmidt (2008), the share of gross electricity production in 2007 was only approximately 6.7%. For the further analysis, these two shares demonstrate on the one hand the contribution of RES to the CO_2 reduction obligations.

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[21] 2008 data; the EU consisted of 27 member states.

Through the RES carbon savings, other sectors have less pressure to save emissions and meeting the NAP target will become cheaper. On the other hand, again, the absolute emissions will not decrease below the cap, and the RES emission savings only represent a permit redistribution with a shift to other sectors.

It is difficult to price the social costs of carbon emissions. The initial place of pollution can be local, but the aftermath or impact can be global. The time perspective makes this task even more difficult. As described by Pigou (1932), the damages through air pollution cannot be immediately measured, but the long-term impacts affected by the uncertainties of long periods and the preferences of today’s consumption make a long run measure difficult. The problem thus arises of how the so called Pigou tax (Pigou, 1912) for environmental waste can internalise the social costs of carbon damages. The optimum is reached when the tax, social costs of carbon emissions, and marginal abatement costs are equal. Because of the higher absorption potential of a cleaner environment, it is easier and cheaper to pollute instead of abate emissions. Vice versa, in case of higher pollution, it is simple and inexpensive to avoaid and therefore save one single unit of emissions. Bovenberg and Smulders (1995) add the specifics of pollution abatement knowledge as a public good and not that new innovations raise the use of pollution abatement technology and "private agents do not internalise the adverse effect of pollution an the aggregate stock of natural capital". Polluters will not decrease the pollution of their plants unless the use of the environment (the air) has a price. If one prices the pollution, the owners of the plants have two options: one is doing business as usual and paying tax for the emitted pollution quantity, as long as it is not economically worthwhile to reduce emissions. The other option is reducing the pollution by updating their manufacturing processes and their technology right from the start to prevent emissions and thus tax payments. Between the two scenarios, every single emitter will have a point, at which pollution will cost more than avoiding emissions, which will encourage innovation towards a cleaner production process.

One can calculate the social costs per ton CO_2 as the aftermath of climate change. The problem is however to examine exactly what "costs" are: only direct costs, which tend to be very low or also long term costs in terms of global warming and the consequences for animals, nature and humans? Man-made warming pushes nature to extremes, reduces the biodiversity and changes the natural conditions for living. It is thus a question of socially accepted costs, bearing in mind that there are also some positive effects of climate change such as lower mortality of people through cold winters or longer crop periods in Northern Europe. In the end, few deny the negative impacts of emissions, but the (current) price of carbon emissions has to be decided. If, as suggested by Krewitt and Schlomann (2006)[22], the costs are €70 per ton of CO_2 emissions, the previously explained substitution of conventional electricity leads to avoided social costs of 5.5 cents per kWh of produced solar electricity. In another dimension, the price for conventional energy from coal must increase by 8 cents per kWh.

If the costs of CO_2 are known then the next question to answer is, what is the information worth. If REFITs per kWh are equal to the social costs of carbon emissions caused by the production of a energy unit, the optimum is reached in accordance with the ideas of Pigou.

The problem of determining CO_2 savings in kilowatt per hour is the uncertainty about which kind of energy is used for production, but also which conventional plants are going to be substituted. It is important to take into account that, during the production process, also for green energies, burning fuel cause gas exhaust and carbon emission. For example, the typical Spenke production process[23] of pure silicon, raw material for a high share of solar cells, creates high energy outputs that degrade the balance of solar energy. New procedures decrease energy consumption for the production and at the same time the degree of efficiency of the produced solar cell is increasing. Krewitt and Schlomann (2006) expect a significant decrease in CO_2 emissions and that the calculated CO_2 emissions per solar kilowatt-hour are expected to halve from 99g (2000) to 54g (2030). Considering the above explanation it appears clear that it is not acceptable to determine saved CO_2 equivalents with expectations for future power production. There are too many uncertainties with regard to the innovation of newly installed (conventional) power plants and unjustified assumptions in the scenarios. It is difficult to reliably calculate the absolute value of GHG savings by photovoltaics. Nevertheless it seems to make sense to take emissions caused by production and erection of solar power plants into account and divide these emissions by the expected

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[22] €70 are the middle bound of the estimated consequences of one ton of CO_2 emission on climate change, where the lower bound is approximately €15 and the upper bound is €280.

[23] Spenke process: the so-called production technique by Siemens is the industrial standard, introduced by Spenke (1956) in the Siemens laboratories: trichlorsilane and hydrogen molecules are triggered in a heat reactor, the result is poly-crystalline silicon. Trichlorsilane is itself a higher order intermediate good, for its production of silica sand and coke fuse to produce raw silicon at 2000 °C, the next processing is conditioning with hydrogen chloride.

solar harvest for an assumed life span of 20 years, which is also the paying-period for many national REFITs.[24]

The *German REFIT* serves here as the example for a deeper analysis of the state-of-the-art promotion of renewable energies. Early German dominance in the installed capacity of solar power plants appears to be linked to its role as an early innovator as other countries did not have a similar promotion system as early as Germany. In the year 2000, German's legislature passed a law to combine various prior laws and decrees to stimulate RES investments and to reorganise the grid access and the feed-in.

The "Erneuerbare Energien Gesetz" (EEG)[25] for renewable energies covers amounts of feed-in tariffs, duration of subsidies payments, free access to and priority in national grids, and the positive discrimination of certain technologies. Only plants located in Germany can apply for subsidies. In this context, positively discriminated by §§23-33 EEG are e.g. photovoltaics and other less efficient, but highly desired, often new and expected to be advantageous in the future, technologies.[26]

It is important to consider that subsidies paid to green energy producers are non-government[27] payments. The paid REFIT subsidies are incorporated into the earnings of the power plant owners, the producers of eligible energy receive guaranteed compensations from the local grid carrier, while the additional costs above market price are a surcharge on the bills paid by all consumers.[28] A nation-wide clearance charges the proportionate costs internally on every kilowatt per hour sold, whether produced renewably or conventionally. The entire financing of both renewable

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[24] The expected lifetime however should be much higher. The German REFIT is already recompensed for an average of 20.5 years, in the year of erection plus 20 years; see EEG, 2008, §18, Par. 2. Through this extension the calculated CO_2 emissions per kilowatt-hour should be reduced by an additional amount of 2.5%. Renken and Häberlin, (1999) report on early test plants in Switzerland that have been in operation for 30 years without showing a significant degradation of annual solar harvest.

[25] While the feed in the grid is covered by §16 EEG, the legal foundation for the general grid access is regulated in the former decree StromNZV; for biogases and renewable fuel classifications see also BiomassV.

[26] The highest tariff is for the privileged solar energy technology, see also BSW (2008): the electricity produced by solar power plants has a share of about 4.6% of all renewable energies, while the share of REFIT compensation (according to EEG §§ 6-11) is around 20%.

[27] See the judgement of the Court of Justice of the European Communities, C-379/98, 2001, I-2099, PreussenElektra: because the obligation to feed-in renewable energies is not granted directly by the state and "does not constitute State aid within the meaning of Article 92(1) of the Treaty."

[28] Exceptions are made for industries with a high quantified consumption of electricity.

energy plant erection[29] and feed-in tariffs comes from the private sector and consumers. Subsidies mean a reallocation within the market that is a steering effect of the EEG. The electricity price increase is thus a kind of environmental tax and should further aim to reduce energy consumption.

The EEG is not only a support of a current technology, but also promotes employment and R&D in this sector. The knowledge allows companies to enter global markets as innovators. The German photovoltaic industry in 2007 for example consisted of 43,000 employees, a turnover of about € 5.7b (BSW, 2008) and an international market share of around 30% (Dürrschmidt and Van Mark 2006); all of which in turn led to an increase in R&D and acceleration of the learning curve. Nevertheless, it must be stated that during this time the prices did not decrease in proportion to the innovative progressions undertaken at the same time (Forst et al., 2006).[30] An issue, which becomes highly important when the REFIT will be set.

With the *Italian Conto Energia II*[31], Italy can be named as an adopter of the EEG where numerous national and regional laws were replaced with the intention of supporting renewable energies. Some local laws in addition to those at the national level are still legal with respect to the national decree[32], but policy makers learned from the failure of the former decree. Local political regimes can no longer avoid solar power plants, but still provide minor influence.[33]

When considering the details there are further differences to the German law, for example the payment for newly installed plants is adjusted annually in accordance with the directive DM 19/02/2007, Art. 6-9, and the legislators focused at a very early stage

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[29] The federal owned KfW bank announced different promotions for private investments in renewable energies, as e.g. interest-reduced credits for grid connected solar power plants with an output of up to 50 kW e.g. the so called "100.000-roof-programme" (2000-2003). Since 2004 the programme has continued with similar promotions. The KfW is organised as a private sector bank.

[30] Caused by high market demand firms sold with increasing margins. In addition, shortages in silicon production led to increasing panel prices between 2004 and 2006, while converter prices were shrinking.

[31] DM 19/02/2007, following a former law, the "Conto Energia I", DM 28/07/05 and 06/02/06.

[32] E.g. for simplification, the simple building notice is at local administration instead of an official building permit. Even the protection of historical architecture expired in certain cases and if the erected power plant is for example roof integrated, regional decrees are allowed for regional architectural compliance or limitation to certain areas.

[33] The limit of a supported capacity of 100 MW was reached in the first month after declaration of the national law, according Pasquini and Vacca (2006). Thus in 2009 the national authority GSE noticed and this led to an increase in new investments instead of boosting it up.

on the hierarchical feed-in tariff with positive discrimination for certain technologies, such as totally or partially integrated roof solar power plants. This led to a significantly higher demand in Italy for the less profitable technology of roof-integrated plants, for example, for which there is no (relevant) market in Germany. In Italy, after the amendment to the Conto Energia II, 26% of the newly installed capacity in 2008 was architecturally integrated, mostly roof-integrated, as discussed by Montanino (2008).

The grid carrier has the obligation to feed-in electricity produced by power plants below 1 MW capacity. As discussed above, other regulations like the former decree of green certificates apply, which forces the grid carrier to absorb a mandatory quota of renewably produced electricity but also means a limit in terms of absorption obligations.

The Italian REFIT is more flexible: the green energy certificate quota applies also to extra-territorial areas. If the German EEG were adjusted in the same way, the calculation done in the next chapter would no longer be hypothetical. The fundamental elements have been laid to open Italy as the German granary for the solar harvest, but some legal issues remain unsolved and the structure must be modified:

1. The Conto Energia II specifies high commission for produced electricity, but is limited through DM 19/02/2007, §13, Par.1, to a maximum capacity of about 1200 MW, which is only a little more than the sum of newly installed solar power plants in just one year in Germany. Thus Italy does not take advantage of its full sun potential and limits itself.[34]
2. The state-of-the-art design of many national REFITs actually led to a higher share of small private investments. The Italian market shares already changed dramatically in the first year after the declaration of the Conto Energia II; the average size of newly installed plants shrank while their sum grew as measured by GSE in 2009. For maximum efficiency, solar parks appear to be the better solution.

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[34] Spain, with similar radiation conditions did not implement such a limitation before 2009 and can count newly installed capacities of almost 2000 MW in the year 2007, as measured by state authority CNE 2008.

3.3 The solar harvest and its limitations through physical conditions

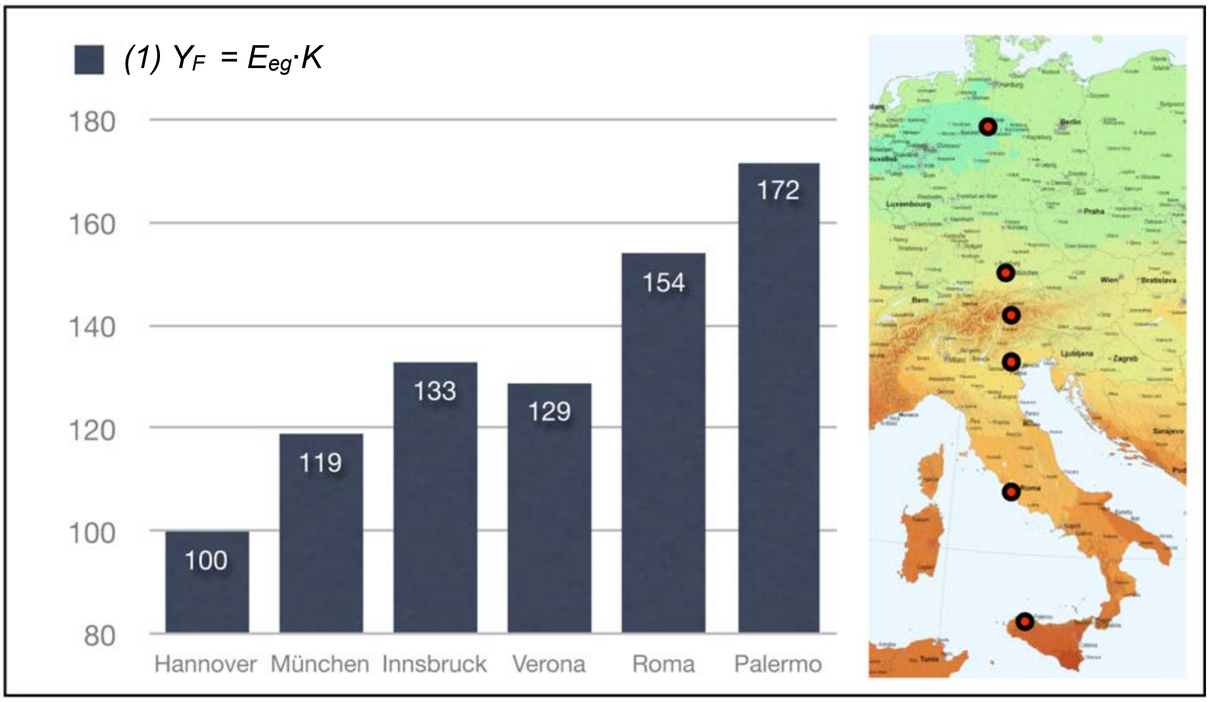

Figure 8: Index for expected final yield, traditional approach, *Hannover = 100*
Source: own calculation according PV-GIS.

The calculation of the solar harvest, the final yield Y_F, would be completed here, if the general calculation would take into consideration only the performance of the plant capacity and the irradiation. The load capacity is the conversation factor of the irradiation input [W] to the output [W] per time unit [h]. For the final yield, multiply the global radiation E_{eg} in Watt by the plant load factor K to get the final yield Y_F in kilowatt-hours:

$$(1) \qquad Y_F\,[kWh] = E_{eg}[W] \cdot K$$

The left side of the equation is the calculated yield, expressed in generated kilowatt-hours. The production results from the right side of the equation, in the intensity of use of one capacity load unit K. In the basic calculation, the simple multiplication of irradiation per load factor capacity K results in the annual harvest. Further modifications are required to take into account other factors of influence like temperature or technical or geographical conditions. The deviations of all these factors from perfect conditions lead to percentage correction factors of the capacity and a decrease of expected solar harvest.

For such a simple calculation we must of course obtain standard test conditions (STC)[35]. In addition, there are some parameters with unclear effects. What impact on the solar harvest do, for example, topography, air pollution or general losses have?

The first calculation resulting from (1) indicates that the increase in efficiency of the solar harvest should be about 72% when installed in Palermo, relative to a plant in Hannover, as shown in Figure 8.

The chosen approach in the following modifies the conventional calculation method due to geological and meteorological conditions but also refers to the technology used. Factors, preconditions and parameters will be discussed and evaluated for the analysis to ensure that the gap between the real harvest and expectation are marginal: the physics are the limitation for the economics and thus limit the return on investment. Hence, the most common state-of-the art technology will be considered. The reader can gain more in-depth technical information in appendix I, which allows further own modifications within on-going technological development for individual calculations of the resulting final yield for specific locations.

Temperature losses: The performance of silicon-based solar panels is dependent on its inner heating. The warmer the cells, the weaker the absorption potential in accordance with the surrounding temperature and the power of solar radiation. For comparisons, the cell temperature coefficient is measured in relation to the STC. Through this generalisation any aberration above 25°Celsius leads to a negative and any below this mark to a positive performance effect. The question thus arises whether solar panels are as effective in the warmer south as in the colder north. Temperature losses appear to be the factor that influences the differences in macro comparisons of regional yields most.

The temperature in the cell is linked to the environmental conditions, but can also be regulated in a certain spread by the cell design. To approximate the annual temperature loss for a specific location, the measured surrounding temperature T_S has

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[35] Generally we cannot have these special conditions outside any laboratory: STC force an inner cell temperature of exactly 25° C, a radiance of 1000 W/m^2 and an air mass of about 1.5. The STC serve to compare different module types from different producers. For different geographical locations one has to take into account the specific environmental conditions that can differ in fundamental dimensions.

to be corrected. A surplus of $\Delta°Kelvin$[36]$=7$ would be sufficient for further calculations due to the often missing data on day length temperatures.[37]

The kind of installation is also important, especially the cooling on the back side of the panels: the correction factor due to installation is T_I, with $\Delta°Kelvin=10$ for on-roof plants and $\Delta°Kelvin=20$[38] for roof-integrated plants.

The radiance intensity in watt is the most important factor when calculating regional differences for expected yields and is also responsible for heating the panels. The cell temperature[39] follows the radiation curve over the day and year and thus leads to a heat surplus of $\Delta°Kelvin=0.03\cdot W$.

The producers of solar panels are intensifying research for a better design of temperature management in the cell[40] that results in a smaller temperature correction factor. Locations exposed to warmth and sun will benefit in particular, the advantage for Sicily for example continues to increase.

The calculation is thus modified by the temperature correction factor K_T as follows:

$$(2) \qquad Y_F[kWh] = E_{eg}[W]\cdot K\cdot K_T \quad ; \qquad \text{where } K_T = 1 - 0.005\,(7 + T_S + T_I + E_{eg}\cdot 0.03)$$

Converter losses: Solar power plants need a converter. Silicon-made solar cells operate as semiconductors and absorb photons, which are light quantums. These particles are the smallest energetically loaded elements of light. Through the absorption of photons in the solar cell it is possible to harness the solar energy. The flow of the photons is the direct current of electricity and will be converted into an

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[36] Kelvin is equivalent to Celsius according to the scale, but does not depend on the dew point of water as zero level, thus it is more reliable and is used unit-less in the mathematical application.

[37] One has to pay attention to the seasonal path of the sun and diverse lengths of days. Solar electricity will be produced over the day, foremost in spring, summer and early autumn. Discrepancies in the day lengths caused by north-south positioning will not be taken into account, but micro climates, influenced by e.g. vegetation or buildings can dramatically differ as shown by Renken and Häberlin (1999).

[38] STC are most equal to installations in the plain or with triangle brackets on flat roofs, while on-roof panels have a higher inner temperature.

[39] There is no generalised correlation for the cell heating. The laboratory experiments and field studies by the named authors, but also Bett et al (2008) refer to heating per $\Delta W/m^2=100$ between $\Delta°Kelvin=4$ and $\Delta°Kelvin=5{,}3$. Not all types of cells are affected in equal measure.

[40] Heating will decrease through extension of surface, better air flow or new materials.

alternate current at the converter side. The converter-charged electricity can be fed into the national grid.

The converter causes losses in operation because of permanent power fluctuations. Other reasons for converter losses are heat, inadequate capacity or frequent voltage fluctuation. In the following an analysis will account for a loss of 3%, which is the lower bound for the average loss of state-of-the-art converters.[41]

The calculation is thus modified by the converter losses correction factor K_C as follows:

$$(3) \qquad Y_F[kWh] = E_{eg}[W] \cdot K \cdot K_T \cdot K_C \quad ; \quad \text{where } K_c = 1 - 0.03$$

General losses: There are other factors that have either a positive or negative influence on the solar harvest such as aerosols and topography. Please refer to the technical appendix for further details. To summarise all these effects, in the following a general correction factor of 0.04 will be introduced to the calculation. Thus conditions that are highly determined by local conditions but equally distributed for all power plants in general are included.

The calculation is thus modified by the general losses factor K_L as follows:

$$(4) \qquad Y_F[kWh] = E_{eg}[W] \cdot K \cdot K_T \cdot K_C \cdot K_L \quad ; \quad \text{where } K_L = 1 - 0.04$$

Radiation angle: Solar cells can produce electricity through photon absorption only if the light energy penetrates them. The light itself is a component of two kinds of radiance: direct normal radiation[42], light which comes directly from the sun, and diffuse radiation, which is broadly dispersed through reflections and mirroring. Both types of radiance when used in conjunction are the so-called global solar radiation and the measuring unit for calculation of the expected yield. In the near future, photovoltaics must be compared with concentrated solar heat, a technique that uses direct normal

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[41] As an exception, that modern converters often beat, the absolute factor influence will increase. See Market survey and regular tests by e.g. Photon, 12/2008, 66-72.

[42] For maximum use of the direct normal radiation, solar panels have to be installed at a 90° angle to the sun light radiance. The angle of installation grows less the further south the position is, on the equator the angle is 0° to the ground.

radiation.[43] This technique has an impact on the direct comparison of the global solar radiation and is using the two decoded components named above. In the following the separation of radiance into two types and the detailed explanation of radiances types is neglected, because the intention of the thought experiment is to analyse the efficiency of photovoltaics in different areas and not conduct an evaluation of techniques.

The structure of power plants is too different to adopt an additional correction factor and investors will seek to erect cells at the best angle. Minor losses due to an incorrect installation angle appear to be marginal and will be included in the general correction factor explained previously.

Module efficiency: The module efficiency is important where space is a limiting factor. The following analysis will be calculated using average module efficiency.[44] Plants that were newly erected in 2008 were constructed with the same shares of mono- and poly-crystalline cells. This technology mix promises an overall module efficiency, the input-output-ratio of radiation to energy production, of about 15%. However due to a rising share of the technologically less efficient, but less expensive, thin film modules[45] the average efficiency decreased to about 12.75%.[46] For the installation on a plain area this signifies the need for approximately 8 m^2 to install a nominal capacity of 1 kW.

The calculation can be modified for the expected yield per square metre, Y_F/m^2, which is important for individual investment calculations where the ground has a price that must be taken into account:

$$(5) \qquad Y_F/m^2[kWh] = E_{eg}[W] \cdot K \cdot K_T \cdot K_C \cdot K_L \cdot K_G \quad ; \\ \text{where } K_G = 1 - 0.875$$

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[43] In southern Europe the direct irradiation is on a very high level that allows the operation of concentrated solar heat plants. Solar radiance is bundled to a very high concentration to heat a carrier like oil. The accumulated heat can be converted into electricity. The advantage is a certain possibility to save heat for later use in the carrier. Energy production costs are low.

[44] The module efficiency is not the same as the cell efficiency that has higher rates but is not relevant in practice. For realised power plants it is very important to know the needed plain because installation does not imply the installation of only cells, but modules.

[45] Forst et. al (2006) mentioned a 93% market share for mono- and poly-crystalline panels.

[46] This is a market typical condition for solar power plants. The basis are markets that offer poly-crystalline cells, e.g. BP 3170, Umweltfreundliche Haustechnik GmbH, Göttingen, Germany 2008.

Prices: Given the question, what is the expected return on investment, one has to estimate the price. Due to the use of the 2008 database, the total costs are fixed for that year. For the erection of a solar power plant with a capacity of 1 kW, approximately €4400 of capital were required for an on-roof installation, while an amount of about €4200 was required for the installation of a plant on top of a plain roof or the ground.[47]

The calculation formula (1) for the final yield has been modified by additional factor, with the results of the corrected formulas (4) for the plant‘s capacity, respectively one square meter of used ground for installation (5):

$$(4) \qquad Y_F[kWh] = E_{eg}[W]\cdot K\cdot K_T[°K]\cdot K_C\cdot K_L$$

$$\text{or} \qquad (5) \qquad Y_F/m^2[kWh] = E_{eg}[W]\cdot K\cdot K_T[°K]\cdot K_C\cdot K_L\cdot K_G$$

where the price is fixed, $P = P_{kW} = P_{2008}$

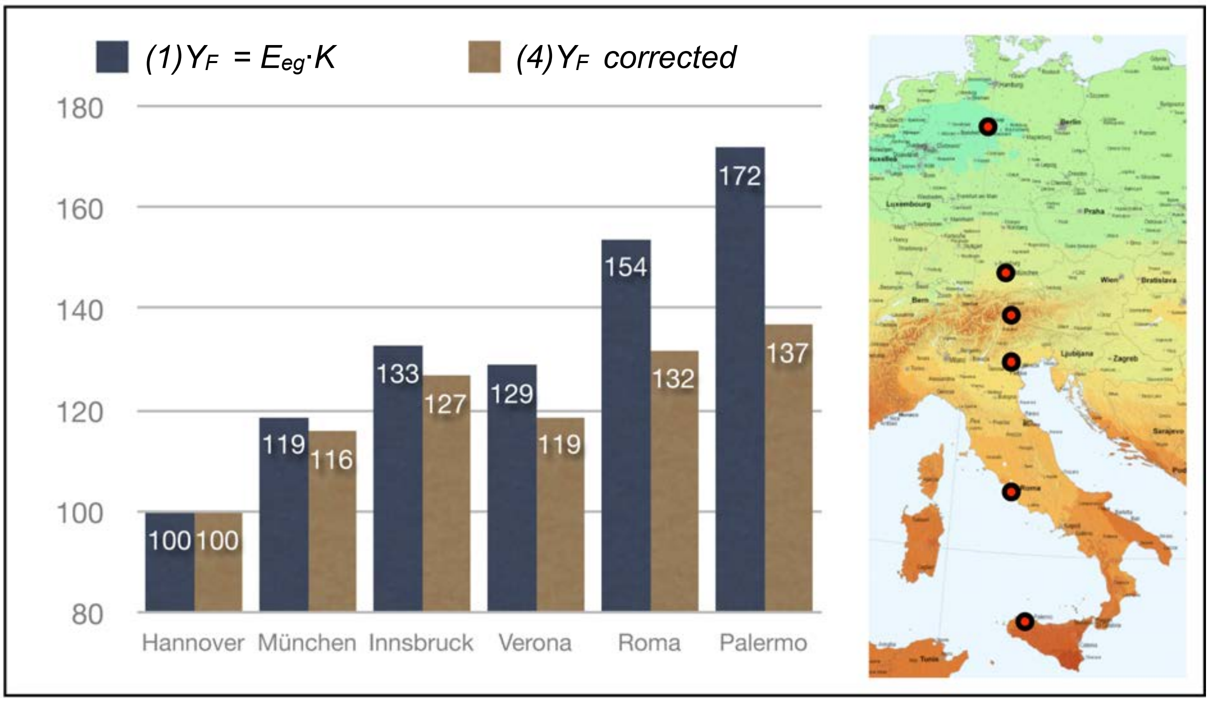

Figure 9: Index of expected final yield, modified approach, *Hannover = 100.*
Source: own calculation according PV-GIS.

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[47] The global financial crisis led to a price dampening effect: it is unknown if this impact is only for the short term or for the long-term also. Further, before analysts noticed an annual price decrease between 6-8%, see e.g. WEST LB Research (2009). The market is changed to a buyers' market, according to Zindler and McCrone (2008).

Taking into account the modified calculation formula for the mentioned cities with their individual annual average of irradiation, the advantage of a position in the south remains, but decreases dramatically, see Figure 9. Palermo as the southernmost city still has the highest solar harvest, but the surplus shrinks to only about 37% in comparison to 72% when using the traditional approach. Some factors are equally influencing the yield and are not affected by regional conditions. Those, all technical based, are important too, if using the calculation to compare different technologies. Here, the basis technology does not change. On the contrary, two factors vary significantly. It is the irradiation, as was mentioned when comparing locations using the simple approach (1) with STC. Taking into account physical conditions of the surrounding, temperatures have a huge, if not the highest, influence on the solar harvest and reduce the theoretical potential of southern regions in the generation of solar energies. Nevertheless, these areas are still favourable and cut costs and raise the energy harvest, which will be discussed further in 3.4.

To summarise here: The simple thought experiment underlines as an example what already could have been reached if RES promotions had been organised on a Europe-wide level.

3.4 Results and implications of the calculations

The application of the Italian Conto Energia II in comparison to the German EEG raises the following question as a thought experiment: what would have been the additional benefits for Italy, if using the same parameters for the RES promotion regimes as in the German EEG? What are the additional CO_2 savings, energy surplus and return on investment for the accumulated investments equal to those made in Germany between 2000 and 2007?

The factors and their influence on solar harvest have been introduced and discussed above. In the following these factors will be drawn together and statistical data from Germany will be used to merge the different years into one table and show the sum of solar energy investments that occurred after the declaration of the EEG. The figures will be a little higher than the calculation presented in this chapter: this can be interpreted as a sign of conservatism in calculations.

Exactly the same amount of investments as Germany's total will be converted for Italy. The calculation follows the determination of Staiß, Schmidt and Musiol (2007) that 1 kWh of solar energy accounts for a saving of about 787g CO_2 equivalent.[48] The CO_2 savings are calculated in accordance with the cross section analysis of Klobasa and Ragwitz (2005) that assumes solar electricity substitutes for 50% natural gas and 50% mineral coal plants.[49] Solar power is not a very secure resource as it is produced following the cycle of the sun, but conversely, a key advantage is that this cycle more or less reflects the typical power consumption curve: peak periods during the day time and summer (air conditioning in offices) are often covered by the high performance of solar power plants at the same time. Due to a continuous lack of accumulators, electricity is not storable and has to be consumed in the moment of production; as a result solar energy cannot yet substitute conventional base load plants in general, but during peaks it can substitute gas and coal peak-load power plants.

Firstly, for the purpose of the analysis, only areas with an average annual radiance of at least 1750 kWh are recommended for on-roof plant installation that can be found particularly in Sicily, but also to a lesser extent on the mainland of Italy (especially Apulia, but also Calabria and Campania) and in the south of Sardinia. No technology processes that occurred after 2008 will be taken into account, the status quo will be fixed for cost prices and the degree of efficiency.

Secondly and importantly for a deeper analysis, arrays will be included: tracking systems that adjust panel orientation over the day and annually track of the sun. Such arrays have a strong positive influence on the final yield. Nevertheless such systems are neither cheap nor dedicated nor financially feasible. However, the advantage is obvious. The solar panel is always orientated to the sun and the direct normal radiation can thus be optimally used ensuring the potential to reach the maximum yield at any time. The benefits are especially present when the direct normal radiation is high.

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[48] CO_2 equivalents are a theoretical measuring unit, which not only take into account direct CO_2 emissions, but also other emissions that are released into the atmosphere and boost the greenhouse effect: CH_4, Methane, and N_20, nitrous oxide. They are converted for better comparison according to scientific standards to show their effect as if they were CO_2. This method is globally accepted and adjusted, to have equality of national emissions analysis.

[49] The CO_2 savings are not calculated explicitly, some observed studies also contain initial operation losses of substituted plants.

Thirdly, the calculation will be completed for the areas exposed to the sun, where additionally the Italian power supplier ENEL could invest in solar farms instead of erecting new nuclear power plants, according to an economic plan after the year 2000. The plan was budgeted as a 24 billion EUR investment. A national referendum put a final stop to the nuclear power plant plan in 2011. Is solar energy an alternative investment? What would be the production cost for one kilowatt-hour in the 2008 thought experiment? The issue of grid parity, the circumstance of equal prices for conventional and RES electricity, or one specific energy source, has to be in the focus of the analysis: Would or will the grid parity be reached now or in the near future, if the solar power plants are shifted south?

1) Table 4 shows all German investments for the erection of new solar power plants between the first declaration of the EEG in 2000 and 2007. These values will be compared with the theoretical harvest of Italy if investments would reach an equal level.

	new installed capacity (MW)	total electricity production (GWh)	Real turnover from construction of solar power pants
2000	42	22	343 Mio. €
2001	78	74	507 Mio. €
2002	80	146	575 Mio. €
2003	150	271	709 Mio. €
2004	610	515	2430 Mio. €
2005	863	1240	3183 Mio. €
2006	830	2178	3888 Mio. €
2007	1100	3458	4782 Mio. €
Total	**3753**		**16417 Mio. €**

Table 4: Global annual irradiation and solar harvest; *source: own calculation according to data of BMU, 2001-2008 and ECB, 2009.*

Values are estimated from an analysis conducted for the German Federal Ministry of Environment. For a better valuation of investments made, amounts are adjusted by the annual inflation rate and thus show the real presence equivalent for 2008. The total German solar energy harvest of the year 2007 was approximately 3458 GWh, produced by the installed power plant capacity of 3753 MW between Rhine and Oder. This accounts for CO_2 savings of around 2,400,000 tonnes in comparison to conventionally produced energy, according to the approach shown above.

General technical conditions are the same for each location and thus can be eliminated from the calculation with relative, but not absolute comparisons: losses by the

converter, soldering joints, cables etc. and the degree of efficiency.[50]

The only correction factor that is always very important is the temperature, which as explained before, minimises the degree of efficiency. The positions of the locations have been taken typically for the chosen regions.[51] Roof-integrated power plants will not be included because they do not account for a high market share.[52]

2) If German EEG supports were converted to Sicily, the expected production cost per kilowatt-hour would be about 19 cents:

		Germany on roof	**Sicily on roof**	**Sicily 2-axis**
irridation	W	1100	1750	1750
inverter loss	%	4%	4%	4%
average air temperature	°C	8.0	15.0	15.0
kind of power plant (temperatur effect of installation)	1 = on ground and 2-axis, 10 = on roof	10	10	1
average module temperature	°C	41.3	72.6	63.6
temperature loss	%	16.50%	29.75%	25.25%
modul efficiency	%	12.75%	12,75%	12.75%
general losses	%	2.00%	2,00%	2.00%
final yield expected per squaremeter (5)	kWh	110.2	147.5	208.7
final yield expected per-capacity factor (4)	kWh	864.1	1,156.6	1,636.8
generation costs/kWh		25.46 ct	19.02 ct	16.49 ct

***Table 5: Expected yield**, own calculation according the technical conditions of chapter 3 in (4) and (5); see apendix 1 for detailed technical assumption.*

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[50] Newly developed solar panel generations are more efficient, but production costs are higher and thus the realisable capacity can be smaller with newer technologies where investment is steady. Technological progresses will influence the yield per installed capacity of 1 kW or reduce the required ground area. The learning curve favours later investments and influences the profitability positively, but is not taken into account in the calculation due to many uncertainties.

[51] Single location positions can differ, but not only positively: higher temperatures or less radiance are examples of negative aberrations.

[52] For individual investment calculations however, the higher heating of on-roof installations with a surplus of 10 degrees in comparison to on ground installations has to be taken into account. That seems to make sense if the recommendation for or against support of on-roof plants or solar parks is intended.

Table 5 shows three example to calculate the expected yield per year in Hannover and Palermo, as well as in Palermo using tracking systems. Multiply the expected yield for the expected lifetime of 20 years and divide the installation costs through the total harvest, the generation costs is about 25,5 ct in Hannover, and in Palermo about 19 ct with on roof installation and 16,5 ct using tracking systems.

The additional solar harvest would provide an energy amount of 860 GWh and a surplus in CO_2 emission savings of 665,000 tonnes and thus for the investors, the additional return would be approximately €370 million per year. Because the lower costs are significant reasons for the installation of huge on-ground solar farms or even the use of tracking systems, the harvest could be enlarged if it was the intention of the (local) policy maker. The investment sum thus leads to a higher installable capacity and lower costs for every produced unit of solar energy.

Similar results are gained when using 2-axis tracking systems. The use of these systems could cut the electricity production price down to 16.5 ct for one generated unit of electricity due to continual re-adjustment of the panels in relation to their ideal to the sun. For an unchanged investment sum, the installable capacity would slightly decrease. The higher costs[53] of a tracking system decrease the installable capacity and its load factor. However the harvest would increase by 20% for a comparable investment sum. Hence tracking systems become a very economical alternative.

3) The public discussions in policy and the Italian society were very controversial for and against the nuclear power investments planed by ENEL. Finally, the plan was rejected. The enormous planned investment sum of about €24 b could be, as an alternative, invested in solar parks with tracking systems. As a result, the expected production costs over a 20-years life span for one kilowatt-hour would be around 12.2 cents.[54] This is highly compatible for the Italian power market and for the end consumer in particular. Prices in 2008 were already far higher, future price increases not considered.

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[53] The calculated costs for 1 kW for on-roof are 4400 EUR, for tracking systems 5400 EUR.

[54] The investments of ENEL in nuclear power plants have never produced any electricity and thus the production costs, as the opportunity costs that are announced by 4.3 cents per kWh, have to be taken into account.

3.5 Conclusions and recommendations of the thought experiment

As described by Nitsch (2008), the German EEG was designed to stimulate the market and force cost reductions through market growth. The conclusion of chapter 3 underlines the success of the REFIT. Moreover, the new installations and the market demand for RES pushed R&D in solar power plants, and an increasing learning curve is expected. But further, it is proved that investments in other European regions would be more lucrative and efficient. Italy can produce a higher solar harvest in the regions of the islands of Sicily and Sardinia and on the southern mainland (Apulia, Calabria, Campania) when having the same installed capacity of phovoltaics power plants. Even without the REFIT, grid parity can be reached in the south of Europe. A scenario with a system of decentralised solar power plants as established in Germany by the EEG would lead to an increase in total efficiency of about 25%. If the investment sum of 2008 would be divided into the expected solar power harvest of one kilowatt-hour, it could be produced for 19.02 cents, while the average market price for end consumer in 2006 was approximately 21.08 cents with an upward tendency, as accounted by Goerten and Clement (2006).

The results are a realistic scenario. For a single European market, countries or even regions have to compete. Technologies will be more efficient in one place than in another. The transportation of electricity is expensive and power losses may be another negative aspect and are a strong argument to use produced electricity at its place of production. Within the near future, the redesign of the electricity mix substitutes in particular fossil fuels like gas and coals. The amount of produces solar energy for example is far away from being a reliable source for energy exports extra-territorial. PV can help to reduce the use of other peak-load plants. European open markets should allow the crediting of RES linked carbon savings in national accounts if the plant itself is located elsewhere in the EU. The cost-shrinking effect for the end consumer has been demonstrated above.

Through better heat management, losses can be reduced in the near future and thus particularly benefits locations with high surrounding temperatures and intensive radiance. The advantages of Italy's location will continue to grow.

It is difficult to complete a monetary valuation of the EEG programme. Surveys conducted by Frondel, Ritter and Schmidt. (2008a and 2008b) estimate subsidies of 108,000 to 205,000 EUR for each employee in the German solar sector. The analysis considers the REFIT transfer payments paid for the past and those estimated for the future. The amount is then divided by the number of employees. The chosen approach calculates a life cycle balance, but remains with a fiscal result without taking into account external social costs of CO_2 emissions and thus the survey differs from the approach of this section.

It is important not only to act as the innovator of techniques, but also for policies. Wiekert (2008) expects a stagnant German market and thus the domestic companies are forced to enter foreign markets. The EEG itself is a successfully exported and accepted model for many countries across Europe and the world. The German EEG is generally adopted with only small adjustments made to meet local needs.

While the European Commission (1996) declared within Directive 96/92/EC that Europe-wide energy markets would be open as the goal for 2007, discrimination by national supporting systems for renewable energies remained legal to avoid a concentration of investors at the most profitable REFIT. Thus, following the results of the calculations completed here, the efficient implementation of solar power plants for example, was not achieved.

Under the condition of an European wide single market with clearing mechanisms, Germany could have accounted for an additional reduction of about 1.2 million tonnes of CO_2 per year, if German investments had been accumulated over the years and invested 2008 in solar parks with tracking systems located in the Sicilian area.

This correlates with two thirds of the 2005 emissions from the production branch *ground transportation and transport in pipelines* or further is even 0.1 million tonnes more than from *shipping*[55]. It also implies a potential avoidance of social costs accrued through CO_2 emissions of approximately €84 million. Measured by the total energy-induced CO_2 emissions of Germany in 2006 at about 819 million tonnes[56] per year, the additional contribution of total GHG savings would be approximately 0.15%. In relation to the obligations as stipulated by the UN Kyoto Protocol[57], this would account for a saving of around 0.5% of total CO_2 equivalent saving obligations, whilst the additional amount of power supply of 1519 GWh accounts for only 0.25% of

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[55] Destatis (German Federal Statistical Office), Document 85111-0001, 2008.

[56] Energy caused CO_2 equivalents, as analysed by Böhme and Dürrschmidt (2008).

[57] The obligations in CO_2 savings according the Kyoto Protocol for Germany account for 257 million tonnes of carbon equivalent emissions by 2012 in relation to the base year of 1990.

gross annual electricity production.[58] The United Nations protocol provides the framework that allows such projects as proposed in the calculation. Kyoto Protocol Annex-A countries, such as Germany and Italy can stipulate "Joint Implementation" and count additional CO_2 savings extra-territorially, but not within other Annex-A countries, as done intra-territorially as compliance of the contractual terms.

The objectives of the policy makers respecting the 20-20-20 by 2020 targets and the subsequent treaty goals would be more rapidly reached if Europe acted as a single player. Member states in the south should now, in particular, accept photovoltaics as one component of their future energy mix and one piece of the puzzle to reach their climate protection goals. A path-goal-strategy must implement a REFIT similar to the German model for market stimulation, and intra-EU concentration of technologies at the place of highest efficiency is recommended. The effects have been shown in the analysis and the figures in this chapter. This approach would reduce CO_2 emissions faster and thus the European Union could apply more pressure on other states worldwide to intensify their contribution and efforts in preventing global warming.

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[58] 2006, datasource: Böhme and Dürrschmidt (2008).

4. Energy Efficiency - The influence of climate change policies

Energy efficiency is more than just energy saving: it depends not only on current energy use in relation to economic production in goods and services. Energy efficiency is only growing in real terms if energy use is decreasing while simultaneously, affluence and population remain constant, are growing or at least shrink less. In a nutshell: energy efficiency increases only if there are other driving factors of influence besides production and population.

The following analysis shows that energy use is not only dependent on economic growth, but that policy measures can influence energy consumption and its efficiency, too. However, there is only a limited ability to increase energy efficiency with policy measures.

The European Union tries to use the limited scope of action to pursue ambitious climate protection policies and requires member states through the 20-20-20 by 2020 targets to raise energy efficiency also in order to reduce greenhouse gas emissions. The EU commission is understanding a raise of energy efficiency is equivalent to the achieving of 20% savings in energy use (European commission, 2008 and 2011). The decrease of primary energy use is one of the headline targets of the European climate change policy strategy.

The reduction of primary energy accounts for the third component of the 20-20-20 by 2020 targets. In contrast to the increase in the share of RES or the reduction of carbon emissions, the decrease of energy use is less specified. First mentioned only as a side effect of the achievement of the emission reductions and the increase in RES capacities (see e.g. European Commission, 2008), it has increasingly become an independent objective. In 2014, the European Commission answered a request by the European Council to explain the necessity for the reduction of primary energy use: The EU-member states have to propose concrete actions to increase energy efficiency and therefore reduce their primary energy use by 20%. One intention besides a lower energy intensity is also a decoupling of growth and energy use. The Commission emphasises further that the EU-ETS in particular makes an important contribution to higher energy efficiency.

The two goals are closely related: The burden sharing agreement is the basis of the EU-ETS, and the individual countries' goals are supposed to have an influence on energy use, too. It was agreed that the common EU Kyoto obligation overall GHG reduction output is redistributed among its member states in the Burden-Sharing Agreement (BSA): The BSA reduction targets for the individual members differ and lead thus to heterogenous obligations. Diverse countries have diverse obligations and while some have to decrease their emissions some countries can remain their level of emissions or are even allowed to expand them. Hence it is possible that both effects (absolute emissions, BSA participation) point into contrary directions. From a panel data analysis, it can be inferred that the obligations of the BSA exercise pressure on EU member states for prompt action to enhance energy efficiency and reduce the linked energy consumption.

4.1 Energy efficiency policies - an introduction

Besides the implementation of green power plants to increase the share of renewable energy sources in total energy production, and the reduction of CO_2 emissions, energy efficiency is the third component of the 20-20-20 by 2020 targets in the European Energy Concept (European Commission, 2008). The chapter 4.1 will answer the political component of energy efficiency policies, while the detailed explanation of the (technological) terms follows in chapter 4.2.

The twin goals of reduction of energy usage through absolute savings and better utilisation of available energy through technical innovation are both closely bound to the increase in energy efficiency. Consequently, this is an important contributor to emission reductions and will also bring other advantages: "Energy saving is without doubt the quickest, most effective and most cost-effective manner for reducing greenhouse gas emissions." (European Commission, 2005). If energy is not being used or even produced, it causes neither emissions nor resource wastage. At the first glance, this policy seems to go against the fundamentals of the European Union, the Treaties of Rome (1957) and the Maastricht Treaties (1992), which postulated (economic) growth and continued development as part of the main objectives for the European future. Energy savings and growth seem to be in contradiction to each other. But within the texts of the treaties, there are other objectives to consider, often linked with the legal basis: the prosperity of Europe has to be in accordance with a framework of environmental protection for people, animals, ground and air.

Therefore, member states, their people and industries, should decrease their energy consumption.

Energy use is a good proxy for the progress towards higher energy efficiency, even in a period of economic decline it should shrink more than the economy itself. To put it simple, the deviation of both rates to each other is the (technological) increase in energy efficiency. This asymmetric development is possible due to the fact that energy efficiency and production growth are not necessarily subject to the same rate of innovation. Thus, the growth rate of technical efficiency should be higher than the increase in production. The energy input-output ratio decreases, as the energy use in the production process is decreasing while the output for every individual unit of energy increases.

Efficiency is a theoretical term, hence its meaning, the effectiveness of measures and actions to reach a given target, cannot be measured directly. As one can measure an efficiency target through the effective use of (given) input factors, or the effective production of a (set) output, energy efficiency is calculated as the ratio of the present national economy's primary energy inputs to its outputs, measured by GDP. The term is thus a good approach to indicate cost and environmentally efficient use of the energy resources.

Individual measures do not have to directly improve technological energy efficiency but could also reduce underlying energy consumption or improve energy utilisation, thus raising the efficiency factor of the energy used. Energy use itself must also be reduced: the amount of energy required to produce a certain GDP, for example the sum of oil equivalents needed to produce €1000 of goods and services. This may be accomplished through innovation processes for the manufacturing processes, technological advances in electricity production and attitude changes. Measures to increase energy efficiency are organised in four areas: appliance standards, financial incentive programmes, information and voluntary programmes and management of governmental energy use (see Gillingham et al., 2006). Nevertheless, consumer behaviour and cultural aspects of energy use are a fifth important factor and can be influenced by education and financial incentives, which is often not the focus of polices (c.f. Geller et al., 2006).

But does the term *energy use* remain theoretical and unmeasurable and is energy input only correlated to the economic output GDP? Which other factors are driving energy usage? Can policy measures influence the efficient use of energy and if so, to what extent?

4.1.1 Long term relations of emissions and growth

Long-term trends show that energy efficiency is consistently increasing (for EU-27, EFTA, EU-Candidate-States, OECD). Some economists see in this a connection to the economic development and have described this fact in the established literature, which is quoted below: In times of increasing economic growth, energy use increases, too, but to a smaller extent. Decreases in energy use are often associated with weakened or negative economic growth rates. The efficient use of every single unit of energy input is higher in periods of economic growth. In most cases, this relationship has been described by the analysis of emerging or transition economies, which lack the economic maturity of Western Europe.

Zhou et al. (2008) analysed nine Asian nations and the US and determined that income and development status dictate how energy consumption and economic growth relate to each other: Empirical findings show that previously highly developed states occasionally even experience a positive economic effect by reductions of energy inputs. Indeed, the authors determined that there must be other variables involved and that shocks lead to structural breaks. Dinda and Coondoo (2006) argue that, especially for Western Europe, but for other developed countries as well, a reduction in emissions and energy use will have a long-term[59] negative effect on incomes. They argue that, in the long run, that European rates of growth of income and emissions are at a stationarity point. Short run shocks to the rate of emission growth will lead to a corresponding shock to the growth rate of income in the next period, with a resulting "reverse causality for Western Europe" (p. 175) of emission to income, while in other countries a "bi-directional causality between income and emission" or "an income to emission causality" (p. 177) was observed.

Soytas et al. (2007) offers evidence which contradicts the above study. They observe that reductions in energy use produce a neutral effect on the growth of the US economy - "the relevant emission reduction policy variable is energy consumption", "there does not appear to be a causal relation between energy use and income, the

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[59] The time frame of their study is from 1960-1990 and the effect is stronger in Western Europe than in Eastern Europe.

US may consider reducing energy consumption as a serious environmental policy that does not harm long run growth prospects." (p. 487).

Similar observations of weak relation between GDP growth and energy use have been made in other national studies, with an increasing tendency to decouple energy usage from economic growth; for example in Turkey (Halicioglu, 2009), Portugal (Tang and Shahbaz, 2011), Spain (Guerra and Sanchob, 2010), or, for the long-term, in a 100-year analysis of Austria, Japan, the United Kingdom and the United States (Warr et al, 2010). These results emphasise the necessity of energy efficiency increases for members of the EU and comparable states, if emission and economic growth goals are to be met at the same time. For the following analysis the importance is obviously to test for changes in energy use: are they based only on changes in production output or on the influence of other factors or are they due to specific conditions of national economies?

4.1.2 Influences of policy measures on emissions

The Kyoto Protocol was adopted during the annual UNFCCC meeting in Kyoto in 1997. The goal of the protocol is to cover different GHGs, with a particular focus on CO_2, and reduce global emissions in 2012 by 5,3% below the level of 1990. It was decided that the binding implementation would start when at least a) 55 countries had ratified the protocol, and b) the signatory countries would have an aggregated share of 55% of all global GHG emissions. Thus, the protocol finally became mandatory at international level with Russia's binding ratification in 2005. Developed countries, listed as Annex-A countries, have to bear the main burden, while emerging and developing countries were considered Annex-B countries. Annex-A countries are allowed to fulfil a part of their obligations in Annex-B countries by transferring technologies and other climate saving measures in the Clean Development Mechanism (CDM) and the Joint Implementation (JI). The expenditures for emission savings would be outsourced and made in developing countries which is, to put it neutrally, cost effective and integrates less developed countries in the market for GHG. Additionally, their manufacturing capacities will become cleaner at an early stage of their economic developing process.

From the literature from 4.1.1, the influence of diverse factors on energy use seems to be obvious and a shift from a strong correlation between energy use, emission and economic growth to a decoupling occurs. Though the descriptive data of the studies quoted above exhibit a positive effect on emission savings after the Kyoto Protocol, most analyses focus on ratification excluding, however, the individual target achievement of the participating country. For example,in the EU, all members ratified the protocol. In an econometric analysis, a participation dummy based on ratification does not provide any information. The EU implemented the Burden-Sharing Agreement to redistribute its overall Kyoto Protocol obligations to its members, where each country has an individual reduction target.

Most literature that discuss the potential influence of international climate change obligations focus on the effect of the Kyoto Protocol ratification or its signatory; however, while the focus in this chapter is on the political pressure and its intensity expressed in the level of achievement of a country's obligation.

Hence, an important question is what contributions have been made by factors linked to the Kyoto Protocol obligations after 1997? How can one identify policies that aim to force emission reductions (trading schemes, appliance standards) and a restructuring of economies through implementation of RES technologies? What variables drive energy use and energy efficiency and how do they have to be considered in the further empirical analysis? To identify the parameters, a literature review helps to find the factors of influence of the Kyoto Protocol and climate change policies.

Johnstone et al. (2009) propose the number of patent application as a suitable proxy for innovation. The observations in data from 1978 to 2003 show a strong influence of public policies on the development of renewable energies, with a boost in the late 1990s.

Grunewald and Martínez-Zarzoso (2009) observe a significant influence on carbon emissions through the effect of the Kyoto Protocol ratification. Further, they try to instrument the dummy variable of the Kyoto ratification with the number of Clean Development Mechanism (CDM) projects to measure the effect on pollution avoidance. The authors describe their approach to overcome a possible endogeneity problem of ratification and absolute emission level.

CDM help less developed countries to update their production capacities with help from abroad. Firms from developed countries transfer technology and help less developed countries to pollute less. In theory, the effect on emission savings is huge due to the fact that the previous plants had heavy pollution. Of course, a small share of carbon saving projects and their emission saving potential is quantified. Under emission trading schemes, the CDM allows industrialised nations and private corporations to limit emissions reductions, to develop climate protection projects or to transfer emission reducing technologies to less developed nations and then receive credit for the calculated emissions reductions. Hence, if allowing CDM, the projects are already part of the carbon emissions and need not be counted twice. Counting the realised CDM projects may help to identify the reduction measures that are to be outsourced offshore. In some cases, unfortunately, a possible consequence of post-Kyoto policies might be nations undertaking their own climate protection efforts but forbidding corporations to take part in the CDM. Doubtless some of the efforts undertaken by corporations would have been policy measures which would have increased energy efficiency.

Jaffe and Stavins (1994) describe a problem in which markets cannot reach optimal solutions for energy efficiency, as they are hindered by the market failure of the missing price for all environmental damages which are a consequence of energy use and unusually high discount rates for consumers due to uncertainties in energy price developments.[60] Social costs will therefore not be covered by the energy prices and thus governmental policy should establish incentives and regulations to raise energy efficiency to the highest technically possible level, which would otherwise not be accomplished by the market. The identification of these influences upon energy efficiency is important in order to guide and ensure the success of policy measures and confirms the need for action; natural innovation processes and rising energy prices alone will not increase energy efficiency.[61]

The current analysis shall determine whether the implementation of the Kyoto Protocol in the BSA and other exogenous factors have a significant influence on the decrease in energy use. Is the pressure of international agreements large enough for policy measures to be effective?

The World Energy Council (2008) mentions the effects of strengthened efforts by almost all OECD nations after the Kyoto protocol negotiations to raise energy efficiency, but is lacking a descriptive analysis.

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[60] Consumers are concerned only about their own costs, not about any associated social costs of energy production or consumption such as emissions and environmental damage.

[61] Electricity is a price elastic good, however, it is a logical consequence of physics, that in the short run one cannot change to a more efficient technology, but in the medium run production capacities can be partly shut down, and in consequences decrease the output.

Mazzanti and Musolesi (2009) compared long periods before and after the Kyoto negotiations and found that especially commitment decides if one country is successfully reducing its abatement: countries that had faced exogenous shocks e.g. oil crisis, had already rebuilt their economies in or before the 1990s and thus could more easily achieve their energy reduction targets. The authors found differences between countries with regards to their success with climate change policies. This underlines the importance of a deeper analysis, since within a very homogenous group of countries such as the EU the Kyoto protocol ratification is an insufficient parameter and other, more specific, variables are able to better demonstrate the influence of individual carbon-saving obligations and its political pressure it carries.

Aichele and Felbermayr (2011) confirm the effect of decreasing carbon emission upon ratification of the Kyoto protocol. The authors analyse the overall carbon footprint of countries and determine it as being unchanged with carbon leakage due to e.g. outsourcing of production.

Grunewald and Martínes-Zarzoso (2012) use a dummy for Kyoto protocol ratification. For those countries, which ratified the protocol, the effect on carbon emission seems to be a decrease of 24,5% in comparison to non-ratification.

The cited literature agrees that the Kyoto protocol ratification has an influence on environmental impact, but that do so other factors. These factors seem to have an influence on the intensity of energy use or carbon emissions. Uncertain is, as yet, how one should go about defining differences within a group of ratified countries. The Kyoto protocol ratification may be correlated to the level of development of an economy or the dependency on fossil fuel burns. Thus, while the effect of a ratification dummy can be measured, it does not distinguish between countries which have not achieved their individual obligation targets from those that already have. It is as yet unclear as to what extent the individual pressure itself influences the environmental impact.

If no causal relationship through energy climate change policies and individual climate change targets, e.g. BSA obligations, on energy efficiency can be confirmed and other factors such as growth or innovation potential are found to be explanatory variables, this still would not mean the collapse of international climate policy, but if other factors have a bigger influence on emission savings and energy efficiency and policy measures might be improved further. Thus, future policies might focus more on R&D support or subsidies for developing and growing industries, with energy efficiency increasing as a side effect. If the Kyoto Protocol and its obligations have no influence on energy inputs and/or energy use is not changing, this must be seen as a warning signal that climate policy has mistaken priorities or that the established goals of global agreements are weak or too lax.

To give an answer to the various issues raised here, the rest of the chapter is organised as follows: section 4.2 focuses on the concept of energy efficiency and seeks to identify other possible factors which influence energy use besides GDP by reference to the established literature. If these influences can be identified, it will be easier to compare and evaluate different approaches. Factors which decrease the energy use and help increase energy efficiency will be identified. Section 4.3 creates an empirical model analysing panel data of 25 European countries over a thirteen-year period. Based on these considerations, theoretical aspects of the model and the results will be discussed. The conclusion in 4.4 closes with the finding that growth is not the only factor to influence energy use, but that policies have an influence, too.

4.2 Energy efficiency, energy savings and growth - the theoretical aspects

At first, it appears quite simple to define energy efficiency:

energy efficiency is the ratio of primary energy usage to output.

The definition is insufficient, however, as it only describes the status quo. The input-output ratio is based on the present. Thus, while it can be used to compare changes over time, the definition does not define the *optimal* energy efficiency. To justify the analysis and the following recommendations, one has to clarify why one should care about energy efficiency. What does it mean to optimise energy efficiency and under which circumstances are the maximum conditions reached? Nevertheless, in order to specifically determine *optimal* energy efficiency, it must first be made clear what exactly characterises *optimal* and whether, for example, a technical, social or economic optimum is the focus.

Jaffe and Stavins (1994) characterise energy efficiency and its optimum with the necessity to close the energy efficiency gap between actual and *optimal* energy use.

They identify five notions of optimality, from the base of a business-as-usual scenario (see p. 808), two economic and two social optimising potentials, and finally a hypothetical potential:

- *the hypothetical potential* is characterised by having eliminated all market failures in energy markets and market barriers, even those were the costs of removal extent the benefits. Thus, the hypothetical potential seems to be impossible to reach or even not desirable.

The authors recommend going one step back to reach a potential on a lower level where economic potential and social potential may overlap or be incompatible, depending on the focus of policies.

Economic potentials, which consider only energy markets, are:

- the *economists' economic potential,* which is reached after eliminating market failures in the market for energy efficient technologies,
- or the *technologists' economic potential,* if furthermore eliminating e.g. discount rates due to uncertainty and overcome inertia, which are described as non-market failures.

Social optimums, which analyse overall benefits, are:

- the *narrow social optimum,* which can be reached after eliminating market failures, whose elimination cost less then the created benefit for the general public pass a test social benefit
- and *the true social optimum* brings additional efficiency through environmental externalities;

Jaffe and Stavins conclude that many literature sources correspond to what they label "technologists' economic potential. That is, they assume that the resolution of the energy paradox must be that the simplest calculations are correct and that a host of market failures explain observed behavior." (p.809) The right measures of energy efficiency are to be assumed.

The reduction of energy use will be the objective of further polices and is one of the main objectives of the EU climate change directives. The goal of the current analysis in this chapter is to examine whether energy use is dependent not only on GDP, but on other factors as well. This requires, at first, a clarification of terms: energy efficiency is concerned with the relationship between input and output, and if the energy intensity per unit output decreases energy efficiency increases.

Belzer (2014) describes the limitation of the terms *energy intensity* and *energy efficiency* and the close relationship of both to energy use: Energy efficiency expresses the output in way of products or activities, which are produced with a given quantity of energy input. The efficiency improves in real terms when the output increases and the input remains unchanged.

The inverse of that is the energy intensity, which measures the input needed to produce a specific amount of output. Using less energy for the same output reduces the intensity.

Both concepts place energy inputs and GDP output in relation to each other. Shifts in efficiency or intensity may result in inflation, structural or behavioural changes, which may be difficult to measure. This could be a reason as to why the EU has agreed to a reduction of primary energy use as the equivalent of an increase in energy intensity. Energy use is also set as the dependent variable for the further analysis. Which factors can be identified besides GDP that influence changes in energy use, energy efficiency and energy intensity?

There is not a common consensus that energy use analysis does refer to only a single input (energy use) and a single output (GDP). However, if a multiple factor approach is chosen, are there two or more factors on the input, on the output, or on both sides of the input-output equation?

The following literatures are chosen to underline the selection of the variables in the further regression analyses, where energy use is taken as the regressand. The regressors will be chosen to explain energy use changes and its influencing factors. In the following, multiple and single factor models are discussed. The main results of various analyses cause the selection of the used variables in the regression analysis of 4.3. An alternative to a simple regression analysis seems to be one of the stochastic frontier methods, which take into account a chain analysis to measure energy efficiency as a benchmark across countries: 4.2.1 will discuss the linear programming (non-parametric) approach of the Data Envelope Analysis as a multiple factor model, in the section of single factor models in 4.2.2, the econometric (parametric) approach of the stochastic frontier analysis has to be mentioned, before spanning the regression model.

4.2.1 Multiple factor models

To evaluate and decide on a single or multiple factor output model, one has to discuss in brief the common concepts surrounding the issue. The general meaning of energy efficiency in the sense of measuring the effectiveness of energy use seems to favour the single factor approach. Statistics often count oil equivalents, for example, as the only input, and GDP as the related output factor. One has to confirm the practicability of that simple method in practice to compare both methodologies.

If reviewing literature concerning two factor analyses, the Data Envelope Analysis (DEA) cannot be ignored as there is a huge variety of different applied studies. DEA is a popular multiple input-output approach and serves as a general comparison of the efficient frontier analysis. This technique transfers the value asset approach that is well known through the financial controlling process of the production sector, to other factors, services and goods, which do not directly have a positive value, e.g. marketing activities, or even negative value, e.g. waste products in the manufacturing process.

DEA was developed to analyse business processes and their diverse input factors with the purpose of cost minimisation (see Shuttleworth, 2005). When used in energy efficiency studies, DEA allows released CO_2 emissions to be included as a negative output, in addition to the positive output GDP. For inputs, not only energy usage can be considered, but also e.g. goods and labour, allowing for a significant substitution effect. Taking nations as units of industrial production enables comparison of their heterogeneous input structures. Using a point scale, nations of differing development status can be compared, even when the input factors, especially physical labour, natural resources and technologies are quite divergent.

At first glance, the DEA seems to have many arguments in favour of it. However, the advantages diminish when examining various studies, e.g. the cross-comparative study of Zhou, Ang and Poh (2007): the authors assemble almost 100 studies and confirm concerns that the various studies, due to the wide choice of the top five factors, can only be compared with difficulty. They conclude that this is caused by distortions through the multiple number of input factors. Therefore one should be cautious when considering the DEA approach.

Another example, a study by Mandal and Madheswaran (2010), emphasises these limitations: the authors include environmental regulations as a factor, thus making their study difficult to compare with others. This is a further demonstration of the wide use of DEA methodology. While it should be an advantage, it can complicate comparisons with other studies. The studies mentioned can measure, evaluate and describe changes and development of selected variables well - but only on an isolated basis, and are hardly comparable to others in the field of environmental economics.

The question arises as to whether the DEA is useful in analysing the influence of the EU BSA policies on energy efficiency as one of the three main components of the 20-20-20 by 2020 targets. The reduction of energy use by 20% is a single goal. As a consequence, using a DEA approach would not clearly identify the factors of influence on a decrease in sole energy use. A single factor model approach seems to be too specific for the question of interest of this study and is better suited to defining further policy recommendations. The difficulties to compare different DEA approaches prevent to use them for an exploratory study, but can help to evaluate potential factors of influence on energy use as well.

4.2.2 Single factor models

An empirical model to analyse changes in energy efficiency or rather energy use has to be simple and comparable. It has to test, which factors are important for policy measures: unless environmental effects, not simple optimisations, are placed in the foreground, DEA will produce a distorted depiction of energy efficiency. It thus appears reasonable to return to standardised values of energy efficiency. In this case, there is a single output to be concerned with, namely GDP. As input basis primary energy units can be used, calculated in their oil equivalents: a decreased energy use then becomes synonymous with an increase in energy efficiency. These values can then be used reliably in flexible economic analyses. Other factors which influence the energy consumption besides GDP have to be considered if one moves away from simple ceteris paribus conditions and adopts a more flexible approach taking into account environmental, economic and social conditions, as well as (technological) development and policies.

Similar to these considerations, there are different analyses of energy use and the factors that influence it. Filippini and Hunt (2011) are doing a calculation of the underlying energy efficiency as a combination of different factors using a stochastic demand frontier approach. The main findings are that energy use is not only driven by improvements in energy efficiency. Following the authors' approach and their results, it is thus redundant to calculate complicated long-chain underlying energy efficiency, as the analysis can be reversed. The technological development of energy efficiency should be included in the empirical model through another adequate factor.

Choosing the single output model, for a further analysis it is important to understand at which exact locations energy consumption might be lowered and the energy effectiveness raised, and moreover, what other factors influence energy consumption. An increase in energy efficiency is not only the result of the saving of energy but also the retention of productive output under limited, i.e. fixed or reduced input factors, the increasing of output under constant consumption or a mix of both, see Gunn (1997). A reduction of energy intensity does not necessarily lead to a loss of wealth, as energy is a limited resource and energy not used as a result of conservation can be redirected to other consumers, thus leading to new production and growing affluence, see Costanza (1980).

Here, though, there is a danger of a rebound effect, or Jevons' paradox, as described by Jevons (1866) for coal burn in England for new steam machines: more efficient fuel burning technologies and a lower energy use for every individual production unit did not decrease England's coal usage, but increased the overall consumption. Jevons' contribution is the basis for all further approaches, which explain the paradox that a more efficient use of resources, e.g. electricity or air pollution, enables others to use more energy or pollute more. The energy or permit price decreases, respectively prices increase less, at one place or sector and leads to higher energy consumption or pollution at another place or sector.

In the context of the analysis done here, increases in global energy efficiency could be undone when cost savings due to lower energy use result in extra released capital, which is then used for new investments or assets that use energy. The end result of this process is actually a higher total energy usage of all assets. Due to the fact that energy prices are continuously increasing, for the further analysis, the rebound effect will not be taken into account: some emitter might act as before, not changing their processes and fuel burning, but the expansion of fuel burnings is causing high costs. The allowances price is only a little part of energy inputs cost and even at a permit price of zero, higher energy use is causing higher costs. In the end, every single emitter will try to decrease its energy use but maybe with less pressure.

If it is possible to instead use the cost reductions as a result of lower permit price to cover the costs of developing renewable energies this rebound effect can be averted and energy intensity sustainably reduced, see Diesendorf (2007). One can conclude that conventional and green energies would become cost equivalent: Therefore individual cost minimisation would signify not fuel switching but a more efficient use of every single unit of energy input through technological innovation.

The climate protection policies of the EU address the issue with several approaches. Following the roadmap of the 20-20-20 by 2020 targets, decrees for a three step policy (European Commission, 2008) are suggested, which might raise energy efficiency both directly and indirectly. For the single factor model, the following three steps of the climate change policies should be mentioned:

Step 1 leads to a reduction of GHG emissions of 20%.[62] A part of these savings will be achieved by a Europe-wide emissions-trading scheme (EU-ETS). The EU-ETS is responsible for the greatest percentage of the savings, as those industrial branches not affected must only achieve a 10% reduction in comparison to the year 2005. Efficiency increases are politically desirable, and are especially expected in the fields of electricity production and heavy industry.

Step 2, in which at least 20% of total energy production must be produced by renewable energy sources, will be cost-intensive. Decentralised energy production as a mix with different sources is often not cost-competitive with conventional energy sources, or is still not reaching the stage of cost equivalency (see e.g. Blazejczak et al., 2010). The higher costs of these renewable energy investments are passed on to consumers by national clearance systems, in order to decrease the competitive disadvantages of renewable energies (through feed-in tariffs, etc. - see e.g. Traber and Kemfert, 2009).

Step 3 is not yet directly stipulated in the treaty, but will be a consequence of steps 1 and 2, as energy efficiency is raised by a minimum of 20%, corresponding to a decrease in energy consumption by 20%: Using this goal, the first two objectives can be reached more quickly, while the energy efficiency targets can be determined, in terms of both energy and cost efficiency. Europe-wide compliance with the efficiency goals can then be better monitored, as precise figures can be uniformly tested. As

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[62] A reduction of about 30% will be accepted by the EU for their GHG saving obligations, when there will be an international agreement for a further emission cut with other developed countries.

energy efficiency has a strong influence on the other two steps through side effects, one should conclude the non-compliance should be sanctioned somehow.

In theory, the trap of the aforementioned rebound effect should be averted by steps 2 and 3. Early state policies to achieve these goals in the framework of the EU-ETS, which require both energy efficiency and RES investments, were, in reality, quite modest. Schleich, Rogge and Betz (2009) found a number of EU-ETS national allocation plans not supporting newly planned investments in the energy sector (for example, in new plants that do not require high degrees of energy usage). The incentives were increased through the customisation of the allocation rules for emissions permits, with the EU requiring that "member states should commit to use at least 20% of their auctioning income for this purpose" (European Commission, 2008, p. 6): measures, to increase the more efficient use of energy where market incentives will not have a substantial effect.

4.2.3 The environmental Kuznets curve

The question of interest for the current analysis is the effectivity of policy measures on energy use as a result of the implementation of the Kyoto Protocol obligations. This raises the question of how realistic the set objectives of the European Union climate change protection policies are and whether they can realistically be fulfilled. Thus, for the EU, as a common economic area, the state of economic evolution must be evaluated.

A very important theory about the further development of emissions is the Environmental Kuznets Curve (EKC). It is based on the theory of Kuznets (1955) about the development of a country, which follows a natural cycle of rapid growth and linked growth of inequality. In theory, after a certain level of affluence, named the income, inequality will decrease if the country continues to experience economy growth. The EKC describes the interrelated trend of growth and damage caused to the environment as a concave curve, with an exact turning point where the correlation between growth and emissions turns from positive to negative: a higher output to the right of the turning point is associated with lower emissions and vice versa.

This theory is highly controversial and various analyses consider a squared income variable to control for the Kuznets' theory and its potential turning points. If a turning

author (year)	countries, period	methodology	Kuz-nets	main findings
de Bruyn et al. (1998)	UK, Western Germany, Netherlands, USA; 1960-1993	regression analysis, measuring CO_2, NO_x, SO_2 in relation to economic growth; testing relations without applying Kuznets turning points	no	unclear effects: growth and emissions may be affected by accident rather than causality; developed countries show positive relation between emission and growth, no decoupling
York et al. (2003)	world wide data for CO_2 emissions (1996) and energy footprint (1999)	STIRPAT, IPAT, ImPACT: analysis of methods to develop further tools to take into account additional factors that are influencing environmental impacts	yes	no evidence for EKC, CO_2 emissions decrease at a declining, absolute energy use at an escalating pace; population as a main factor for energy use
Stern (2004)	world wide data	literature review of cross-country analysis with theoretical discussion of the common results	yes	Kuznets theory seems to be antiquated, the once showing evidence can hardly be replicated nowadays but general relations of growth and emissions are certainly true
Dinda and Coondoo (2006)	88 countries; 1960-1990	test on causality of income and emissions: panel unit root test with the null hypothesis that a unit root exists, panel data cointegration test and related error correction model (ECM)	no	cointegrated relationship between income and CO_2 emissions for Africa, Central America, Europe; ECM shows bi-directional causality for Africa, income to emission causality for Central America and emission to income causality for Europe
Soytas et al. (2007)	USA; 1960-2004	Granger causality test using VAR with GDP, gross fixed capital, labor force, energy use, CO_2 emissions; no variable for technological change	yes	evidence against an EKC, no causal relation between energy use and income; reducing growth of energy consumption as effective policy to decrease emission
Zhou et al. (2008)	OECD, Middle East, Former USSR, Non-OECD Europe, China, Asia, Latin America, Africa; 2002	DEA with single input and diverse output models, e.g. GDP, CO_2 emissions and energy consumption	no	energy intensity as a useful factor and alternative to CO_2 emission for measuring the evolution of countries; CO_2 emission not only driven by carbon intensity and carbon factor
Tamazian et al. (2009)	BRIC, USA, Japan; 1992-2004	panel data analysis testing correlation of energy consumption and CO_2 emission; Kyoto Protocol signatory and ratification as dummy variables	yes	positive impact of Kyoto ratification, lagged variables without significance, acceptance of Kuznets but due to increasing imports of goods
Marrero (2010)	EU-27 without Malta, Cyprus, Luxembourg; 1990-2006	dynamic panel approach testing simultaneously emissions, growth and energy	yes	no evidence for the existence of Kuznets, no significance for industrial share; emissions driven by technology
Filippini and Hunt; (2011)	29 countries; 1978-2006	stochastic frontier analysis to test influence of underlying energy efficiency on energy use	no	energy intensity is a good proxy for energy efficiency in EU-countries

Table 6: Literature review I *of analysis used as a basis of the empirical model of chapter 4.*

point exists, it can help to identify country groups with homogenous development and / or economic conditions.

Table 6 summarises the most important sources of the following literature review including some of the studies already cited. All the sources provide further input for the variables of the applied model in 4.3. It gives a scheme of the panel data analysis in the following chapter and the linkages of each of the studies to the general Kuznets discussions.

According to de Bruyn et al. (1998), the long-term trend in developed nations, of an association between growing emissions and times of economic growth is not clearcut: once GDP is on a high level and only growing moderately, high-level technical innovations compensate for growth in emissions. However, this cannot be conclusively measured. The authors describe individual differences in nations Kuznets curves, in which in general increasing incomes lead to increasing emissions until, at a certain level, emissions again decrease while incomes continue to rise.[63]

This emphasises the examination by Soytas et al. (2007) regarding the causes of CO_2 emissions in the USA, whereby long-term energy consumption has an effect on overall emissions, while changes in income have only a short-term effect. The authors found a Kuznets relation for income and energy consumption, but not for income and emission. Thus economic growth and emissions are not directly correlated and a reduction in emissions does not necessarily cause a lower growth rate. They close with the recommendation that sustainable environmental policy should focus on measures to lower emissions through reductions in energy intensity. Stern (2004) does not discard the EKC theory, but confirms that by adopting innovative technologies, poorer countries show the same effects, with only a short time lag at a lower income level. Geller et al. (2006) empirically prove a decoupling of growth and rising energy usage, as more efficient technologies show meaningful substitution effects: end consumers use more electricity, instead of producing the power themselves, and power production through the utility sector has a higher degree of efficiency.

At first glance, the findings of Ciarreta and Zarraga (2010) appear to contradict these results, showing a positive correlation between energy consumption and GDP growth. Their dataset described the period 1970 - 2003. While the effect over the

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[63] Kuznets theory is based on the differences between countries, but also concerns the standard deviation in homogeneity over a time period analysis in a single country.

long term is indisputable, at least in the short run no effect can be demonstrated. Thus the analysis fits the data.

The controversial discussion of the EKC can hardly be summarised, as the literature does not clearly decide for or against the Kuznets curve theory. In every case, all the analyses show the interest in and the presence of other factors besides GDP, which may influence energy use.

Dasgupta et al. (2002) try an evaluation of the theory without testing it empirically. They propose to take into account the technological development, international cooperation, and the higher accumulation of capital nowadays, which allows even less developed countries to follow a growth path without extending damages to the environment. Thus, the Kuznets curve is expected either not to exist, become flatter, or have the turning point shifted left which means that growth is coupled with a lower or negative marginal growth rate of emissions with the consequence that high income economies are having a lower increase of GDP in relation to the growth of emissions (or energy consumption) than low income economies have.

Another crucial point to address is the concentration of most applied Kuznets analyses on CO_2 and/or other ecological damages. As shown in chapter 2, theses damages are difficult to determine and to value. The Kuznets curve may describe theoretical turning points of nations' GDP where higher emissions cause a decrease in economic development, but the relation itself remains unclear. All citied studies can explain well the factors which influence energy consumption respectively emissions apart from their positive or negative assumption regarding the Kuznets hypothesis. The factors must to be considered in a further analysis.

The conclusion from the above literature review (see table 6 for an overview) is that an applied econometric model should demonstrate the influence of various factors on energy use on the one hand, and on the other, that the relation between environmental impacts, carbon emissions or energy consumption and GDP is not as close as postulated by the environmental Kuznets hypothesis. In addition to factors like affluence or growth, other influences have to be taken into account, for example the influences of the obligations of the BSA obligations on energy efficiency (e.g. through policy measures, new compliance standards, or regulations) or pressure on policy makers through the emission level of the economy.

4.2.4 Modelling the key factors population, affluence, technology

Energy efficiency begins much earlier than polices do, however. While policies are unable to directly regulate the energy consumption and efficiency increases by the end consumer, measures can be enacted at many levels to reduce energy intensity, including the possibility of raising the energy efficiency over the entire life cycle of a product, beginning with the product design.

Despite this, Graedel (1994) suggests that energy consumption of goods is not drastically decreasing. Only small improvements are made during the manufacturing process and along the penalty costs producers are faced with, whereas the life-cycle energy use of goods consumed by costumers are much higher. Thus, more efficient technology could lead to energy savings, which would be a multiple thereof. But the consumer price of the kilowatt-hour must be extraordinarily high for the modified goods to be accepted by the market, otherwise consumers are not willing to spend money on new products to replace old ones that are still usable. Consumers are not very rational. In this Graedel supplements Ross (1989), who finds large possible savings in industrial finishing, as well as Gibbons and Blair (1991): by a permanent lowering of energy consumption, goods with high initial investment costs are advantageous over the long-term.

Another contribution by Graedel (1996) adds to the discussion the research of the "biological ecologists", transferring their concepts of species and nature to apply to goods in an economy, too. An analysis ties the system's initial growth to the cost of resources while later quality improvements are brought on by optimisations in resource management. The type and potential of energy efficiency increases are then dependent on the development status of the economic system, whether undeveloped ("biological") or completely developed ("industrial"). This view reaffirms the theory that technically developed countries can reduce energy intensity especially through technological innovation.

As mentioned above, policy makers can, if necessary, directly affect consumers and producers by the possible implementation of regulations and restrictions, or indirectly through taxes or energy prices. There are expected interdependencies, as depicted in two possible examples: If policy makers enact regulations forbidding high energy consumption, producers will be forced to change their processes, which may cause product prices to increase. Consumers cannot avoid paying for the higher initial investment costs, but because of the higher standards, their consumption will decline over the long-term, bringing cost advantages.

On the other hand, higher energy costs can force consumers to demand products with lower energy requirements. Consumers demands are creating market pressure on producers to offer only more efficient products. This means that energy efficiency can also increase because of market participants. Energy markets, as the primary sector for fuel burnings, are not all perfectly competitive: market equilibrium will be disturbed by single events which can also be caused by powerful players who are exploiting advantages for themselves, for example through implementation of innovative technology, reduction of institutional transaction costs, and subsidies. Especially industrial market participants, but private households, too, can thus achieve the cost advantages sought and thereby attain increased energy efficiency (Diesendorf, 2007).

A very important contribution in the context of additional factors of influence besides GDP is made by York et al. (2003). They examine three different analytical methods, beginning with IPAT, coming to ImPACT and closing with STIRPAT. The IPAT is based on Ehrlich and Holdren's (1971) approach of a multiplicative conjunction of only three key factors: (P)=population, (A)=affluence[64] and (T)=technology on (I)=the ecological impacts, e.g. emissions or energy use:

$$(1) \qquad I_i = \beta_1 P_i^{\beta 2} A_i^{\beta 3} T_i^{\beta 4} e_i$$

The ImPACT reconceptualises IPAT with disaggregated factors that take into account other influences that have an impact on the key factors. Finally, the STIRPAT is developed to easily identify the respective factors as elasticities. They are all in logarithmic form, except for the dummy variables, and additional factors are allowed. They can easily be added and interpreted. See (2) for the basic model of the STIRPAT approach where the authors suggest that T, and all other factors that are not population P or affluence A, should be captured in the residual term $e_{i,t}$, cf. York et al (2003, p. 354):

$$(2) \qquad \log I = \beta_1(\log A_{i,t}) + \beta_2(\log P_{i,t}) + e_{i,t}$$

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[64] Represented by per capita consumption or production, thus the most used proxy for affluence is GDP per capita with the assumption that consumption is increasing in relation to the output growth.

The popular STIRPAT approach is a basic instrument for a broad range of applied analyses. Its intuitive combination of factors underlines the influence of diverse different factors on the ecological impact.

The following model in section 4.3 is linked to this literature. A regression analysis will follow the IPAT approach of Ehrlich and Holdren (1971) and the more recent modifications (ImPACT, STIRPAT) point the way to add other factors of influence on the ecological impact to improve the model results.

4.2.5 Additional factors affecting energy efficiency

The remaining question is which other factors have to be considered in an empirical model. Liddle (2004) focuses on *demographic dynamics* and *environmental impacts* on per capita road energy use: the key findings are to reject the variable of energy prices, if for example gasoline prices have an influence on the quantity used but prices are also endogenous. Hofman and Labar (2007) analyse energy use depending on *sectoral* changes.

Literature on the impact of emission-saving policies is rare, but there are a few studies about the *Kyoto Protocol* ratification. The study by Tamazian, Chousa and Vadlamannati (2009) chooses dummy variables for protocol ratification and being a signatory, which have a significant association with CO_2 emissions at the 1% confidence level. Further factors are current GDP growth and trade. While GDP growth is positively related to emissions, trade has a negative impact on pollution; high emission manufacturing seems to be outsourced and could be the reason for the environmental Kuznets theory; lagged GDP growth seems to be without significant influence on energy consumption.

As already shown by the reviewed studies, the main factors for the analysis are set, namely energy consumption and affluence, respectively the often used proxy variable GDP. It seems to be an indisputable fact that a model can be explained to a large extent by these factors. The question remains, what other factors should be under consideration? The general technological level is suggested as well as the intensity of production. Some authors focus on the industrial structure or the rate of labour intensity, and last but not least general factors like structural data of geographical or physical conditions of a country, e.g. information about the specifications of climate, population density or extent of landmass are included.

This combination of factors can be examined with the help of a panel. The question remains whether policies have an influence on the increase in energy efficiency, and whether the consequences and obligations due to the 20-20-20 by 2020 targets and the BSA obligations are strong enough to put pressure on energy consumption of consumers and producers. Do the CO_2-emissions reduction commitments have an additional influence on changes in energy use and energy efficiency? Besides other factors, how much do increases in energy consumption correlate to economic growth, and how should one judge the influence of policy commitments on emission reductions? Are they effective and if so, how strong is their effect?

Since the focus of interest of this study is on factors that influence the increase in energy efficiency, the literature discussed above frames the model, namely the factors that have to be considered. The further regression model should test for present economic growth and BSA obligations, while the Kuznets theory and its contribution to the model remains unclear and will be skipped in this analysis. The implementation of other factors may better explain the significant correlations and can be explained directly.

Reliable measured data has to be identified to show the percentage growth rates or first deviations to easily indicate the correlation between measures aiming to decrease energy use. This will be done in the following section. The design of the model will add independent variables that are already chosen by different authors to test for influences on environmental impact.

The decomposition of different factors contributes answers to the question of the interactions of energy efficiency in terms of the usage-bound related energy consumption in relation to growth, population and other economic conditions, as well as development of technological efficiency. Thus, the model helps to explain if and to what extent energy efficiency is under the control of the policy makers.

4.3 Policies influences on energy efficiency - the empirical model

The EU member states are highly developed countries, which are homogenous insofar as they are, in comparison with emerging economies for example, relatively culturally and demographically equal. This homogeneity is also reinforced by the European Community Treaties which propose the alignment of living conditions across the EU in all areas where comparable living, economic and social conditions are not yet reached. The influence of these treaties also expresses itself through production standards and regulations, which must be adhered to by each national economy. This results in a convergence process, exhibited by the decreasing heterogeneity of the examined group.

However, the unified EU laws do not cover all fields of policies. In particular, energy markets are still seen as the responsibility of national policy, as long as the member states are not willing to abandon their sovereign right of energy grids. But the EU influence also makes itself noticed here, for example through accepted regulations and commitments such as the EU's burden-sharing of the Kyoto Protocol's emission reduction commitments. The so-called burden-sharing agreement (European Council, 1998) distributes the reduction burdens across the member states, taking into consideration such factors as status quo power plants, industry structure, energy mix and expected economic growth rates. In this way each member state has its own emission reduction commitments, while at the same time the communal policy measures are adopted, leading to equality in energy usage rates and the share of RES in overall energy production.[65],[66]

Table 7 shows the literatures which describe the variables used in the empirical analysis in the following section, and can be divided into two groups. The first group of papers observes energy use or a similar variable as the dependent variable, this includes the studies by Filipini and Hunt (2011), Hofman and Labar (2007), and Liddle (2004). They provide important contributions in the identification of the factors of influence and their significance. The study of Tamazian et al. (2009) makes use of a double approach and takes firstly energy consumption, secondly emissions as the dependent variable. Thus, in contrary to the first group of papers, the variables

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[65] The Kyoto Protocol itself was first agreed upon in 2002 (see European Council, 2002), though a number of the measures had been previously adopted.

[66] See European Commission (2005): recommendation for sustainable energy efficiency policies.

authors (year)	dependent variable	independent Variables	Statistics approach	database
Filipini and Hunt (2011)	aggregate energy consumption	GDP, energy price, climate, area size, industrial sector, service sector, time dummies	Stochastic frontier analysis (SFA)	29 OECD countries, 1978-2006
Hofman and Labar (2007)	energy intensity	coal price, GDP, ratio industry, ratio services, ratio light industry, ratio state enterprises, ratio raw coal	FE and two stages FE	China (province-level dataset of 30 provinces), 1990-2004
Liddle (2004)	road energy use	GDP, urbanization, primacy, share of people aged 20-39, population density, average household size	panel data - OLS FE	OECD countries, over 5 time periods (e.g. 10-year intervals from 1960 to 2000)
Tamazian, Chousa and Vadlamannat (2009)	a) energy consumption b) CO_2 emissions	economic growth rate, investments, share of industry, population growth, vehicles, energy imports, energy exports, energy production, lagged energy consumption, oil consumption, Kyoto Protocol ratification and signatory, financial liberalisation, stock market value added, stock market capitalisation	panel data - feasible general least squares (FGLS); pooled regression analysis - pooled ordinary least squares (POLS)	BRIC countries + USA and Japan, 1992-2004
Grunewald and Martínez-Zarzoso (2009)	CO_2 emissions	population, GDP, GDP^2, industrial activity, Kyoto obligations dummy, lagged CO_2, time dummies	dynamic panel data model - IV and system GMM	213 countries, 1960-2009 (unbalanced panel)
York et al. (2003)	emissions	population, affluence, technology, climate, energy consumption, emissions per unit of energy consumption	OLS regression - for national CO_2 emissions and national energy footprint	146, 138 nations respectively - representing over 97% of the world‘s population and economic output
Johnstone et al. (2009)	patent applications	policy dummy variables for existing R&D support, tax measures, invest- ment incentives, differentiated tariffs, voluntary programs, quantity obligations and tradable certificates; R&D expenditures, electricity consumption, electricity price, EPO filings	Panel data - negative binomial model	25 countries, 1978-2003

Table 7: Literature review II *of analysis used as a basis of the empirical model of chapter 4.*

energy use and the ecological impact, namely emissions as a side product of energy use, are linked in one model.

Similarly, the analyses that take emissions as the dependent variable link energy consumption and energy use as the effect of time-lagged emissions or energy consumption and are one of the independent variables, such as the study by Grunewald and Martínez-Zarzoso (2009) or York at al. (2003).

The analysis of Johnstone et al. (2009) gives evidence of another important variable. This analysis examines the relation between the promotion of renewable energy and the number of patent applications. The result is important because it determines that patents express which level of technology a country has reached. This proxy will be used in the following analysis.

4.3.1 Dataset and variables

The examination in this section focuses on the EU states as a largely homogeneous area with partly heterogeneous national specificities from north to south, e.g. geographical conditions, from west to east, e.g. political and economic conditions after the fall of the Berlin wall, and between countries, e.g. nuclear power plants in France or the economy extremely focused on the tertiary sector in Luxembourg.

The dataset used in this analysis is limited to the years between 1998 and 2010 without any gaps, thus the data is characterised as a balanced panel. In 1997 the Kyoto Protocol was (informally) adopted, as the European Union obligated itself to enact the protocol even if no international ratification process took place. Individual commitments for the post-Kyoto period were quickly agreed upon. Thus it is assumed that after 1998 national governments immediately began enacting policy measures to reach the emission targets, which are obligated to be reached by the year 2012.

It was supposed that, in order to have economically efficient goals, the "pressure" on the governments to act is counted analog to the emissions of the Kyoto Protocol indicated GHGs. Thus, emissions will indicate not only the emissions amount, but also the target achievement. Every country has an individual Kyoto target, which for itself is the index base of 100 for the emission index. Through this standardisation, the index comparison becomes easier. The index represents the country's target emission level. High values, above 100, describe the meeting of the target, the target range. The higher the value, the better the emission reduction achievement. Low values on the other hands are within the section that represents underperformance. An index value of 100 indicates the accurate meeting of the goal. Through this, emission reductions in relation to the individual Kyoto obligations are easily indicated, and the target achievement across countries is understandable at a glance.

The variable underlines the necessity for the enactment of policies for values below 100, which index the 2012 Kyoto Protocol allowed emissions. In the case of over-achieving member states' targets, national governments may decide for passivity in the field of environmental politics and let things slide, and the index will have values above 100.

The dataset ends in 2010, as afterwards only incomplete data is available. The same applies to the data collected before 1998, but also in the case of available data, in any event, before 1997 there was no coordinated action in the EU to reduce emissions. Efficiency increases in energy usage were based on improvement of competitive capabilities to reduce input factor costs, and were only loosely directed

Factor	Mean	Std. Dev.	Min.	Max.
Energy use (Energy use per capita in oil equivalents.)	3,715.70	1,503.60	1,565.80	9,207.60
GDP (Per capita national gross domestic product.)	20,314	14,374	1,400	80,800
Population (Total population.)	19,508,300	22,738,300	427,700	82,541,000
Emission (Index of present Kyoto gas emissions)	108.63	22.93	63.60	154.00
BSA-Dummy (presence of pressure to reduce emissions according EU Burden-Sharing Agreement)	0.42	0.49	0	1
Patent applications (Number of applications per million inhabitants.)	2,130.24	4,583.43	0.67	23,907.20
Technological efficiency (Energy conversion as input-output-relation of primary energy.)	0.71	0.12	0.29	0.96

Table 8: Descriptive statistics: minimum and maximum of country means, with mean and standard deviation for the pooled country means, own calculation according the dataset.

toward environmental protection. Taking into account data for 1997 and earlier will not improve the main implication of the model and could only measure the changes in energy use and efficiency before and after the Kyoto Protocol application. Instead it could threaten the objective results of correlations between variables in the Kyoto era as distort the load of the factors.

In total 25 of the current 28 EU countries were considered: Cyprus and Malta have no emission reduction targets, and Croatia became a new member of the European Union in 2013. All three are thus unimportant for the purposes of this study. The current dataset contains up to N=325 observations for each of the described variables. The variances show in some cases a broad range (see table 8 for descriptive statistics) for the mean of different countries. When comparing, for example, the emissions have a spread of country-specific means from 63.60 up to 154.00, which is an indicator of heterogeneous conditions for governmental efforts on emission-saving policies. Population, too, is very heterogeneous with small countries, e.g. Luxembourg (427,700) and huge countries, e.g. Germany (82,541,000). The absolute values cannot indicate common trends such as general trends in population growth such as the decline of the population in some countries, or technological development of energy efficiency that might have a global trend of a higher conversion rate of primary energy inputs. Heterogeneous countries in the relatively homogenous group of EU member states require one to test different model specifications for the empirical analysis and the question is whether group- or time-specific errors are more influential than the comparison of growth. Under the assumption that differences-in-differences methods show trends in the rates of change which do not depend on the level of (technological) development or structural conditions, this approach might be advantageous, and must be tested as well.

As the literature review (see table 6 for an overview) could not identify a clear result for whether EKC should be applied or not, and if it should, whether the turning point was out of reach, the analysis here will ignore the proof of the theory, so the squared values of GDP will not be taken into account. For the independent variables, general factors like population, technological level and GDP are considered, as well as physical efficiency of energy use and the emissions of Kyoto gases, which will be the parts of the model that are interpreted as the political impacts. Other factors rarely improve the model, e.g. structural data of the labour market, characteristics of energy production, and energy prices. Climate conditions are omitted as it is not clear whether cold winters (heating) or hot summers (cooling) have a larger contribution to the climate footprint. However, during the model designing process they were tested and the results will be mentioned later on.

4.3.2 Explaining the empirical model

As explained before, the model in this chapter will follow the Ehrlich and Holdren (1971) approach and its recent modifications (1) and (2) to measure the ecological impact of selected influencing factors.

The European Union's efficiency goal to decrease the energy use by 20% would imply a decrease in GDP, if not identifying other influencing factors. The STIRPAT approach allows other variables, but every additional factor needs a justification to be added to the model.

The stochastic frontier analysis of Filippini and Hunt (2011) discusses energy consumption as a product of structural conditions of an economy as well as technological development. The authors are testing the impact of different factors on energy consumption:

$$(3) \qquad E_{it} = E\,(P_{it}, Y_{it}, C_i, A_t, ISH_{it}, SSH_{it}, D_t, EF_{it})$$

Following their model design, the use of energy (E = energy consumption) is driven by diverse factors such as production (Y = GDP), economic sector share (ISH = industry and SSH = services), but also country-specific variables (e.g. C = climate, A = area size) and a series of time dummies (D) for effects that have an equal, but unobservable influence on all observed countries (awareness of climate change, international oil prices, shocks), and the (end consumer) price of electricity (P) as well as the underlying energy efficiency (EF). All factors are in natural logarithms, with the exception of sectoral shares of production and dummies. The authors assume that their model already adequately captures group-specific effects by including different dummies and country specific variables, so that a fixed effects model is not necessary.

They specify their general assumption in a panel log-log functional form:

$$(4) \qquad e_{it} = \alpha + \alpha^{y} y_{it} + \alpha^{p} p_{it} + \delta_t D_t + \alpha^{C} DC_i + \alpha^{a} a_t + \alpha^{I} ISH_{it} + \alpha^{S} SSH_{it} + v_{it} + u_{it}$$

Filippini and Hunt define the error term as a variable that represents energy efficiency. They further decompose it into two residual terms: v_{it} assembles unmeasured factors that influence energy efficiency, in particular energy intensity, while u_{it} captures the so-called underlying energy efficiency as a self-calculated benchmark in relation to the most efficient country in the dataset. The so computed error term u_{it} tends to zero for most European countries. Thus energy efficiency only marginally deviates from the remaining error term v_{it}.. The authors conclude that energy intensity is a good proxy for energy efficiency.[67]

Fillippini and Hunt use stochastic frontier analysis, which does not necessarily have to be applied. If one is calculating the influence of diverse factors on energy efficiency, but energy use seems to be an adequate substitute, one can abandon this approach and directly interpret the influence of the variables on energy use. For European countries, it seems to be reasonable to add technological efficiency, political influence and economical development as influencing factors in a regression analysis, due to the fact that the efficiency error term u_{it} seems to contain to less information for the selected countries in the own analysis:

For the design of the model in this chapter, the authors' arguments have to be taken into consideration as well as their introduced variables, which as a consequence should improve the model and allows a better application of different model designs because the error term does not contain information that is fundamental for the model and the further implications. The ecological impact is explained as the energy use and will be interpreted as the energy efficiency, following the earlier discussion in this chapter. Therefore, every resource can be used only once and used energy inputs are tantamount to a waste of resources. A low value of energy inputs means high energy efficiency and is environmentally less burden some than a high value. As energy efficiency is in the focus of EU climate change policies, the energy use variable is the applied indicator of energy efficiency and it is exactly the variable that should be controlled by the EU policies and regulations. The influences of factors like population, production, and others, such as policy measures, can explain changes over time in energy use. An additional advantage of the approach is that energy efficiency is removed from the error term. The remaining error term no longer contains information which is related to explanatory variables, but only unobserved

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[67] The conclusion cannot be generalised but seems to be acceptable for most EU countries, while not absolutely homogenous for all member states: Greece and Italy have a marginally higher deviation.

variables like country-specific influences of cultural or geographical factors, or globally occurring shocks. This should lead to an improvement of the model results and conclusions. Energy efficiency is divided into two variables: the dependent variable energy represents the factor that can be influenced directly through changes in behaviour and production quantity, for example. The technological impact of energy efficiency is related in the long term to production capacities of primary energy and general aspects of other assets that use energy for production, heating or transportation. It is changing over the time and is captured in an individual independent variable, see below the explanation of the variables.

To test the set of hypotheses above, a panel dataset is used and take into account various variables: these of (2) enhanced by variables for BSA, technological level, efficiency and behavioural influencing factors such as the level of emissions.

The regression model in this chapter applies the following equation:

$$(5)\qquad \log(ENERGYUSE)_{i,t} = \beta_1 \log(GDP_{i,t}) + \beta_2 \log(POP_{i,t}) \\ + \beta_3 \log(EMISSION_{i,t}) + \beta_4 (BSA_{i,t}) \\ + \beta_5 \log(PATENTS_{i,t}) + \beta_6 \log(TECH\text{-}EFFICIENCY_{i,t}) + u_{i,t}$$

where i = 1, ..., 25 indexes the cross sectional unit (country), and t = 1998, …, 2010 indexes the time (year). The dependent variable **ENERGYUSE** measures energy use per capita in oil equivalents. Explanatory variables are **GDP** (the per capita national gross domestic product), **POP** (total population in the selected country), **EMISSION** (the present emission target level of GHG specified in the Kyoto Protocol, where a value of 100 indicates compliance with the Kyoto Protocol obligations, a value below 100 the failure to meet the goal, while a value above 100 indicates emissions in the target range and Kyoto goal over-achievement), **BSA** as a dummy variable (indicating present emissions still above the Burden-Sharing Agreement targets with "1"), **PATENTS** (the number of patent applications of a country), and **TECH-EFFICIENCY** (losses in the energy conversion process, measured as the raw energy input in relation to the raw energy output, which can be used for production, heating and transportation).

The explanatory variables beyond the influences of the BSA obligations are control variables, which can be directly measured and explain and isolate causal relations.

These variables are often included in the cited literature. Their influence on energy use has already been confirmed. Not take them into account will decrease the precision of the coefficient estimates.

As the STIRPAT proposes in (2), the model (5) also considers affluence (namely the proxy GDP) and population. Technology will be captured in the patent applications as a proxy for the level of technological development of an economy. The ecological impact is measured as the dependent output variable energy use, as shown in (4), and the proxy for energy efficiency: high values of energy intensity indicate a less efficient input-output ratio of energy and the use of every individual unit of energy is not very efficient. Low values imply a high capacity factor of energy, i.e. the degree of efficiency is high as the ratio between energy input (oil equivalents used) and the output of produced goods and services (GDP) is high.

The model is expected to show evidence of a significant influence of the presented variables on energy use. The evidence of the implications of equation (4) clarifies that the deviation of ENERGYUSE is that part of the change in energy efficiency which results from changes in the quantity of the production output (GDP) and population growth (POP), but is also influenced by other additional factors like political pressure (BSA), general efficiency increases (TECH-EFFICIENCY) due to innovation, technological level (PATENTS), and lastly from unobserved influences of variables like changes in behaviour and cultural aspects, covered by the error term.

4.3.3 The model parameters in detail

The most important difference from other analyses and the contribution of the model chosen here, is that the influence of the percentage decrease in energy intensity will be shown and explained in detail. The question of interest is which measures would cause to increase by 20%, the goal for all EU member states. In other words, which variables cause decreases in energy use while the output (GDP) remains on a steady growth path? When using the natural logarithms of the variables, the association between an exogenous variable and the endogenous variable, the coefficient of the explanatory variable, can be read as a direct elasticity under ceteris paribus conditions.

To use the data this way, it is important to know the details of each of the selected variables, their interpretations and resulting implications for the chosen scenario.

The dependent variable **ENERGYUSE** is the energy consumption in an economy as calculated by Eurostat: energy use measures net domestic energy use per capita. It is the combined usage of coal, electricity, oil, natural gas and renewable sources. Secondary sources (e.g. non-fuel energies) are reflected by their oil equivalents. Using the per capita energy consumption reflects not only the level of energy efficiency, but also the relative importance: high energy uses tend to show the most potential for further improvements in energy efficiency. The variable ENERGY USE is the main objective of EU energy efficiency policies and helps to evaluate the ecological efficiency. For example, a low value of energy input means high energy efficiency, ceteris paribus. Economic activities that use less energy are more efficient in terms of the utilisation rate of the input factor energy.

The chosen explanatory variables in detail are as follows:

GDP is a measurement per capita in EUR in current prices, again provided by Eurostat. A per capita value reflects the affluence and the differentiated development levels of the examined countries, and allows to infer, whether countries with higher GDPs exhibit different energy intensities than those with lower GDPs. In the aforementioned IPAT model it is one of the key factors.

POP is the measure of total population. The database is provided by the World Bank. According to Ehrlich and Holdren (1971), who suggested the basic IPAT framework, environmental damage, including GHG emissions, is dependent on population size and growth. Following this theory, if the population increases, ceteris paribus, emissions must also increase. Population is an important control variable. A huge variety of studies have analysed the effect of population levels and growth on environmental impacts.

EMISSION is a behavioural variable. It expresses emission levels, where high levels force policy makers to intensive actions against high levels of energy use. The index showing emissions in relation to the Kyoto base year 1990. The higher the index, the lower the absolute emissions. The index is based on the GHG indicated as national target with the actual base year as base = 100, where the CO_2 equivalents are based on the 1990 output levels. Also if the emission exhaust of energy use is to decrease through modern technologies, it is likely to risk some endogeneity of emission and other variables. Thus, the direction of causality is unclear and has to be discussed further in the application of the regression analysis and through the relevant test procedures.

BSA is a participation dummy variable, indicating whether a country's present emissions are below (=0) or above (=1) the calculated annual emission level needed to reach the final BSA allowed redistributed Kyoto gases in absolute emitted tonnes of CO_2. If countries are not complying with the contractual commitments regarding the emission reductions, the BSA obligations put pressure (=1) on policy makers' environmental policies. Countries indicated with "0" can even increase their emissions without incurring any punitive action. The use of a dummy should underline the effect of BSA through an underlying time series analysis with respect to only those individuals having the specific treatment.

This dummy variable represents BSA compliance. It can thus be seen as generating political pressure for the enactment of measures increasing energy efficiency. With the resolution from autumn 1997, the EU states were made aware of the necessity of binding and sustainable emission reductions. The reduction goals were jointly determined and, in accordance with the treaty, have to be reached between 2008 and 2012. The EU has committed itself to reducing its emissions by 20% by 2020 and by 30% in bilateral accords with other industrialised countries.[68] These accords aim to force countries such as Canada, Australia, the USA and other large polluters to ratify Kyoto or similar agreements, but also to signal to emerging countries such as India, Russia, China, Brazil or South Africa that, by signing these comprehensive international agreements, the EU is strongly committed to climate protection goals.

The dummy variable BSA risks some endogeneity especially with EMISSIONS. It is important to mention that the BSA obligations were set and will not be changed within the period of interest. Some countries can even expand emissions. Hence it is possible that both effects (emissions, BSA dummy) point into contrary directions. Thus, the danger of endogeneity exists, but should be only weak or not resist. The direction of correlation should be equal for both variables.

Within the burden-sharing agreement, the old EU-15 countries have individual targets under the Kyoto Protocol and a collective 8% reduction goal, and the Eastern

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[68] This issue is also analysed by Eichhammer et al. (2006): the EU preferred a linear yearly goal progression, enabling deviations between national implementations and replacing final goals with annual benchmarks, making country comparisons difficult.

	OLS	RE	FE	FD
const	12.6344 *** (2.054100)	12.4852 *** (0.566104)	15.8649 *** (2.061850)	-0.022925 *** (0.007716)
GDP	-0.005091 (0.087582)	0.053116 *** (0.011728)	0.060750 *** (0.021680)	0.133776 *** (0.027944)
POP	-0.22887 *** (0.055268)	-0.120454 *** (0.031675)	-0.332583 ** (0.136051)	-0.351516 (0.395398)
EMISSION	-0.359689 (0.269860)	-0.643871 *** (0.039190)	0.640387 *** (0.094135)	-0.604663 *** (0.074595)
BSA	-0.167507 ** (0.075674)	-0.009198 (0.009565)	-0.012107 (0.010342)	0.003358 (0.002799)
PATENTS	0.158762 *** (0.037417)	0.012034 * (0.007084)	0.004413 (0.012779)	0.002334 *** (0.000781)
TECH-EFFICIENCY	-0.285364 (0.224721)	-0.085968 ** (0.041688)	-0.050359 (0.099699)	-0.010435 * (0.005711)
Note: Standard errors are displayed in parentheses. Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.				

Table 9: Model results

European Union member states are required to reduce their Kyoto emissions according their individual Kyoto Protocol targets ranging from 6% to 8%.

PATENTS is a Eurostat data figure, counting the number of patent applications at the European Patent Office (EPO) per million inhabitants. The registration of European patents can be interpreted as an indicator of the technological level, research intensity and innovation potential of the EU members, see e.g. Johnstone et al. (2009)[69]. Countries with a high number of patent applications conduct intensive research. New technologies are more quickly brought to market and can then be the basis of further technologies and research. Thus this variable is an expression of the accommodation capability for new, technologically complex processes or techniques. In countries with a high number of patent applications these attributes are also more highly valued than in countries with a limited number of patent applications.

TECH-EFFICIENCY is the technological efficiency in the transformation process of energy. The input-output ratio shows conversion losses of the raw energy consumption between transformation input and transformation output. A value close

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[69] This concept represents a cumulative effect, because the number is also affected by various policies (e.g. R&D subsidies, appliances standards, etc.).

to 1 signifies a high efficiency and reduction of wastage of raw energy inputs in the energy conversion. It is favourable to reduce losses and make a higher share of every individual unit of energy usable for production, heating and transportation.

As mentioned previously, the panel data consist of observations over 13 years of 25 countries. Logically, there are several reasons to build a Fixed Effects (FE) model since, with I=25 countries over N=13 years, it is questionable if the necessary length of time periods is present to construct an adequate Ordinary Least Square (OLS) or Random Effects (RE) model, which is also known as a generalised least square model (GLS). Thus, general model test statistics to opt for one of the different model designs are identical for OLS and RE to test for or against FE.

To validate the selection of the model for the dataset, OLS, RE and FE models were applied and compared, see table 9. A fourth model will be applied in the further discussion about the test statistic. It is the first differences method (FD) and will be advantageous if autocorrelation occurs, which would be problematic. The FD estimator recalculates the model variables by regressing changes on changes and uses OLS, especially if growth rates and not levels have the potential to accelerate their influence on the dependent variable. Distortions due to time-invariant effects will be eliminated. Individual heterogeneity as well as group-specific, time-variant group effects do not distort the estimators. Dummies and proxy variables that identify levels of development, for example, will not be affected of first differences and are considered with the absolute figures in logarithmic form or the constant dummy values for the reference year.

4.3.4 OLS model

The simple OLS model has to be tested first. Only a few variables are significant on the 0.99 confidence level (POP and PATENTS), and the BSA dummy on the 0.95 level. The adjusted squared residuals are at 0.72. That might go along with autocorrelation, which is also indicated by a low Durbin-Watson value of d=0.12. According Durbin and Watson (1950, 1951), statistical evidence on positive autocorrelation of the error terms exists if the calculated value d is below a lower bound d_L or above an upper bound d_U, while the range of inconclusive results spans from d_L to d_U.[70] Values of d=0 indicate for positive autocorrelation with a coefficient of p=1 and d=4 for negative autocorrelation with p=1.

Additionally, in a direct comparison between OLS and FE, applying the Breusch-Pagan test for homoskedasticity of the estimators[71], a low p-value of 2.518e-284 counts against the null hypothesis that the pooled OLS model is adequate, hence the alternative of the FE model is preferred.

4.3.5 RE model

Secondly, the RE model has to be calculated and compared before definitively opting for the FE model.

The considered variables are significant at the 0.01 significance level, except for the TECH-EFFICIENCY (0.05 significance) and PATENTS coefficients (0.1 significance). The BSA dummy is not significant at any of those significance levels. The mathematical sign of the GDP variable has changed in comparison to the OLS model from negative to positive.

All significant variables have the expected sign. The ENERGY USE is increasing if affluence (GDP output) is growing ceteris paribus, or the PATENTS variable, as a proxy for high intensity of research and development (R&D) is increasing.

A rising population (POP) seems to decrease the per capita energy use and may indicate a better usage of energy intensive infrastructure and home appliances. Less populated countries can use their own infrastructure less efficient: the average utilisation rate is lower.

A higher technological TECH-EFFICIENCY of energy input conversion is negatively correlated with ENERGY USE. The utilisation factor of energy may increase due to technology, and affect also the amount of the negative by-product *air pollution*. The EMISSION variable, which is interpreted as a behaviour variable, and its levels have a negative impact on energy consumption. The lower the index, the stronger the pressure on the policy maker to drastically reduce energy use. If EMISSION increases but still shows values far below 100, the pressure on the policy maker to strengthen efforts to decrease the energy intensity is higher than before. As the value

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[70] For negative autocorrelation, the corresponding test is 4-d < d_L for statistical evidence, 4-d > d_U for non evidence, and d_L < (4−d) < d_U for inconclusive results.

[71] Breusch and Pagan (1979) developed a test to estimate if the variance of the residuals is dependent on the values of the independent variables.

gets closer to 100, the pressure lessens and energy consumption reductions can occur in a much slower ongoing process.

The sum of the squared residuals in the RE model is high with a value of 24.428. The standard error of the regression (0.277) is also high, especially in comparison to the further application of a FE or FD model. This may be the result of a potentially inconsistent estimator.

4.3.6 The FE model

The FE model tries to solve the potential problem of inconsistent estimators in the OLS and RE models, which can occur due to correlation between the independent variables and individual heterogeneity. Since a FE model is supposed to control for the heterogeneity of country-specific characteristics, the unitary pooled error term u_{it} of equation (5) is decomposed in the unit-specific time-invariant component α_i, and the observation (country) specific error $\varepsilon_{i,t}$.Time effects capture as a proxy all variables that are unobserved, but common across countries while they vary over time:

$$\begin{aligned}(6)\qquad log(ENERGYUSE)_{i,t} = {} & \beta_1 log(GDP_{i,t}) + \beta_2 log(POP_{i,t}) \\ & + \beta_3 log(EMISSION_{i,t}) + \beta_4(BSA_{i,t}) \\ & + \beta_5 log(PATENTS_{i,t}) + \beta_6 log(TECH\text{-}EFFICIENCY_{i,t}) + \alpha_i + \varepsilon_{i,t}\end{aligned}$$

In case of autocorrelation in the FE model, time effects may not be included in the group or general error term and thus the evidence of the results for some or all examined variables risk to tend to zero. The design of the model chosen here reveals indicators of autocorrelation, but first of all the question of model selection has to be solved.

The RE model in 4.3.5 failed the Hausman-test on endogeneity of the variables due to unobserved individual factors (cf. Hausman, 1978). The null hypothesis of consistent estimators will be rejected with p=1.114e-06, hence the alternative hypothesis for correlation between explanatory variables and the error term is accepted. The test therefore points towards the FE model.

In the FE model, the White-test (cf. White, 1980) is the corresponding routine to the Breusch-Pagan-test in the RE model. It again concerns fixed effects: the null hypothesis that groups have a common intercept, e.g. the same country-specific error, can be rejected with p=2.455e-214. Thus, the use of the FE model is adequately supported. The conclusion is underlined by a high significance of the F(30,294)-test with the p-value close to 0. Especially for applied studies, Baltagi and Raj (1992) propose in their literature review of econometric tests to use the F-test for random individual effects.

The adjusted R-squared is considerably high at 0.992. One of the characteristics of the FE model approach are group specific dummies to calculate the time-invariant individual effects. The use of dummies leads to a loss in degrees of freedom, as each dummy is considered as its own variable: in the applied model N=25 countries. On the other hand, the dummies can improve the ratio of explained variance of the model.

The variance of the residual seems to be autocorrelated over time, as the DW value for the estimated FE model is d=0.918, which is far from the range of uncertainty without statistical evidence (in the range of inconclusive values for the FE sample, d_L=1.7786 to d_U=1,8549, according to the extended Durbin-Watson-tables by Savin and White (1977)[72]) and the proof of not being positive autocorrelated (if $d>d_U$).

Bhargava, Franzini and Narendranathan (1982) extend the discussion about the exact interpretation of the Durbin Watson test to FE-models with the affirmation of Durbin and Watson (1971), that the DW test seems to be the most powerful test, but added to the discussion one crucial point. For a case like above, where positive serial correlation cannot be rejected, it remains unclear if autocorrelation is really a crucial issue to address or can remain in the model. They developed additional tables for FE models with the result that positive autocorrelation cannot be generally rejected if $d < d_U$. In that case, the authors propose to test if the residuals form a random walk. Eigen-vector routine based tables for lower (R_{PL}) and upper (R_{PU}) bounds for the random walk give evidence on the serial correlation of the estimators, if $d < R_{PL}$. In the examined model, d was calculated as 0.918, thus $d > R_{PL}$=0.588. Hence it does not clearly underline this finding, but it is relatively close to R_{PL}, and far away from d_u, thus it is highly probable that the residuals are following a random walk, the variables are correlated over time and may continuously grow or decrease, and the mean value is not in a steady state but changing over time. For that special case, in a

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[72] The original Durbin-Watson tables were calculated for 15 to 100 observations and a maximum of 5 regressors due to the lack of adequate computing power in the 1950s.

further analysis, Sargan and Bhargava (1983) propose to use first differences FD estimators.

With the implementation of robust standard errors, a methodology can be found to face the latent hazard of autocorrelation or heteroskedasticity. The standard FE model was modified using robust standard errors according to Newey and West (1987). The Newey-West standard errors provide a covariance matrix estimator to replace parameters that harm the standard assumption of regression analysis in time series models. Therefore they are heteroskedasticity and autocorrelation consistent and are favoured over other popular robust standard errors in econometrics, such as White (1980). As in the FE model, and also in the other model applications presented in the analysis here, Newey-West corrected values show marginal variations and can improve the significance. The method is adopted for all model calculations.

4.3.7.1 The FD model

Under the random walk theory, an autocorrelated FE model has to be rejected. The following first differences (FD) equation will estimate efficient parameters. Group specific effects in α_i will be removed from the model: they are constant over time with a zero variance. Time-variant variables remain in the model as before, if they are not exposed as indices[73] and can be interpreted as levels of technological development (PATENTS and TECH-EFFICIENCY), or are dummies (BSA). For ENERGY-USE, GDP, POP and the EMISSION variable, log-differences eliminate differences in the stage of development, but register only changes over time, making countries more easily comparable:

$$(7) \qquad \Delta log(ENERGYUSE_{i,t}) = \beta_1 \Delta log(GDP_{i,t}) + \beta_6 \Delta log(POP_{i,t}) + \\ + \beta_3 \Delta log(EMISSION_{i,t}) + \beta_4 (BSA_{i,t}) \\ + \beta_5 log(PATENTS_{i,t}) + \beta_6 log(TECH\text{-}EFFICIENCY_{i,t}) + u_{i,t}$$

As said before, variables to measure levels of development, here the proxy variables PATENTS and TECH-EFFICIENCY for technology, will just be put in logarithmic form, while it is reasonable to take first differences of the logarithms for GDP output, EMISSION and POP, because the correlation of the growth rates calculated in this

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[73] For PATENTS and TECH-EFFICIENCY absolute levels are in the focus, not changes-in-changes.

way with (the rate of change of the) energy use is on a percentage basis. Policy measures can try to influence directly the further growth conditions, which are correlated with the present energy use. Technological development with the proxy PATENTS and the underlying TECH-EFFICIENCY, the technological development level of raw energy conversion, are more related to the long term and represent the physical conditions of assets, the infrastructure and the sectoral mix of an economy.

The influence on politics of the BSA obligations is a) interpreted as a dummy variable (BSA), and b) as a behaviour influencing variable EMISSION, which is an index and interprets values lower than 100 as not achieving the burden-sharing agreement redistributes Kyoto Protocol GHG emission obligations. An additional BSA participation dummy which is equal to "1" implies pressures on policy makers to decrease emissions, while an increasing index indicates the absolute pressure, where higher values imply a lower pressure or, if EMISSION > 100, as the burden-sharing agreement obligations are already fulfilled, can even allow countries to increase the present emissions.

The chosen FD model shows an adjusted R-squared of 0.477. The portion which is not explained by the variables 0.523 can be attributed to unobserved influences of cultural or political conditions, price effects, shocks and climate extremes, and measurement errors of the data sources. The standard tests already applied in the OLS, RE and FE models underlined the need for the first differences design. Finally, the chosen model has to be tested for causality. Granger (1969) specified causality as an estimator of an endogenous variable y with respect to the exogenous variable x, which will be improved by including lagged variables Y_{t-1}, ….. Y_{t-s}.[74] The Granger causality theorem requires time series methods to be applied, like the FD model. Through differentiation of the FE model, the group-specific effects were eliminated, thus the correlation of variables should be independent of group-specific influences in the levels. The F-test in the FD model already determined the correlation. A Wald test (Wald, 1943) can control for the omission of a variable of significance, as the H_0-hypothesis represents a zero value of the regression coefficient of the observed variable. For the given model, the proof of the Wald test gives the same significances for the variables as the standard F-test. The F-test for testing the relations between

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[74] Kirchgässner (1981) pointed out, that the Granger test requires modified stationary residuals that can cause multicollinearity. Taking differences or growth rates reduce the problem.

the exogenous variables and the error terms has the required power with F(6, 293) and a p-value of about 7.86e-40.

The DW value of about d=1.783, again, cannot clearly confirm the absence of autocorrelation. But it is already in the range of inconclusive test results and rather close to the d_U value in the original Durbin-Watson-tables, thus autocorrelation cannot be clearly excluded. But as the DW value is very close to the d_U value, it can be assumed that autocorrelation is not high, if it exists. Further such small differences might be explainable by errors in measurement.[75]

4.3.7.2 The FD model significances - results

The coefficients display the expected values, but one has changed in comparison to all former applied models: BSA has a negative association, even though the coefficient is not significant. Energy efficiency is not directly depicted in this model, but is reflected by the auxiliary variable ENERGYUSE as a decrease in energy use ceteris paribus is equivalent to an increase in energy efficiency. Appropriately, energy consumption falls if a) the EMISSION output increases[76], or b) the underlying technological TECH-EFFICIENCY, the conversion of raw energy, namely the utilisation rate of every individual unit of energy, is increasing, and there seems to be c) a slightly negative association with POP, the population, which is obviously under ceteris paribus conditions through a better use of energy using infrastructure and home appliances, even though this variable shows a non-significance.

Energy use rises if a) energy use due to a higher production output (GDP) is expanding, or b) PATENTS are positively correlated with a growing energy use.

The non-significance of POP and BSA need further investigation. Especially POP seems to be an important and fundamental control variable: population is one of the main factors in the STIRPAT model as well as of the approach of Ehrlich and Holdren (1971).

The existing literature focuses on analysing the correlation between energy use and GDP in relation to the level of development of different countries and permits. The

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[75] The Durbin-Watson-values for the FD sample of k=6 and n=300 are calculated as the following lower and upper bound: d_L = 1.7700 d_U = 1.8516.

[76] Due to the design of the model, a negative correlation between the fulfilment of the Kyoto obligation and the energy use indicates there is no need to reduce the energy use as long as the Kyoto goals are already reached and the index is above 100.

analyses of European industrialised economies have results deviating from the expected values, for example the influence of the tertiary sector.

There are more other factors showing statistical non-significance, which is observed for the share of renewable energies or fossil fuels in overall electricity production, population density, or the share of the tertiary or industrial sector as well as a combination of both. Thus, these variables are unaccounted in the computation of the above model. Nevertheless, the non-significance has to be mentioned below to assure the reader that the absence of the variables can be legitimated. If the number of variables is changed, the quality criterions Akaike (AIC)[77], Schwarz (BIC)[78] and Hannan-Quinn[79], all more sensitive than the adjusted R-squared value, do not improve. There seems to be no need to add the named factors. In contrast, POP, and to a smaller extent BSA, too, have a positive impact on the criterion, while the direction of influence still remains unclear. These control variables are often used in other literature, too, as mentioned before. The findings underline the general importance of stressing other factors besides GDP that have an influence on energy use, while affluence and population remain the main factors driving energy use and thus energy efficiency.

Population effects, represented as population growth in the FD model from above, have a non-significant influence with a coefficient of -0.352. A study by Martinez-Zarzoso et al. (2007) could not confirm the influence of population changes in Europe, which is barely growing, or even shrinking, and the impact on energy efficiency could not be determined, requiring a more complex examination.

The influence of the pressure through the BSA redistributed Kyoto Protocol obligations is observed to be significant at the 0.99 confidence level, characterised by a coefficient of -0.645. Using a dummy variable for all countries, which are under

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[77] Under the assumption, that models can only be close to the unknown reality, Akaike describes the loss of information due to the chosen estimation model function as a multi-dimensional distance to the always more complex truth. Akaike (1974) describes the application of *A*n *I*nformation *C*riterion, as the basic principles of AIC are founded by Akaike (1973) in a formal adoption (the 1973 source is not readily available and published as a symposium article). The model with the smallest AIC should be chosen and seems to indicate the model closest to reality when considering the data.

[78] AIC favours models with many variables, the BIC criterion by Schwarz (1978) is deriving the estimators in a Bayesian a-posteriori, exponential form, thus BIC penalises models with many explanatory variables more and accepts the models as quasi-truth. Again, the model with the smallest BIC fits best with reality, while models with small samples face the threat of being underfitted.

[79] The criterion of Hannan-Quinn (1979) is a modification of AIC using a squared residual term to correct the bias in favour of huge samples by Akaike, without penalising these samples exceedingly. The authors propose their attempt to "provide some compromise" (p. 195) between AIC and BIC. As before, small values are better.

pressure to reduce their emissions more or less drastically, the results show a lower correlation of about 0.0034, but non-significance. On the one hand, both results are in agreement, but on the other hand contrary to Grunewald and Martinez-Zarzoso (2009) and Tamazian et al. (2009). Both studies found a significant effect (0.1 significance level) of the Kyoto Protocol ratification, but are merely testing a dummy variable relation. Tamazian et al. (2009) split the Kyoto effect into two dummies: protocol ratification and signatory. They find a significant correlation between ratification and CO_2 emissions, and suggest that the signatory is insignificant due to missing obligations to cut emissions. Countries which did not specify any reduction goals will not reduce their emissions. Again, the question arises, if the driving factor for emission reductions is to find in the political decision-making and not in international treaties, but the Kyoto Protocol is one or the only homogenous framework that can be identified to compare countries‘ efforts in global climate change policies.

Affluence and population are the effects, besides technology, that are the basic variables in the STIRPAT model and explain the highest share of influences on ecological impacts, while time and other effects are subsumed in an aggregated error term. The applied FD model follows this approach, with GDP (coefficient 0.134) and PATENTS (coefficient 0.002) being significant at the 0.01 level, and at the 0.1 significance level the TECH-EFFICIENCY (as expected by the definition of the raw energy input-output ratio) with a coefficient of -0.01. POP has a coefficient of -0.352 but due to non-significance the effect is unclear.

The significance of GDP growth is, as expected, high. However, the explanation of the reasons for this appears to have some uncertainties, as in the studies cited in chapter 4.2. It is unclear to what extent GDP influences energy use and if there is an underlying Kuznets curve, or whether economic growth and energy use are decoupled. Core European countries such as Germany, France and the Benelux countries have reached a high economic level and grow only moderately. They can reduce their energy intensity at this high level through innovation, while new member states, e.g. Romania and Bulgaria are at the other end of the scale. These countries are renewing their production capacity, and in this convergence process can quantitatively reduce their energy intensities, see e.g. Eurostat (2010), Saikku et al.

(1998), Cornillie and Fankhauser (2004)[80]. As a consequence, one should be cautious about the interpretation of the correlation of European countries GDP and energy intensity or energy efficiency and the consequence for the ecological impacts. But to declare that GDP growth is pushing the demand for energy, neither the growth intensity nor the development level are taken into account to find a correction factor or even the level of maturity of an economy or its structure.

As table 9 shows by the results of the applied model, it is economically and ecologically worthwhile to calculate additional factors directly in a single model to specify the relations and influences on the dependent variable that indicate the ecological effect of measures.

First, the positive sign of PATENTS with a coefficient of 0.002 seems to be the wrong way round and is at first surprising. The influence is insignificant in FE calculations, but it seems unclear as it is significant when using OLS, RE and FD estimators. To explain the positive sign, it is suspected that a higher share of research and development activities is associated with industry, which is quite energy-intensive, or with the convergence effect in the Eastern European member states with a higher pressure to innovate. If one goes deeper into the sector specifics of the German patents, for example, it is striking that the characteristics of new patents in highly developed countries can at least partly represent services, including some energy-intensive activities like the construction sector, waste disposal, and cleaning services, but also the railway sector, transportation and airports, and heating, cooling and lighting in offices, hotels, restaurants and related other assets having high energy consumption. Innovation in energy saving technologies is not as common in the service sector as it is in the industrial sector (see Schlomann et al., 2009). Instruments that lead to a reduction in environmental pollution and encourage innovations in (production) technologies often focus on the industrial sector, e.g. the EU-ETS for carbon savings in the heavy industry branches. Hofman and Labar (2007) emphasise that the influence of the tertiary sector is not as important as the technological changes in the industrial sector, which lead to energy savings in much higher quantities. To conclude from the above, it seems clear that patents have a minor, but significant influence on energy use, while the correlations between energy

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[80] The authors confirm the general trend, but also detect differences. The energy intensity drops especially quickly if privatisation and the opening of markets occur and competition increases quickly.

consumption, industrial sector and tertiary sector remains unclear and without significance.

The literature cited in this chapter to some extent includes other factors to measure influences on emissions or energy use. While developing the model and processing different tests, a non-significant impact was shown for the named factors. The remaining factors from above were neither affected substantively in their coefficients or their significances, nor were the tests for the basic model fundamentally altered. Small changes do not legitimate the consideration of other influences when there is no positive result for the proof of the hypotheses of this analysis.

4.3.7.3 FD model with Chow test

	coefficient	**std. error**	**t-ratio**	**p-value**
EU-new POP	1.125990	0.756559	1.488	0.1378
EU-new EMISSION	-1.706140	0.118881	-14.350	1.49e-35***
EU-new BSA	-0.023148	0.011672	-1.983	0.0483**
EU-15 POP	-1.958450	0.879533	-2.227	0.0267**
EU-15 EMISSION	1.220440	0.125767	9.704	1.98e-19***
EU-15 BSA	0.027013	0.012558	2.151	0.0323**
Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.				

***Table 10: Chow test**, main results*

Using the test routine of Chow (1960) for structural breaks, the non-significance of POP and BSA can be explained, as two sub-groups of the dataset have different explanations for the independent variables. Using another dummy variable not yet considered, it will be tested whether there is a structural disparity that can explain different conditions for the influence of factors. For the dataset used here, it seems obviously a good idea to separate the old and the new EU member states.

The old EU-15 have a different industrial and social structure and are faced with other challenges than the new, often former Warsaw Pact members. The former have to fight against rising budget deficits and costs of the welfare state, while the latter have to reform their economies and rebuild a new industrial structure.

Testing the FD-model with the Chow test considering an EU-15 DUMMY (Belgium, Denmark, Germany, Ireland, Greece, Spain, France, Italy, Luxembourg, Netherlands, Austria, Portugal, Finland, Sweden and UK), the hypothesis of a structural break along the dummy has to be accepted, see model 5 in appendix 2.

The further results clearly support the above done discussion and the consideration of POP and the BSA dummy in the base model, see table 10.

The new EU members have, with the exception of Slovenia, BSA obligation respectively Kyoto targets far above present emissions. Thus, they could even increase their GHG emissions without any consequences regarding the common EU climate change decrees. They can remain on a growth path of their new economies and rebuild the old branches. Heavy industry and the replacement of heavily polluting coal power plants with new, highly efficient power plants are even saving more emissions than the newly built industrial plants will emit. The significant coefficient of the BSA dummy for the new EU members is based only on a very few observations counting "1" for Slovenia; the more meaningful EMISSION variable, indexing the emissions, has a negative sign as the correlation of less emissions comes with a decrease of energy consumption.

The EU-15 members, on the other hand, have to fight against increasing emissions. The pressure on policy makers to act vigorously against pollution is higher, as the present emissions of Kyoto gases are far away from the BSA obligation targets. The dependency between BSA and ENERGYUSE is positive and shows that the energy consumption of a country is higher if the allowed goal is not yet fulfilled. The negative sign of EMISSION seems to be contrary to these findings, but it implies the tendency to become negligent in fighting for emission reduction when coming closer to the BSA respectively Kyoto protocol obligation targets. For the industrialised EU-15 members the rate of change of emissions is higher when closer to or above the BSA target.

Closing the discussion about the Chow test results here, the influence of POP, the population, has to be mentioned with the result that matured EU-15 members have a significant, negative correlation with ENERGYUSE (-1.958) while the new EU member states show a positive, but not significant correlation. This can be explained through the demographic structures of the old member states. Most countries are experiencing only marginal population growth or even face a negative development of population. Thus, the infrastructure will be used lavishly, for example through bigger flats, which imply the need for more energy for heating or cooling. If population is growing, the existing structures will have a higher utilisation rate and less wastage.

4.3.8 Other factors

Other factors, which were considered in the cited literature were tested but led to results that are not in line with the theoretical considerations:

There is no significance observable for the tertiary or industrial sector. If the share of industry or services in total production of goods and services (GDP) is taken into account, it shows the same result of non-significance. Both factors should indicate differing development levels of the examined countries, and allow one to infer whether countries with larger tertiary sector exhibit different energy intensities than those with a lower share. The analysis by Hofmann and Labar (2007) showed similar results with non-significance for the industrial, but significance for the tertiary sector. While they are studying China, they conclude a general (positive) effect of services on energy efficiency if an economy is not already matured, while industrial development may be closely related to innovation in less energy-intensive manufacturing processes at a lower development level. For European countries, which have only marginal changes in the sector share, and no large shift, Schleich et al. (2006) criticise the fact that the service sector is often less integrated in the national allocation plans and, as a negative consequence, the emissions can be only poorly controlled and the sector needs other incentives to save energy if not affected with some delay through increasing prices on electricity and the elasticity on consumption.

The regional availability of goods and labour is also dependent on the population density. In heavily populated areas the infrastructure for transport of goods and services is often better and the organisation of goods, logistics and supply chains more flexible. Unfortunately the factor has no significance. The idea of a direct influence of urban structures, which, due to structural considerations, require the provisioning of more energy into the urban environment, fails. An attempt to explain these findings can be found in Martínez-Zarzoso (2009): the author analyses country-groups of different development levels and observes a non-significant influence of population on emissions for most OECD countries, and no change of the estimated coefficients of the explanatory variables, with respect to the finding, that in low- and middle-low-income countries the influence of population (growth) seems to be higher.

The closely related variables of the shares on total energy production of fossil fuels and renewable energies show neither a better fit of the base model nor are they significant. Of course, if increasing the green energy installations, the demand for fossil fuel decreases. But if there is more energy available in the market, the price effect upon electricity, an elastically priced good, must also be considered. In the case that the new power generating capacity does not replace older plants but just raises the total production capacity, energy will become cheaper and the effect on energy efficiency can, as a possible consequence, be negative. In general, renewable energies could, as it was noted earlier (merit-order effect, see chapter 2 for comparison), reduce electricity prices in response to market conditions and thereby work against energy efficiency goals (e.g. rebound effects, see above). In addition, it appears that the usage of fossil fuels does not increase energy intensity per se: it measures the burning of fossil fuels such as gas, coal and oil. Here we are asking, "How large is the share of fossil fuels on the entire energy consumption?" This is not just the share remaining after the subtraction of renewable energies. Especially nuclear energy, with relatively low CO_2 emissions, produces a large amount of the electricity in some EU countries. Nuclear power plants have a very special control system characteristic and the gear of them is not very variable: they cannot be combined with other plants to serve as a flexible source of energy and will often be operated in base-load duty. The addition of the fossil fuel variable might indicate if an increase in the usage rate of primary energy units is caused by changes in energy efficiency. Coal and gas power turbines can be started more easily and controlled as peak-load power plants.

Another factor to take into consideration are the conditions of labour markets. Testing the influence of the labour participation rate indicates the intensity of the production of goods and services in the observed economies. A large workforce can be interpreted as the country having sufficient population in the employable age and/or the unemployment rate being low. In reverse, if the labour participation is low, a relatively small part of the population has to be highly productive and innovative to supply and facilitate young and old, as well as unemployed parts of the population, with their earnings and tax payments. Unfortunately, neither the significance was not given for any of the four panel data models applied here, nor were criteria like BIC, AIC or Hannan-Quinn improved.

The model does not completely explain the dependent variable. It is obvious that additional influencing factors can be found, which may also have considerable influence on energy intensity but are not even tested here due to lack of data or as they are of no interest for the here conducted analysis and the topic of this thesis. First of all the price of fossil fuels: energy has a finite price elasticity - demand lowers as prices increase. However, industrial purchase price information is quite fragmentary and priced in Dollars, while data used in the model, though available for the entire time period, is priced in Euro. It would thus not be meaningful to use this as a factor, as it may lead to distortions, as Eurostat's convergence course is unknown and exchange rate fluctuations over the years can lead to difficulties of a direct comparison. In addition, energy consumption is dependent on a country's climate. This can be explained by Europe's great expanse, with a Mediterranean climate in the south, a temperate climate in Central Europe, and continental influenced climate in the east. The investigation has not yet controlled for these particular influences (see e.g. de Cian et al., 1997).

If concentrating on the factors that can be influenced by the policy maker with the aim to redesign the conditions of energy use through appliance standards, incentives and prohibition of unfavourable techniques, the applied model is an approach to explain the driving factors with feasible and usable results. The interpretation of the discussed models will follow in the next chapter.

4.4 Model results and recommendations

Energy efficiency is more than just energy saving. It is clear that the rate of change in energy use accompanies first and foremost GDP growth. There is only a limited ability to decrease energy use and thus increase energy efficiency with policy measures like such as the pressure to fulfil Kyoto Protocol obligations through the redistributed BSA targets. But also other factors such as underlying energy efficiency and technological development have some influence.

The interdependence between emissions (and environmental damage) and population observed by Ehrlich and Holden (1971) can be decoupled. As shown in the literature review above, the environmental Kuznets curve theory is in the focus for a huge variety of analyses by ecological economists. The EKC theory determines the exact turning point where growth and emission reverse their relationship: further growth no longer causes environmental damages, for example growth of emissions, but even leads to lower emissions. Most authors testing for the correlation of the two factors come to different results, however, when summarising, it can be shown that on the one hand, the relationship is not clear, and on the other hand, other factors have to be examined to find a better fit of the chosen models, as their impact is uncertain. The biggest obstacle seems to be the turning points, which are at very high levels almost out of reach for any country in the near future. In the analysis done in this chapter, the EKC concept was not considered for the model design. Nevertheless, one has to keep in mind the positive relation between growth and emissions.

It has been shown that the EU member states have different structures regarding their economies. There are structural breaks between the old EU-15 and the new EU members for the variables POP and EMISSION, in particular the BSA dummy variable. Old, matured economies seem to be challenged by other economic and social conditions. The analysis shows that the climate change policy objectives for the new EU members seem to be in most cases too lax and even allow the expansion of emission pollution quantity, and might be further reduced to generate relevant and real savings of emissions. Through a stricter involvement of all EU member states, the EU as a whole could generate much higher savings of GHG emissions.

The addition of further variables shows that policy measures can, however, have a significant influence on the energy use, even if the effect is small. The obligations set by the EU create pressure for action, which significantly affects the energy use related energy efficiency. It is not proven whether expectations of policy measures alone lead to innovations in modern environmental technology and economical resource consumption, or whether concrete laws and regulations must be enacted so that market participants take an active part in climate protection actions. While this was not the purpose of the examination, it is nonetheless assumed that the interaction of high expectations regarding probable policy actions and stringent regulation can contribute significantly towards compliance with the Kyoto obligations, respectively the redistributed BSA obligations.

The European Union is pursuing ambitious climate protection policies and requires member states to raise energy efficiency in order to also reduce GHG emissions. The effectiveness was tested in the aforementioned model and cannot be dismissed. The influence of diverse exogenous factors upon the endogenous variables, the focus of observations, was examined using the panel dataset and first differences (FD) projections, and energy efficiency through the proxy energy use as shown. The dataset represented the years 1998 - 2010. In 1998 the members of the EU began to enact policies to reach their self-imposed climate protection targets, calculated from their Kyoto Protocol obligations. The direct influence of the policy consequences of the Kyoto Protocol and the BSA redistributed targets among the 25 countries was completely represented and investigated. Other specifics of national economies, for example population growth or the innovation capacity with the proxy of PATENTS, also seem to have an influence on energy intensity. While policies have little or no effect on population growth, regulations can affect the formation and control of the general framework of the economy, as the conditions of growth processes initiate optimisation processes, and innovations result in highly energy-efficient plants. But this influence is indirect, as it is on population growth. Further research in this area must clarify these open questions regarding additional interactions exist and how policy makers can have an influence.

The above model tested the policy pressure caused by the Kyoto Protocol and the following BSA obligations among EU members: the redistribution of Kyoto obligations with different reduction goals for different countries may result in different levels of pressure for one country in relation to another to cut emissions, also if global economic challenges and conditions are quiet more similar. Other previous analysis used simple dummy variables to quantify emission reduction linked to the Kyoto Protocol ratification in comparison to non-signatory states, and the meeting of the goal over the years, but not changes in compliance.

The findings of the model expanded from the studies presented in this chapter are as follows: within a group of countries that have homogenous policy conditions of contractual obligations due to international treaties, it can be positively inferred that the obligations of the Kyoto Protocol redistributed through the BSA exercise pressure on EU member states for prompt enactment.

It has been shown that the ecological impact can be influenced also by policy measures, as suggested when the simple IPAT was adapted to the STIRPAT methodology with additional variables. The proof of the empirical model with enhanced consideration of diverse influential factors implies that climate change can be countered, if there is political consensus. This interrelation and the effectiveness should again be further examined to explain how to strengthen the influences. If necessary, market expectations and trust in policy implementation could be included as variables.

The probability of sustainable environmental policies could serve as an indicator and as a benchmark for international agreements when implementing control mechanisms to achieve global targets. If there is consensus that treaties are loaded with power, future policies will be encouraged to give priority to the development of further mechanisms of international agreements to strengthen the synergies of international cooperation in the fight against climate change.

Country groups like the EU should also be further analysed, to determine whether corresponding measures, for example innovation standards in product manufacturing, subsidies for environmental investments or minimum standards for emission limits, might thwart or perhaps even accelerate economic growth and the related energy efficiency.

5. Final conclusions and recommendations for policy makers

If the European Union is becoming or remaining a global player and innovator in the fight against global warming, announcing policies is not enough. The application of environmental policies has to be powerful enough to be anticipated by individuals and markets, otherwise policy makers would be helpless to address the global challenge to slow down global warming.

While the question about the efficiency of a cap-and-trade system was solved in a theoretical approach by modelling the market for emission permits, the problem of technological maximisation of the energy harvest was calculated under realistic conditions for two different countries. Finally, the doubt about the influence of the Kyoto Protocol obligations with binding targets on emission savings was tested with an applied econometric model based on a cross-country panel. To conclude, the three propositions presented in chapter 1 were evaluated and tested and can be answered as follows:

> *Proposition 1:*
> *If shocks foil emission reduction plans, the policy maker has to*
> *ensure the achievement of national climate protection plans.*
>
> *Conclusion 1:*
> *True: Shocks can be dealt with by regulations of allowance*
> *quantities and lead to higher emission savings for the economy*
> *at comparable costs.*

As shown in chapter 2, shocks do not influence the emission saving target in a cap-and-trade system, which will always be achieved. Through shocks the demand for emission permits changes and system participators will enhance their individual economic optimisation. As shocks are most often related to a decreasing demand for emission permits and consequently decreasing prices, emission savings on the individual emitter level will decrease, too, while the absolute system cap does not change and the total amount of carbon savings remains the same, as examined in the example of the joint application of the EU-ETS cap-and-trade system and technology support systems for RES in Germany. From an economic point of view, the results of the shock reduce the costs without negative impacts on the environment, the saved financial resources can be spent elsewhere and the total economic burden of the instrument is limited to a lower level.

The findings of chapter 2 show in this context the lack of evaluation of the ecological efficiency: the high social costs of air pollution and German as a possible "role model" that could influence other nations are not taken into account. If, as done in Germany by means of support systems for RES capacities, these technologies are developed faster, this provides political leeway to cut emissions faster. Thus, the cap is not at all exogenous: through policies, green power plants and technologies become endogenous factors that influence the cap for the next period.

Chapter 2 confirmed the theoretical potential for policies to put pressure on the system with the intention of cutting emissions faster. It endorses joint application of different instruments of climate change policies. The question remains open, and is under consideration in the following chapters: in what quantity can RES support systems lead to additional emission savings and what are their costs?

> *Proposition 2:*
> *Green technologies are too expensive, without subsidies*
> *a share of green energies of 20 percent of total energy*
> *production is out of reach.*
>
> *Conclusion 2:*
> *False: A fit between technology and geographical*
> *conditions leads to a higher total energy harvest for an*
> *unchanged investment sum.*

The calculations in chapter 3 proved that the RES energy harvest can be improved and in what proportion, if a specific technology, e.g. solar power plants, is not supported randomly but in specific geographic areas. The findings show that, as a result, the German technology support regimes lead to (private) investments in RES sources, even if they are economically uncompetitive. The REFIT for solar energy production is paid by all consumers and thus can be interpreted as an environmental tax and the internalisation of the social costs of carbon emissions: the erected green energy capacities reduce emissions and boost the price of consumption.

With the same costs and comparable return on investments[81], Germany could have accounted for an additional reduction of about 1.2 million tons of CO_2 per year. This also implies a potential avoidance of social costs accrued through CO_2 emissions of approximately 84 million EUR; the additional contribution of total GHG savings would be approximately 0.15%. The conditions to realise this potential are clear: investing extraterritorially if the harvest can be higher or stopping the support of specific technologies, e.g. solar power plants in Germany, and using others like wind engines instead.

With a European roadmap for RES, the EU could fulfil the Kyoto Protocol obligations more easily, more cheaply and earlier. Simultaneously, the objectives of the 20-20-20 by 2020 targets would be reached more rapidly. This thesis' recommendation is to implement a path-goal-strategy: a REFIT, parallel to the German model for market stimulation, and intra-union concentration of technologies at the place where they will generate the highest harvest. The legal framework for such a policy is given on the national (e.g. Germany), European and worldwide (Kyoto) level.

As long as Europe does not act as a single player, but like a choir with 28 voices, the efficiency of climate change policies is going to be suboptimal from an ecological and economic point of view. Otherwise, it is beneficial if policies intend to decentralise the electricity production and promote a convergence in the production share of green energies and the conditions of energy use. Whether policies can put pressure on all individuals of a state or the EU to green their consumption is an open question to examine within the analysis of the impact of Kyoto Protocol obligations on national plans for emission savings, as conducted in chapter 4.

Proposition 3:
If emissions are correlated to output and growth,
the Kyoto Protocol obligations and energy saving policies
have no effect on the emission output quantity.

Conclusion 3:
Unclear: The Kyoto Protocol might fail on a global scale,
but strong policies on national level put pressure to use

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[81] The calculation assumes a lower REFIT but higher harvest per kWh, in conclusion the investors' return remains steady.

energy more efficiently, on the individual or firm level
and improve the country's energy efficiency.

The anticipation by the policy maker of the Kyoto Protocol and the following burden-sharing agreement redistributed obligations and the implementation of policy measures lead to increased pressure on individuals to raise the energy efficiency and thus lower energy input.

The panel data analysis in chapter 4 shows that energy consumption is highly influenced by GDP, but also reveals the dependency of energy use on other factors. The test of a participation dummy variable of BSA obligations and its target achievement in an econometric FD panel data analysis shows the pressure of action, which significantly affects the energy use of economies. Also if the effect seems to be weak, plausible policy actions and regulations can contribute a significant influence on individuals towards increasing their energy efficiency and thus decreasing their use of energy inputs. The whole economy will decrease energy use and the overall energy efficiency should rise. Well-directed policies may control and influence growth and innovation processes. Appliance standards, regulations and environmental taxes set the framework for individuals to interact in a more environmentally friendly market, namely market participators can generate positive effects of energy savings and minimisation of costs through decreasing energy use.

Instruments like the EU-ETS and REFITs are policies that intend not only energy savings and new RES capacities, but both have a side effect on energy efficiency, too. If emissions because of fuel burnings have a price, one should decrease the individual input of energies and the input itself will become greener; the costs of emission permits can save expenses. To conclude: the joint application of different instruments is neither going to cause the Kyoto Protocol, and e.g. the following policies like the BSA, to fail nor the instruments to fail per se, but instead of economic optimisation in the present, ecological optimisation would imply bringing down the potential (social) costs of tomorrow.

It is recommended to design legal conditions which continue the success of REFITs as technology support regimes. The increasing demand for green technologies in the power plant sector leads to decreasing costs through the growing market, the learning curve, and innovations in production, R&D and design; but also the increase of competitive players on the supply side. The cost-shrinking effect as well as the fit bet-ween technology and geographical conditions should be the measure for the tariff for feed-in energy and decline in the same proportion. As long as the output remains attractive for investors and positive above market interest rates, the ecological efficiency is in the focus instead of (individual) economic optimisation. Finally, the national economies and their societies realise higher benefits. The correlation was demonstrated in chapter 3. An additional benefit can be seen in the greater amount of total carbon savings, for example.

If promoting RES, policies should align linked measures, for example the EU-ETS. If initially not taken into account, trading schemes should be adjusted after a shock to prevent an increase of emissions at the location of the single emitter, as has been illustrated in chapter 2. A stronger regulation of trading schemes, allocation of permits and a tentative withdrawal of certificates within the trading scheme period have to be discussed.

The Kyoto obligations are not at risk: the compulsory and redistributed BSA targets of the European Union and its member states will be achieved, as long as policies are powerful enough to impart confidence in the sustainability of the legal conditions to individuals. As shown, side effects of measures for Kyoto compliance give the political scope to go ahead with more stringent targets and cut emissions faster on a comparable cost level. Today's policies may have an influence on the energy efficiency. However, future measures can be improved if the influential factors are analysed more deeply. The identification of these influential factors need further research. It is worthwhile to intensify research to have a better knowledge about the correlation of the factors on ecological-economic output of energy saving polices. Limited resources can be better used, the impact on the environment causes less damage and leads to a more sustainable development.

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Appendix 1: Technical appendix to chapter 3

Technological terms and conditions used for the approach outlined above.

Temperature losses: An aberration from STC of Δ°C=1 leads to a temperature loss of 0.5% for silicon based cells, as broadly shown in a series of papers (Armani et al., 2007 (verifying Bucher, 1997), Häberlin, 2007, Rüdiger et al., 2007). The authors demonstrate the influence of the natural surrounding temperature. The reasons for a lesser performance appears to be a worsening absorption potential of silicon, and another coloration of the light, a variation in wave lengths, which cannot be absorbed from the cell, with a boosting of the effect the higher the temperature is.

Converter losses: Even if the sun is shining brightly, the radiation alternates permanently. The converter tries to "catch" the maximum power point (MPP) valid in a certain moment. It is an approximation and is forced to be done uninterrupted. It seems to be clear that it cannot be more than a try of optimisation. At low radiation converters are less efficient because of physical limitations. The higher the radiance, the lower the losses of the converter are. If the nominal capacity of the solar power plant is less than 30% of the converter capacity, the degree of efficiency also decreases significantly.

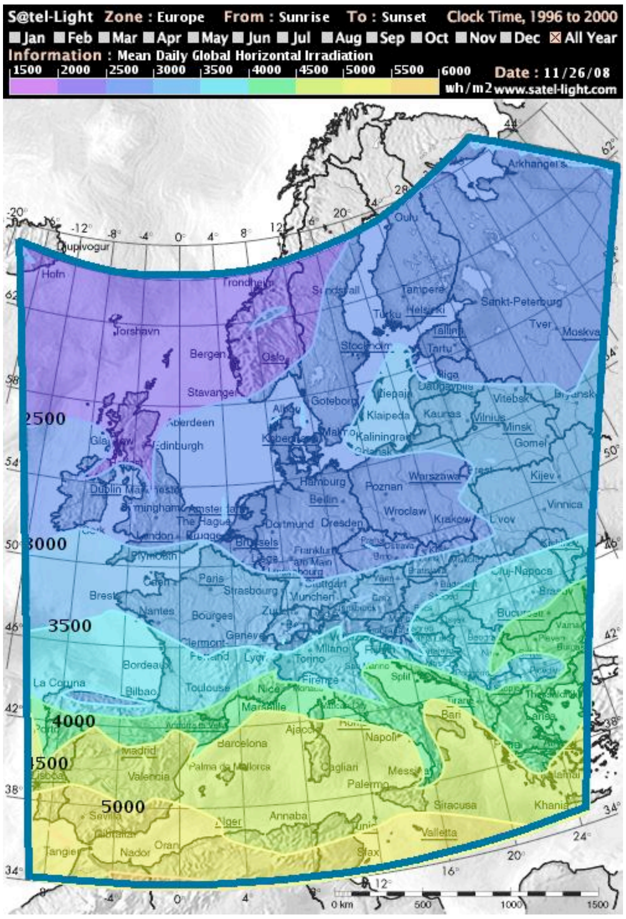
General losses:

- Ground and topography: Different soils have different absorption characteristics. Barren, rocky soils for example reflect more radiance due to a lower absorption potential of photons, in opposition to e.g. green lawns. Pollution through pollen of near plants or the specific micro-climate (wind, rainfall, heat) also affect the system performance.
- Geographic location: Urban areas are heated more than rural areas. Locations near to the sea will benefit from light reflections of the water surface; sandy ground reflects radiation, while forests absorb photons. In the mountains it is more likely to have snow, with subsequent failure of performance of the covered modules, as in the lowland areas.
- Aerosols: Aerosols are the smallest particles of air pollution. They have a direct impact on the location of their origin, but are not necessarily affected adversely by urban areas. Metropolitan areas basically have a high level of air pollution caused by exhaust emissions from traffic and industrial pollution, but here reflected global radiation can even increase. Thus the reduction of direct radiation caused by misty skies can at least be compensated. In contrast, rural areas are more polluted by pollen. Near to the seaside salt particles impact the pureness of the sky.

  In accumulation, aerosols can reach higher air layers of the atmosphere. They influence the formation of clouds in quantity and quality. Lohmann (2006) describes this as follows: The less the land mass, the less the sky cover.
- Altitudes: Higher locations are more favourable than valleys, they benefit particularly in months with minor radiance. The exposed positions lead to an advantageous angle between the panel and the sun, and the manner of sun radiation is shorter (the so called "air mass"). Is the sun is low, the incoming radiance to fix-mounted panels on mountains is better than in the plains. In addition, covered skies and temperatures are lower over the annual period.

These pros can be named for solar power plants in the mountains, but seem to be less relevant for most investors.

- General losses: An almost optimal installation cannot prevent losses through e.g. breaks of soldering joints or cables, leakage currents or the occurrence of minor defects and a little degradation over time, but Renken, Häberlin (2003) mentioned no significant effect in the long term survey.



Daily to annual average of global horizontal irradtion:

2500 wh/d ~ 900 kw/y	4000 wh/d ~ 1450 kw/y
3000 wh/d ~ 1100 kw/y	4500 wh/d ~ 1650 kw/y
3500 wh/d ~ 1300 kw/y	5000 wh/d ~ 1800 kw/y

Figure Appendix 1: Horizontal irradition in Europa, source: Satel-light.com, Cordis project by EU community, University Oldenburg, years of observations: 1996-2006.

Radiation angle: Useful for the final yield is the all penetrating radiance: especially when skies are covered by clouds, reflected radiance by mist or aerosol pollution can reach high values and compensate installations not done in the optimum angle. For latitudes of <45 ° North the proportion of diffuse radiation can become even more important than the direct normal one, as shown by Quaschning, Geyer (2001).

The installation angle appears to be very tolerant: +/- 20° aberration to the optimised angle that led to a radiance loss of around 5%: Even if different locations in Europe are compared by optimum angle and 0° (=plain) installation of solar panels, the difference is not very high. In addition, an azimuth aberration of up to 60° in West-East-direction from optimum South-positioning has only a marginal influence.

The optimisation of the installation angle is a necessity in reaching at least periodically the best fitted angle to radiance input for maximum solar harvest. Private investors must (and do) ensure a fit to the optimum installation angle, for the macro analysis it is negligible.

	optimum installation angle	0° angle	loss
Goteborg	1070kWh (39°)	918 kWh	14.20%
Nürnberg	1210 kWh (36°)	1060 kWh	12.40%
Napoli	1690 kWh (33°)	1500 kWh	11.25%

Table Appendix 1: Global annual irradiation per square meter
own calculation, data source: PV-GIS, 2008,. http://re.jrc.ec.europa.eu

Module efficiency: Solar cells cannot absorb the radiance in a 1:1 relation. Due to the limitations in the design, modern cells make use of only a part of light wavelength, the different types are shown in the graphic below. Mostly based on mono- or poly-crystalline silicon, the absorption potential is limited to the absolute potential of the raw material. Mono-crystalline cells consist of purer silicon than the poly-crystalline ones, that are based no doubt on their name, on several (=poly)crystals. Poly-crystalline cells are a little bit less expensive but the efficiency is also slightly reduced. The modularly assembled cells are the product from wavers, cut slices from heavy silicon cubes. The abstract is much simpler than the reality, but enough for the time being to understand the fundamentals of how cells are working.

Prices: Where do the system costs come from? The greatest costs come from the solar panels. Their prices are dependent on raw materials, mainly silicon, which is the fundamental component of cells: Häberlin (2007) mentioned that mass production of panels intends to set a learning curve that could lead to cost reductions of about 20% if the production was doubled.

Approximately 8-12% of costs are for the installation and the initial operational procedures. These costs will increase proportionately with the inflation rate. If the degree of efficiency rises, required space will be reduced and the costs will reduce in parallel.

Cable, clamp systems, brackets and other installation materials account for 5% of costs, prices are relatively steady in relative prices. Marginal differentiation caused by the installation type (on-roof, on-plain) are negligible. One type of installation requires a few more small parts and the other more human power. In sum it should be more or less equal.

The converter is the last cost component in the calculation. The converter price increased substantially over the past years, but remains at 8-12% of the total power plant costs. For the whole investment, no more significant reduction is expected, but little reductions are imaginable. It is often not declared that converters are not expected to have a life span of more than 15 years. To take this into account, the following analysis will count converter prices twice, which leads to a huge percentage increase in the costs of the converters.

For the final yield calculation, there is an alternative in the market: two axis tracking systems, which adjust panels over the day and year in position to the sun track. They have additional costs per one capacity load factor of about 1000 EUR. One must consider whether the tracking systems are a rewarding investment, because with the same investment sum installable capacity could be increased by 20%.

Appendix 2: Panel Data models of chapter 4

Model 1: Ordinary Least Squares (Pooled OLS)

using 325 observations
included 25 cross-sectional units
time-series length: 13
Dependent variable: ENERGYUSE
Robust (HAC) standard errors

OLS-model	coefficient	std. error	t-ratio	p-value
const	12.6344	2.05410	6.151	2.31e-09***
GDP	-0.005091	0.087582	-0.058	0.9537
POP	-0.228872	0.055268	-4.141	4.43e-05***
EMISSION	-0.359689	0.269860	-1.333	0.1835
BSA	-0.167507	0.075674	-2.214	0.0276**
PATENTS	0.158762	0.037417	4.243	2.90e-05***
TECH-EFFICIENCY	-0.285364	0.224721	-1.270	0.2051

Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.

Mean dependent var	8.148019	S.D. dependent var	0.374977
Sum squared resid	12.14900	S.E. of regression	0.195459
R-squared	0.733322	Adjusted R-squared	0.728290
F(6, 318)	145.7415	P-value(F)	3.75e-88
Log-likelihood	72.91394	Akaike criterion	-131.8279
Schwarz criterion	-105.3411	Hannan-Quinn	-121.2570
rho	0.932465	Durbin-Watson	0.121761

Model 2: Random-effects (RE)

using 325 observations
included 25 cross-sectional units
time-series length: 13
Dependent variable: ENERGYUSE

RE-Model	coefficient	std. error	t-ratio	p-value
const	12.4852	0.566104	22.05	4.72e-66***
GDP	0.053116	0.011728	4.529	8.39e-06***
POP	-0.120454	0.031675	-3.803	0.0002***
EMISSION	-0.643871	0.039189	-16.430	2.40e-44***
BSA	-0.009198	0.009565	-0.962	0.3370
PATENTS	0.012034	0.007084	1.670	0.0903*
TECH-EFFICIENCY	-0.085968	0.041688	-2.062	0.0400**

Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.

Mean dependent var	8.148019	S.D. dependent var	0.374977
Sum squared resid	24.42844	S.E. of regression	0.276728
Log-likelihood	-40.59250	Akaike criterion	95.18501
Schwarz criterion	121.6718	Hannan-Quinn	105.7559

'Within' variance = 0.0011277
'Between' variance = 0.0403591
theta used for quasi-demeaning = 0.953639

Breusch-Pagan test -
Null hypothesis: Variance of the unit-specific error = 0
Asymptotic test statistic: Chi-square(1) = 1298.4
with p-value = 2.51763e-284

Hausman test -
Null hypothesis: GLS estimates are consistent
Asymptotic test statistic: Chi-square(6) = 38.0188
with p-value = 1.1139e-06

Model 3: Fixed-effects (FE)

using 325 observations
included 25 cross-sectional units
time-series length: 13
Dependent variable: ENERGYUSE
Robust (HAC) standard errors

FE-Model	coefficient	std. error	t-ratio	p-value
const	15.8649	2.061850	7.694	2.16e-13***
GDP	0.060751	0.021680	2.802	0.0054***
POP	-0.332583	0.136051	-2.445	0.0151**
EMISSION	-0.640387	0.094135	-6.803	5.74e-11***
BSA	-0.012107	0.010342	-1.171	0.2427
PATENTS	0.004413	0.012779	0.345	0.7301
TECH-EFFICIENCY	-0.050359	0.099699	-0.505	0.06139
Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.				
Mean dependent var	8.148019	S.D. dependent var		0.374977
Sum squared resid	0.331543	S.E. of regression		0.033581
R-squared	0.992722	Adjusted R-squared		0.991980
F(30, 294)	1336.802	P-value(F)		2.3e-295
Log-likelihood	658.1161	Akaike criterion		-1254.232
Schwarz criterion	-1136.934	Hannan-Quinn		-1207.418
rho	0.473655	Durbin-Watson		0.918364

Test for differing group intercepts -
Null hypothesis: The groups have a common intercept
Test statistic: F(24, 294) = 436.636
with p-value = P(F(24, 294) > 436.636) = 2.45528e-214

Test for normality of residual -
Null hypothesis: error is normally distributed
Test statistic: Chi-square(2) = 66.4463
with p-value = 3.72711e-15

Model 4: First Differences (FD)

using 300 observations
included 25 cross-sectional units
time-series length: 12
Dependent variable: ENERGYUSE
Robust (HAC) standard errors

FD-model	coefficient	std. error	t-ratio	p-value
const	-0.022925	0.007716	-2.971	0.0032***
GDP	0.133776	0.027944	4.787	2.69e-06***
POP	-0.351516	0.395398	-0.889	0.3747
EMISSION	-0.604663	0.074595	-8.106	1.44e14***
BSA	0.003358	0.002799	1.199	0.2315
PATENTS	0.002334	0.000781	2.987	0.0031***
TECH-EFFICIENCY	-0.010435	0.005711	-1.827	0.0687*

Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.

Mean dependent var	-0.00442	S.D. dependent var	0.043990
Sum squared resid	0.296544	S.E. of regression	0.031813
R-squared	0.487470	Adjusted R-squared	0.476974
F(6, 293)	46.44564	P-value(F)	7.86e-40
Log-likelihood	612.2199	Akaike criterion	-1210.440
Schwarz criterion	-1184.513	Hannan-Quinn	-1200.064
rho	0.079191	Durbin-Watson	1.782756

Model 5: Chow test for FD (Model 4) for structural difference

with respect to dummy variable EU15
F(7, 286) = 14.9259 with p-value 0.0000

using 300 observations
included 25 cross-sectional units
time-series length: 12
Dependent variable: ENERGYUSE
Robust (HAC) standard errors

FD-model Chow test	coefficient	std. error	t-ratio	p-value
const	-0.00540509	0.013588	-0.3978	0.6911
GDP	0.037623	0.031558	1.192	0.2342
POP	1.125990	0.756559	1.488	0.1378
EMISSION	-1.706140	0.118881	-14.350	1.49e-35***
BSA	-0.023148	0.011672	-1.983	0.0483**
PATENTS	0.000464	0.002670	0.174	0.8622
TECH-EFFICIENCY	-0.022082	0.014213	-1.554	0.1214
EU15	0.004478	0.018223	0.246	0.8061
EU15 GDP	0.086420	0.059572	1.451	0.1480
EU15 POP	-1.958450	0.879533	-2.227	0.0267**
EU15 EMISSION	1.220440	0.125767	9.704	1.98e-19***
EU15 BSA	0.027013	0.012558	2.151	0.0323**
EU15 PATENTS	-0.000665	0.002971	-0.224	0.8230
EU15 TECH-EFFICIENCY	0.014082	0.020854	0.675	0.5000

Note: Variables indicated with *, ** and *** show significance at 10%, 5% and 1% levels, respectively.

Mean dependent var	-0.00442	S.D. dependent var	0.043990
Sum squared resid	0.217197	S.E. of regression	0.027558
R-squared	0.624608	Adjusted R-squared	0.607544
F(13, 286)	36.60534	P-value(F)	3.06e-53
Log-likelihood	658.9281	Akaike criterion	-1289.856
Schwarz criterion	-1238.003	Hannan-Quinn	-1269.104

Covariance matrix of regression coefficients:

CONST.	GDP	POP	EMISSION	BSA	PATENTS	TECH-EFFICIENCY	
5.95369e-05	-1.75636e-04	-3.11332e-04	-2.52072e-05	-2.59146e-06	-5.28391e-06	3.71120e-05	**CONST.**
	7.80851e-04	0.00100803	2.64110e-04	1.56526e-05	1.49410e-05	-7.57023e-05	**GDP**
		0.15634	-0.00536643	-6.57906e-04	-5.16881e-05	-6.58110e-04	**POP**
			0.00556442	8.89238e-05	-6.21073e-06	-2.40298e-05	**EMISSION**
				7.83375e-06	1.36173e-07	1.93763e-06	**BSA**
					6.10380e-07	-2.74469e-06	**PATENTS**
						3.26151e-05	**TECH-EFFICIENCY**

Appendix 3: Panel Data description of chapter 4

Data description: from original sources, if not modified as descriped below.

$$\begin{aligned} \textit{(basic model)} \quad \log(ENERGYUSE)_{i,t} = {} & \beta_1 \log(GDP_{i,t}) + \beta_2 \log(POP_{i,t}) \\ & + \beta_3 \log(EMISSION_{i,t}) + \beta_4 (BSA_{i,t}) \\ & + \beta_5 \log(PATENTS_{i,t}) + \beta_6 \log(TECH\text{-}EFFICIENCY_{i,t}) + u_{i,t} \end{aligned}$$

ENERGYUSE: Worldbank data [EG.USE.PCAP.KG.OE] - Energy use (kg of oil equivalent per capita) - Energy use refers to use of primary energy before transformation to other end-use fuels, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE (August 2012, updated: February 2013)

GDP: Eurostat data [nama_gdp_c] - GDP and main components - The data are recorded at current and constant prices and include the corresponding implicit price indices. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_gdp_c&lang=en (August 2012)

POP: Worldbank data [SP.POP.TOTL] – Population, total - Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship--except for refugees not permanently settled in the country of asylum, who are generally considered part of the population of their country of origin. The values shown are midyear estimates. http://data.worldbank. org/indicator/SP.POP.TOTL (August 2012).

EMISSION: Eurostat data [tsien010] - Greenhouse gas emissions, Kyoto base year (source: EEA) - Index of greenhouse gas emissions and targets - In CO_2 equivalents (Actual base year = 100): This index shows trends in total man-made emissions of the "Kyoto basket" of greenhouse gases. It presents annual total emissions in relation to "Kyoto base year". In general the base year is 1990 for the non-fluorinated gases and 1995 for the fluorinated gases. The "Kyoto basket" of greenhouse gases includes: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the so-called F-gases (hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride (SF_6)). These gases are aggregated into a single unit using gas-specific global warming potential (GWP) factors. The aggregated greenhouse gas emissions are expressed in units of CO_2 equivalents. The indicator does not include emissions and removals related to land use, land-use change and forestry (LULUCF); nor does it include emissions from international aviation and international maritime transport. CO_2 emissions from biomass with energy recovery are reported as a Memorandum item according to UNFCCC Guidelines and not included in national greenhouse gas totals. With the exception of Cyprus and Malta all Member States have individual targets under the Kyoto Protocol. The EU-15 agreed (Council Decision 2002/358/EC) to a collective 8% reduction of its greenhouse gas emissions by 2008-12. This agreement sets the contribution of each individual EU-15 Member State towards reaching the common EU Kyoto target. Eastern European Member States have individual targets under the KP, with reduction requirements ranging from 6% to 8% .

http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsien010 (August 2012)

BSA: Dummy variable, bases on the EU Burden-Sharing Agreement, indicates countries with 1 that are under pressure to reduce emissions (present emissions are above allowed emissions), or with 0 if the emission reduction goals are already met.

PATENTS: Eurostat data [tsiir060] - Patent applications to the European Patent Office (EPO) - Number of applications per million inhabitants: Data refer to applications filed directly under the European Patent Convention or to applications filed under the Patent Co-operation Treaty and designated to the EPO (Euro-PCT). Patent applications are counted according to the year in which they were filed at the EPO and are broken down according to the International Patent Classification (IPC). They are also broken down according to the inventor's place of residence, using fractional counting if multiple inventors or IPC classes are provided to avoid double counting.
http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsiir060 (August 2012)

TECH-EFFIENCY: Technological efficiency in the transformation process of energy. The input-output relation is showing conversions losses of the raw energy consumption between transformation input and transformation output. The ratio based an Eurostat data [nrg_100a] - Annual data on crude oil, oil products, natural gas, electricity, solid fuels and renewable covering the full spectrum of the energy balances positions from supply through transformation to final energy consumption by sector and fuel type. All the data is measured in physical units (t, TJ, kWh, toe, etc.). Basic data are on energy quantities are in fuel specific units e.g. liquid fuels in thousand tonnes, electricity in kilowatt-hours, while structural data on the capacity of installations are in Megawatt, thousand tonnes per year (production capacity) or thousand square meters of installed surface in case of solar panels. The basic energy quantities data are converted to energy units, i.e. in Terajoules and Tonnes of oil equivalent to allow the addition of different nature fuel types.
http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_100a&lang=en (February 2013)

Appendix 4: Dataset of chapter 4

		ENERGY-USE	GDP	POP	EMISSION	BSA	PATENTS	TECH-EFFICIENCY
BEL	1998	5659.70793	22400	10203000	89.1	1	1155.32	0.795416152296797
BEL	1999	5689.22355	23400	10226000	93.5	1	1343.52	0.787146038816417
BEL	2000	5706.984	24600	10252000	93.2	1	1315.18	0.801332663218819
BEL	2001	5673.66579	25300	10287000	93.4	1	1212.79	0.812753214726088
BEL	2002	5454.65983	26000	10333000	94.5	1	1328.94	0.825627650118755
BEL	2003	5709.09237	26600	10376080	92.7	1	1359.09	0.817318702981635
BEL	2004	5650.92778	28000	10421120	92.8	1	1515.08	0.815467523304862
BEL	2005	5600.43517	29000	10478650	95.4	1	1492.14	0.792648755562881
BEL	2006	5509.3128	30200	10547958	99	1	1499.15	0.786324645331574
BEL	2007	5366.70525	31600	10625700	103.1	0	1524.6	0.786397381655624
BEL	2008	5470.73507	32299	10708433	101.1	0	1449.8	0.803588306498416
BEL	2009	5299.74752	31600	10788760	106.5	0	1435.69	0.762197477958481
BEL	2010	5212.9228	32700	10895785	101.5	0	1414.54	0.765547221275145
BGR	1998	2424.24609	1400	8257000	135.7	0	9.1	0.624027567482901
BGR	1999	2225.02437	1500	8208000	139.6	0	8.01	0.631155072698773
BGR	2000	2314.26799	1700	8060000	139.8	0	7.43	0.618990580933195
BGR	2001	2464.2225	2000	7910000	139.5	0	15.98	0.596148999445537
BGR	2002	2416.31719	2200	7869000	141.8	0	14.63	0.587855906874312
BGR	2003	2493.92816	2400	7823000	137.8	0	22.45	0.597193454846728
BGR	2004	2418.84077	2600	7781000	138.4	0	17.78	0.61923459504738
BGR	2005	2569.25065	3000	7740000	138.7	0	23.82	0.613846903949293
BGR	2006	2655.53278	3400	7699020	137.7	0	27.13	0.629726866565336
BGR	2007	2624.49339	4000	7659764	134.8	0	12.05	0.636127263272349
BGR	2008	2594.51334	4600	7623395	136.6	0	17.9	0.641113671636175
BGR	2009	2304.54108	4600	7585131	148	0	15.93	0.633517786561265
BGR	2010	2370.14919	4800	7534289	146	0	12.2	0.609402113898091
CZE	1998	3983.52582	5600	10294900	117.2	0	65.73	0.65752520968806
CZE	1999	3727.51143	5700	10283000	119.4	0	59.98	0.639726537381122
CZE	2000	3918.11784	6200	10273300	116.1	0	66.58	0.636192393881329
CZE	2001	4034.72222	7000	10224000	115	0	72.37	0.633728052266231
CZE	2002	4097.16828	8200	10204853	117.2	0	91.82	0.627232347985909
CZE	2003	4349.0179	8300	10207362	117.6	0	112.66	0.625215939191524
CZE	2004	4452.71425	9000	10216016	116.8	0	112.21	0.621278644874373
CZE	2005	4386.94359	10200	10235828	117.2	0	108.59	0.633505647019161
CZE	2006	4463.95967	11500	10269134	116.4	0	153.21	0.628724556385549
CZE	2007	4429.77465	12800	10334160	116.1	0	182.01	0.61782156359522
CZE	2008	4281.51971	14800	10424336	119.2	0	206.72	0.63304395755822
CZE	2009	4140.24063	13500	10489970	123	0	239.43	0.614877024595081
CZE	2010	4024.19259	14200	10519192	120	0	268.17	0.618434121286075
DNK	1998	3774.75948	29300	5301000	69.6	1	799.42	0.799977651134205
DNK	1999	3604.36171	30700	5319111	73.8	1	864.01	0.818072976054732
DNK	2000	3481.69427	32500	5337344	80.5	1	980.16	0.830873199359772
DNK	2001	3575.66887	33500	5355082	78.5	1	926.17	0.829197080291971
DNK	2002	3527.18656	34400	5374255	79.6	1	961.81	0.830053034767236
DNK	2003	3725.88671	35000	5387174	72.2	1	1103.29	0.812964873228731
DNK	2004	3589.21768	36500	5401177	80.9	1	1097.56	0.843986418061595
DNK	2005	3471.76447	38300	5415978	86.9	1	1166.85	0.853807171723651
DNK	2006	3714.36264	40200	5437272	75.6	1	1103.6	0.814037260088929
DNK	2007	3599.05212	41700	5461438	82.6	1	1247.8	0.830119375573921

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
DNK	2008	3460.37704	42800	5493621	86.9	1	1251.15	0.844815363794548
DNK	2009	3368.66855	40600	5529270	91	1	1279.25	0.854928229665072
DNK	2010	3547.94389	42500	5547683	91	1	1337.8	0.853118840211102
DEU	1998	4184.78433	23700	82047000	93	1	19577.73	0.707320513248782
DEU	1999	4088.56457	24400	82087000	95.6	1	20994.54	0.703001937830763
DEU	2000	4102.79771	24900	82210000	95.9	1	22105.79	0.705188271303197
DEU	2001	4219.14664	25500	82333000	94.6	1	21918.08	0.691848347627901
DEU	2002	4111.88006	25900	82508000	96.2	1	21818.75	0.693461400562339
DEU	2003	4144.24347	26000	82541000	96.7	1	22119.43	0.723354596650386
DEU	2004	4163.17998	26600	82516250	97.9	1	23039.1	0.723788631524614
DEU	2005	4106.91723	27000	82469400	99.7	1	23861.72	0.746050108838242
DEU	2006	4142.40958	28100	82376451	99.2	1	23838.88	0.738725168472433
DEU	2007	4046.59877	29500	82266372	101.3	0	23907.18	0.702943658619272
DEU	2008	4083.34678	30100	82110097	101.3	0	22655.19	0.707040585955597
DEU	2009	3893.84579	29000	81879976	105	0	22253.01	0.706807369328523
DEU	2010	4053.720444	30500	81776930	103	0	21724.39	0.689211482642969
EST	1998	3702.20747	3600	1386200	146.1	0	5.23	0.447405727246952
EST	1999	3498.7114	3900	1375649	149.4	0	7.28	0.457805907172996
EST	2000	3442.83065	4500	1369512	149.3	0	5.58	0.444835680751174
EST	2001	3606.78029	5100	1364097	148.6	0	9.67	0.459612518628912
EST	2002	3465.96338	5700	1358641	150.1	0	5.7	0.470447044704471
EST	2003	3832.22961	6400	1353520	145.5	0	10.73	0.459583671262503
EST	2004	3916.23855	7200	1348998	144.8	0	8.85	0.42042042042042
EST	2005	3836.26774	8300	1346100	146.5	0	6.37	0.425378885178526
EST	2006	3748.28718	10000	1343547	147.6	0	21.22	0.438694267515924
EST	2007	4182.84052	12000	1341672	140.3	0	28.22	0.436550595933629
EST	2008	4026.33002	12200	1340675	144.5	0	34.27	0.411403293192431
EST	2009	3542.85738	10300	1340345	154	0	43.57	0.38329490135793
EST	2010	4083.67801	10700	1340161	144	0	51.02	0.395643153526971
IRL	1998	3425.08551	21400	3712900	96.6	1	187.31	0.639367266232938
IRL	1999	3539.54727	24300	3755000	94	1	235.01	0.622499350480645
IRL	2000	3599.88437	27800	3805400	91.2	1	208.61	0.654187431627568
IRL	2001	3739.6061	30600	3866450	87.8	1	252.13	0.634321550741163
IRL	2002	3695.50842	33400	3931800	91.2	1	224.29	0.636341986187187
IRL	2003	3576.84511	35300	3995700	91.6	1	225.82	0.646831156265119
IRL	2004	3569.66412	37000	4068450	92	1	273.24	0.642315470171891
IRL	2005	3459.64271	39300	4159100	89.2	1	274.4	0.645580378824672
IRL	2006	3444.21071	41800	4260773	90.2	1	284.88	0.680108857001484
IRL	2007	3441.87227	43500	4356931	91.3	1	314.44	0.668958031837916
IRL	2008	3385.02036	40500	4425675	91.7	1	320.89	0.683947912863576
IRL	2009	3215.87206	35900	4450446	102	0	336.39	0.667836415170738
IRL	2010	3338.55442	34900	4474356	103	0	353.56	0.668473351400181
GRC	1998	2364.5593	11300	10835000	111.8	0	59.94	0.791283893321466
GRC	1999	2363.41082	12100	10883000	111.9	0	52.31	0.771088389613884
GRC	2000	2480.97092	12600	10917500	108.3	0	56.37	0.78526922172584
GRC	2001	2557.4546	13400	10949950	107.1	0	71.77	0.778179536218025
GRC	2002	2577.55369	14300	10987550	107.4	0	75.95	0.778221448300709
GRC	2003	2643.52228	15600	11023550	103.9	0	84.9	0.781129224421004
GRC	2004	2685.5606	16700	11061750	103.6	0	65.82	0.771011289648169
GRC	2005	2724.0634	17400	11104000	100.8	0	110.74	0.769509607450195
GRC	2006	2710.95739	18700	11148460	104.7	0	105.08	0.783804121324381

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
GRC	2007	2699.69086	19900	11192763	101.7	0	104.18	0.77630246119309
GRC	2008	2707.0166	20700	11237094	106.4	0	90.12	0.776421246157824
GRC	2009	2609.18623	20500	11283293	108	0	83.25	0.780535949276229
GRC	2010	2387.47761	20100	11315508	114	0	75.97	0.79047137245566
ESP	1998	2790.85927	13500	39721100	98.1	1	627.44	0.771579299620086
ESP	1999	2910.99214	14500	39926250	88.2	1	732.96	0.75027702798693
ESP	2000	3028.79553	15600	40263200	83.6	1	804.19	0.741214866499732
ESP	2001	3070.42285	16700	40720450	83.7	1	879.73	0.744395918682848
ESP	2002	3119.72106	17700	41313950	77.9	1	939.44	0.729379140064306
ESP	2003	3171.68399	18600	42004500	75.4	1	961.4	0.733892036144015
ESP	2004	3257.87361	19700	42691650	69.9	1	1209.5	0.737295319680543
ESP	2005	3268.1347	21000	43398150	64.8	1	1352.54	0.741109765975422
ESP	2006	3206.96767	22400	44116441	67.5	1	1342.81	0.738634022388572
ESP	2007	3205.73489	23500	44878945	63.6	1	1371.38	0.737015224883305
ESP	2008	3046.66488	23900	45555716	75	1	1407.85	0.749693186998142
ESP	2009	2755.90975	22800	45957671	89	1	1426.29	0.761338936386031
ESP	2010	2781.27825	22800	46070971	92	1	1454.12	0.76371819960861
FRA	1998	4275.77999	21900	58398000	97.4	1	6777.16	0.650162851400984
FRA	1999	4252.61527	22700	58622514	100.4	0	7214.72	0.635800544075384
FRA	2000	4276.50549	23700	58895516	101.2	0	7307.25	0.640910775651028
FRA	2001	4397.89492	24500	59192410	100.8	0	7301.64	0.645740133889924
FRA	2002	4381.05948	25000	59598597	102.5	0	7432.07	0.627795410601583
FRA	2003	4418.77913	25600	60154851	101.7	0	7929.53	0.631332466746203
FRA	2004	4456.01307	26500	60521142	102	0	8313.55	0.630284295075037
FRA	2005	4441.00011	27300	60873000	101.3	0	8345.53	0.621272570410045
FRA	2006	4350.93414	28400	61352572	104.2	0	8399.38	0.624296284558536
FRA	2007	4260.51896	29600	61938464	106	0	8516.85	0.624512594469676
FRA	2008	4279.15846	30100	62277432	106.5	0	8577.84	0.629691804789029
FRA	2009	4040.66098	29200	62616488	109	0	8655.28	0.621300999349306
FRA	2010	4060.36003	29900	65075569	107	0	8740.58	0.597177597177597
ITA	1998	2912.70836	19200	56910950	89.1	1	3353.02	0.81137918944539
ITA	1999	2957.05229	19900	56921550	87.9	1	3734.43	0.797522328634456
ITA	2000	3011.87387	21000	56948600	87.1	1	4006.28	0.785777532909624
ITA	2001	3021.07556	22000	56980700	86.1	1	3992.72	0.800615160735547
ITA	2002	3016.16239	22800	57157400	85.9	1	4231.78	0.793062621163429
ITA	2003	3114.73119	23300	57604650	83.1	1	4394.86	0.785524547444933
ITA	2004	3121.58253	24000	58175300	82.4	1	4580.23	0.787229780181755
ITA	2005	3137.35293	24500	58607050	82.7	1	4889.72	0.799221663888323
ITA	2006	3089.50405	25300	58941499	84.8	1	4997.35	0.790084681983301
ITA	2007	3016.32216	26200	59375289	86.6	1	4835.18	0.791095108457012
ITA	2008	2942.09576	26300	59832179	88.7	1	4647.69	0.789852261040393
ITA	2009	2735.04936	25200	60221211	98.5	1	4567.01	0.796517154056961
ITA	2010	2813.52051	25700	60483385	96.5	1	4423.56	0.798539071873156
LVA	1998	1783.81743	2500	2410000	147.3	0	4.67	0.836468885672938
LVA	1999	1642.67782	2900	2390000	150.3	0	1.7	0.802448979591837
LVA	2000	1565.76728	3600	2372000	152.6	0	8.97	0.804967801287949
LVA	2001	1725.30733	3900	2359000	150.1	0	5.13	0.815264527320035
LVA	2002	1706.15911	4200	2338000	150.2	0	6.53	0.819148936170213
LVA	2003	1819.5174	4300	2325341	149.6	0	7.61	0.826238053866203
LVA	2004	1879.97953	4800	2312791	149.5	0	9.82	0.811981566820277
LVA	2005	1920.45208	5600	2300500	148.2	0	18.82	0.82878645343367

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
LVA	2006	1987.37034	7000	2287948	146.6	0	17.42	0.835174953959484
LVA	2007	2051.7552	9200	2276100	144.6	0	16.33	0.832850241545894
LVA	2008	1978.73522	10100	2266094	146.1	0	22.77	0.80990099009901
LVA	2009	1871.4269	8200	2255128	150	0	24.09	0.826219512195122
LVA	2010	1971.263	8600	2239008	145	0	25	0.824546240276578
LTU	1998	2649.50774	2800	3555000	144.1	0	0.67	0.76681153694192
LTU	1999	2262.81507	2900	3531000	149.7	0	3	0.761915220733582
LTU	2000	2037.98942	3600	3499527	152.8	0	4.69	0.795124133303512
LTU	2001	2336.19938	3900	3481295	150.5	0	3.15	0.791602531212588
LTU	2002	2512.18336	4400	3469093	149.7	0	2.66	0.769533814839134
LTU	2003	2627.78505	4800	3454239	149.1	0	16.85	0.770298086452695
LTU	2004	2670.57901	5300	3435584	147.5	0	11.12	0.794943820224719
LTU	2005	2521.161	6100	3414300	145.5	0	8.92	0.843432899814206
LTU	2006	2497.58256	7100	3394082	144	0	9.67	0.85347516596017
LTU	2007	2740.83146	8500	3375618	140.5	0	9.8	0.811612903225806
LTU	2008	2732.78312	9700	3358115	142.8	0	16.2	0.856864161849711
LTU	2009	2511.66328	8000	3339550	152	0	18.63	0.839183489002711
LTU	2010	2106.959	8400	3286820	150	0	21.62	0.963897000265463
LUX	1998	7061.45514	40700	424700	103.9	0	74.23	0.318181818181818
LUX	1999	7238.51559	46200	430475	100.8	0	62.48	0.297297297297297
LUX	2000	7602.56704	50400	436300	96.8	1	80.7	0.326315789473684
LUX	2001	7788.91343	51100	441525	94.5	1	72.98	0.416184971098266
LUX	2002	8102.20205	53800	446175	86.3	1	60.84	0.497950819672131
LUX	2003	8453.82282	57200	451630	83	1	87.33	0.50000000000000
LUX	2004	9157.48917	60000	458095	71.7	1	114.74	0.508532423208191
LUX	2005	9207.62408	65200	465158	71.2	1	97.97	0.51038062283737
LUX	2006	9114.8175	71800	472637	71.8	1	107.87	0.510708401976936
LUX	2007	8791.79488	78100	479993	74.9	1	70.72	0.513812154696133
LUX	2008	8429.34616	80800	488650	77.1	1	91.57	0.50635593220339
LUX	2009	7934.06966	75200	497854	85	1	89.44	0.524436090225564
LUX	2010	8294.27186	79500	506953	80	1	83.3	0.522441651705566
HUN	1998	2501.80927	4200	10266570	126	0	57.16	0.699960246471874
HUN	1999	2490.73751	4400	10237530	125.7	0	115.02	0.696161616161616
HUN	2000	2448.24905	4900	10210971	127.2	0	121.64	0.701851558790948
HUN	2001	2512.07942	5800	10187576	125.4	0	99.84	0.695314973092751
HUN	2002	2520.12874	6900	10158608	127.2	0	121.8	0.688476616420959
HUN	2003	2580.17334	7300	10129552	124.6	0	133.73	0.696498054474708
HUN	2004	2587.97093	8100	10107146	125.5	0	152.6	0.7010888252149
HUN	2005	2734.49621	8800	10087050	124.8	0	134.63	0.708011429780929
HUN	2006	2713.6328	8900	10071370	126.3	0	164.35	0.720333281581535
HUN	2007	2657.97382	9900	10055780	128.4	0	185.7	0.705885237861697
HUN	2008	2635.73466	10500	10038188	130.6	0	178.41	0.704865398863917
HUN	2009	2480.06895	9100	10022302	136	0	193	0.699856969963693
HUN	2010	2544.13835	9700	10000023	135	0	202.55	0.713414014034374
NLD	1998	4600.84087	22900	15698000	87.4	1	2595.77	0.912089265247743
NLD	1999	4520.40494	24400	15805000	93	1	2966.53	0.908197239594139
NLD	2000	4598.24288	26300	15925431	93.3	1	3465.53	0.914784795176822
NLD	2001	4712.23797	27900	16046091	92.6	1	3920.92	0.907000501495199
NLD	2002	4687.56647	28800	16148891	92.8	1	3547.33	0.906070682120464
NLD	2003	4807.07034	29400	16225267	92.2	1	3484.26	0.908887749120751
NLD	2004	4854.8887	30200	16281732	91.6	1	3650.84	0.908704787902733

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
NLD	2005	4827.18898	31500	16319850	94.3	1	3476.92	0.916421867163431
NLD	2006	4696.96107	33100	16346101	96	1	3670.73	0.906591147001645
NLD	2007	4897.90556	34900	16381696	96.9	1	3241.12	0.877876148659996
NLD	2008	4845.12781	36200	16445593	96.9	1	3360.87	0.88162928602171
NLD	2009	4729.15996	34700	16531294	101	0	3322.19	0.871357843369498
NLD	2010	5015.1663	35400	16615394	95	1	3206.01	0.878073448889199
AUT	1998	3593.50331	23900	7982461	83.4	1	956.06	0.853205686103858
AUT	1999	3580.77155	24900	8002186	85.5	1	1073.28	0.855516742953505
AUT	2000	3559.3565	26000	8011560	85.4	1	1183.38	0.871263322069145
AUT	2001	3758.78916	26600	8043015	80.1	1	1208.51	0.867921059083109
AUT	2002	3789.38234	27300	8083639	77.9	1	1281.99	0.872328800388538
AUT	2003	3973.36717	27700	8117800	70.7	1	1387.85	0.856004282400523
AUT	2004	4003.08268	28700	8174700	72	1	1444.31	0.860793584295888
AUT	2005	4128.47825	29800	8233300	69.5	1	1515.66	0.858612563940456
AUT	2006	4067.89124	31300	8282424	73.5	1	1723.2	0.855846892192438
AUT	2007	4005.88474	33000	8300788	77	1	1676.84	0.855396190924054
AUT	2008	3987.80078	33900	8336926	77.4	1	1589.12	0.862203594189585
AUT	2009	3784.40745	33000	8364095	86	1	1613.61	0.859508186668302
AUT	2010	3941.19148	34100	8389771	80	1	1577.08	0.849964985994398
POL	1998	2469.60228	4000	38666145	120.6	0	28.39	0.683893953381029
POL	1999	2405.37534	4100	38658000	122.7	0	36.25	0.681800167334537
POL	2000	2317.48487	4900	38453757	124.7	0	43.39	0.680500292360131
POL	2001	2346.07879	5600	38248076	125.3	0	58.07	0.687657718025121
POL	2002	2324.19969	5500	38230364	127.7	0	84.42	0.682857017041701
POL	2003	2384.66236	5000	38204570	125.5	0	111.47	0.691919688645975
POL	2004	2394.38658	5300	38182222	125.4	0	124.38	0.697525859658932
POL	2005	2420.43524	6400	38165450	124.8	0	124.03	0.687385062796698
POL	2006	2550.91159	7100	38141267	122.5	0	140.26	0.695819101331851
POL	2007	2544.42747	8200	38120560	123	0	199.65	0.704167163230445
POL	2008	2567.31938	9500	38125759	123.8	0	228.99	0.704844397366622
POL	2009	2452.51061	8100	38149886	126	0	263.98	0.701991556143119
POL	2010	2663.7051	9300	38183683	123	0	305.22	0.71234219399357
PRT	1998	2254.91164	10800	10129000	101	0	26.85	0.833085465000991
PRT	1999	2409.47513	11700	10174000	88.5	1	36.33	0.799766300537509
PRT	2000	2412.81774	12500	10225803	91.8	1	41.98	0.805206832681622
PRT	2001	2410.87674	13100	10292936	89.4	1	41.45	0.815380736258195
PRT	2002	2490.66236	13600	10368326	81.8	1	41.23	0.791656356708072
PRT	2003	2407.03854	13700	10441045	90.2	1	66.72	0.824152972205315
PRT	2004	2460.20637	14200	10501964	86.2	1	58.48	0.81925882410535
PRT	2005	2505.91263	14600	10549450	83	1	123.91	0.805902331558656
PRT	2006	2329.76177	15200	10584344	90.5	1	107.22	0.825656004596821
PRT	2007	2362.76475	16000	10608335	94.2	1	122.83	0.822094100689797
PRT	2008	2274.342	16200	10622413	96.7	1	112.07	0.821156057280234
PRT	2009	2266.25524	15800	10632069	103	0	108.12	0.79773897470338
PRT	2010	2211.17927	16200	10637346	110	0	108.42	0.837084313066846
ROM	1998	1806.0703	1700	22503000	138.1	0	5.23	0.798322720919398
ROM	1999	1607.40091	1500	22457994	144.3	0	7.71	0.764546684709066
ROM	2000	1612.35129	1800	22443000	143	0	6.12	0.761994529459599
ROM	2001	1679.51383	2000	22132000	141.3	0	10.36	0.770266459890032
ROM	2002	1721.5419	2200	21803128	139.1	0	11.35	0.769803494934385
ROM	2003	1791.00126	2400	21742028	136.7	0	16.27	0.740417877404179

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
ROM	2004	1769.02031	2800	21684883	136.1	0	23.2	0.765186550297298
ROM	2005	1769.63949	3700	21634350	138.3	0	28.68	0.79737379827823
ROM	2006	1845.63723	4500	21587666	136.6	0	20.35	0.768608783541456
ROM	2007	1824.67312	5800	21546873	137.1	0	32.77	0.752120890774125
ROM	2008	1830.46816	6500	21513622	139.6	0	33.47	0.735792159591742
ROM	2009	1601.75571	5500	21482395	148	0	35.07	0.734394313967861
ROM	2010	1632.15554	5800	21438001	148	0	39.98	0.734264848663937
SVN	1998	3252.79935	9800	1982600	97.5	1	39.03	0.436755712906341
SVN	1999	3238.47897	10500	1985500	100.7	0	31.37	0.460866526904263
SVN	2000	3224.23328	10800	1989000	99.5	1	50.62	0.444764303706369
SVN	2001	3379.51807	11500	1992000	95.3	1	51	0.400491400491401
SVN	2002	3425.27583	12300	1994000	94	1	84.33	0.385844748858447
SVN	2003	3463.44662	12900	1995699	95.5	1	73.44	0.398697291738087
SVN	2004	3569.85494	13600	1996999	94.2	1	112.88	0.398596725693284
SVN	2005	3645.5886	14400	2000500	92.7	1	108.58	0.399357945425361
SVN	2006	3648.47115	15500	2006868	91.6	1	99.76	0.399541884816754
SVN	2007	3627.13453	17100	2018122	90.9	1	119.11	0.391680000000000
SVN	2008	3826.71487	18400	2021316	87.4	1	139.91	0.392617449664429
SVN	2009	3416.62838	17300	2043241	96	1	150.35	0.398045602605863
SVN	2010	3462.44599	17300	2048583	96	1	167.21	0.403639909002275
SVK	1998	3256.18937	3700	5390657	121.1	0	11.97	0.722148955368918
SVK	1999	3272.03405	3600	5395115	122.1	0	15.42	0.696421471172962
SVK	2000	3292.60594	4100	5388740	123.7	0	11.23	0.711668709282074
SVK	2001	3456.65471	4400	5378900	121.8	0	12.49	0.70857042294832
SVK	2002	3482.55284	4800	5379100	122.8	0	24.6	0.70844428664418
SVK	2003	3464.72355	5500	5379649	121.2	0	31.14	0.706426794701221
SVK	2004	3409.78583	6300	5382449	121.6	0	20.61	0.717302725968436
SVK	2005	3495.45201	7100	5387000	122.5	0	31.3	0.71663425844087
SVK	2006	3457.35224	8300	5391409	122.8	0	39.56	0.716827626573017
SVK	2007	3307.01285	10200	5397318	125.7	0	36.85	0.73767925355376
SVK	2008	3385.47553	11900	5406626	124.2	0	33.67	0.713513853113024
SVK	2009	3086.14566	11600	5418156	131	0	34.46	0.734725186766275
SVK	2010	3179.80243	12100	5430099	128	0	32.76	0.741181159901681
FIN	1998	6320.00776	22500	5153000	99	1	1179.23	0.788563735562956
FIN	1999	6284.06447	23700	5165446	100	1	1428.93	0.783054297848443
FIN	2000	6203.20204	25500	5176197	102.7	0	1434.39	0.785168838447527
FIN	2001	6341.7558	26800	5187995	95.3	1	1407.21	0.761070426391075
FIN	2002	6653.27477	27600	5200596	92.3	1	1282	0.772491321932423
FIN	2003	7046.42823	27900	5212995	81.4	1	1286.04	0.752432945644434
FIN	2004	7063.1195	29100	5228143	87	1	1375.59	0.758724157589942
FIN	2005	6498.54177	30000	5246100	103.6	0	1313.37	0.785364204833531
FIN	2006	7049.0146	31500	5266268	87.8	1	1327.87	0.761434051342579
FIN	2007	6925.87242	34000	5288720	90	1	1237.88	0.779425338692869
FIN	2008	6635.11248	34900	5313399	101.2	0	1232.6	0.801750978760135
FIN	2009	6212.8967	32299	5338395	107	0	1205.68	0.795498809781432
FIN	2010	6639.70405	33300	5363352	95	1	1164.95	0.781527372371478
SWE	1998	5769.10911	25700	8851800	101.8	0	2082.24	0.739340492415452
SWE	1999	5661.8195	27400	8857400	106.5	0	2209.4	0.750971523220998
SWE	2000	5362.04758	30200	8869000	108.6	0	2299.07	0.781920956523762
SWE	2001	5681.58309	28500	8894000	107.7	0	2147.3	0.729914858203700
SWE	2002	5802.77902	29900	8924000	106.5	0	2061.96	0.710614077993686

		ENERGY-USE	GDP	POP	EMIS-SION	BSA	PATENTS	TECH-EFFICIENCY
SWE	2003	5651.85351	31100	8956000	105.8	0	2042.77	0.704142529238168
SWE	2004	5847.86867	32400	8991994	106.4	0	2223.4	0.691644871560935
SWE	2005	5711.07841	33000	9024040	110.2	0	2395.66	0.699890123822001
SWE	2006	5526.56488	35000	9080505	110.8	0	2587.73	0.701336307672508
SWE	2007	5469.00928	36900	9148092	112.3	0	2739.74	0.695110909913988
SWE	2008	5378.95364	36100	9219637	115.3	0	2695.76	0.722990315553351
SWE	2009	4883.39353	31500	9302123	121	0	2795.79	0.752937013446568
SWE	2010	5414.47929	37200	9378126	112	0	2865.14	0.743136533760249
GBR	1998	3786.86659	22300	58487141	96.9	1	5200.63	0.734593533271368
GBR	1999	3783.75374	24000	58682466	101.1	0	5793.06	0.726696012428793
GBR	2000	3785.47263	27200	58892514	100.9	0	6084.31	0.724170896974305
GBR	2001	3785.73796	27700	59108687	100.4	0	5680.63	0.708018557589782
GBR	2002	3682.12748	28600	59327658	103.2	0	5627.96	0.722899106589192
GBR	2003	3730.99827	27600	59568776	102.4	0	5639.18	0.72057134775845
GBR	2004	3705.87008	29500	59879865	102.7	0	5565.87	0.731498392854169
GBR	2005	3691.54774	30700	60226500	103.2	0	5581.17	0.720962079245304
GBR	2006	3612.71112	32299	60604901	103.8	0	5621.56	0.715908049138247
GBR	2007	3444.768	33800	60980304	105.1	0	5353.65	0.721666510494753
GBR	2008	3394.56812	29500	61406928	106.6	0	5118.65	0.728146590567738
GBR	2009	3195.42204	25500	61838154	113.5	0	4964.48	0.717693622949781
GBR	2010	3281.85035	27500	62231336	111.5	0	4745.45	0.718685792192331