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Determination of the country specific environmental intensities of electricity in Europe: An analysis incorporating different principles for determination of the electricity mix.

Kaja Sofie Fallsen Berg

Master of Energy and Environmental Engineering
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Supervisor: Anders Hammer Strømman, EPT

Norwegian University of Science and Technology
Department of Energy and Process Engineering

NTNU

Norwegian University
of Science and Technology
NTNU

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Master Thesis
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Kaja Sofie Berg

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Determination of the country specific environmental intensities of electricity in Europe: An analysis incorporating different principles for determination of the electricity mix.

Evaluering av miljøbelastningen knyttet til elektrisitet i europeiske land. en analyse som inkorporerer ulike prinsipper for bestemmelse av elektrisitetsmiks.

Background

The electricity power generation sector is one of the key contributors to greenhouse gas emissions and air pollution worldwide. These impacts generate repercussions throughout the economy and influence the carbon and environmental footprints of different products. At the same time there is a large variation in the environmental impacts associated with different technologies and systems. While coal power generally generates high emissions levels, other alternatives, e.g wind power offers much lower impacts. Knowing the composition of the electricity mix is then evidently pivotal for getting its environmental footprint right. This is again essential for environmental assessment of products and services.

What assumptions to use for the electricity mix in different situations is hotly debated in the LCA community. Traditionally, the use of national average production mixes has been applied. However the electricity grids are transnational with continuous flows of imports and exports of electricity. This clearly influences the electricity mix consumed in different countries. In addition to this, the issue is further complicated by trade of certificates. There are different types of these certificates, but the common functionality is that they are financial instruments that transfer rights associated with the environmental attributes of electricity. In total, all these aspects make it challenging to define a harmonized understanding of what the electricity mix in a given country is.

Aim

The objective of this analysis is to determine the electricity mix and subsequent environmental footprint subject to different methodological principles.

The analysis should include following elements:

a) Determination of the key principles for definition of the electricity mix.
b) Determination of existing national electricity production mixes in Europe.

c) Determination of physical and financial transactions in the European electricity market.
d) Determination of the environmental profiles of the national electricity technologies.
e) Development of a model for determining electricity mixes based on different principles.
f) Analysis and discussion.

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Department of Energy and Process Engineering, February 2012.

Professor Olav Bolland Head of Department	9/3-2012 Date
Professor Anders Hammer Strømman Academic Supervisor	01.03.2012 Date

Richard Wood, PhD co-supervisor

PREFACE

This report is a result of the work I did for my master thesis during spring 2012, at the Norwegian University of Science and Technology. The thesis completes my master's degree in Energy and Environmental Engineering, at the Department of Energy and Process Engineering.

My supervisor, Anders Hammer Stømman, has been invaluable during the thesis work. I want to thank you for all you guidance and for the helpful discussions we had throughout the semester. I also want to thank you for giving me the opportunity to work with such an interesting topic, it made this semester very fulfilling.

I would also like to thank my father, Harald Fallsen. Your proofreading and inputs really helped me to finish this thesis. I am so grateful that you took the time, even thou it was not the best timing for you.

My classmates and friends in Trondheim have made my five years as a student into some of the best years of my life and for that I want to thank you. I will never forget the fun things we did and the interesting conversations we have had. Thank you for making me laugh. Anne, you are the best office partner ever, we can talk about everything and for that I am so grateful. I also want to thank Henriette for being such a support and for having the capability to make me feel better when things get tough.

ABSTRACT

This study aims at determining country specific environmental characteristics for the electricity sector in Europe. Traditionally, a country's production mix has been applied for environmental assessments. However, the consumed electricity is influenced by trade of physical electricity from one country to another. In addition there is trade of renewable certificates, transferring the rights to electricity attributes. These factors make it hard to achieve a common understanding of the electricity mix.

In this study, two models for determining the electricity mix have been developed. One calculates the electricity mix for the consumed physical electricity and the other calculates the electricity mix for the consumption of attributes of electricity. The physical consumption mix includes production adjusted for physical import and export of electricity. In the attribute model the production is adjusted for financial flows of traded attributes and fictional trade is introduced to balance available attributes and physical consumption. The traded attributes are certificates guaranteeing the origin of the corresponding physical electricity to be renewable energy. The certificates included in this study are EECS certificates. This includes mostly Guarantees of Origin but also RECS certificates. The attribute model calculates a residual mix and a consumption mix. The residual mix is the consumption without certificates. In the consumption attribute mix the residual mix and the certificates are included. The attribute model can be used as a methodology for electricity mix calculations in the purpose of Electricity Disclosure. In order to determine environmental characteristics of the European countries global warming potentials of the different electricity generation technologies connected to the calculated electricity mixes.

The results show that the electricity mix of a country is strongly dependent on calculation method and model assumptions. The differences between the electricity mixes vary between the assessed countries, but there are some common features. The net exporters of certificates get a higher share of electricity from fossil and nuclear energy in their attribute mixes than in their physical mixes. The net importers of certificates on the other hand, have generally a higher share of renewable energy in their attribute consumption mix than in their physical mixes. A common feature for all the countries was the higher share of renewable energy sources in the attribute consumption mix, than in the attribute residual mix. This is explained by the inclusion of renewable certificates in the attribute consumption mix. When the

environmental characteristics of the countries are calculated, it is seen that the differences in electricity mix are reflected in the countries' impact potentials. The countries that are net exporters of certificates have higher global warming potentials when the attribute mixes is used for the calculation, than when the physical electricity mix is used for the calculation. The countries that are net importers of certificates have generally lower global warming potentials from the consumed attribute mix than from the physical mixes. For Norway the attribute residual mix gives 545 % higher global warming potential than the physical consumption mix. This shows how important the choice of electricity mix is in environmental evaluations.

SAMMENDRAG

Målet med denne studien er å bestemme miljøpåvirkningene knyttet til kraftsektoren i europeiske land. Tradisjonelt er produksjonsmiksen i et land brukt i miljøvurderinger. Imidlertid er strømmen vi konsumerer påvirket av handel av fysisk elektrisitet over landegrensene. I tillegg handles det med fornybare sertifikater, der rettighetene til attributter ved den fysiske elektrisiteten blir overført fra et land til et annet. Disse faktorene gjør det vanskelig å oppnå en felles forståelse av et lands elektrisitetsmiks.

I denne studien har to modeller for utregning av elektrisitetsmiks blitt utviklet. Den ene beregner elektrisitetsmiks for konsumert fysisk elektrisitet og den andre beregninger elektrisitetsmiks basert på forbruk av attributter. Den fysiske forbruksmiksen inkluderer elektrisitetsproduksjon justert for fysisk import og eksport. I attributtmodellen er produksjonen justert for finansielle transaksjoner av attributter over landegrensene, og fiktiv handel er innført for å balansere tilgjengelige attributter og fysisk forbruk. Attributtene er sertifikater som garanterer at opprinnelsen til den tilhørende fysiske elektrisiteten er fornybar energi. Sertifikatene som er inkludert i denne studien er EECS-sertifikater. Dette inkluderer for det meste opprinnelsesgarantier, men også RECS-sertifikater. Attributtmodellen beregner en residualmiks og en total forbruksmiks. Residualmiksen er forbruk av attributter uten sertifikater. Forbruksmiksen inkluderer residualmiksen og sertifikatene. Attributtmodellen kan brukes til å beregne elektrisitetsmiksen i et land for varedeklarasjon av elektrisiteten. For å bestemme miljøpåvirkningen til de europeiske landene er globaloppvarmings-potensialer for de ulike produksjonsteknologiene knyttet til de beregnede elektrisitetsmiksene.

Resultatene viser at elektrisitetmiksen i et land er avhengig av beregningsmåte og antagelser i modellen. Forskjellene mellom de ulike elektrisitetmiksene varierer mellom de analyserte landene, men det er noen fellestrekk. De landene som er netto eksportører av sertifikater får en høyere andel av elektrisitet fra fossil og kjernefysisk energi i attributtmiksene enn i de fysiske miksene. Land som er netto importører av sertifikater derimot, har generelt en høyere andel fornybar energi i sin attributtforbruksmiks enn i de fysiske miksene. Et fellestrekk for alle landene er høyere andel fornybare energikilder i attributtforbruksmiksen, enn i attributtresidualmiksen. Dette er grunnet inkluderingen av fornybare sertifikater i attributtforbruksmiksen. Når miljøpåvirkningene til landene beregnes, kan det tydelig ses at at

forskjellene i elektrisitetsmiksene gjenspeiles i landenes påvirkningspotensialer. De landene som er netto eksportører av sertifikater har høyere globaloppvarmings-potensial når potensialet er beregnet basert på attributtmiksene, enn når det er brgnet basert på de fysiske elektrisitetsmiksene. De landene som er netto importører av sertifikater har generelt lavere globaloppvarmings-potensialene beregnet fra attributtforbriksmiks enn beregnet fra de fysiske miksene. For Norge fører attributtresidualmiksen til 545 % høyere påvirkningspotensial enn den fysiske forbruksmiksen. Dette viser hvor viktig valget av elektrisitetsmiks er i vurderingen av miljøpåvirkninger.

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ABBREVIATIONS

AIB	Association of Issuing Bodies
CHP-GO	Guarantees of Origin for electricity from Combined Heat and Power
EECS	European Energy Certificate System
EPED	European Platform for Electricity Disclosure
GHG	Greenhouse Gases
GO	Guarantees of Origin
GWP	Global Warming Potential
LCA	Life Cycle Assessment
RECS	Renewable Energy Certificate System
RE-DISS	Reliable disclosure systems for Europe
RES-GO	Guarantees of Origin for electricity from Renewable Energy Sources

1 INTRODUCTION

Climate change is the most important environmental issue of our time (UNEP, n.d.). With the threat of a runaway greenhouse warming, climate mitigation is crucial, and it is a severe challenge for governments and regulators around the world. 65 % of the global anthropogenic greenhouse gas emissions occur in the energy sector (C2ES, 2005). Because of its essential part in the European energy system, the electricity sector has become one of the most important focal points for energy and climate change policies in Europe (Tzimas et al. 2009; CEPS, 2008). There are large variations in the environmental impacts associated with different electricity generation technologies and systems. While power generation from fossil fuels leads to large amounts of greenhouse gas emissions, other technologies like hydro power has considerably lower impacts. In order to assess the environmental footprint of acquired electricity, it is therefore important to know the shares of the different technologies in the electricity mix.

Traditionally, national production mixes have been applied in assessments of the environmental impacts from use of electricity. However, todays electricity transmission grids cross national borders and electricity is continuously imported and exported from one country to another. The consumed electricity mix in a country is affected by this trade. The physical import has another electricity mix that the importing country's own production mix. The electricity mix consumed in one country is therefore not the same as the production mix of that same country. In addition to the physical trade of power across borders, electricity certificates are traded between nations. The certificates are financial instruments that are used to transfer the rights of environmental attributes of electricity. The certificates are traded independently of how the physical electricity is traded. With an electricity system consisting of production, consumption, physical power trade and financial trade of certificates, it is challenging to achieve a uniform understanding of a country's electricity mix. This has resulted in different approaches for calculating the electricity mix for use in environmental assessments.

The Kyoto Protocol sets binding targets for the reduction of greenhouse gas emissions. When a country's internal emissions are accounted according to the Protocol, it is the emissions from the production in a country which is accounted. Thus it is the country's production mix which is used for calculating emissions. Demand side management, including energy efficiency and load shifting, has over the last decade become a strategy for governments to reduce the impacts from the electricity sector. The emission reductions resulting from Demand Side Management are taken on the consumer side of the electricity system. It would therefore be natural to use the consumed electricity mix when calculating the environmental gains.

In 2003 the Directive 2003/54/EC stated that all EU countries have to disclose their electricity mix and their subsequent environmental impacts. This was meant as a means to get a harmonized understanding of the electricity mix and to make the consumed electricity mix transparent and availably to the consumer. Guarantees of origin (GO) certificates were meant to be used in the purpose of explicit tracking and included in the disclosures. In addition to the GOs, the Electricity Disclosure of a country should consist of a residual mix representing the rest of the consumption. When certificates are exported from one country to another, the attributes are sometimes included in both countries' electricity disclosure. This double counts the renewable attributes. In order to avoid the double counting, it is important to have a common standard for Electricity Disclosure and a reliable methodology for the calculation of a countries residual mix.

1.1 State of the field

Today no such common standard for Electricity Disclosure and certificates is implemented in the European countries. Research institutions and assigned projects have been working to come up with methodologies for residual mix calculations and a common platform for Electricity Disclosure. In 2007 the E-track project was started as a cooperation between several research institutions in Europe. Phase 1 of the project, investigated the feasibility of a harmonized standard for tracking of electricity generation attributes in Europe (E-track, 2009). Phase 2 of the project, successfully developed a blueprint for a European tracking standard and a methodology for calculating the residual mix in a domain (E-Track, n.d.; Timpe, 2009). Many countries in Europe have today adopted the principles from the standard. Phase 2 also looked into the implementation of GOs for high-efficient cogeneration, strategies for further development and implementation of certification schemes and activities to support the actual implementation of the E-Track standard. The project ended in 2009, but was succeeded by the RE-DISS project.

The RE-DISS (Reliable Disclosure) project started up in 2010 as a follow up of the E-Track project and is supposed to last until October 2012 (RE-DISS, 2010). The project aim is to significantly improve the reliability and accuracy of the information given to consumers of electricity in Europe regarding the origin of the electricity they are consuming. The project wants to help the European countries to properly implement systems for Guarantees of Origin, tracking and disclosure that are compatible with the E-Track standard. RE-DISS also has established, and are now supporting, a group of "Competent Bodies" which have been designated by major European countries and which are dedicated to improve the procedures for Guarantees of Origin and Electricity Disclosure in their countries. The RE-DISS project released in November 2011 the report “Best Practice Recommendations: For the implementation of Guarantees of Origin and other tracking systems for disclosure in the electricity sector in Europe” (RE-DISS, 2011a). The document is meant to provide guidance to competent bodies and legislators which are implementing and managing systems of Guarantees of Origin and other tracking systems for purposes of Electricity Disclosure in Europe. The RE-DISS document recommends all countries to have set up a full disclosure system including a system of GOs and Electricity Disclosure with calculations of the residual mix, including the disclosure of CO_2-emissions and radioactive waste. The RE-DISS project adopted the methodology for residual mix calculations from the E-Track project, and in chapter 5 the recommendation states that: “A Residual Mix should be provided for disclosure of electricity of unknown origin, based on the methodology developed in the RE-DISS project(…) As a default, the Residual Mix should be calculated on a national level. However, in case that electricity markets of several countries are closely integrated (e.g. in the Nordic region), a regional approach to the Residual Mix may be taken.” (RE-DISS, 2011a). RE-DISS have published the residual mix for 2010 for several European countries calculated by the use of the E-Track methodology. Their calculated residual mix for Norway consisted of 50 % electricity from fossil fuels, 27 % nuclear power and 23 % electricity from renewable sources (RE-DISS, 2012b). The calculated CO_2-emissions were 380 g/kWh (Raadal, 2011c).

RE-DISS is closely related to the European Platform for Electricity Disclosure (EPED), created in 2009 (GSE 2012). EPED is designed as a common platform for the competent bodies assigned by governments to calculate and publish the residual mix for disclosure purposes. This is a voluntary project of unlimited duration, which is intended to help EU Member States to avoid the double counting of electricity in fuel mix disclosure calculations and to ensure its traceability. The EPED project was initiated by RECS International (an organization representing the market players) and the Association of Issuing Bodies (the association administrating the EECS certificates).

Another research project is Energy Trading and Environment 2020 managed by the Norwegian research institution Østfold Research (Østfoldforskning n.d.). The projects overall objective is, as for the other above mentioned projects, to develop guidelines to ensure a good practice within the existing regulation of Electricity Disclosure. In addition, Energy Trading and Environment 2020 is looking into the effect Electricity Disclosure can have to reduce greenhouse gas emissions from energy production and consumption (Østfoldforskning 2010). The project is evaluating how to best calculate the residual mix regarding the inclusion of GOs and other trading mechanisms. The project recommends that the methodology developed by RE-DISS is used to calculate the residual mix of countries (Raadal, 2011). For the Nordic countries, the project recommends a common Nordic residual mix. This harmonizes with the

Nord Pool region and they claim the residual mix region should be the same as the region for the physical electricity trade.

Elforsk is a Swedish research institution which in the period from 2006 – 2009 had a project that looked into Electricity Disclosure and guarantees of origin (Elforsk, 2009; Elforsk, n.d.). A study on the possibility to develop a system for Guarantees of Origin for electricity in Sweden, which at the same time fulfills the preferences of the market players and is in accordance with the EU regulations, was conducted by Elforsk researchers in 2009 (Gode and Axelsson). The same researchers also mapped the situation regarding current research projects, certificate schemes and current models for Electricity Disclosure in 2009 and developed their own methodology for calculations of a domains residual mix (Jakobsson, 2009).

For the disclosure of environmental impacts from electricity, the RE-DISS project uses national onsite CO_2-emissions in their calculations of European residual mixes (RE-DISS, 2012a). The E-Track project recommended a development into using LCAs in the future (Timpe, 2009). The Energy Trading and Environment 2020 project has looked into the use of life cycle assessment for Electricity Disclosure, and their researchers have calculated LCA emissions related to electricity mixes (Raadal and Svanes, 2012; Raadal, 2011). Many studies agree on the use of LCA for evaluating the environmental performance of electricity generation systems (Varun et al. 2009; Dotzauer, 2010; Sebastian et al. 2011; Warner and Heath, 2012; Whitaker et al. 2012). Also other studies agree for applying an LCA for documentation of environmental performance, for instance for carbon footprint calculations (Frischknecht and Stucki, 2010; European Commision 2010; BSI, 2011; GHG Protocol, 2012).

1.2 Objective

The objective of this study is to determine the electricity mix of European countries and their subsequent environmental footprint. Two models for determining the electricity mix will be developed, one calculating the electricity mix for the consumed physical electricity and the other calculating the electricity mix based on the consumption of the attributes of the electricity. The model based on attributes is meant as a methodology for residual mix calculations in the purpose of Electricity Disclosure. The import and export of guarantees of origin will be included in the model and a fictional trade of attributes will be introduced to balance the generation and the consumption of attributes. The fictional export will be taken from the exporting countries' residual mixes and the fictional import will be calculated from the residual mixes of the countries importing explicit attributes. This is made possible through simultaneously solving the attribute model for all the countries at once.

Life cycle assessment will be used to evaluate the environmental impacts from the calculated electricity mixes. Global warming potentials of different electricity generation technologies will be gathered from previous life cycle assessment studies and connected to the technology categories in this study. The environmental impact of each category are connected to the electricity mixes in each country and will establish the environmental footprints of the here included European countries. 23 European countries are included in the study and the electricity mixes include ten categories for generation technologies.

1.3 Content

The body of this study is chapter two to seven. Chapter two offer background information and will address the concepts of electricity disclosure, residual mix and certificate systems. Two existing methods to calculate the residual mixes will be described, before the current implementation of Electricity Disclosure and Guarantees of Origin is looked upon. The development of the models for electricity mix calculations will be presented in chapter three. This involves explanation of the methodology, equations and a description of the calculation method. Chapter four contains the data used as input in the models. This includes generation statistics, production electricity mix, physical trade data and statistics regarding attribute certificates. Life cycle assessment is explained in chapter five. Global warming potentials for the ten technology categories are presented and then follow an explanation on how the life cycle impact data is connected to the electricity mixes. Then the results will presented and analysed in chapter six. Three calculated electricity mixes; physical consumption mix, attribute residual mix and attribute consumption mix, will for comparison be presented together with the production electricity. Then the environmental characteristics of the countries will be presented; global warming potential for the countries depending on mix; comparison of the global warming potentials for physical consumption mixes, attribute residual mixes and attribute consumption mixes; and total volumes of emitted CO_2-equivalents. Chapter seven gives a discussion of the results. Key assumption in the model will be discussed and compared to available literature, and implication of the result will be addressed. Finally a conclusion of the main findings will be presented.

2 BACKGROUND

Several EU directives serve as an incentive to develop and establish a common standard for Electricity Disclosure, Guarantees of Origin and a methodology for the calculation of residual mixes. In 2001 the first directive on the matter, Directive 2001/77/EC, was accepted. The directive deals with the promotion of electricity produced from renewable sources in the internal electricity market (Regjeringen, 2005)(EU, 2001). The objective of this Directive was to increase the share of electricity from renewable energy sources. In addition to include elements like national targets and individual support schemes, the Directive suggests that the producers of renewable electricity can get Guarantees of Origin (RES-GO) for the electricity they produce. The Guarantee of Origin shall declare which energy source is used for the production and when and where the electricity is produced. The Directive states that a system for Guarantees of Origin should be operational from 27 October 2003.

The Electricity Directive 2003/54/EC from 2003 establishes common rules for the generation, transmission and distribution of electricity. In article 3(6) it is stated that the countries in the European Union shall make sure the electricity suppliers specify the energy sources and their share in the fuel mix of the supplier for the preceding year. The directive also states that information on environmental impact shall be made available to the customer. The environmental impact information includes at least emissions of CO_2 and the radioactive waste resulting from the power production. This Directive was repealed by Directive 2009/72/EC in 2009, but the new directive says more or less the same as the previous about Electricity Disclosure.

Following the 2003/54/EC directive on Electricity Disclosure, directive 2009/28/EC repealed 2001/77/EC in 2009. The Directive deals with the promotion of energy from renewable sources. In contrast to the previous Directive it includes the use of energy in the transport sector and for heating/cooling purposes. The main objective of this Directive is to establish a common framework to promote the use of renewable energy towards the EU goal of 20 % share in 2020 (Europalov, 2012; Dii, 2012). In article 15(1) it is stated that "…Member States shall ensure that the origin of electricity produced from renewable energy sources can be guaranteed…"(EU 2009a). Further, the directive provides a framework for the issuing, transfer and cancellation of GOs.

Also guarantees of origin for electricity from combined heat and power (CHP-GO) are treated in an EU directive (EU 2004). The 2004/8/EC directive on the promotion of cogeneration requires that a Guarantee of Origin of electricity produced from a high-efficiency combined heat and power plant can be issued to the combined heat and power producer on request (DECC, 2007).

The Directive 2009/28/EC established the link between Guarantees of Origin and Electricity Disclosure, and based on this Directive RES-GO and CHP-GO should be regarded as tracking systems for disclosure (Timpe, 2009). It is discussed whether RES-GOs and CHP-GOs should become part of a more comprehensive system of Guarantees of Origin for all electricity generated, including all types of energy sources. But the EU countries have not come to an agreement on this yet.

To achieve a better understanding of the concept, and build a broader foundation for the further development of a methodology for electricity mix calculations, basic notions and concepts will be explained. Then already developed models are presented. The current practice for Electricity Disclosure today will also be assessed to some extent.

2.1 Basic notions and concepts

It is now required that the suppliers of electricity disclose their electricity mix to the final customers (RE-DISS, n.d.). This is called Electricity Disclosure. The energy sources and their share in the fuel mix of the supplier for the preceding year must be made available in the Electricity Disclosure. The suppliers must also disclose relevant environmental impact indicators, first of all the CO_2-emissions and the volume of radioactive waste from production. Electricity Disclosure is a requirement stated in the Electricity Market Directive (2003/54/EC) as mentioned above. The objective of Electricity Disclosure is to provide relevant information about the power generation to the customer. This enables the customer to choose his supplier not only with regard to price alone. For a proper disclosure of the electricity mix, suppliers can use Guarantees of Origin or other reliable tracking systems to account for their share of green electricity, or they can use the calculated residual mix for their region, see Figure 1 (EU, 2009a; RE-DISS, n.d.).

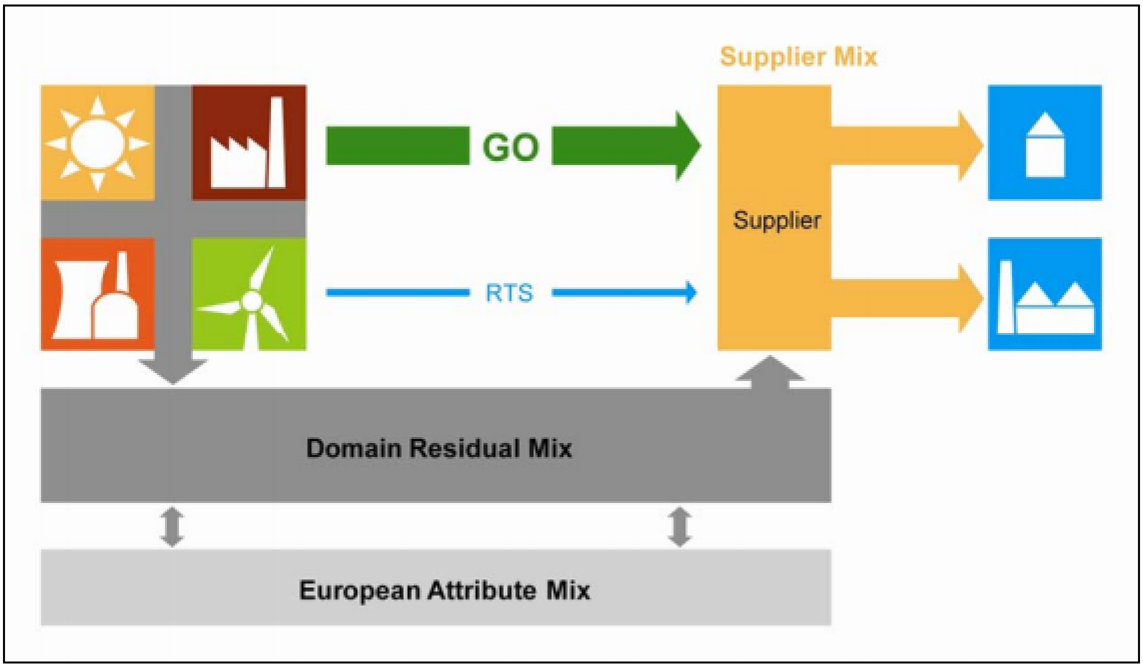

Figure 1: Elements of a Consolidated Tracking System for Electricity Disclosure (Timpe, 2009)

Electricity attributes are characteristics linked to physical electricity. The characteristics of electricity that is relevant for Electricity Disclosure are the energy source and technology that is used to produce one unit of physical electricity and the subsequent emissions (Timpe, 2009). The attribute of 1 kWh depends on the energy source used in the production of the corresponding physical electricity. The attribute of 1 kWh can hence be hydro, nuclear, wind, a fossil fuel and so on.

To be able to track the electricity attributes from producer to consumer, we need systems of tracking. The E-Track project distinguishes between two types of tracking, explicit and implicit (Timpe, 2009). Explicit tracking creates a bilateral link between generation and consumption. Explicit tracking can be divided into contract-based tracking and de-linked tracking. In contract based tracking, electricity generation attributes are allocated to consumers based on bilateral contracts of electricity deliverance concluded in the electricity market. This tracking option is used as the basic method for tracking of disclosure information in many countries. This tracking option can be implemented ex-ante or ex-post, the first one meaning that the attributes are specified in the contract, while the second meaning that the attributes are determined at a later stage. The ex-ante contract-based tracking can be difficult to implement in the framework of liquid electricity markets where the electricity is often traded several times before it is actually produced. Also the trading on power exchanges does not work well with ex-ante contract based tracking, since there is no bilateral link. For ex-post contract-based tracking the attributes will typically be the average attribute mix of the selling company. This ex-post tracking method can be easier to implement, but does not give any preference to trading partners based on their disclosure attributes, since these are allocated at a later stage.

The other option for explicit tracking is de-linked tracking (Timpe, 2009). De-linked tracking use transferable certificates to track the attributes of the electricity. With these certificates, it is possible to allocate attributes from generators to consumers independently from the physical electricity market. Certificates are issued based on the volumes and attributes of the electricity generation. After issuing, they can be transferred independently from the physical electricity market. The attributes represented in a certificate are used by cancelling the certificate, which is then removed from circulation in the market. The most comprehensive certificate system for electricity in Europe is the European Energy Certificate System (EECS). Also several European countries have introduced their own national certificate systems.

The other type of tracking is implicit tracking, which use a default set of attributes for the purpose of electricity disclosure (Timpe, 2009). Here, the electricity attributes from a group of generators are allocated to a large group of suppliers or final consumers. In this case, no bilateral link is created between generation and consumption of electricity. Implicit tracking is widely being used by providing a default set of electricity attributes for the disclosure of electricity of unknown origin. This mechanism is actually vital for disclosure systems, because it has proven practically impossible to cover 100% of any electricity market with explicit tracking. Often the generation statistics of the respective country are used as the basis for determining the attributes for implicit tracking. However, this combined with the explicit attributes will lead to double counting of the attribute. It is therefore important to correct the generation statistic for the explicitly tracked attributes in order to get the correct attribute mix for the implicit tracking. An effect of implicit tracking for electricity disclosure is that all retailers who rely on the default attributes will display the same disclosure information to the customers. This prevents consumers from choosing retailer based on electricity mix. Because of this effect, it is advisable to limit the implicit tracking to the absolute necessary level and use explicit tracking systems whenever possible.

The Residual Mix is the electricity mix delivered to consumers who do not have a contract to get explicitly tracked electricity from their supplier (RES-E, 2012). Calculation of the residual mix is a means to implicit track the attributes of the electricity. When calculating the residual mix, several aspects should be taken into account, see Figure 2. The production statistics of a country, or a region, are usually the basis for the residual mix. The Guarantees of Origin certificates and other reliable tracking certificates that are imported and exported should be taken into account and so should the internally cancelled certificates. In addition to this, physical import and export of electricity should be included in the residual mix calculation. It is important that the traded electricity mix is regarded the same way by the importer and by the exporter, or else double counting might occur. The volume made available for disclosure in the residual mix added to the internally cancelled certificates should equal the total volume of physical electricity available for consumption (Timpe, 2009). If this is not the case fictional trade should be introduced.

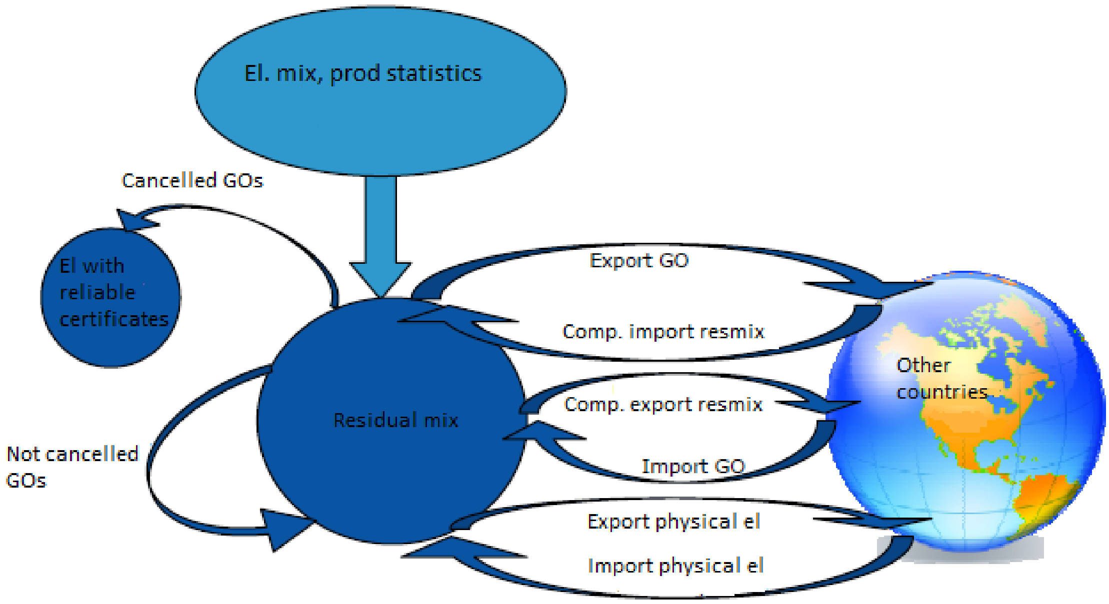

Figure 2: Elements to include in calculation of a country's residual mix (Gode and Axelsson, 2009).

In general two types of certificate systems exist in Europe; support certificates and the Guarantees of Origin. Certificate systems that are linked to an obligation are called support certificates. By having an obligation, usually set for the supplier, a demand is created that drives the market and this is used as a system to promote renewable energy and support the producers of electricity from renewable energy sources. The Guarantees of Origin is primarily meant as a tracking instrument for disclosure purposes and is not originally meant as a support system.

The European Energy Certificate System (EECS) is a European framework developed by the Association of Issuing Bodies. This is done to provide a properly regulated platform for the issuing, holding, transferring and otherwise processing of electronic records called EECS Certificates (CEN, 2008) (EECS, 2012). The EECS certifies, in relation to specific quantities of output from power plants, attributes of its source and/or the method and quality of its production. EECS Certificates may be Guarantees of Origin issued according to EU Directives and implemented by member states, or they can be in connection with other legislative support certification schemes or other, entirely voluntary, arrangements.

In a broad sense, guarantees of origin are used as a general term for proofs of the origin of electricity for purposes of electricity disclosure. Guarantees of Origin in a narrow sense however, is a certificate system under the European Energy Certificate System (EECS) which is used as a tool for explicit de-linked tracking of attributes (Timpe, 2009). Guarantees of Origin are established to prove the origin of the electricity (RE-DISS, n.d.). Guarantees of Origin are only issued for electricity generated from renewable sources, RES-GO, and from high-efficient cogeneration, CHP-GO. The government in the EU Member States is responsible for the Guarantees of Origin system and they usually appoint, or design, a competent body to be the Issuing Body for the Guarantees of Origin (RECS International, n.d.). The Issuing Body submits the Guarantees of Origin certificates to the electricity producers proportionally to the electricity they produce from renewable sources or cogeneration. Each Guarantee of Origin is standarised to represent 1 MWh. This means that the producers get one Guarantee of Origin for every MWh of electricity produced from renewable sources or cogeneration (EU 2009a). A Guarantee of Origin shall, according to Directive 2009/28/EC, specify at least: “The energy source, start and end dates of production; the identity, location, type and capacity of the installation where the energy was produced; whether and to what extent the installation has benefited from investment support, whether and to what extent the unit of energy has benefited in any other way from a national support scheme, and type of support scheme; the date on which the installation became operational; and the date and country of issue and a unique identification number.” (EU, 2009a, article 15(6)).

For the purpose of electricity disclosure, it is important that the same unit of energy from renewable sources or cogeneration is accounted only once (EU, 2009a). When a GO has been used it shall therefore be cancelled. The Guarantees of Origin in one of the member countries shall be valid in all the other countries and the GOs can be traded both internally in a country and between countries. When trading GOs, the amount of energy from renewable sources, corresponding to the Guarantees of Origin transferred, must be subtracted from the electricity mix of the selling party and added to the electricity mix of the buying party. This will avoid double counting. The use of a GO has to take place within 12 months of production of the corresponding physical energy unit or else the benefit of the GO will be gone.

The tracking of electricity attributes with the use of Guarantees of Origin can be used for different purposes (Timpe, 2009). In addition to Guarantees of Origin used for Electricity Disclosure, as stated in Directive 2009/28/EC and explained above, a tracking system can be valuable for support mechanisms for certain types of electricity attributes. Financial support systems for certain technologies of electricity production are implemented in most European countries. Some of these systems require a proof of generation before the support is given. RES-GO or CHP-GO can be used for this purpose and information on whether the instance of electricity generation has received support or not can be included in the GO. This will avoid over-subsidization.

The Guarantees of Origin tracking system can also be used by governments to track the share of renewable energy in their goal to fulfill quantitative targets for the share of renewable energy. Such targets are set for the year 2020 in the 2009/28/EC Directive. Usually the degree of achievement of these targets is verified based on statistics on the renewable production, but since certain transfers of renewable energy between the countries are possible in order to add flexibility to the national target, a tracking systems of GOs will be more accurate.

One of the voluntary support systems for renewable energy certificates is the Renewable Energy Certificate System (RECS) (Statnett, 2011). The RECS certificates are, like the Guarantees of Origin, administered according to the EECS framework. The RECS certificates provid evidence of the production of a quantity of renewable energy, and offers a methodology which enables renewable electricity trade. This helps create a market for renewable energy and thereby promotes the development of new renewable energy capacity in Europe. It is seen that the GOs gradually are replacing the RECS certificates (RECS, 2012). The RECS certificates are seen as reliable for explicit tracking of attributes for disclosure of the electricity.

In addition to these two types of certificates there are other types of certificate systems. Some of these certificates are reliable as tracking mechanisms, while others are only meant as a support mechanism. An example is the Norwegian-Swedish green electricity certificates. These certificates are not used for tracking attributes, but as a support mechanism. Since the main focus of this thesis is the calculation of countries electricity mixes and their subsequent environmental footprint, certificates used as support mechanism is not discussed any further.

2.2 Existing models for calculating the residual mix

Two current methodologies for calculating residual mix will be described. The first is the methodology developed by E-track, which is currently the only widely accepted methodology, implemented by many European countries. The other is the methodology developed by the Swedish Elforsk. The two models have a lot of similarities, but they also differ in some essential ways, which make it interesting to look closer at both of them.

The E-Track project developed a method for calculating the residual mix of a region, see Figure 3 (Öko-Institut, 2010). The methodology was further developed by the RE-DISS project, and EPED made it into a model for the calculation of residual mixes. The starting point for the calculation is the net generation statistics in a domain, excluding pumped hydro. The generation is distributed to the technology categories fossil, nuclear and renewable. The generation statistics are then adjusted for the Guarantees of Origins in the domain. The imported GOs are added to the generation, while the cancelled GOs, exported GOs and attributes allocated by other reliable tracking systems are subtracted. After these corrections, the first step of the calculation is completed and the preliminary residual mix in the domain is set. Step two of the model is the determination of an attribute surplus or deficit. This involves the comparison of the final consumption of physical electricity in the domain and the volumes of attributes available for disclosure. The attributes available for disclosure is the attributes of the net generation plus the imported attributes minus the exported attributes. The domain has a deficit of attributes if the consumption is higher than the attributes available and a surplus of attributes if the consumption is lower than the attributes available.

E-TRACK METHODOLOGY FOR CALCULATING RESIDUAL MIX

Step 1: Preliminary Residual Mix in a Domain

- Starting Point: Net Generation Statistics in a Domain (excluding pumped hydro)
- Corrections:
  - Add attributes of GO which have been imported
  - Subtract attributes of cancelled GO
  - Subtract attributes of exported GO
  - Subtract attributes already allocated by other (reliable) tracking mechanisms
- Result: Preliminary Residual Mix in the Domain

Step 2: Determination of Attribute Surplus / Deficit

- Compare
  - Final consumption of electricity in the Domain (including network losses)
  - Volume of attributes available for disclosure

    Volume of net generation in the Domain
    + Volume of Attributes imported, e.g. based on GO
    – Volume of Attributes exported, e.g. based on GO
    = Volume of attributes available for disclosure
  - Deficit: Consumption is higher than the attributes available
  - Surplus: Consumption is lower than the attributes available

Step 3: Exchange with the European Attribute Mix

- The European Attribute Mix is filled from the preliminary Residual Mixes of the Domains which have a surplus in attributes.
- The European Attribute Mix is used to fill up the Residual Mixes of the Domains which have a deficit in attributes.

Figure 3: The E-Track model for residual mix calculations (Öko-Institut, 2010).

In order to offset the deficit or surplus, the model introduces a European pool of attributes, see Figure 4.

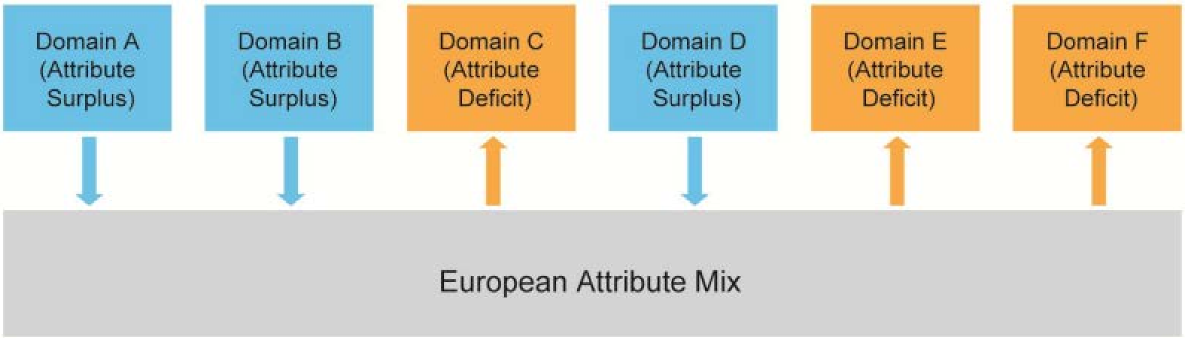

Figure 4: The domains exchange with the European attribute mix(Öko-Institut, 2010).

The pool is filled by the domains with surplus of attributes. The surplus attributes are taken from the domains preliminary residual mix and together with the attributes from the other countries with a surplus, make up the European Attribute Mix pool. The domains having a deficit of attributes, recieve attributes from the European Attribute Mix pool.

When RE-DISS further developed the methodology, regional attribute mixes were introduced into the model in addition to the European Attribute Mix, see Figure 4. Two or more domains are in the same region. The domains with a surplus of attributes give the attributes to the regional pool. This makes up the regional attribute mix. The countries with deficit attributes gets the attributes they need from the regional attribute mix pool. The regional pool can have a surplus or deficit of attributes after the exchange with the domains. The surplus attributes from the regions make up the European Attribute Mix and the regions with deficit attributes gets attributes from this pool.

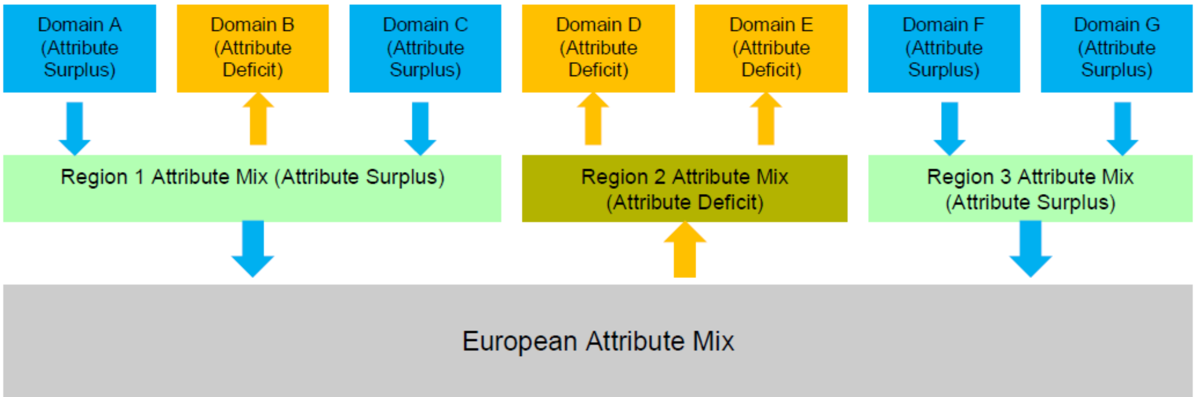

Figure 5: The domians exchange with regional attribute mixes and the regions exchange with the European attribute mix(Öko-Institut, 2010).

Elforsk has also developed a model for residual mix calculation. As an example see Table 1 for the calculation of the Norwegian residual mix for 2007. Elforsk's model, like the E-Track model, uses the production electricity mix of a domain as the starting point for calculation of the residual mix (Gode and Axelsson, 2009). The energy sources in the production mix are allocated to three technology categories; renewable, nuclear and fossil, which are the only categories in the residual mix calculation. Physical export and import are then subtracted and added to the production mix. For the physical exports, the domain's production mix adjusted for internally cancelled certificates, is used as electricity mix. Regarding the physical import, it is the electricity mix in the exporting domains that are used as electricity mix. These mixes are, in the current calculations, not adjusted for cancelled certificates. This is done because of lack of data. After adjusting for the physical trade, the trade of Guarantees of Origin is taken into account. First the GOs exported are subtracted from the mix's renewable share. Then the exports of GOs are compensated by adding the quantity of the exported GOs to the mix. The electricity mix of the added quantity is the production mixes of the countries importing GOs. After adjusting for exported GOs, the imported GOs are added. The import is compensated by subtracting the same quantity imported from the electricity mix adjusted for cancelled certificates. The last step of the Elforsk model is to subtract the internally cancelled certificates. After this last step the residual mix is calculated.

NORWAY	Renewable	Nuclear	Fossil	Total	Description
Norwegian electricity production	134.6	0.0	1.5	136.1	
Physical export	-15.2	-0.0	-0.1	-15.3	Norwegian el. mix adjusted for internally cancelled GO
Physical import	2.4	1.7	1.1	5.2	El. mix from exporting countries, no adjustment for certificates
Export GO	-26.0	0.0	0.0	-26.0	
Compensation for export GO	9.4	4.9	11.7	26	El. mix from importing countries, no adjustment for certificates
Import GO	0.4	0.0	0.0	0.4	
Compensation for import GO	-0.4	0.0	0.0	-0.4	Norwegian el. mix, only adjusted for cancelled GO
Cancelled GO internal	-27.0	0.0	0.0	-27.0	
Total (TWh)	78.2	6.6	14.2	99.0	
Residual mix %	79.0 %	6,7 %	14,3 %	100 %	

Table 1: Elforsk's residual mix calculation for Norway for 2007 (Gode and Axelsson, 2009)

2.3 The situation today

According to EU Directives, all the EU Member States were supposed to implement Guarantees of Origin for renewable energy sources, RES-GO, by 2003, and Guarantees of Origin for cogeneration, CHP-GO, by 2007 (EU, 2001; EU, 2004). The link between GOs and Electricity Disclosure was established by Directive 2009/28/EC. This Directive states that GOs shall be used for tracking attributes in the purpose of electricity disclosure. The Directive should have been implemented by the EU countries by December 2010 (EU, 2009a). The current situation and degre of implementation in the European countries (the 27 Member States, Norway and Switzerland), do not comply with the EU Directives (Draeck et al., 2009). Several countries fail to properly implement the regulations on Electricity Disclosure, and many countries have not yet implemented appropriate regulations on RES-GO and CHP-GO. Even if many countries have insufficient regulations and implementation, a number of countries have managed to follow the Directives and chosen to implement advanced systems for Guarantees of Origin and/or disclosure. In most of these cases many elements from the E-Track standard recommendation from phase 1 of the project are implemented in the national regulations.

When it comes to Electricity Disclosure, currently most of the European countries have several mechanisms of accounting for generation attributes for disclosure purposes (Draeck et al., 2009). The systems in operation include national Guarantees of Origin and RECS certificates, some of which are coordinated by the European Energy Certificate System. In addition there are schemes such as private green power quality labels and national accounting schemes for disclosure mix calculations. But only 12 European countries has implemented systems for Electricity Disclosure which is regarded comprehensive enough (Draeck et al., 2009). The other countries either have not yet passed regulations on disclosure, the passed regulations are not properly implemented or the operational disclosure systems are insufficient on some criteria. The common criteria that fail the most are the disclosure of environmental impacts, CO_2-emissions and nuclear waste, and the accuracy of the tracking, including insufficient tracking of GOs and calculation of residual mixes.

Most of the western European countries have an operational RES-GO system implemented, while for the eastern European countries some regulations and implementation is needed to get sufficient systems up and running (Draeck et al., 2009). The remaining weaknesses for the RES-GO systems are; 1. the systems are not reliable and accurate enough; 2. the transfers, imports and exports are not sufficiently tracked and 3. double counting is frequently done. When it comes to CHP-GO, the systems are not yet fully implemented in Europe (E-track, 2009). In 2009, 25 out of 31 countries and regions in Europe had passed their primary legislation on CHP-GO, but still there were only nine countries that allowed transfer of CHP-GOs and twelve countries that allowed imports. In 2009 no exports of CHP-GO had yet taken place. Also the information provided for the CHP-GOs in the countries differ, and are in most cases insufficient. Apart from the Netherlands and Wallonia (one of the regions in Belgium), no countries disclose the CO_2-emissions from the electricity produced by cogeneration. In addition, the time and date of production are also somewhat imprecisely defined for the CHP-GOs.

In Norway the Directive from EU on Electricity Disclosure is valid through the regulation on measurements and accounting (NVE, 2012). Statnett is appointed to be the Issuing Body for Guarantees of Origin (Statnett, 2012a). Electricity suppliers using Guarantees of Origin are allowed to make their own individual Electricity Disclosure. Those suppliers, who don't have GOs covering their supply, have to refer to the Electricity Disclosure calculated by NVE (The Norwegian Water Resources and Energy Directorate). The calculations done by NVE are, from the year 2011, based on the methodology developed by the E-Track project and further by the RE-DISS project. NVE uses a Norwegian residual mix in its Electricity Disclosure calculations. The methodology developed by RE-DISS is corrected to coincide with the Norwegian regulations on the use of guarantees of origin. The Electricity Disclosure for 2011 can be seen in Figure 3.

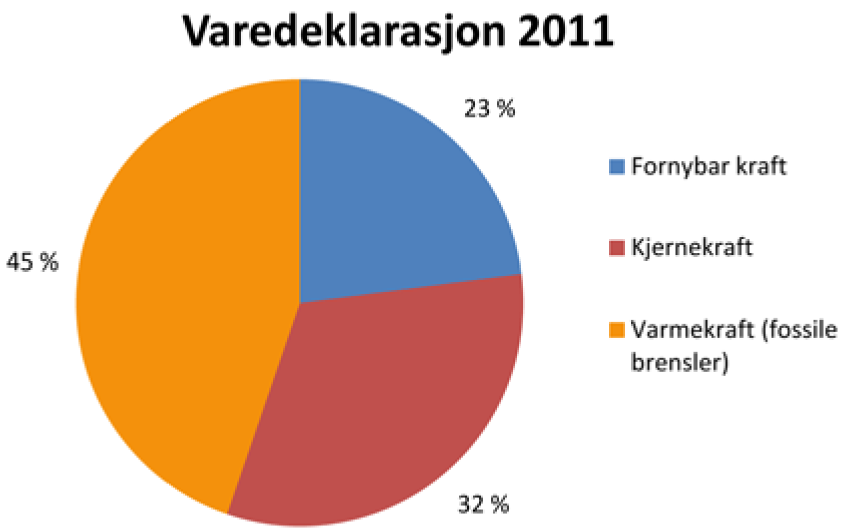

Figure 6: Electricity Disclosure for the residual mix in Norway for 2011.

The disclosure for 2011 resulted in an electricity mix of 45 % electricity from fossil fuels, 32 % from nuclear energy and 23 % from renewable sources. When it comes to the disclosure of the environmental impacts, NVE has provided a number for the CO_2-emissions of 307 g/KWh (NVE, 2012).

3 MODEL DEVELOPMENT

The objective of this thesis is to determine the electricity mix of a country and its environmental footprint. In order to determine the electricity mix, a model of the system and method for the calculation, needed to be developed. During the development of a final model, several modeling options were looked into.

Two model principles were finally chosen and models for each principle developed. The first model is based on physical flows, while the second model is based on the attributes of the electricity and the attribute flows in and between countries. The attribute model is thought as input to the process of developing a model for Electricity Disclosure with Guarantees of Origin, as made mandatory by EU (EU, 2009a). Both models are based on the energy balance between production and consumption. The models are consumption based, which means they calculate the electricity mix for the consumption in a given country, opposed to the production technology mix which is based on the produced electricity. The trade in both models is modeled bilateral and re-export are not taken into account. The timeframe for the models is one calendar year. Transmission losses in the grid during the transportation of electricity from production facility to end customer are not included in the models.

3.1 Physical model

The physical model describes the physical flows of electricity in Europe, or more specific the physical electricity that is produced, traded and consumed in the European countries. The flows are distributed among the various technology categories, and are split into two variables, one parameter describing the quantity produced, exported, imported or consumed and one technology mix vector, containing the percent of each technology associated with the parameter. Each country has its unique production technology mix and consumption technology mix. The traded technology mix is assumed equal to the production mix in the origin country. The technology mix exported is then modeled the same as the exporting countries own production mix, and the import technology mix is the same as the production mix in the country where the import is originated. The purpose of the model is to find the technology mix of the consumed physical electricity in each country and this is the final output of the model.

The construction of the physical model is based on the energy balance between production and consumption, as seen in equation (1).

$$PG_i + \sum_{j=1}^{n} PI_{ji} = PC_i + \sum_{j=1}^{n} PE_{ij} \quad (1)$$

Physical electricity generated in a country, i, plus the sum of all imports to country i, equals consumption in country i and the sum of all exports from country i. For explanation of the variables, see Table 2 below.

Variable	Description
PG_i	Physical generation in country i
PC_i	Physical consumption in country i
PI_{ji}	Physical import from country j to i
PE_{ij}	Physical export from country I to j
$T_{i,t}^{P}$	Technology mix for the physical generation in country i
$T_{i,t}^{C}$	Technology mix for the physical consumption in country i
$T_{ji,t}$	Technology mix for the physical imports from country j to i
$T_{ij,t}$	Technology mix for the physical exports from country I to j

Table 2: Variables used in the physical model

The variables in equation (1), are parameters describing the physical volumes generated, imported, consumed and exported. To be able to calculate the technology mix for the consumed electricity in each country, vectors representing the technology mixes are introduced, see equation (2). The vectors are explained in the above table.

$$PG_i \times T_{i,t}^{P} + \sum_{j=1}^{n}(PI_{ji} \times T_{ji,t}) = PC_i \times TC_{i,t}^{P} + \sum_{j=1}^{n}(PE_{ij} \times T_{ij,t}) \quad (2)$$

The imported and exported technology mixes are assumed to be equal to the generation technology mix in the exporting country, as mentioned previously. When this is introduced, equation (2) becomes equation (3).

$$PG_i \times T_{i,t}^{P} + \sum_{j=1}^{n}(PI_{ji} \times T_{j,t}^{P}) = PC_i \times T_{i,t}^{C} + \sum_{j=1}^{n}(PE_{ij} \times T_{i,t}^{P}) \quad (3)$$

In the above equation, the physical generation, volume and technology mix, and the import and export volumes are known variables, for available data and numbers see chapter 4. The objective is to find the technology vector for the consumption and the equation is then solved for the consumption, see equation (4).

$$PC_i \times T_{i,t}^{C} = PG_i \times T_{i,t}^{P} + \sum_{j=1}^{n}(PI_{ji} \times T_{j,t}^{P}) - \sum_{j=1}^{n}(PE_{ij} \times T_{i,t}^{P}) \quad (4)$$

To find the quantity of the physical consumption, equation (1) is solved for the consumption. The only unknown variable are then the consumption technology mix vector, $T_{i,t}^{C}$, see equation (5). This is the desired output of the physical model.

$$T_{i,t}^{C} = (PG_i \times T_{i,t}^{P} + \sum_{j=1}^{n}(PI_{ji} \times T_{j,t}^{P}) - \sum_{j=1}^{n}(PE_{ij} \times T_{i,t}^{P}))/PC_i \quad (5)$$

The program Matlab is used for the programming and solving of the physical model. The programmed model's output is a matrix consisting of all the countries and their physical consumption technology mix. This technology mix is further combined with environmental impact data to obtain an environmental characteristic for each country. This is explained further in chapter 5.

3.2 Attribute model

The attribute model is based on the balance between the generated, traded and the consumed attributes of the electricity. The basis is a principle of all electricity having certain characteristics or attributes depending on the electricity generating technology used in production, as explained in chapter two. Every produced MWh of electricity has attributes, no matter what energy source. The attribute information says which technology is used to produce that specific MWh. MWh is chosen as unit, since that is the unit used for issuing Guarantees of Origin and the associated certificates trade are given in that unit (AIB, 2012). The attributes comes into existence when the physical electricity is generated, and therefore, for the purpose of this model, a country's generated attributes is the same volume and technology mix as the same country's produced amount of electricity and the production technology mix. Except for the generation of attributes, the attributes are independent of the physical electricity and are traded and cancelled independently of the physical electricity. Attributes can be traded both between countries and internally in a country. Internal trade is not relevant for this case, since it is the consumption of a country as one, which is looked into. In addition, trade is modeled bilateral, no re-export is included in the model.

When attributes is sold from one country to another, the country of origin no longer has the possibility to claim those attributes to their physical electricity. The rights to those attributes are no longer theirs, but belong to the buying country and should be included in the buying country's technology mix proportional to the traded amount. The traded attributes are for that reason subtracted from the exporting country's attributes and added to the importing country's attributes, in the same way as for the physical electricity.

The amount of total attributes in a country has to match the consumed amount of electricity on a yearly basis. In order to achieve this equality, fictional import and export are introduced into the model.

The construction of the attribute model is as mentioned earlier, based on the energy balance, or the equality between generated, traded and consumed attributes. Equation (6) shows the equality.

$$AG_i + \sum_{j=1}^{n} AI_{ji}^E + \sum_{j=1}^{n} AI_{ji}^F = AC_{ii}^E + \sum_{j=1}^{n} AC_{ji}^E + AC_i^R + \sum_{j=1}^{n} AE_{ij}^E + \sum_{j=1}^{n} AE_{ij}^F \quad (6)$$

Generated attributes in country, i, added to explicit import and fictional import must equal the consumed attributes added to the explicit export and the notional export. For explanation of the variables, see Table 3 below.

Variables	Description
AG_i	Attribute generation in country i
AC_{ii}^E	Attributes generated in country i and consumed in country i
AC_{ji}^E	Attributes generated in country j and consumed in country i
AC_i^R	Attributes in the residual mix consumption in country i
AI_{ji}^E	Attribute import from country j to i, explicit
AE_{ij}^E	Attribute export from country i to j, explicit
AI_{ji}^F	Attribute import from country j to i, fictional
AE_{ij}^F	Attribute export from country i to j, fictional
$T_{i,t}^P$	Technology mix for the attribute generation in country i
$T_{ii,t}^E$	Technology mix for the attribute generated and consumed in country i
$T_{i,t}^R$	Technology mix for the residual consumption in country i
$T_{j,t}^R$	Technology mix for the residual consumption in country j
$T_{ji,t}^E$	Technology mix for the explicit attribute import from country j to i
$T_{ij,t}^E$	Technology mix for the explicit attribute export from country i to j
PC_i	Physical consumption in country i
NIE_i^F	Net fictional trade of attributes from country j to i

Table 3: Variables used in the attribute model

In order to be able to calculate the technology mix, technology vectors are introduced in the same way as for the physical model, se equation (7).

$$AG_i \times T_{i,t}^P + \sum_{j=1}^{n}(AI_{ji}^E \times T_{ji,t}^E) + \sum_{j=1}^{n}(AI_{ji}^F \times T_{j,t}^R) = AC_{ii}^E \times T_{ii,t}^E + \sum_{j=1}^{n} AC_{ji}^E \times T_{ji,t}^E + AC_i^R \times T_{i,t}^R + \sum_{j=1}^{n}(AE_{ij}^E \times T_{ij,t}^E) + \sum_{j=1}^{n}(AE_{ij}^F \times T_{i,t}^R) \quad (7)$$

In the physical model the import and export has the same technology mix as the exporting country's generation mix, but this is not the case for the attribute model. When attributes are traded it is not only the quantity that matter, as for physical trade, but more important is the attribute itself and the production technology used to produce the electricity once connected to that attribute. Only certain types of attributes are traded. Since this attribute model is thought as input to the process of developing a model for electricity disclosure in Europe, the trade of explicit attributes in the model, is the same as traded GOs and RECS certificates.

The technology mix of the fictional import is determined by assuming the imported quantities' technology mix being the same as the residual mix in the country of origin. The fictional export from a country, i, has the same technology mix as the residual consumption in that country. The technology mix for the fictional export is therefore assumed to be the same as the residual mix in the exporting country.

In addition to the energy balance equation above, there are two more equations to help solve the model, see equation (8) and (9).

$$AI_{ji}^{E} \times T_{ji,t}^{E} \ = \ AC_{ji}^{E} \times T_{ji,t}^{E} \qquad (8)$$

$$PC_i = \ AC_{ii}^{E} + \ AC_{ji}^{E} + AC_{i}^{R} \qquad (9)$$

The explicit attribute import to country i, and the attributes generated and explicitly consumed in country i, have the same value and technology mix and thereby, in the above equation (8), the two terms are the same. Since the two terms are on opposite sides of the equal symbol, the terms can be removed from the equation to make it simpler. The simplified version of the equation can be seen in equation (10).

Equation (9) states that the quantity of the consumed attributes must equal the quantity of the consumed physical electricity. Except the equality between generated attributes and generated physical electricity, the equality in equation (9) is the only connection between the attribute model and the physical power system. The explicit consumed attributes, AC_{ii}^{E} and AC_{ji}^{E}, are known, and with equation (9) we then find the consumed residual of attributes, AC_{i}^{R}.

$$AG_i \times T_{i,t}^{P} + \sum_{j=1}^{n}(AI_{ji}^{F} \times T_{j,t}^{R}) = AC_{ii}^{E} \times T_{ii,t}^{E} + AC_{i}^{R} \times T_{i,t}^{R} + \sum_{j=1}^{n}(AE_{ij}^{E} \times T_{ij,t}^{E}) + \sum_{j=1}^{n}(AE_{ij}^{F} \times T_{it}^{R}) \qquad (10)$$

After introducing equation (9), the unknown terms in equation (10) are AI_{ji}^{F}, AE_{ij}^{F}, T_{it}^{R} and T_{jt}^{R}. For input data see chapter 4 and appendix 4. To find the fictional import and export quantities, the technology vectors are removed from equation (10), see equation (11).

$$AG_i + \sum_{j=1}^{n} AI_{ji}^{F} = \ AC_{ii}^{E} + \ AC_{i}^{R} + \ \sum_{j=1}^{n} AE_{ij}^{E} + \ \sum_{j=1}^{n} AE_{ij}^{F} \qquad (11)$$

Equation (11) is further changed to find the fictional trade, see equation (12) and (13).

$$\sum_{j=1}^{n} AI_{ji}^{F} \ - \ \sum_{j=1}^{n} AE_{ij}^{F} \ = \ AC_{ii}^{E} + \ AC_{i}^{R} + \ \sum_{j=1}^{n} AE_{ij}^{E} - \ AG_i \qquad (12)$$

Net fictional import is defined as fictional import minus fictional export, see equation (13).

$$NIE_i^F = \sum_{j=1}^{n} AI_{ji}^F - \sum_{j=1}^{n} AE_{ij}^F \tag{13}$$

$$NIE_i^F = AC_{ii}^E + AC_i^R + \sum_{j=1}^{n} AE_{ij}^E - AG_i \tag{14}$$

If a country's net fictional trade is greater than zero, the country has shortage of attributes and need fictional import from other countries. If a country's net fictional trade is less than zero, the country has excess attributes and fictional export of attributes.

$$NIE_i^F > 0 => \left|NIE_i^F\right| = |\sum_{j=1}^{n} AI_{ji}^F|$$

$$NIE_i^F < 0 => \left|NIE_i^F\right| = |\sum_{j=1}^{n} AE_{ij}^F|$$

The fictional import to a country is calculated in two steps and two different methods, depending on whether the country has explicit export of attributes or not. The first step deals with the countries in need of fictional import that export explicit attributes to other countries. For these countries, the fictional import to the country, i, is imported from the countries of which country i has explicit export to. The fictional import is distributed proportionally to the exported quantities from country i to each of the other countries, see equation (15). The technology mix of the fictional import is determined by the assumption of the imported quantities' technology mix being the same as the residual mix in the country of origin, as explained earlier and seen in equation (10).

$$AI_{ji}^F = (NIE_i^F \times AE_{i,j}^E) / \sum_{j=1}^{n}(AE_{ij}^E) \tag{15}$$

For a better understanding, an example with three countries, where country one has a shortage of attributes and is in need of fictional import, is demonstrated:

$$\sum_{j=1}^{n} AI_{j1}^F = ((NIE_1^F \times AE_{1,2}^E) / \sum_{j=1}^{n}(AE_{1j}^E)) + ((NIE_1^F \times AE_{1,3}^E) / \sum_{j=1}^{n}(AE_{1j}^E))$$

The fictional import of one country calculated in step 1 cannot be larger than that country's export of explicit attributes. If a country needs more fictional import than the quantity of explicit attributes exported, it gets the same amount as explicit exported in step 1 and the rest of the needed fictional import are dealt with in step 2.

After step 1, the net fictional import is adjusted for the fictional imports treated in step 1. The already distributed fictional import is subtracted from the net fictional import, NIE, and the belonging distributed fictional exports are added to NIE. The vector containing the corrected net fictional imports for all the countries is then divided in two separate vectors, net import, NI, and net export, NE.

In step 2 all the fictional export, NE, is collected in a pool of electricity attributes. The attributes in this pool are then distributed among the rest of the countries in need of fictional import, NI. All the countries receiving fictional import from the pool, import their fictional attributes from all of the countries having fictional export going into the pool. The quantity imported from each of the exporting countries is proportional to the fictional export from each country, see equation (16).

$$AI_{ji}^{F} = (NI_{i}^{F} \times NE_{j}^{F}) / \sum_{j=1}^{n}(NE_{j}^{F}) \tag{16}$$

This is how the second method for finding fictional import works. The technology mix for the fictional export is assumed the same as the residual mix in the exporting country, see equation (10). The fictional imports and exports can be found in Table 16 in Appendix 3.

After determining the fictional import and export, the only unknowns left in equation (10) are $T_{i,t}^{R}$ and $T_{j,t}^{R}$ for all i and j, which represent the residual technology mixes in each country. By solving for the unknowns, equation (10) becomes equation (17).

$$-(AC_{i}^{R} + \sum_{j=1}^{n}(AE_{ij}^{F})) \times T_{i,t}^{R} + \sum_{j=1}^{n}(AI_{ji}^{F} \times T_{j,t}^{R}) = AC_{ii}^{E} \times T_{ii,t}^{E} + \sum_{j=1}^{n}(AE_{ij}^{E} \times T_{ij,t}^{E}) - AG_{i} \times T_{i,t}^{P} \tag{17}$$

By solving this equation for all countries, i, simultaneously, you find the consumed attribute residual electricity mix in each country. This is one of the outputs of the attribute model.

The explicitly consumed attributes are not included in the residual technology mix and so to find the countries' total consumed technology mixes, the technology mixes are introduced into equation (9) which leads to equation (18).

$$PC_i \times T_{i,t}^{E+R} = \; AC_{ii}^{E} \times T_{ii,t}^{E} \; + \; \sum_{j=1}^{n} (AC_{ji}^{E} \times \; T_{ji,t}^{E}) + AC_i^{R} \times \; T_{i,t}^{R} \tag{18}$$

Only $T_{i,t}^{E+R}$ is unknown in equation (17) and by solving it, the attribute consumption electricity mix for all the countries included in the model are calculated. This is the second output of the attribute model.

Linear matrix algebra is used for solving the model and finding the attribute residual mix and the attribute consumption mix. This is demonstrated for the residual mix using an example of three countries and two technologies.

Three countries and two technologies give a system of six equations:

$$-(AC_1^{R} + AE_{12}^{F} + \; AE_{13}^{F}) \; \times T_{1,1}^{R} + (AI_{21}^{F} \times T_{2,1}^{R}) + (AI_{31}^{F} \times T_{3,1}^{R}) = AC_{11}^{E} \times T_{11,1}^{E} + (AE_{12}^{E} \times T_{12,1}^{E}) + (AE_{13}^{E} \times T_{13,1}^{E}) - \; AG_1 \times T_{1,1}^{P} \tag{18}$$

$$-(AC_1^{R} + AE_{12}^{F} + \; AE_{13}^{F}) \; \times T_{1,2}^{R} + (AI_{21}^{F} \times T_{2,2}^{R}) + (AI_{31}^{F} \times T_{3,2}^{R}) = AC_{11}^{E} \times T_{11,2}^{E} + (AE_{12}^{E} \times T_{12,2}^{E}) + (AE_{13}^{E} \times T_{13,2}^{E}) - \; AG_1 \times T_{1,2}^{P} \tag{19}$$

$$-(AC_2^{R} + AE_{21}^{F} + \; AE_{23}^{F}) \; \times T_{2,1}^{R} + (AI_{12}^{F} \times T_{1,1}^{R}) + (AI_{32}^{F} \times T_{3,1}^{R}) = AC_{22}^{E} \times T_{22,1}^{E} + (AE_{21}^{E} \times T_{21,1}^{E}) + (AE_{23}^{E} \times T_{23,1}^{E}) - \; AG_2 \times T_{2,1}^{P} \tag{20}$$

$$-(AC_2^{R} + AE_{21}^{F} + \; AE_{23}^{F}) \; \times T_{2,2}^{R} + (AI_{12}^{F} \times T_{1,2}^{R}) + (AI_{32}^{F} \times T_{3,}^{R}) = AC_{22}^{E} \times T_{22,2}^{E} + (AE_{21}^{E} \times T_{21,2}^{E}) + (AE_{23}^{E} \times T_{23,2}^{E}) - \; AG_2 \times T_{2,2}^{P} \tag{21}$$

$$-(AC_3^{R} - AE_{31}^{F} + \; AE_{32}^{F}) \; \times T_{3,1}^{R} + (AI_{13}^{F} \times T_{1,1}^{R}) + (AI_{23}^{F} \times T_{2,1}^{R}) = AC_{33}^{E} \times T_{33,1}^{E} + (AE_{31}^{E} \times T_{31,1}^{E}) + (AE_{32}^{E} \times T_{32,1}^{E}) - \; AG_3 \times T_{3,1}^{P} \tag{22}$$

$$-(AC_3^{R} + AE_{31}^{F} + \; AE_{32}^{F}) \; \times T_{3,2}^{R} + (AI_{13}^{F} \times T_{1,2}^{R}) + (AI_{23}^{F} \times T_{2,2}^{R}) = AC_{33}^{E} \times T_{33,2}^{E} + (AE_{31}^{E} \times T_{31,2}^{E}) + (AE_{32}^{E} \times T_{32,2}^{E}) - \; AG_3 \times T_{3,2}^{P} \tag{23}$$

The equations (18) to (23) are then solved using matrix algebra. The combined equation on matrix form is seen in equation (24),

$$M \times t^{R} = k \tag{24}$$

where M is a matrix consisting of the residual consumption and the fictional imports and exports,

$$M = \begin{bmatrix} -(AC_1^R + AE_{12}^F + AE_{13}^F) & 0 & AI_{21}^F & 0 & AI_{31}^F & 0 \\ 0 & -(AC_1^R + AE_{12}^F + AE_{13}^F) & 0 & AI_{21}^F & 0 & AI_{31}^F \\ -(AC_2^R + AE_{21}^F + AE_{23}^F) & 0 & AI_{12}^F & 0 & AI_{32}^F & 0 \\ 0 & -(AC_2^R + AE_{21}^F + AE_{23}^F) & 0 & AI_{12}^F & 0 & AI_{32}^F \\ -(AC_3^R - AE_{31}^F + AE_{32}^F) & 0 & AI_{13}^F & 0 & AI_{23}^F & 0 \\ 0 & -(AC_3^R - AE_{31}^F + AE_{32}^F) & 0 & AI_{13}^F & 0 & AI_{23}^F \end{bmatrix}$$

t^R is the unknown residual technology mixes for the three countries combined in one combined residual mix vector,

$$t^R = \begin{bmatrix} T_{1,1}^R \\ T_{1,2}^R \\ T_{2,1}^R \\ T_{2,2}^R \\ T_{3,1}^R \\ T_{3,2}^R \end{bmatrix}$$

and k is a constant vector containing the internally issued and cancelled consumption, the explicit exports and the generation and the belonging known technology vectors.

$$k = \begin{bmatrix} AC_{11}^E \times T_{11,1}^E + (AE_{12}^E \times T_{12,1}^E) + (AE_{13}^E \times T_{13,1}^E) - AG_1 \times T_{1,1}^P \\ AC_{11}^E \times T_{11,2}^E + (AE_{12}^E \times T_{12,2}^E) + (AE_{13}^E \times T_{13,2}^E) - AG_1 \times T_{1,2}^P \\ AC_{22}^E \times T_{22,1}^E + (AE_{21}^E \times T_{21,1}^E) + (AE_{23}^E \times T_{23,1}^E) - AG_2 \times T_{2,1}^P \\ AC_{22}^E \times T_{22,2}^E + (AE_{21}^E \times T_{21,2}^E) + (AE_{23}^E \times T_{23,2}^E) - AG_2 \times T_{2,2}^P \\ AC_{33}^E \times T_{33,1}^E + (AE_{31}^E \times T_{31,1}^E) + (AE_{32}^E \times T_{32,1}^E) - AG_3 \times T_{3,1}^P \\ AC_{33}^E \times T_{33,2}^E + (AE_{31}^E \times T_{31,2}^E) + (AE_{32}^E \times T_{32,2}^E) - AG_3 \times T_{3,2}^P \end{bmatrix}$$

To solve the equation, the inverse of M is multiplied with k, see (25).

$$t^R = M^{-1} \times k \tag{25}$$

The attribute residual mix, t^R, are inserted in equation (18) and the attribute consumption mix is calculated.

Matlab is used to program and solve the attribute model. The programmed model's output is two matrixes. One consists of all the countries included and their attribute residual electricity mix, and one consist of all the countries and their total attribute consumption electricity mix. This electricity mixes is further combined with environmental impact data to obtain environmental characteristics for each country. This is explained in chapter 5.

4 ELECTRICITY DATA

To be able to use the models developed and calculate the electricity mixes in the European countries and their environmental impact, attribute data and physical electricity data is needed. The case used for calculations for both models in this thesis consists of a system of 23 countries and 10 technology categories, see Table 4.

Countries	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherland, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, United Kingdom
Technologies	Coal, Gas, Oil, Nuclear, Hydro, Wind, Bio and waste, Solar, Geothermal, Tide, wave and ocean.

Table 4: Overview of the countries and the technology categories used in this case

The countries and technologies used for this case are chosen because of data availability and contemporary trade of GO's. Numbers on generation statistics for each country and each technology; physical import and export; and trade of attributes are necessary inputs to do the model calculations. Wherever possible, data is collected from 2010, but if not available other numbers are used.

Some of the data is needed in both models and some is specific for each model. The physical generation data is needed for both models. These numbers are found from IEA's Electricity Information 2011 (IEA, 2011). The numbers on total electricity generation can be seen in Table 5. The production for each of the 23 countries included in the models, are given and the numbers are in TWh. For the attribute model this table is used as totally generated attributes in each country.

Country	Generation(TWh)
Austria	69,6
Belgium	96,3
Czech Republic	86,0
Denmark	38,5
Estonia	12,9
Finland	80,0
France	572,8
Germany	617,9
Greece	61,5
Hungary	37,4
Ireland	28,4
Italy	297,4
Luxembourg	4,6
Netherland	114,6
Norway	124,2
Poland	157,7
Portugal	53,0
Slovak Republic	27,4
Slovenia	16,4
Spain	298,1
Sweden	153,0
Switzerland	68,3
United Kingdom	381,2

Table 5: Electricity generation for 23 European countries

As seen in Table 5, there are large differences between how much electricity the countries produce. Germany are the biggest electricity producer, with a production of 617,9 TWh in 2010. France had a production of 572,8 TWh the same year, which makes it the second biggest producer in Europe. Among the countries producing least we find Luxembourg, Estonia and Slovakia, with respectively 4,6 TWh, 12,9 TWh and 16,4 TWh of production. Norway with a production of 124,2 TWh in 2010 is neither one of the largest producers, nor one of the smallest.

The production mix in each country is compiled from generation statistics for each technology in each country. The ten categories used are the same as the categories given in the IEA statistics (IEA, 2011). The percentage mix seen in Table 6 is calculated from Table 12 in Appendix 1 and Table 5 above.

From Table 6 we see that the technology mixes vary a lot between the countries. As an example we can see that near to 75 % of France' electricity generation is from nuclear energy. 12 % comes from hydro power and not more than 10 % from fossil fuel power plants. This technology mix differs a lot from for example Germany's technology mix, which consists of 44 % electricity from coal and has a total of 59 % of its produced electricity coming from fossil fuel. Norway produces 95 % of its electricity from hydro power and has a totally different production technology mix than both France and Germany.

In general the technologies most widely used in the countries' electricity generation are coal and gas, followed by nuclear and hydro. Except for hydro power, renewable energy only contributes to a small part of the electricity production in the European countries. Eastern European countries as Estonia, Poland and the Czech Republic produce most of their electricity from coal. The percentage being respectively 89,9 %, 87,7 % and 58,4 %. These countries have the largest coal percentage in their electricity mix. Of the western European countries, Denmark and Germany has the highest coal percentage, 43,9 % and 43,8 %. Luxembourg, Netherland, Ireland and Italy are the countries with the highest percentage of gas in their electricity mix. More than 50 % of the electricity produced in these four countries are from gas power plants. France is the country with the largest percentage of nuclear power in the electricity mix, 75 % as mentioned above. Also Belgium, Hungary, Slovak Republic, Switzerland and Sweden have a large amount of nuclear power in their generation mix.

	Coal	Oil	Gas	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	9,1 %	0,0 %	20,8 %	0,0 %	55,5 %	2,9 %	11,8 %	0,0 %	0,0 %	0,0 %
Belgium	8,1 %	0,3 %	32,3 %	49,7 %	1,8 %	1,3 %	5,6 %	0,8 %	0,0 %	0,0 %
Czech Rep	58,4 %	0,2 %	1,3 %	32,6 %	4,0 %	0,3 %	2,6 %	0,7 %	0,0 %	0,0 %
Denmark	43,9 %	2,1 %	20,5 %	0,0 %	0,0 %	20,3 %	13,2 %	0,0 %	0,0 %	0,0 %
Estonia	89,9 %	0,0 %	2,3 %	0,0 %	0,0 %	2,3 %	5,4 %	0,0 %	0,0 %	0,0 %
Finland	26,6 %	0,8 %	13,9 %	28,5 %	16,1 %	0,4 %	13,8 %	0,0 %	0,0 %	0,0 %
France	4,6 %	1,1 %	4,6 %	74,8 %	11,9 %	1,7 %	1,1 %	0,1 %	0,0 %	0,1 %
Germany	43,8 %	1,2 %	13,7 %	22,8 %	4,2 %	5,9 %	6,5 %	1,9 %	0,0 %	0,0 %
Greece	44,6 %	12,5 %	26,8 %	0,2 %	12,2 %	3,4 %	0,3 %	0,0 %	0,0 %	0,0 %
Hungary	16,8 %	1,3 %	31,0 %	42,2 %	0,5 %	1,3 %	6,7 %	0,0 %	0,0 %	0,0 %
Ireland	23,9 %	2,1 %	60,9 %	0,0 %	2,5 %	9,9 %	0,7 %	0,0 %	0,0 %	0,0 %
Italy	14,0 %	7,2 %	51,7 %	0,0 %	18,1 %	2,8 %	3,8 %	0,5 %	1,8 %	0,0 %
Luxembourg	0,0 %	0,0 %	63,0 %	0,0 %	32,6 %	2,2 %	2,2 %	0,0 %	0,0 %	0,0 %
Netherland	22,0 %	1,1 %	62,2 %	3,5 %	0,1 %	3,5 %	7,5 %	0,1 %	0,0 %	0,0 %
Norway	0,1 %	0,0 %	3,9 %	0,0 %	94,9 %	0,7 %	0,3 %	0,0 %	0,0 %	0,0 %
Poland	87,7 %	1,8 %	3,0 %	0,0 %	2,2 %	1,1 %	4,1 %	0,0 %	0,0 %	0,0 %
Portugal	13,6 %	4,3 %	27,9 %	0,0 %	31,1 %	17,2 %	5,1 %	0,4 %	0,4 %	0,0 %
Slovak Rep	15,3 %	2,2 %	6,9 %	53,3 %	20,4 %	0,0 %	1,8 %	0,0 %	0,0 %	0,0 %
Slovenia	32,3 %	0,0 %	3,0 %	34,8 %	28,7 %	0,0 %	1,2 %	0,0 %	0,0 %	0,0 %
Spain	8,8 %	5,5 %	31,3 %	20,7 %	15,2 %	14,7 %	1,6 %	2,2 %	0,0 %	0,0 %
Sweden	2,3 %	1,8 %	2,8 %	37,6 %	46,7 %	2,3 %	6,5 %	0,0 %	0,0 %	0,0 %
Switzerland	0,0 %	0,1 %	1,2 %	39,1 %	55,3 %	0,0 %	4,1 %	0,1 %	0,0 %	0,0 %
UK	28,8 %	0,9 %	46,0 %	16,3 %	1,8 %	2,6 %	3,6 %	0,0 %	0,0 %	0,0 %

Table 6: Production technology mix for the European countries

For hydro power, Austria, Switzerland and Sweden have the largest percentage share after Norway, with a share of around 50 % for all the three countries. The country with the largest percentage share of wind power in its electricity mix is Denmark, with 20,3 % power from wind, followed by Portugal and Spain, with shares of 17,2 % and 14,7 %. Finland, Denmark and Austria are the three countries where bioenergy and waste contribute the most to the countries mix, the percentages being 13,8 %, 13,3 % and 11,8 %. Solar power contribute with a 2,2 % share in the electricity mix for Spain, which makes Spain the country with the biggest share of solar power. The two last technology categories, geothermal power and tide, wave and ocean power can be found only in a few countries. Since the percentage shares are so small, they are only explained when looking at the renewable electricity production below.

The European countries trade electricity with each other. Some countries produce more electricity than they consume and are therefore net exporters of electricity. Other countries consume more electricity than they are able to produce, and are net importers of electricity. But there are fluctuations in both the production and the consumption of electricity. The consumption pattern shows a higher use of electricity some hours during the day than what is the case during the night. On the other hand the production varies according to weather conditions, fuel availability and prices. Because of all these factors the net exporting countries do have some import and the net importing countries some export.

Data for physical import and export are needed only for the physical model and can be found in Table 11 in Appendix 1. The data could not easily be collected for 2010 and therefore 2009 data are used instead. The production statistics from 2009 and 2010 are approximately the same for most countries, and the trade data from 2009 is assumed to be a good estimate. The import and export statistics given by IEA do not align. The transmission losses in the grid and different sources can be reasons for the difference. Table # is based on the import statistics.

Germany is the country exporting the largest amount of electricity. Over 51 TWh did Germany export in 2009. France and Switzerland are the second and third biggest exporter of electricity. The export from France was 43 TWh in 2009 and the export from Switzerland was 32 TWh. The country importing most electricity was in 2009 Italy. 47 TWh was imported. Both Germany and Switzerland also import a lot of electricity. 41 TWh was imported to Germany and 31 TWh to Switzerland in 2009.

For physical trade, mostly neighboring countries trade with each other, as seen in Table 11 in Appendix 1. The reason for this is the higher transmission losses the longer the distance, and also because of the lack of long distance transmission lines. But when it comes to electricity attributes the distance sets no limits. Since there are no physical flows, no grids are needed for transmission and no transmission losses exist. Attributes are therefore sold to countries independent of the distance between them. The import and export trade of attributes certificates between the 23 countries is given in Table 14 in Appendix 2. The main source used in compiling this table is CMO.grexel, a central registration database for European Energy Certificate System (EECS) certificates, including GO and RECS (CMO.grexel, 2011). Specific trade data is found for Sweden, Finland, Denmark, Germany and Luxembourg. In addition, data for Norway is gathered from Statnett, the Issuing Body for Guarantees of Origin in Norway (Statnett, 2012b). All data is from 2010, except for Sweden, as 2010 wasn't easily available. The data for Sweden is mostly compiled using data from the other countries. Export from Sweden is found using import numbers from the other countries, and export numbers for the other countries are used in order to find import numbers for Sweden. These numbers are from 2010. However, where other numbers could not be found, 2011 data regarding Swedish trade are used. This data is from the same source as the other data, only with one year difference. Trade data is only collected for these countries because of availability, but since the countries mentioned above are countries which together account for a large part of the EECS certificate export, it is assumed to be enough data to serve the purpose of this project.

Table 14 shows that Norway is the country exporting most EECS certificates. Over 76 million certificates, each stating renewable attributes for 1 MWh of electricity, were exported from Norway in 2010. Finland is the second largest exporter of certificates. 17 million certificates were exported from Finland in 2010. Sweden and Denmark also export a lot of EECS certificates, 10 million and 3 million respectively. Norway, Finland and Denmark are net exporters of certificates. Even if Sweden has large export of certificates, even more certificates, 20 million, are imported to the country. The country importing most EECS certificates are Germany. The country imports almost 33 million certificates. Sweden, Belgium and Netherland are the countries importing the largest amounts of attribute following Germany. 17 million certificates, equal 17 TWh of electricity, is imported to Belgium and 12 million to Netherland.

The quantities of EECS certificates traded are accessible data, but information regarding the technology mix of the certificates is harder to obtain. The renewable production technology mix is given in Table 7. The table is compiled from Table 13 in appendix 1, showing renewable energy production for the 23 countries. The numbers in this table are used as the technology mix for traded attributes and the internally produced and cancelled attributes in the attribute model. The attribute export from a country is given the same technology mix as the renewable mix in the exporting country, and the imported attributes has the same technology mix as the country of origin. This is done in order to have a technology mix for the attributes inserted into the model, and then further be able to calculate the final residual and consumption mixes.

	Hydro	Wind	Bio & waste	Solar	Geothermal	Tide, wave, ocean	% renewable of total el prod
Austria	79,1 %	4,1 %	16,8 %	0,0 %	0,0 %	0,0 %	70,1 %
Belgium	18,5 %	14, %	58,7 %	8,7 %	0,0 %	0,0 %	9,6 %
Czech Republic	52,3 %	4,6 %	33,9 %	9,2 %	0,0 %	0,0 %	7,6 %
Denmark	0,0 %	60,5 %	39,5 %	0,0 %	0,0 %	0,0 %	33,5 %
Estonia	0,0 %	30,0 %	70,0 %	0,0 %	0,0 %	0,0 %	7,8 %
Finland	53,3 %	1,2 %	45,5 %	0,0 %	0,0 %	0,0 %	30,3 %
France	79,8 %	11,3 %	7,5 %	0,8 %	0,0 %	0,6 %	14,9 %
Germany	22,6 %	31,8 %	35,2 %	10,5 %	0,0 %	0,0 %	18,6 %
Greece	76,5 %	21,4 %	2,0 %	0,0 %	0,0 %	0,0 %	15,9 %
Hungary	6,3 %	15,6 %	78,1 %	0,0 %	0,0 %	0,0 %	8,6 %
Ireland	18,9 %	75,7 %	5,4 %	0,0 %	0,0 %	0,0 %	13,0 %
Italy	66,8 %	10,4 %	14,0 %	1,2 %	6,7 %	0,0 %	27,1 %
Luxembourg	88,2 %	5,9 %	5,9 %	0,0 %	0,0 %	0,0 %	37,0 %
Netherland	0,8 %	31,3 %	67,2 %	0,8 %	0,0 %	0,0 %	11,2 %
Norway	98,9 %	0,8 %	0,3 %	0,0 %	0,0 %	0,0 %	96,0 %
Poland	29,9 %	14,5 %	55,6 %	0,0 %	0,0 %	0,0 %	7,4 %
Portugal	57,5 %	31,7 %	9,4 %	0,7 %	0,7 %	0,0 %	54,2 %
Slovak Republic	91,8 %	0,0 %	8,2 %	0,0 %	0,0 %	0,0 %	22,3 %
Slovenia	95,9 %	0,0 %	4,1 %	0,0 %	0,0 %	0,0 %	29,9 %
Spain	45,2 %	43,6 %	4,7 %	6,6 %	0,0 %	0,0 %	33,7 %
Sweden	84,2 %	4,1 %	11,7 %	0,0 %	0,0 %	0,0 %	55,5 %
Switzerland	92,8 %	0,0 %	6,9 %	0,3 %	0,0 %	0,0 %	59,6 %
United Kingdom	22,0 %	32,9 %	45,1 %	0,0 %	0,0 %	0,0 %	8,0 %

Table 7: Renewable technology mix for the European countries and their share of electricity generated from renewable energy

In Table 7 it can be seen that hydro power is the largest contributor to the renewable production in the European countries. Hydro power is an old renewable technology and is therefore well developed and the resources are nearly exhausted. Norway, Slovenia and Switzerland have the largest percentage hydropower, respectively 98,9 %, 95,9 % and 92,9 % of the renewable electricity production is from hydropower.

Wind power and bioenergy are technologies that have become more developed and economically feasable over the last decade and these technologies are today used in many countries for big scale power generation (Grønhaug, 2011; IEA Bioenergy, 2011). The European countries with the largest renewable share of bioenergy and energy from waste incineration are Hungary and Estonia. Respectably 78,1 % and 70 % of their renewable electricity production originates from bio and waste. However, these numbers are of course considerably smaller when the total electricity mix is taken into account. As mentioned earlier, Finland and Denmark have the largest share of power from bio and waste, 13,6 % and 13,3 % respectively.

Solar power, geothermal power and power from tide, wave and ocean only accounts for a small part of the total electricity produced from renewable energy sources. These technologies are new renewable energy technologies and are not yet developed as well as the other renewable energy technologies. Power from geothermal energy and power from tide, wave and ocean can only be found in a few countries. Italy has the largest power production from geothermal energy. 1,8 % of the total production, or 6,7 % of the renewable production is from geothermal. In addition to Italy, Portugal is the one other country with geothermal electricity production. 0,4 % of its total electricity production originates from geothermal energy. When it comes to tide, wave and ocean power, only one country has this type of production plants. France's electricity mix contains 0,1 % of tide, wave and ocean power. The numbers for both categories under discussion are small and do not have a large influence on the renewable share of the technology mix.

The numbers for the total renewable production, which can be seen in Table 13 in appendix 1, vary a lot between the European countries. In Norway 96 % of the total production comes from renewable sources, mostly hydropower, and this makes Norway's technology mix the one with the largest renewable percentage. Next to Norway, Austria has the second largest renewable share. 70 % of the total production comes from renewable energy, primarily from hydropower. On the other end of the scale we find Poland and the Czech Republic, both countries with slightly more than 7 % of their electricity production coming from renewable energy sources.

In addition to attribute trade data, one needs to have numbers on how many of the attributes produced in a country that are cancelled in the country of origin. These numbers are not easily to be found. The basis for compilation of these numbers is data from AIB, the Association of Issuing Bodies (AIB, 2012). But because these numbers include re-export and because of the different systems for attributes and collection of data, the numbers from AIB does not align with the attribute trade data. The data for produced and internally cancelled attributes are therefore manipulated in such a way as to fit the assembled trade data. A manipulation of numbers is done in order to have numbers to feed the models. In order to obtain sufficient output reliability it will be necessary to have a minimum amount of data inserted into the model. The internally produced and cancelled attributes can be seen in Table 15 in appendix 2. The technology mix used for these attributes are the same as for the traded attributes; the renewable production mix in the country in question.

5 ENVIRONMENTAL CHARACTERISTIC OF ENERGY SYSTEMS

To be able to connect emissions to the technology mix in each country, data concerning emission impacts from the different electricity generation technologies is needed. It is important not only to analyse the direct emissions from an energy system, but to assess the entire life cycle. Life cycle impact data compiled through life cycle assessments are therefore used to find environmental characteristics of the electricity systems in Europe.

Life cycle assessment is a methodology with the objective to compile and evaluate the environmental impacts from all types of products and production systems (Brattebø et al. 2007; Strømman 2010). The entire life cycle, from cradle to grave, is considered when doing an LCA, and the method is well suited to identify where in the life cycle you find the best opportunities for improvement.

The purpose of doing an LCA is to be able to compare the environmental impacts from two or more systems offering the same service (Brattebø et al. 2007). The service offered from the energy systems compared in this project is 1 kWh of electricity. This is the external demand from the system and is called the functional unit (Strømman, 2010).

There is a widely accepted framework on how to do an LCA, including standardized phases and stages. An LCA study is structured into four phases; goal and scope definition, inventory analysis, impact assessment and interpretation, see Figure 7 (ISO 14040, 2006; Brattebø et al. 2007). The first phase is a description of the system and is meant to define the purpose of the analysis and the system boundaries. In the second phase all necessary data must be compiled and the system is modeled and analyzed. The intention behind the third phase, impact assessment, is to give increased understanding of the results from the inventory analysis, in order to make it easier to understand the environmental impacts. In the last phase the results are interpreted.

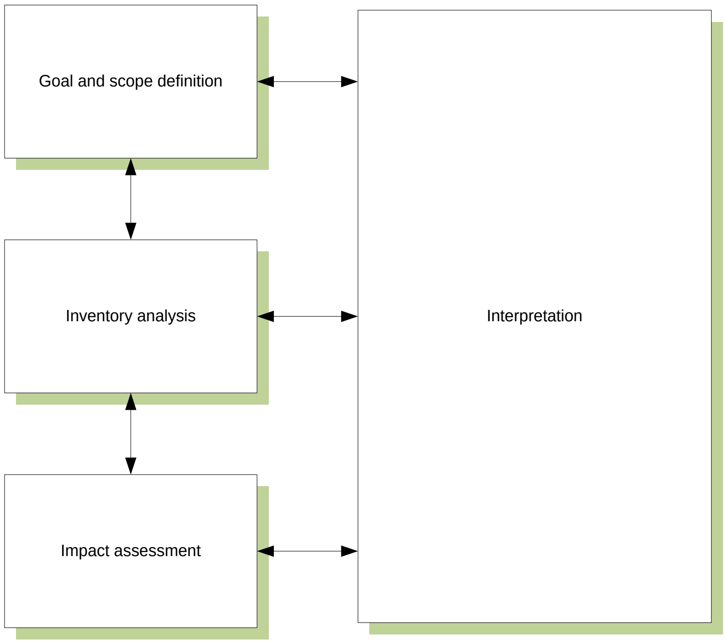

Figure 7: LCA framework (ISO 14040, 2006; Brattebø et al. 2007)

The results of an LCA study have several direct applications (Brattebø et al. 2007). In developing and improving a product, an LCA can be used in order to find the hot spots in the production chain, so that improvements can be done to make the production chain more efficient and the product more environmentally friendly. In a marketing perspective, LCA can be used to compare the environmental footprint of several products. A superior environmental profile can give a competitive advantage. LCA's are also used for public policy making. This mostly applies for LCA's of processes and systems. A comparison of the environmental profiles of energy systems before construction of new generation facilities are one example how LCA can be used in public policy making.

The full life cycle inventories, assessments and interpretation are not carried out in this thesis. Numbers are instead found from already existing LCA studies and databases. There are several impact categories for environmental characteristic, but in this thesis only the global warming potential is included. Global warming is currently the environmental issue getting the most attention from the public and the global warming is also highly relevant when considering the impacts from different energy systems. Therefore global warming is chosen as the only impact category considered for the electricity generation technologies in the making of the European countries environmental characteristics.

The global warming potentials used for the different technologies in this project can be seen in Table 8. The global warming potential (GWP) for coal are the calculated average of GWP results for 19 European countries carried during this authors master project autumn 2011. The European GWP for coal is found to be 1073,7 g CO_2-eq/kWh.

For oil power plants, no relevant European study on life cycle emissions was found. In order to obtain impact data, a case study from Singapore was used. A global warming potential of 932 g CO_2-eq/kWh, was found in the Singaporean case study and used for further analysis in this thesis (Kannan 2004).

The global warming potential for gas, hydro and bio and waste are all processed data from the database EcoInvent, available through the Simapro software (Simapro, 2012). A graphical user interface in Matlab's runtime environment is used to access the resulting impacts found in the life cycle assessment. As average European numbers were not available in the database, the numbers and results for Germany were used as an estimate. Since the technology category bio and waste, used in this thesis, is a combined category, the number in Table 8 are compiled from to different processes found in EcoInvent, one is electricity from wood, with a GWP of 13 g CO_2-eq/kWh and the other is electricity from biowaste, respectively with a GWP of 147 g CO_2-eq/kWh. Each of the two processes is said to count for 50 % in the combined category. New studies have shown that the impact value of bioenergy is higher than the values found from EcoInvent (Cherubini 2011). This is because of the impact of biogenic CO_2. Traditionally, CO_2 emissions from biomass combustion are said to be climate neutral, but according to Cherubini, this is not the case. The GWP for bio and waste in Table 8 are therefore believed to be too low, but because of the scope of this thesis, this will not be considered any further.

Technology	Global Warming Potential
Coal	1073,7
Gas	562,5
Oil	932,0
Nuclear	15,0
Hydro	5,1
Wind	15,8
Bio & waste	79,9
Solar	59,0
Geothermal	41,0
Tide, wave, ocean	50,0

Table 8: Life cycle global warming potentials for the technologies, given in g CO_2-eq/kWh (Simapro, 2012; Gagnon, 2002; Tremeac, 2009; Pehnt, 2006)

For nuclear energy, 15 g CO_2-eq/kWh is used as global warming potential. This number is found in a study by Gagnon on life cycle assessments of different electricity generation options (2002). Even though there may be concerns regarding high impacts for nuclear energy in other impact categories, nuclear power is a good option for electricity generation in a climate change perspective.

For the GWP number on wind energy, Tremeac et al.'s study of a 4.5 MW wind turbine in France is used as data source (2009). The CO_2-eq/kWh is, as can be seen in the table above, 15,8 g. Ardente et al's study regarding an Italian windfarm, results in approximately the same impact potential, 14,8 g CO_2-eq/kWh (Ardente et al. 2008), and Tremeac's result is therefore seen as a valid global warming potential for Europe. The GWP used is for electricity from an onshore wind farm. This study does not separate between onshore and offshore wind in the technology category and neither for the LCA data combined to the category. This is sees as a valid simplification since the share of offshore wind in Europe still are low and the GWP for offshore wind is 32 g CO_2-eq/kWh which does not differ too much from the onshore GWP result (Wagner et al. 2011).

The technology category on solar power is assumed to consist of both power from photovoltaic (PV) installations and solar thermal power. The global warming potential from PV electricity generation is 104 g CO_2-eq/kWh and the global warming potential from solar thermal power is 14 g CO_2-eq/kWh (Pehnt 2006). A 50 % mix of each of the solar technologies is assumed and the impact potential for the solar technology category is then calculated to be 59 g CO_2-eq/kWh.

The global warming potential used for power production from geothermal energy is 41 g CO_2-eq/kWh. This was found in the same study as for the solar energy technologies (Pehnt 2006). For the last technology category, tide, wave and ocean, no valid source of life cycle results was found. The global warming potential was therefore estimated and 50 g CO_2-eq/kWh was decided to be the impact potential for further use in this study.

The global warming potentials vary a lot for the different power generating technologies. The fossil fuel technologies have large impacts on climate change. Coal is the definite worst technology regarding CO_2-emissions, emitting 1073,7 g CO_2-eq/kWh in average. The power plants combusting oil to generate electricity have a lower impact than coal-fired power, 932 g CO_2-eq/kWh are the life cycle emissions from oil power generation. Gas technology for power generation has even lower impacts than oil and has the lowest impacts on climate change of the three fossil fuel categories. The global warming potential for gas is 562,5 g CO_2-eq/kWh. Compared to the other technologies, all the fossil fuel technologies have high impact potentials. The renewable energy technologies have global warming potentials in range from 5 g CO_2-eq/kWh for hydro to 80 g CO_2-eq/kWh for bio and waste, which is substantially lower than for the fossil technologies. Also electricity from nuclear power plants has a low impact potential on global warming. A potential of 15 g CO_2-eq/kWh is the second lowest climate change potential, only beaten by hydro power.

The global warming potentials and the countries' technology mix are combined, and this is used to find the countries' impacts on climate change. Here this is said to be the environmental characteristics of the European nation's electricity production.

6 RESULTS AND ANALYSIS

This part of the report will present the most important results from the analysis of the European electricity mix. First the results for the European countries' electricity mixes will be presented, then the impact data are taken into consideration and finally the countries' corresponding environmental footprint are presented. The results are generated using the program Matlab to make the models for finding the technology mixes. Matlab is also used to generate the environmental characteristics of the countries based on their electricity mixes.

6.1 Electricity Mix

The electricity mix of a country can be calculated in several ways. A common way of describing the electricity mix today is on a physical production basis. The electricity mix is then the technology mix of physically produced electricity when no trade is taken into account. The methods used in this thesis result in consumption based electricity mixes. The physical model results in the electricity mix representing the consumed physical electricity in the country of interest. Physical production, import and export are included in this model. The electricity mixes of the physical production and the physical consumption are shown in Figure 8.

When comparing the two electricity mixes, it can be seen that for some countries the differences in the percentage mix are small, but for other countries there are substantial differences. Norway, Germany, France and Belgium, among others, have approximately the same electricity mix for the two different ways of accounting. Norway imports electricity from countries with coal and nuclear production in their production electricity mix and therefore Norway's physical consumption mix consists of a small percentage of coal and nuclear. For Germany, France and Belgium, no significant differences can be seen. The countries physical trade does not lead to any new technologies in their mix or to any other changes notable.

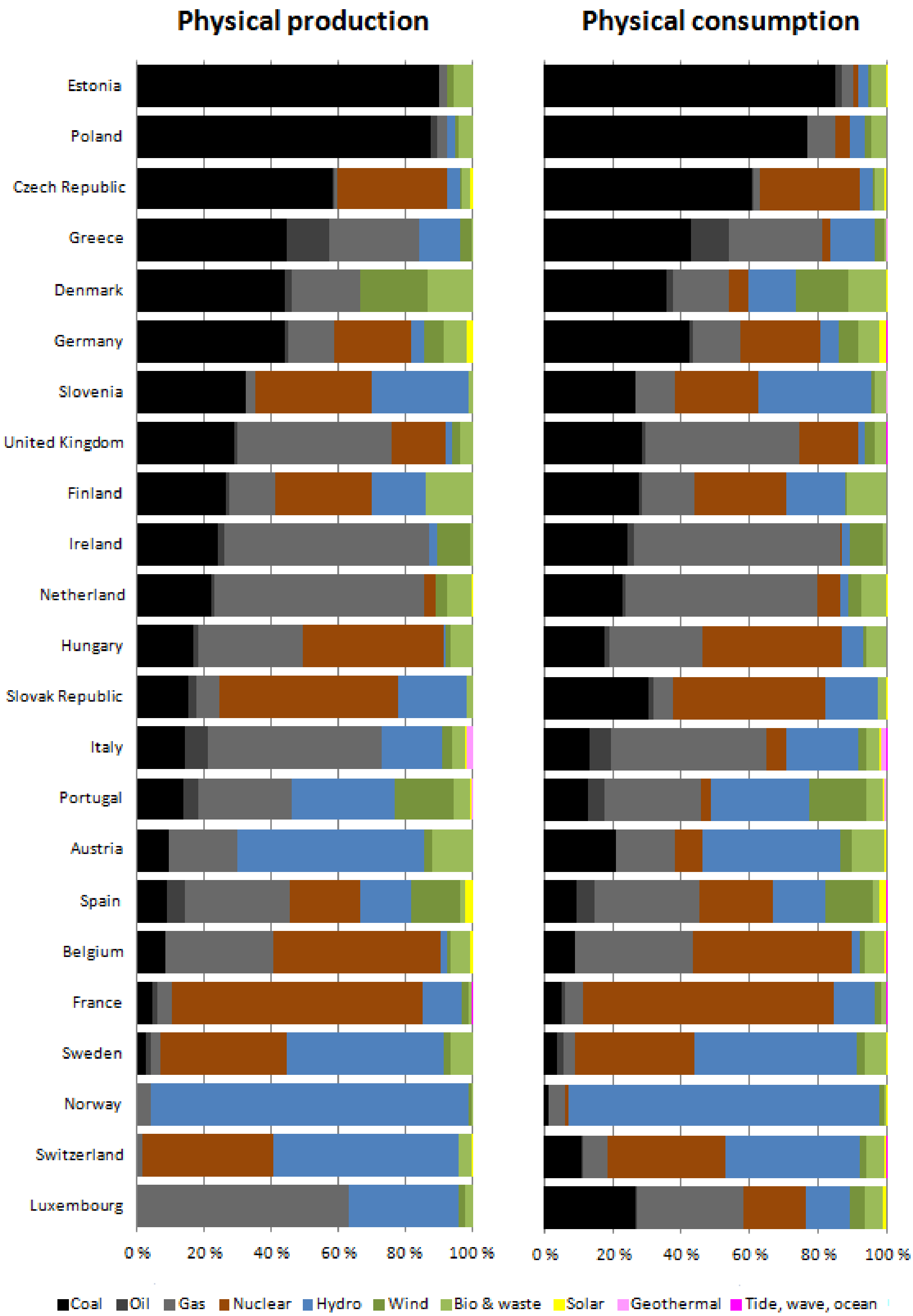

Figure 8: Physical production electricity mix and physical consumption electricity mix for the total consumption in 23 European countries

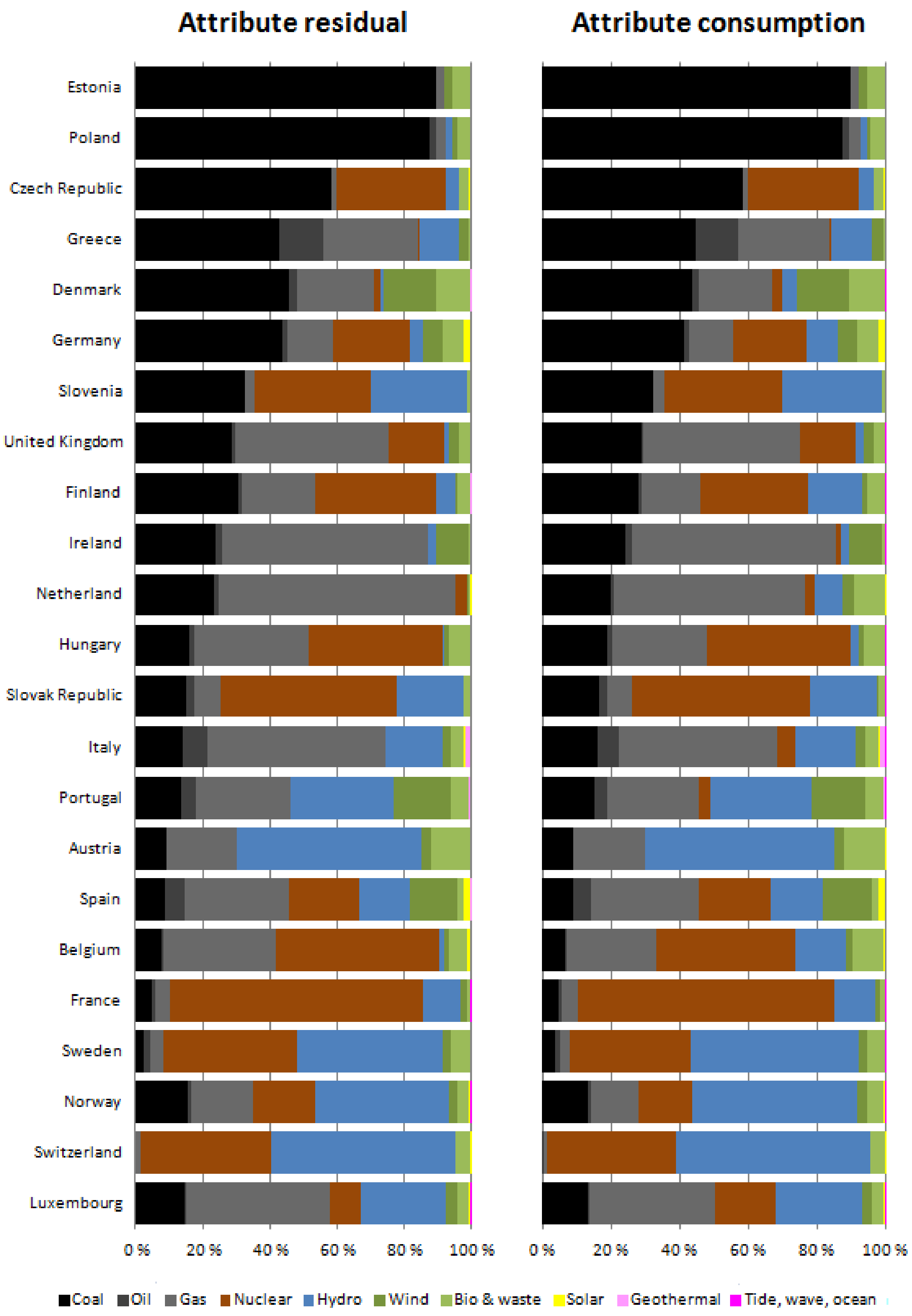

Figure 9: Residual attribute electricity mix and attribute consumption electricity mix in 23 European countries

Significant differences between the two ways of accounting the electricity mix can be seen for Luxembourg, Switzerland, Austria, Slovak Republic and Denmark. Let us for example look at Luxembourg. The physical consumption mix for Luxembourg includes a great amount of coal and nuclear, 26 % and 18 % respectively, while the physical production mix does not. The reason behind this is because Luxembourg imports electricity from other countries, such as France and Germany. France has a production electricity mix mostly consisting of nuclear, and Germany has a production electricity mix including great amounts of coal. When importing electricity from these countries, coal and nuclear becomes a part of Luxembourg's physical consumption electricity mix. The percentage bioenergy and wind power in the electricity mix increases too. The increase in wind- and bioenergy and the percentage nuclear and coal in the physical consumption mix makes the percentages of hydro and gas respectively 20 % and 32 % less in the physical consumption mix than in the physical production mix.

Austria's electricity mix change in accordance with the two methods of accounting for the electricity mix in a similar way as for Luxembourg. The imports from countries as France and Germany, leads to a higher percentage of coal and nuclear in the physical consumption mix than in the physical production mix. Coal and nuclear imports increases therefore the physical consumption mix with respectively 10 % and 8 % compared with the physical electricity mix.

The change in Switzerland's and Slovak Republic's electricity mix when accounting the mix on consumption basis instead of production basis, are mainly a larger amount of coal power in the electricity mix. Also power from gas increase for Switzerland, while the percentage of hydropower decrease. For Slovak Republic, the increase in coal power leads to a decrease of nuclear and hydro power in the electricity mix.

The change in Denmark's electricity mix differs from the countries mentioned above in such a way that the consumption of electricity from fossil fuels is less than the production of electricity from fossil fuels. This is primarily due to Denmark's import of electricity from Norway and Sweden. Denmark originally has no production of hydropower, but because import from Norway, more than 14 % of the physical consumed electricity is hydropower. Also nuclear power is introduced into the electricity mix when accounting on consumption basis. Due to the import from nuclear power producers, around 5 % of the consumed electricity comes from nuclear power.

The two other electricity mixes modeled and calculated in this thesis are residual attribute electricity mix and total attribute consumption electricity mix. The results for the electricity mix calculations can be seen in Figure 9.

When comparing the two attribute mixes, the overall difference is a larger amount of renewable energy technologies in the total consumption attribute mix than in the residual attribute mix. This difference comes from the inclusion of the explicit attributes in the total consumption mix, while these attributes are excluded from the residual mix. The biggest differences between the two electricity mixes are in Belgium, Finland and Netherland. For Belgium the renewable technologies increase from around a 10 % share to about a 30 % share in the total mix. In Netherland the residual renewable share is less than 1%, while for the total consumption the share has increased to 20 %. Finland has more than 10 % increase in the renewable share from residual to consumption based attribute calculations.

If the two attribute electricity mixes are compared to the two physical electricity mixes, the biggest difference between the physical and the attribute mix can be seen for Norway. For the physical electricity mixes the renewable share is over 90 % for both consumption based and production based mix. When calculating the attributes the renewable share is much smaller. The residual attribute mix has around a 50 % share of renewable energy technologies and the attribute consumption of renewable attributes is a little under 60 %, see Figure 9. The reason behind this is Norway's large export of renewable attributes, while the imports of the same type of attributes are very low. This makes Norway a net exporter of attributes and in order to cover all the Norwegian consumption with attributes, the country gets a lot of fictional import. The fictional imports are coming from the countries Norway exports attributes to, like Belgium, Germany, Netherland and Sweden. All these countries has a residual mix consisting of coal, gas and nuclear, and the fictional imports to Norway then contribute to a large amount of these technologies in Norway's attribute mixes.

For Finland the same trend as for Norway can be seen, just on a much smaller scale. Finland is also a net exporter of renewable attributes, and the fictional imports the country receives in order to cover the consumption, is from countries with a lot of gas in their residual mix. The sale of renewable attributes together with the fictional import with a lot of gas attributes, leads to a higher percentage fossil fuel and a lower percentage renewables in the attribute mixes than in the physical electricity mixes.

Denmark is also one of the net exporting countries of attributes. The differences in the electricity mix when using attribute mix instead of physical mix are, like for Norway and Finland mentioned above, less renewable share in the attribute mixes than in the physical mixes. This is because the share of coal and gas increases. In the physical consumption mix nuclear power and hydro power is a part of the mix because of physical imports from Denmark's neighbor countries. The attribute mixes also have a small share of nuclear and hydro power. This is because of the fictional import.

For Switzerland and Austria there are differences between the physical consumption and the attribute mixes, but the physical production mix and the attribute mixes do not differ much. The physical trade included in the physical consumption mix is the reason why these countries' electricity mix stands out from the others. For these countries the attribute trade, explicit and fictional, almost does not affect the electricity mix in the country, and the attribute mixes are almost equal to the production mixes. The countries have net import of explicit attributes, which give a small increase of the renewable share in the attribute consumption mix, but both countries produce more than they consume and their fictional export does not affect the overall mix.

If we look at Netherland, the renewable share of the attribute residual mix is less than the renewable share in both the physical electricity mixes. The reason for this is both fictional import and a small explicit export of attributes. The attribute consumption mix has the highest share of renewables of the four mixes, because of the inclusion of a large explicit import of renewable attributes.

Luxembourg's electricity mix changes a lot depending on the method of calculating the mix. There are two main reasons for the differences. The first is the countries shortage in electricity production compared to consumption. Luxembourg consumes almost twice as much electricity as the country produces, and this has a large influence on the consumption based electricity mixes. The physical consumption mix includes a large amount of physical import from other countries with a different electricity mix, as explained earlier. In both the attribute models, Luxembourg has large fictional import of attributes and this is the reason for the main differences between the attribute mixes and the physical mixes. The attribute consumption mix also includes the explicit import of renewable attributes which leads to a somewhat higher percentage of renewable technologies than in the residual mix.

6.2 Environmental Characteristics

The environmental characteristics of the electricity systems in the European countries are calculated combining life cycle impact data on global warming potentials, for each technology, to the technology mixes for each country. Environmental characteristics are found for all four electricity mixes; physical production; physical consumption; residual attribute; and attribute consumption electricity mix for each of the 23 counties in question. That means, the 23 countries each has four different global warming potentials, depending on the electricity mix chosen, see Table 9.

The environmental characteristic for the electricity mix in each country differ according to the technology mix. The countries that have the largest environmental impact values are Poland and Estonia, with impact values in range between 800 g CO_2-eq/kWh and 1000 g CO_2-eq/kWh, see Table 9. The same countries have the largest amounts of coal in their electricity mix, independent of electricity mix chosen. This explains the high impact values. Also countries such as Germany, Ireland, Netherland and United Kingdom have high global warming potentials, around 600 g CO_2-eq/kWh for all four countries. On the other end of the scale we have countries such as Switzerland, Sweden, Norway and France. Switzerland has the lowest impact, only about 20 g CO_2-eq/kWh, when looking at the attribute mixes and the production mix, while the impact from the physical consumption mix is much higher, 171 g CO_2-eq/kWh. When considering the physical consumption mix, Norway has the lowest impact. The emissions of CO_2-eq for the physical consumption in Norway are 44 g/kWh. When considering the attribute mixes, Norway gets impact values of over 200 g CO_2-eq/kWh, which is much higher. Sweden has a global warming potential between 60 g CO_2-eq/kWh and 90 g CO_2-eq/kWh and France has around 100 g CO_2-eq/kWh for all assessed electricity mixes. The countries responsible for the lowest emissions per kWh have electricity mixes consisting of a large amount of technologies with low life cycle impact. This might be renewable energy technologies, as for Norway, or nuclear power, as for France, or a combination of both, which are the case for Switzerland and Sweden.

[g CO_2-eq/kWh]	Physical production	Physical consumption	Attribute residual	Attribute consumption
Austria	227	334	226	220
Belgium	284	302	278	231
Czech Rep	644	674	591	591
Denmark	620	505	647	618
Estonia	983	878	929	929
Finland	387	405	462	407
France	99	106	97	96
Germany	569	555	563	532
Greece	747	719	716	716
Hungary	380	366	384	384
Ireland	622	620	614	614
Italy	514	461	500	492
Luxembourg	358	474	370	343
Netherland	604	578	659	538
Norway	28	44	283	233
Poland	979	955	971	971
Portugal	352	349	353	353
Slovak Rep	234	381	247	247
Slovenia	372	359	359	358
Spain	331	332	333	332
Sweden	70	88	91	80
Switzerland	20	171	20	19
UK	582	574	581	578

Table 9: Global warming potential in g CO_2-eq/kWh for 23 European countries and four different ways of calculating electricity mix

The differences between the environmental impacts depending on the method chosen for calculation of the electricity mix can be seen in Figure 10. The figure shows the relative difference between the attribute mixes and the physical consumption, the latter being basis for the comparison.

Figure 10: Percentage increase or decrease in global warming potential when calculating attribute electricity mixes relative to physical consumption mix

The difference between the attribute residual mix and the physical consumption mix is caused by the fictional attribute trade included in the attribute residual model and physical trade included in the physical consumption model. When looking at the residual mix compared to the physical consumption mix, the countries with the relative largest increase in environmental impact are countries with fictional import from countries with higher global warming potential than the countries in question. But the increase can also be reasoned by the physical import to those countries being from countries with low impact mixes, which lowers the impacts from the physical consumption. Some countries have a lower impact from the attribute residual mix than in the physical consumption mix. The main reason for this is the physical import included in the physical consumption. In these cases the physical import brings larger shares of high impact electricity sources into the electricity mix. Since this import is not included in the attribute model, the residual mix in these cases has lower impact.

The differences between the attribute consumption mix and the physical consumption mix is much like the differences explained above. The fictional attribute trade is included also in the attribute consumption model and this, together with the physical trade, is included in the physical consumption responsible for some of the differences in the same way as for the comparison of the attribute residual and the physical consumption mix. In addition to this, also explicit trade of attributes and the internal cancellation of attributes are included in the total attribute consumption. This leads to lower environmental impacts, due to the included additional renewable attributes.

For the countries exporting the most of the explicit attributes on the marked, it is typical with higher impact values for the attribute mixes than for the physical mix. This is because of sale of renewable attributes and fictional import from countries with a more polluting electricity mix. This can clearly be seen for Norway. Norway has the largest increase in global warming potentials when using attribute mix compared to physical electricity mix. The global warming potential when using the attribute residual mix is 545 % larger than the GWP for the physical production mix. When including the explicit attributes imported or internally cancelled, the difference is somewhat smaller. The difference between the GWP for attribute consumption and physical consumption is 430 %. The difference between GWP for physical and attribute electricity mix in Norway is bigger than for any other country.

Denmark and Finland are also net exporters of renewable attributes. These countries do also get higher values for global warming potential when using the attribute residual mix for calculation than when using the physical consumption mix. The percentage differences are 14 % and 28 % respectively for Finland and Denmark, see Figure 10.

Some of the large net importers of explicit attributes, like Germany, Netherland and Belgium have lower emissions when calculating for the attribute consumption mix versus the physical consumption electricity mix. This is because the imported attributes are from renewable energy sources with low global warming impacts. The decrease in global warming potential is 4 % for Germany, 7 % for Netherland and 23 % for Belgium.

Switzerland is the country with the largest decrease in global warming potential, as can be seen in Figure 10. The decrease in global warming potential is 88 %. Switzerland is one of the countries that are net importers of attributes and this is partly the reason behind the decrease. The other reason is the fact that the physical import to Switzerland consists of an electricity mix with higher environmental impacts than Switzerland's own mix. This leads to high impacts for the physical consumption mix.

Two other countries for which the inclusion of the physical trade in the physical consumption mix makes a large difference on the environmental impacts are Slovak Republic and Austria. Slovak Republic is the country with the second largest decrease in environmental impacts, see Figure 10, and Austria has the third largest decrease. Both countries have physical import that contributes to a higher share of coal in the countries' physical consumption mix and the global warming potential for the physical consumption mix is higher than for the attribute consumption mix. The difference is around 35 % and 34 % for respectively Slovak Republic and Austria.

Up until now the emissions and impacts have been looked at on a per kilowatt-hour basis. In addition, it is interesting to take the total amount of electricity into account in order to see which countries' electricity mix is having the biggest impacts. The total numbers for emitted CO_2 can be seen in Table 10. For the total CO_2-emissions for each electricity mix per country per technology, see Table 20 to Table 23 in Appendix 4.

Table 10 shows that independent of the way of counting the electricity mix, Germany is the biggest emitter of CO_2. The megatonnes of CO_2 emitted from Germany vary between 324 for the attribute consumption calculation and 352 for the physical production based calculation. United Kingdom has the second largest emissions. The variations between the different ways of counting are here insignificant. The biggest CO_2-emission is 223 Mt from the residual mix and the smallest is 220 Mt from the physical consumption.

On the opposite side we have Luxembourg and Switzerland. When it comes to Luxembourg the low numbers is explained by the low numbers for production and consumption of electricity. The CO_2-emissions are in range from 2 to 4 Mt. Switzerland's production and consumption, which is much higher than Luxembourg's, are in range with the production and consumption in Austria. The emissions nevertheless, are significantly lower. Because of the large share of renewable and nuclear energy in the electricity mix, Switzerland has low CO_2-emissions. For physical production and attribute consumption respectively, 1 Mt are emitted. The emission from the physical consumption is higher, 12 Mt, due to the imports of electricity from fossil fuel.

The largest internal differences can be seen for Norway. As explained earlier, the global warming potential for the Norwegian attribute mixes are substantially higher than the impact potential from the Norwegian physical electricity mixes. This is visible also when looking at the total emitted CO_2. The physical production mix contributes to the lowest emissions, which is 4 Mt. Looking at the attribute residual mix, Norway instead emits 33 Mt CO_2 per year.

[Mt CO_2-eq]	Physical production	Physical consumption	Attribute residual	Attribute consumption
Austria	16	22	15	14
Belgium	27	29	26	22
Czech Rep	55	49	43	43
Denmark	24	20	26	24
Estonia	13	12	13	13
Finland	31	37	43	38
France	57	58	53	53
Germany	352	337	343	324
Greece	46	48	48	48
Hungary	14	18	18	18
Ireland	18	18	18	18
Italy	153	158	171	169
Luxembourg	2	4	3	3
Netherland	69	69	79	64
Norway	4	5	33	27
Poland	154	148	151	151
Portugal	19	20	20	20
Slovak Rep	6	12	7	7
Slovenia	6	5	6	5
Spain	99	101	101	100
Sweden	11	14	14	12
Switzerland	1	12	1	1
UK	222	220	223	222

Table 10: Total amount of Mt CO2-eq emitted per year from each of the 23 European countries and the four different ways of calculating the electricity mix

7 DISCUSSION AND CONCLUSION

This study aimed at using different methodologies to calculate the electricity mixes in the European countries and their subsequent environmental footprints. Two models are developed for calculating the electricity mix. One physical model and one attribute model. The physical model calculates the electricity mix for the physical electricity consumption in a country. It is based on the energy balance between production and consumption and includes both physical imported and exported electricity. The attribute model is based on the attributes of the electricity and includes; generation of attributes; explicit trade of Guarantees of Origin; internally cancelled attributes; residual consumption; and fictional trade of attributes. The fictional trade is introduced to balance the available attributes and the physical consumption. The attribute model calculates two different electricity mixes; the attribute residual mix and the attribute consumption mix. The attribute residual mix is the electricity mix consumed without guarantees of origin. The attribute consumption mix is the electricity mix for the entire consumption in a country, including the residual mix and guarantees of origin. In order to develop environmental characteristics related to the electricity mix in the European countries, greenhouse gas (GHG) emissions were connected to the electricity mixes. Life cycle assessment was used as methodology, and global warming potentials from previous life cycle assessments were compiled for the ten technology categories included in this study.

The results show that the electricity mix of a country is strongly dependent on calculation method and model assumptions. The differences between the electricity mixes vary between the assessed countries, but there are some common features. In general the net exporters of certificates get a higher share of electricity from fossil and nuclear energy in their attribute mixes than in their physical mixes. This is because of fictional import from the countries importing the certificates. Because the certificates guarantee a renewable origin of production, the net importers of certificates have a higher share of renewable energy in their attribute consumption mix than in the physical mix. A common feature for all the countries was the higher share of renewable energy sources in the attribute consumption mix than in the attribute residual mix. This is due to the inclusion of renewable certificates in the attribute consumption mix. In addition, there are variations between the physical consumption mix and all the other electricity mixes because of the physical trade included in the physical consumption model.

For the environmental characteristics of the European countries, the results show that the total global warming potentials of the countries vary depending on the method of calculating the electricity mix. The countries being net exporters of certificates have higher GWP when it is calculated from the attribute mixes, than when it is calculated from the physical electricity mixes. On the other hand the net importers of certificates have in general lower calculated GWP based on consumed attribute mix. In addition it is seen that physical trade included in the physical consumption model influence the environmental characteristics. The relative difference between GWP based on different mixes is 0 - 50 % for most countries. For Norway it is seen that the GWP for the attribute mixes is 430 - 545 % higher than the GWP for physical mix. This shows that the choice of electricity mix is important in environmental evaluations.

The following part of this thesis will evaluate the results by discussing model characteristics, key assumptions and data quality. The models developed in this study and the subsequent results will be compared to other existing models and available literature. Then implications of the results and further strategies will then be discussed, before a conclusion is presented.

7.1 Internal evaluation

When calculating the electricity mix of the consumed energy in a country or domain it is important to avoid double counting. Several measures were taken with the purpose of avoiding double counting when developing the models in this study. The main measure was the linear energy balance equation between generation and consumption. By using this equation as starting point, the aspects of the electricity system are kept separated and clear. Each element of the equation consists of two terms. One parameter is describing the quantity electricity of attributes and one vector is describing the technology mix. The vector describing the technology mix of the quantities makes the model transparent and it is easy to follow the attributes through the equation and see which attributes follows each electricity flow or transaction. Another step taken in order to avoid double counting, and to make the model as realistic and good as possible, is to solve all the countries electricity mixes simultaneously. In the attribute model this is a necessity since all the countries' residual mixes are inputs for solving one country's residual mix.

One of the assumptions made in the development of the models was to keep attributes and physical power separated. This says that the main difference between the models is the inclusion of trade. The physical consumption model includes the physical traded electricity, while the attribute model includes financial trade of attribute certificates and no physical flows. This difference between the models is one of the reasons for the differences in the calculated electricity mixes. Another way of modeling the attribute model would have been to include the attributes of the physical traded electricity. This would have made the differences between the electricity mixes smaller, but it would have been harder to avoid double counting of attributes.

The attribute model developed in this thesis can be seen as a model for Electricity Disclosure in a country and used for calculation of residual mixes. If a model avoiding double counting was developed, the inclusion of both the physical trade and the certificate trade as explained above, would have resulted in a more favorable methodology for Electricity Disclosure. Not only the electricity mix, but also the environmental footprint of a country would be influenced by changing the model. For some countries it would have a greater impact than for others. For instance Switzerland would get a totally different result for the methodology including both physical and attribute trade, since the physical import has a large influence by bringing in large amounts of coal. This would have a negative effect on the environmental footprint of Switzerland because the country would get a higher global warming potential for the combined model compared to the attribute model. Denmark on the other hand would get a positive effect on its environmental footprint when using the combined model compared to the attribute model. The imports to Denmark bring larger shares of hydro power, with low GWP, into the country's electricity mix.

An important assumption in the attribute model is that the available attributes in a country and that country's physical consumption have to balance. There is no standard answer for how to do this, and therefore different models have different approaches. This study's attribute model used fictional trade. The thought behind the fictional trade in this model is that the countries exporting certificates get their fictional imports from the residual mix of the countries which import the certificates. By doing this, the countries importing certificates give their surplus attributes to the exporting countries. This is step one. In order to balance the available attributes and the consumption in all the countries, not only the ones trading certificates, a common pool of attributes is used in step two. This pool is filled by the surplus attributes of the countries still having more available attributes than they need to cover their consumption. As explained, the fictional trade balances available attributes and physical consumption. The available attributes of a country with no trade of certificates are the quantity and the technology mix of the physical electricity production. The fictional trade will then balance the production and the consumption of attributes. Also countries with no explicit trade of certificates will hence get fictional imports of attributes. They get the attributes from the attribute pool if they consume more than they produce, and are filling the pool with attributes if they produce more than they consume.

The main focus of this study has been the development of models for electricity mix calculations and environmental characteristics. The collection of trade data has mainly been done to provide numbers for the models. The credibility of the collected physical data is hard to evaluate since it is collected through the IEA. This data is therefore not evaluated any further. Most of the attribute data used in this study are gathered from Grexel and AIB as explained in chapter four. The data from the two sources are not always compatible.

Sometimes they are given in a manner which cannot be used as model input. Therefore assumptions were made and data were even manipulated in order to get appropriate inputs to the model. This can be seen as a possible source of errors. For the traded certificates, only the quantity exported and imported between countries was available. The origin of the certificates was not easily available and the attribute mixes traded were therefore assumed to be the same as the renewable attribute mix in the exporting country. More reliable data for attribute mix would have been preferable to make the analysis even more accurate. For the attribute data, the quality and reliability of the Norwegian data can be seen as the best. The Norwegian data for exported, imported and cancelled certificates is collected directly from the Issuing Body for Guarantees of Origin in Norway, Statnett. The collected data included the source of the attributes sold, which gave the opportunity to use accurate attribute mix for import and export. Since this kind of data was only available for Norway, the traded mixes were assumed as previously mentioned. It would have been optimal to have gotten data directly from the Issuing Bodies also for the other countries, and this is to be recommended in further studies.

The available data on cancelled EECS certificates, from AIB, do not align with the Grexel numbers on import. One of the attribute model assumptions is bilateral trade. In the model, cancelled certificates in a country equal the imported certificates plus the certificates which are both issued and cancelled internally. In reality, it is not evident that all the imported certificates are cancelled in the importing country. Some of the imported certificates can be exported from the importing country to another country. This is called re-export. In addition to that some of the imported certificates are being re-exported, some of them may never be cancelled. Another reason for uncertainty when it comes to the attribute data is the lack of a uniform system for certificates and Guarantees of Origin. The E-Track recommends that the GOs must be cancelled during the year after it is issued (Timpe, 2009). The recommendation is more or less adopted by several countries, but the standard recommendations are often arranged to fit the local legislations (NVE, 2012).

The environmental characteristics in this study are made combining life cycle assessment results to the electricity mixes. When investigating the environmental footprint of a process or system it is viewed as important to include the whole life cycle and not only the direct onsite emissions (Dotzauer, 2010). The electricity mixes contain ten technology categories, and GWP from previous LCA's are obtained for each of them. By distributing all the electricity on to ten categories, simplifications are done. The reality is more complex and for example the solar category is photovoltaic power and solar thermal power aggregated assuming a 50/50 share of the market. If this study should have had a higher level of accuracy, more technologies than included here could have been used. Another possibility would be to aggregate the GWP numbers for each category according to current statistics on technology shares in each country. The level of accuracy in this study is nevertheless seen as adequate because the LCA result for the technologies using the same source do not differ too much, as seen for wind energy in chapter five.

The GWP results used are seen as average for Europe and the same numbers are used for all the countries. By including country specific global warming potentials instead, an even more realistic environmental footprint could have been established. It is not possible to connect country specific data to the current models, because of the models output of the countries' electricity mixes and following connection to GWP. The GWP for electricity from coal power plants in Germany would then be used for the coal share in Germany's consumed electricity mix. This mix consists of coal imported (attributes or physical) from other countries in addition to production in Germany. The use of German GWP for coal would therefore not be optimal. The GWP used for the coal power share in Germany's mix should instead be a combination of the GWP for coal produced in the exporting countries in addition to the GWP for coal power in Germany. In order to include country specific GWP results proportionally to the percentage share originating from each of the countries, the GWP should initially be included in the model equations. Another way of doing it would be to give the mix of origin countries for each technology category in the electricity mix as an output from the models. The country specific GWP could then be combined to the shares of origin country and technology.

7.2 Model comparison

The attribute model can be used as a model for electricity disclosure and the methodology can calculate the residual mix of a domain. It is therefore relevant to compare this with residual mix calculations done in other studies. If we compare the three available methodologies; the attribute model in this study, the E-Track model and the Elforsk model, the three models have certain similarities and some discrepancies.

As already mentioned, an optimal residual mix calculation includes both physical trade and attribute trade. The making of a methodology, which includes both physical and attribute flows, without any errors like double counting of attributes are complicated. Simplifications have therefore been done in the making of the current methodologies. As for the attribute model in this study, the E-Track/RE-DISS model for residual mix calculation only include the financial trade of attributes and exclude the physical trade of power (Timpe, 2009). In opposition to the E-Track model and this study's attribute model, the methodology developed by Elforsk does include physical trade in addition to the financial attribute trade (Gode and Axelsson, 2009). The electricity mix of the exported physical electricity is said to be the production mix compensated for cancelled certificates. The electricity mix of the imports on the other hand, is the production mix in the exporting countries, not compensated for cancelled certificates. The cancelled certificates in a country are used internally in the exporting country and should therefore be taken out of the traded physical electricity mix. Because of this inconsistency in the Elforsk model, a double counting of renewable attributes occur. If Europe is seen as a closed system, as done in this study, the total amount in kWh of renewable attributes in Europe have to be equal to the total amount of kWh generated electricity from renewable energy sources. The double counting in the Elforsk model will lead to a larger share of renewable attributes disclosed for Europe as one, than the corresponding share of European generation of physical electricity from renewable sources.

The methodologies for residual mix calculations have different ways of balancing the available attributes and the physical consumption. The model developed in this study use fictional trade in order to balance the available attributes and the consumption, as explained in chapter three and discussed previously in this chapter. The two models described in chapter two have other ways of balancing the available attributes to the consumption than the attribute model developed in this study. The E-Track/RE-DISS model uses a common pool as explained in chapter two (Timpe, 2009). The pool is filled by attributes from countries with more available attributes than they need to cover their consumption. All these attributes together make up the European attribute mix. The countries in need of attributes get these attributes from the European attribute mix. The Elforsk model has another way of treating fictional trade (Gode and Axelsson, 2009). As already mentioned, this model includes the physical trade, and the physical trade balances the production and the consumption. If the certificate trade is excluded, the country in question already has enough attributes to cover the consumption in the country. For that reason the fictional trade only needs to balance the trade of certificates, and not the generation and consumption. The Elforsk model introduce compensation for the exported certificates equal to the amount exported, and compensation for the imported certificates equal the amount imported. The compensation for the imported certificates are subtracted from the country's attributes, the mix being the country's production mix minus cancelled certificates. The compensation for the exported certificates are added to the country's attributes, the mix being the production mix in the importing countries, still including cancelled certificates. As for the physical trade explained above, this leads to double counting of renewable attributes.

The attribute model in this study includes all EECS certificates, including GO and RECS, as explicit tracking of attributes. It is the EECS certificate trade which is considered as explicit attribute trade and cancelled EECS certificates are the only consumed attributes excluded from the residual mix. The Elforsk model on the other hand, includes fewer certificates. Only GOs are included in their model (Gode and Axelsson, 2009). The E-Track model includes other reliable tracking systems and contract based tracking, explained in chapter two, in addition to EECS certificates (Öko-Institut, 2010). The inclusion of certificates other than GOs, contract based tracking and other reliable tracking systems, increases the explicit tracking of attributes for disclosure. As mentioned in chapter two, it is advisable to have as high level as possible of explicit tracking and to limit the use of implicit tracking to a necessary level (Timpe, 2009). As the situation is today, the E-track model for Electricity Disclosure have higher share of explicit tracking, and is in this sense more reliable and transparent than the other two models. As mentioned in chapter two it is seen that the GOs gradually are replacing the RECS certificates (RECS, 2012). In addition there are plans to expand the GO system to other types of attributes, like fossil of nuclear (Timpe, 2010). In future calculations it will therefore probably be enough to include GOs for explicit tracking of attributes.

Another assumption in the models developed in this study is that one domain, equals one country. Every country is looked upon individually. It is the country's own production and production mix and that country's trade and consumption that are used as model inputs and the country specific residual and consumption mixes are the output. This is in accordance with the Electricity Disclosure system in Norway. Norway is treated as one individual domain and the residual mix is calculated based on Norwegian production, consumption and trade of certificates (NVE, 2012). The domain does not have to be a country, but can be several countries in a region or only part of a country. The E-Track/RE-DISS model uses each nation as a domain as a default, as done in this study. The RE-DISS recommendations, however, suggests the use of regional domains in the cases where electricity markets of several countries are closely integrated (RE-DISS, 2011a). According to RE-DISS the Nordic region is one such region that could have a common regional residual mix. Raadal agrees with the RE-DISS recommendation and argues for the use of regional domains. She says the Nordic region should be one domain because it harmonizes with the physical electricity trade market (2011). In Belgium, instead of disclosing the electricity for the country as one, the country is divided into three domains which results in three Electricity Disclosures (RE-DISS, 2011b).

The electricity mixes in this study shows the share of ten different energy sources, or technology categories, as previously called it, in the electricity mix. This gives a level of detail not given in any other model for electricity disclosure. The E-Track model and the Elforsk model both use only three energy source categories, and distribute all the electricity to the three categories (Timpe, 2009; Gode and Axelsson, 2009). Different electricity production technologies have different environmental emissions. When it comes to the disclosure of the emissions, associated with the electricity mix, the disclosed emissions will be closer to the actual emissions the higher the level of detail. This means that by including more technology categories, the more specific emission details are calaulated. In this sense the model developed in this study can be said to be more accurate than other models.

The EU Directive 2009/72/EC states that at least CO_2-emissions and volumes of radioactive waste shall be included in Electricity Disclosures (EU, 2009b). This study only includes environmental characteristic associated with climate change. LCA global warming potentials are used when calculating the emissions associated with the electricity mix in this study. This includes the CO_2-emissions and other greenhouse gas emissions related to the process of delivering electricity to the market. RE-DISS does not take the whole life cycle into account, but uses national onsite CO_2-emissions in their calculations of European residual mixes (RE-DISS, 2012a). The RE-DISS recommendations are adapted by many countries and so the emission factors in most national Electricity Disclosures are actually CO_2-emissions from the production facility. This will picture the electricity system more environmentally friendly than it actually is. It is important that the whole production chain is considered when calculating emissions (Dotzauer, 2010). For disclosure of the consumed electricity, it is important that the emissions also cover the transmission from electricity producer to consumer. Life cycle impact data on global warming potential should therefore be to ensure that the total emissions associated with the electricity consumption are included in the disclosures (Raadal and Svanes, 2012).

The differences between the models are reflected in the calculated electricity mix. The results in this thesis are calculated from data valid for 2010. If the attribute residual mix for Norway calculated in this study is compared to the residual mix calculated by the RE-DISS project for 2010, it can be seen from Figure 11 that there are substantial differences.

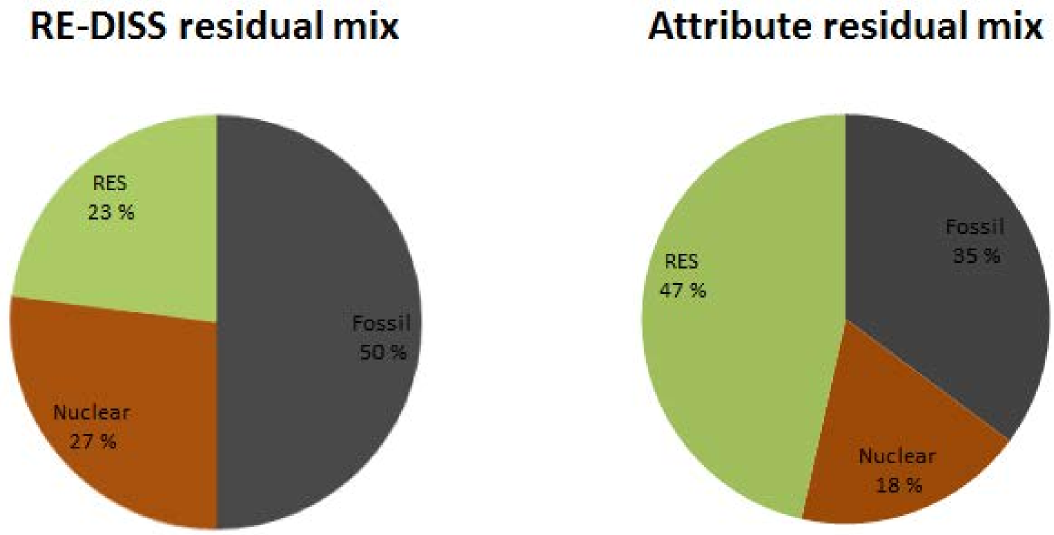

Figure 11: Norwegian residual mix for 2010. Result from the RE-DISS model and the attribute model developed in this thesis, the attribute residual mix is merged into three categories to facilitate comparison (RE-DISS, 2012b).

The reasons for the differences are the inconsistencies between the models as explained above. The Norwegian CO_2-emissions calculated by RE-DISS were 380 g/kWh. This study calculated the global warming potential for the Norwegian attribute mix to be 283 g CO_2-eq/kWh. The difference in emissions is mainly reasoned by the differences in the calculated electricity mix. The RE-DISS residual mix has a 50 % share of electricity from fossil fuel, while the residual mix calculated in this study only has 35 % share of electricity from fossil fuel. The differences between the residual mixes and environmental impact in the two models show the importance of having a common standard used in all countries.

7.3 Implications

The results show that the choice of electricity mix and calculation method influences the environmental performance of electricity significantly. These results are highly relevant with regards to climate mitigation tools and incentives. Today there is no common standard for the choice of electricity mix or the methodologies for calculating the mixes or emissions. To achieve a uniform understanding of a country's electricity mix and emissions, one possible solution is to use the attribute approach whenever an electricity mix is needed. With the current regulative developments, regarding Directives and standards, this is seen as the future path of development (EU, 2009a; EU 2009b; GHG Protocol, n.d.; Raadal, 2011b; BSI, 2011).

With increased consumer awareness, informed consumer choices can be taken regarding the desired electricity mix. This can be valuable in order to achieve a more climate friendly electricity sector. The share of energy sources should be displayed to enable the customers to take the most environmental friendly choices. The current practice of disclosing the attributes of the consumed electricity does not inform the consumers of what physical electricity mix they get in their contact plugs. It is about the consumed mix of attributes the customers get information. Consumers can thus take environmental friendly choices based on the attribute mix of electricity. They can choose to buy electricity which is guaranteed, by use of GOs, to be 100 % from renewable sources. A possible outcome is that the consumers feel they use clean energy and no longer have to reduce their electricity consumption to reduce their environmental footprint. On the other side, the electricity stated as renewable using Guarantees of Origin will be more expensive, because of the cost of buying the GOs. This extra cost will give the consumers an incentive to reduce their consumption in order to save money. The consumers buying electricity with renewable attributes will maybe not have environmental reasons to reduce their consumption, but they will have financial reasons. The customers, who do not by electricity guaranteed renewable with the use of GOs, consume the residual mix. The renewable certificates are excluded from this mix and the residual attribute mix will in most cases therefore be less environmentally friendly than the physical electricity they get in their plugs. The informed attribute residual mix will give the consumers even more reason to reduce their consumption of electricity than if they got information about the physical mix.

An important aspect of disclosing the attributes of electricity is that the practice must be the same everywhere. As the situation is today, the information to the customers is insufficient. In Norway we produce electricity almost entirely from hydro power and this is the Norwegian customers aware of. They feel they consume environmental friendly electricity. In the calculated attribute residual mix, the share of hydro power is below 40 % and this is what the customers need to know. The suppliers are required to inform their customers of the attribute mix of the electricity they buy. The level of this information that reaches the customers however is insufficient. As of today, both the customers in Norway and the customers in the countries the attribute certificates are exported to, feel they consume clean energy. The total amount of customers with an incentive, environmental or financial, to reduce their use of electricity is therefore too low.

The attribute certificates have the purpose of explicitly tracking the attributes for disclosure of the attribute electricity mix. The certificate system also works as an incentive for producers of electricity to produce more electricity from renewable energy sources. By selling their renewable attributes, they get income in addition to the physical electricity price received. In order to reduce the GHG emissions from the electricity sector, a change in the mix of energy sources is required. Combustion of fossil fuels with high carbon content needs to be phased out and renewable energy sources have to take on a bigger share of the electricity mix. The renewable certificates can drive the electricity production towards a higher share of renewable energy. In order for both producer and society to benefit from increased renewable production, it is important that the required infrastructure is in place. The transition to renewable energy technologies can create problems because of the unpredictable and fluctuating electricity production, for example from wind farms or photovoltaic installations.

In the electricity system the supply of electricity has to equal the demand at all times. The demand varies during the day and the supply has to vary accordingly. Electricity production from traditional sources, like coal, gas, nuclear and hydro, can be controlled to cover the demand. Gas and hydro power has short response time and are often used to cover peak loads. Coal and nuclear has longer response time and are used to cover the base load of the demand. The electricity production from fluctuating renewable energy sources cannot be controlled in the same way as the traditional power plants. Another characteristic of the electricity system is the transmission grids that limit the transportation distance of the electricity. The grid capacity is limited and bottlenecks occur wherever the capacity is too small. The supply of electricity in one area should therefore more or less equal the demand in the same area. The attribute approach and the renewable certificates can result in more renewable production of electricity. A possible negative cause of the attribute approach is that renewable production plants are built for the main reason of producing renewable attributes. It is also important that it fits into the existing physical electricity system. Both the supply/demand balance and the limiting transmission grids need to be taken into account when building new renewable capacity. The production facilities have to be built where there is transmission capacity and where the renewable production will fit into the supply/demand balance in terms of peak and base load.

Demand side management through load shifting, and a development of the transmission grids towards smart grids and super grids can enable a larger share of the electricity mix being from renewable sources. The principle of demand side management is to vary the demand to fit the supply instead of the traditional way of varying the supply to fit the demand. By shifting the time of the load, the peaks in demand for electricity can occur when the fluctuating renewable electricity production is high. Smart grids and smart meters can enable a centralized control of the load shifting. Because of the limitations in the transmission grids the load shifting should happen in the same region as the renewable production is localized. In order to control the system so that the load shifting can happen in the right places at the right time, it is therefore necessary to use the physical electricity mix. The attribute approach will in this sense present the wrong picture of the electricity system.

Another aspect regarding Demand Side Management is how to calculate the environmental gains from energy efficiency. Energy efficiency measures are taken on the consumer side of the electricity system. The actual reduction in emissions is a result of the decreased physical consumption. The actual environmental gain for a specific energy efficiency measure is therefore calculated from the physical consumption mix. If the attribute mix is used for the calculation this will not display the actual emission reduction. Let us say a factory buys electricity with guarantees of origin. The physical electricity the factory consumes, on the other hand, is produced in a coal power plant. The factory changes its equipment to become more energy efficient. If the attribute mix is used to calculate the environmental gains from the reduced electricity consumption, the gains will be much smaller than the actual environmental gains from the reduced consumption. Because of small environmental gains from energy efficiency when buying electricity with guarantees of origin, the energy efficiency measure might not be implemented at all. It can hence be argued that the attribute mix should not be used in these types of calculations. On the other hand, consumers that do not buy electricity with guarantees of origin will have an attribute mix that has higher environmental footprint than the physical consumed electricity. When applying energy efficiency, the environmental gains for these consumers will be higher when calculated from the attribute mix compared to physical consumption mix. These consumers will therefore have higher reasons to implement energy efficiency measures when using attribute mix. Because of this, it can be argued that the total environmental gains for energy efficiency measures are the same, whether or not the gains are calculated from the attribute or physical consumed electricity mix. It also needs to be mentioned that implementing energy efficiency has financial reasons in addition to environmental reasons. If a customer buys electricity with guarantees of origin, the electricity will be more expensive. The financial reason to reduce consumption by applying energy efficiency measures is therefore higher when consuming electricity with guarantees of origin.

When setting targets for a country’s emissions, as done in the Kyoto Protocol, it is the emissions from the physical production that is targeted. This gives the countries an incentive to increase their own electricity production with low environmental footprint and decrease their electricity production with high environmental impact. If the attribute approach was to become the standard for all electricity mix calculations, a country’s environmental footprint would be depending on the amount of guarantees of origin cancelled in that country. The guarantees of origin cancelled in a country can be acquired in two ways; they can be issued in the country itself proportional to the renewable production in the country, or they can be imported from other countries. A country could therefore improve its environmental footprint by importing certificates. The countries would have an easy way of improving its footprint without actually doing any physical improvements, like energy efficiency or increase renewable production. This would be an easy way for rich countries to meet emission reduction targets, and could result in the richest countries getting richer and the poorest countries getting poorer. In the poorer countries, the GOs might be exported out of the country for financial reasons. The countries might not meet their targets and hence have to pay sanctions.

A similar situation could also be the case for companies. Companies could buy electricity with GOs to reduce their environmental impacts. Companies often have financial reasons, such as current regulations or marketing opportunities, to reduce their environmental impacts. By buying electricity with GOs, the companies can reduce their environmental impact, depending on the impacts being calculated using a life cycle perspective. This could possibly lead to rich companies getting richer on behalf of others. To offset this effect, the extra price for buying electricity with GOs would have to be the same as the opportunity cost of not reducing environmental impacts.

When compiling a Life Cycle Assessment, electricity is one of the inputs in almost every products or process' life cycle. The choice of electricity mix is therefore highly relevant with regard to calculations of environmental footprints. The aim when compiling an LCA is to describe the physical reality as closely as possible (Dones et al. 1998). The electricity inputs should therefore describe the physical consumed electricity. The attribute electricity mix does not describe the physical consumption and is therefore not suited in LCAs. If the attribute approach was to become the standard for all electricity mix calculations, it would influence LCA evaluations greatly. An LCA can be used to find the "hot spots" in a production chain. This makes it possible to implement measures that will reduce environmental impacts were you can get the highest environmental gains. If a product is produced with an electricity input produced from coal, then reducing the impacts from the electricity input will reduce the overall impact of the product. An attribute electricity mix will not give the actual physical emissions associated with the electricity use. If the electricity is said to be renewable, the electricity input to the product will get low calculated impacts and there will be no reason to implement any measures, like installing heat pumps or photovoltaic cells, to reduce it any further. This could lead to lost opportunities for reducing environmental impact. In other cases, the attribute mix might show higher environmental impacts from the electricity inputs of a product than what is the physical reality. In these cases mitigation measures might be implemented even though the actual environmental gain is low. Using an attribute mix in process life cycle assessments, can hence lead to decreasing the total environmental gains of mitigation measures. The process LCA only analyses emissions. If a hybrid analysis was used for evaluation instead the cost of the electricity would have been displayed in addition to the environmental impacts. The cost of electricity with guarantees of origin are higher than the cost of electricity residual mix and this would be a reason to implement measures like installing heat pumps and photovoltaic cells. This could help to offset the negative effect of using an attribute mix for environmental evaluations.

7.4 Conclusion

The electricity system is complex and consists of production, consumption, physical power trade and financial trade of certificates. This makes it hard to achieve a uniform understanding of a country's electricity mix. Today, there is no common standard for how to calculate the electricity mix of a country. The electricity mix is calculated using different approaches for different purposes.

The results of this study show that the share of energy sources in a country's electricity mix is depending on chosen calculation method and model assumptions. The different models for calculating the electricity mix in some cases give completely different results. There are large variations in the environmental impacts associated with different electricity generation technologies and systems. Therefore the environmental impacts of a country differ significantly according to the electricity mix chosen for the evaluation.

The current regulative developments seems to be working in the direction of establishing a common standard for the use of an attribute approach, including guarantees of origin certificates, for calculating the electricity mix for all purposes. If attribute mix was to become the electricity mix used for all purposes, it would be important to have a consistent system. This means a common standard for the calculation of the attribute mix used by all countries. Regional variations or an inaccurate model, can lead to double counting of attributes. In the attribute model developed in this study, a linear energy balance and fictional trade were used for the purpose of avoiding double counting. One way of increasing the reliability of the system would be to expand the use of GOs to cover other types of attributes, like fossil and nuclear. This would increase the share of explicitly tracked attributes and hence the reliability.

Such a system would be hard to implement in all countries with same level of accuracy. In addition, the attribute approach can have negative effects, like decreasing total environmental gains from climate mitigation measures or building of production sites for renewable energy without the required infrastructure. For these reasons the best option regarding choice of electricity mix is assessed to be a continued use of different calculation methods for different purposes. This is the recommended practice at least until a standard methodology for attribute mix is well established. The aim should be to develop practices and methods which facilitate the use of different approaches. As a way of doing this the different methods should be made compatible with each other. There is also a need for a higher level of information to the customers. This is important in order to increase the harmonized understanding of the electricity mix and its subsequent environmental impacts.

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9 APPENDICES

This chapter includes all electricity production and trade data that is not included in the other chapters. The resulting electricity mixes for the 23 countries is given for each electricity mix and the total GHG emissions are also included.

9.1 Appendix 1: Physical trade data

In this appendix the physical electricity data that are not included in the main report can be found. This includes physical export and import, total production distributed to energy source and renewable production distributed to energy source.

E\I	AT	B	CZ	DK	EE	FI	FR	DE	GR	HU	IR	IT	LU	NL	NO	PL	PT	SK	SI	ES	SE	CH	UK
Austria	-	-	-	-	-	-	-	8356	-	1392	-	1192	-	-	-	-	-	-	3584	-	-	8886	-
Belgium	-	-	-	-	-	-	6611	-	-	-	-	-	906	3772	-	-	-	-	-	-	-	-	-
Czech Republic	6856	-	-	-	-	-	-	8685	-	-	-	-	-	-	-	129	-	6555	-	-	-	-	-
Denmark	-	-	-	-	-	-	-	6411	-	-	-	-	-	-	1452	-	-	-	-	-	2310	-	-
Estonia	-	-	-	-	-	1785	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Finland	-	-	-	-	135	-	-	-	-	-	-	-	-	-	126	-	-	-	-	-	2959	-	-
France	-	1832	-	-	-	-	-	10612	-	-	-	11939	-	-	-	-	-	-	-	3942	-	8473	6524
Germany	1195	-	-	3598	-	-	1432	-	-	-	-	-	5116	8867	-	5616	-	-	-	-	1128	13433	-
Greece	-	-	-	-	-	-	-	-	-	-	-	2192	-	-	-	-	-	-	-	-	-	-	-
Hungary	238	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85
Italy	-	-	-	-	-	-	589	-	311	-	-	-	-	-	-	-	-	-	52	-	-	576	-
Luxembourg	-	1867	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Netherland	-	5787	-	-	-	-	-	3509	-	-	-	-	-	-	1215	-	-	-	-	-	-	-	-
Norway	-	-	-	3828	-	112	-	-	-	-	-	-	-	2813	-	-	-	-	-	-	7114	-	-
Poland	-	-	7095	-	-	-	-	134	-	-	-	-	-	-	-	-	-	2337	-	-	254	-	-
Portugal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2801	-	-	-
Slovak Republic	-	-	-	-	-	-	-	-	-	6001	-	-	-	-	-	62	-	-	-	-	-	-	-
Slovenia	468	-	-	-	-	-	-	-	-	-	-	6772	-	-	-	-	-	-	-	-	-	-	-
Spain	-	-	-	-	-	-	2343	-	-	-	-	-	-	-	-	-	7596	-	-	-	-	-	-
Sweden	-	-	-	3782	-	1855	-	967	-	-	-	-	-	-	2634	1394	-	-	-	-	-	-	-
Switzerland	24	-	-	-	-	-	4182	3184	-	-	-	24975	-	-	-	-	-	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-	3360	-	-	-	939	-	-	-	-	-	-	-	-	-	-	-	-

Table 11: Physical trade between European countries, rows represent export and columns import, in GWh.

	Coal	Gas	Oil	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	6,3	14,5	-	-	38,6	2	8,2	-	-	-
Belgium	7,8	31,1	0,3	47,9	1,7	1,3	5,4	0,8	-	-
Czech Republic	50,2	1,1	0,2	28	3,4	0,3	2,2	0,6	-	-
Denmark	16,9	7,9	0,8	-	0	7,8	5,1	-	-	-
Estonia	11,6	0,3	-	-	0	0,3	0,7	-	-	-
Finland	21,3	11,1	0,6	22,8	12,9	0,3	11	-	-	-
France	26,5	26,2	6,3	428,6	68	9,6	6,4	0,7	-	0,5
Germany	270,5	84,5	7,5	140,6	25,9	36,5	40,4	12	-	-
Greece	27,4	16,5	7,7	0,1	7,5	2,1	0,2	-	-	-
Hungary	6,3	11,6	0,5	15,8	0,2	0,5	2,5	-	-	-
Ireland	6,8	17,3	0,6	-	0,7	2,8	0,2	-	-	-
Italy	41,6	153,8	21,5	-	53,8	8,4	11,3	1,6	5,4	-
Luxembourg	-	2,9	-	-	1,5	0,1	0,1	-	-	-
Netherland	25,2	71,3	1,3	4	0,1	4	8,6	0,1	-	-
Norway	0,1	4,9	-	-	117,9	0,9	0,4	-	-	-
Poland	138,3	4,8	2,9	-	3,5	1,7	6,5	-	-	-
Portugal	7,2	14,8	2,3	-	16,5	9,1	2,7	0,2	0,2	-
Slovak Republic	4,2	1,9	0,6	14,6	5,6	-	0,5	-	-	-
Slovenia	5,3	0,5	-	5,7	4,7	-	0,2	-	-	-
Spain	26,1	93,4	16,5	61,8	45,3	43,7	4,7	6,6	-	-
Sweden	3,5	4,3	2,7	57,6	71,5	3,5	9,9	-	-	-
Switzerland	-	0,8	0,1	26,7	37,8	-	2,8	0,1	-	-
United Kingdom	109,8	175,5	3,4	62,1	6,7	10	13,7	-	-	-

Table 12: Total electricity production for each country and technology, in TWh.

	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean	Total RES
Austria	38,6	2,0	8,2	0,0	0,0	0,0	48,8
Belgium	1,7	1,3	5,4	0,8	0,0	0,0	9,2
Czech Rep	3,4	0,3	2,2	0,6	0,0	0,0	6,5
Denmark	0,0	7,8	5,1	0,0	0,0	0,0	12,9
Estonia	0,0	0,3	0,7	0,0	0,0	0,0	1,0
Finland	12,9	0,3	11,0	0,0	0,0	0,0	24,2
France	68,0	9,6	6,4	0,7	0,0	0,5	85,2
Germany	25,9	36,5	40,4	12,0	0,0	0,0	114,8
Greece	7,5	2,1	0,2	0,0	0,0	0,0	9,8
Hungary	0,2	0,5	2,5	0,0	0,0	0,0	3,2
Ireland	0,7	2,8	0,2	0,0	0,0	0,0	3,7
Italy	53,8	8,4	11,3	1,6	5,4	0,0	80,5
Luxembourg	1,5	0,1	0,1	0,0	0,0	0,0	1,7
Netherland	0,1	4,0	8,6	0,1	0,0	0,0	12,8
Norway	117,9	0,9	0,4	0,0	0,0	0,0	119,2
Poland	3,5	1,7	6,5	0,0	0,0	0,0	11,7
Portugal	16,5	9,1	2,7	0,2	0,2	0,0	28,7
Slovak Rep	5,6	0,0	0,5	0,0	0,0	0,0	6,1
Slovenia	4,7	0,0	0,2	0,0	0,0	0,0	4,9
Spain	45,3	43,7	4,7	6,6	0,0	0,0	100,3
Sweden	71,5	3,5	9,9	0,0	0,0	0,0	84,9
Switzerland	37,8	0,0	2,8	0,1	0,0	0,0	40,7
UK	6,7	10,0	13,7	0,0	0,0	0,0	30,4

Table 13: Renewable electricity production for each country and technology, in TWh.

9.2 Appendix 2: Attribute data

E\I	AT	B	CZ	DK	EE	FI	FR	DE	GR	HU	IR	IT	LU	NL	NO	PL	PT	SK	SI	ES	SE	CH	UK
Austria	-	-	-	-	-	-	-	39090	-	-	-	-	-	-	500000	-	-	-	-	-	-	-	-
Belgium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Czech Republic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Denmark	-	685000	-	-	-	610200	-	-	-	-	-	-	-	327348	1232772	-	-	-	-	-	-	11480	-
Estonia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Finland	832000	8532399	-	152702	-	-	-	450134	-	-	-	610334	-	4326370	1879583	-	-	-	-	-	219791	170001	-
France	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Germany	7513	30000	-	-	-	6440	-	-	-	-	-	-	141775	40000	502636	-	-	-	-	-	261000	139203	-
Greece	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hungary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Italy	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Luxembourg	-	-	-	-	-	-	-	14916	-	-	-	-	-	-	11709	-	-	-	-	-	-	-	-
Netherland	-	-	-	8000	-	230527	-	5000	-	-	-	-	6929	-	17500	-	-	-	-	-	21460	-	-
Norway	-	8105285	-	984458	-	6102654	983411	29832924	-	865	-	877871	330484	5698984	-	-	64	-	-	233	19602023	1851073	1896593
Poland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Portugal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slovak Republic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	500000	-	-	-	-	-	-	-	-
Sweden	-	75000	-	209824	-	2334526	-	2316786	-	-	-	20000	-	1515346	3518182	-	-	-	-	-	-	-	-
Switzerland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	10142	-	-	-	-	-	-	-	-
United Kingdom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 14: Trade of EECS, in MWh.

	EECS cancelled	Import	Issued and cancelled internally	Export
Austria	1948056	839513	1108543	539090
Belgium	17427684	17427684	-	-
Czech Rep	-	-	-	-
Denmark	1354984	1354984	500000	2866800
Estonia	-	-	-	-
Finland	9284347	9284347	2000000	17173314
France	5421017	983411	4437606	-
Germany	32658850	32658850	2300000	1128567
Greece	-	-	-	-
Hungary	865	865	-	-
Ireland	-	-	-	-
Italy	5678056	1508205	4169851	-
Luxembourg	452563	479188	200000	26625
Netherland	23418632	11908048	11510584	289416
Norway	21606111	8172524	13433587	76266922
Poland	-	-	-	-
Portugal	5906	64	5842	-
Slovak Rep	-	-	-	-
Slovenia	35681	-	35681	-
Spain	1090857	233	1090624	500000
Sweden	20104274	20104274	800000	9989664
Switzerland	2171757	2171757	50000	10142
UK	1896593	1896593	-	-

Table 15: Certificates cancelled, in total and issued internally, import and export of certificates, in MWh.

9.3 Appendix 3: Fictional trade

	AT	B	CZ	DK	EE	FI	FR	DE	GR	HU	IR	IT	LU	NL	NO	PL	PT	SK	SI	ES	SE	CH	UK
Austria	0	0	0	38132	0	647867	0	0	0	322906	38542	2031802	177516	8676	91551	0	216404	127677	0	0	381742	0	85609
Belgium	0	0	0	690662	0	4700512	0	0	0	695409	83004	4375674	382296	18686	6536948	0	466047	274963	0	0	822116	0	184367
Czech Republic	0	0	0	153420	0	965202	0	0	0	1299199	155073	8174861	714226	34909	368350	0	870693	513701	0	0	1535921	0	344444
Denmark	0	0	0	0	0	74878	0	0	0	0	0	0	0	0	770023	0	0	0	0	0	0	0	0
Estonia	0	0	0	16731	0	105260	0	0	0	141684	16911	891508	77890	3807	40170	0	94953	56022	0	0	167500	0	37563
Finland	0	0	0	542091	0	0	0	0	0	0	0	0	0	0	4773369	0	0	0	0	0	0	0	0
France	0	0	0	253698	0	1596074	0	0	0	2148376	256431	13518080	1181056	57727	1378314	0	1439791	849464	0	0	2539823	0	569577
Germany	0	0	0	174887	0	1320975	0	0	0	1480980	176770	9318667	829075	39794	23754581	0	992518	585577	0	0	1750823	0	392637
Greece	0	0	0	19074	0	119996	0	0	0	161520	19279	1016320	88794	4340	45794	0	108247	63865	0	0	190950	0	42822
Hungary	0	0	0	0	0	0	0	0	0	0	0	0	0	0	677	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	299278	0	0	0	0	0	0	0	0	686652	0	0	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0	0	258498	0	0	0	0	0	0	0	0
Netherland	0	0	0	290810	0	2121444	0	0	0	0	0	0	0	0	4457627	0	0	0	0	0	0	0	0
Norway	0	0	0	1095174	0	921657	0	0	0	0	0	0	11709	0	0	0	0	0	0	0	0	0	0
Poland	0	0	0	26557	0	167076	0	0	0	224891	26843	1415067	123632	6043	63761	0	150717	88922	0	0	265868	0	59623
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0
Slovak Republic	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovenia	0	0	0	36545	0	229913	0	0	0	309472	36939	1947270	170130	8315	87742	0	207401	122365	0	0	365860	0	82047
Spain	0	0	0	27338	0	171992	0	0	0	231507	27633	1456698	127270	6221	65819	0	155151	91538	0	0	273689	0	61377
Sweden	0	0	0	0	0	107775	0	0	0	0	0	0	0	0	15332294	0	0	0	0	0	0	0	0
Switzerland	0	0	0	26597	0	186527	0	0	0	138866	16575	873778	76341	3731	1487242	0	93065	54907	0	0	164168	0	36816
United Kingdom	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1483476	0	0	0	0	0	0	0	0

Table 16: Fictional trade, in MWh.

9.4 Appendix 4: Result graphs and tables

9.4.1 Electricity mixes

	Coal	Oil	Gas	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	20,7 %	0,2 %	17,4 %	7,9 %	40,4 %	3,1 %	9,8 %	0,4 %	0,0 %	0,0 %
Belgium	8,7 %	0,4 %	34,2 %	46,4 %	2,5 %	1,5 %	5,6 %	0,8 %	0,0 %	0,0 %
Czech Rep	60,7 %	0,4 %	2,0 %	29,1 %	4,1 %	0,4 %	2,7 %	0,6 %	0,0 %	0,0 %
Denmark	35,7 %	1,8 %	16,6 %	5,7 %	14,0 %	15,3 %	10,7 %	0,2 %	0,0 %	0,0 %
Estonia	77,1 %	0,0 %	8,1 %	4,4 %	4,2 %	1,8 %	4,4 %	0,0 %	0,0 %	0,0 %
Finland	27,8 %	0,7 %	15,5 %	27,0 %	17,0 %	0,4 %	11,7 %	0,0 %	0,0 %	0,0 %
France	4,9 %	1,1 %	5,3 %	73,4 %	12,0 %	1,7 %	1,2 %	0,1 %	0,0 %	0,1 %
Germany	42,4 %	1,2 %	13,7 %	23,2 %	5,3 %	5,8 %	6,5 %	1,8 %	0,0 %	0,0 %
Greece	42,8 %	11,1 %	27,3 %	2,3 %	13,1 %	3,0 %	0,3 %	0,0 %	0,0 %	0,0 %
Hungary	17,4 %	1,3 %	27,6 %	40,7 %	6,1 %	1,1 %	5,7 %	0,0 %	0,0 %	0,0 %
Ireland	24,1 %	2,1 %	60,4 %	0,5 %	2,4 %	9,6 %	0,8 %	0,0 %	0,0 %	0,0 %
Italy	13,2 %	6,4 %	45,2 %	6,1 %	20,9 %	2,5 %	3,7 %	0,5 %	1,6 %	0,0 %
Luxembourg	26,4 %	0,7 %	31,0 %	18,4 %	12,8 %	4,3 %	5,1 %	1,2 %	0,0 %	0,0 %
Netherland	22,7 %	1,1 %	56,3 %	6,3 %	2,7 %	3,5 %	7,2 %	0,2 %	0,0 %	0,0 %
Norway	1,0 %	0,1 %	4,8 %	1,0 %	91,4 %	1,0 %	0,7 %	0,0 %	0,0 %	0,0 %
Poland	85,2 %	1,8 %	3,5 %	1,2 %	2,7 %	1,3 %	4,2 %	0,1 %	0,0 %	0,0 %
Portugal	13,0 %	4,5 %	28,4 %	2,7 %	29,0 %	16,8 %	4,6 %	0,6 %	0,3 %	0,0 %
Slovak Rep	30,3 %	1,7 %	5,5 %	44,6 %	15,5 %	0,2 %	2,2 %	0,2 %	0,0 %	0,0 %
Slovenia	26,4 %	0,0 %	11,8 %	24,1 %	33,5 %	0,7 %	3,5 %	0,0 %	0,0 %	0,0 %
Spain	9,3 %	5,3 %	30,9 %	21,2 %	15,4 %	14,1 %	1,6 %	2,1 %	0,0 %	0,0 %
Sweden	3,7 %	1,7 %	3,4 %	35,0 %	47,3 %	2,5 %	6,4 %	0,0 %	0,0 %	0,0 %
Switzerland	10,6 %	0,5 %	7,1 %	34,8 %	39,4 %	1,8 %	5,2 %	0,5 %	0,0 %	0,0 %
UK	28,4 %	0,9 %	45,3 %	17,3 %	1,9 %	2,6 %	3,6 %	0,0 %	0,0 %	0,0 %

Table 17: Physical consumption electricity mix for the 23 European countries

	Coal	Oil	Gas	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	9,5 %	0,0 %	21,3 %	0,0 %	56,0 %	2,9 %	11,9 %	0,0 %	0,0 %	0,0 %
Belgium	7,6 %	0,3 %	32,3 %	46,8 %	1,7 %	1,3 %	5,3 %	0,8 %	0,0 %	0,0 %
Czech Rep	64,1 %	0,2 %	1,3 %	35,8 %	4,3 %	0,4 %	2,8 %	0,8 %	0,0 %	0,0 %
Denmark	44,8 %	2,2 %	22,5 %	1,7 %	1,1 %	15,0 %	10,0 %	0,0 %	0,0 %	0,0 %
Estonia	82,0 %	0,0 %	2,3 %	0,0 %	0,0 %	2,1 %	5,0 %	0,0 %	0,0 %	0,0 %
Finland	27,9 %	1,0 %	20,0 %	32,8 %	5,3 %	0,4 %	3,6 %	0,1 %	0,0 %	0,0 %
France	4,8 %	1,1 %	4,6 %	77,3 %	11,6 %	1,6 %	1,1 %	0,1 %	0,0 %	0,1 %
Germany	43,8 %	1,2 %	13,8 %	22,8 %	4,1 %	5,7 %	6,3 %	1,9 %	0,0 %	0,0 %
Greece	41,0 %	12,5 %	26,8 %	0,1 %	11,2 %	3,1 %	0,3 %	0,0 %	0,0 %	0,0 %
Hungary	13,1 %	1,4 %	27,8 %	32,8 %	0,4 %	1,0 %	5,2 %	0,0 %	0,0 %	0,0 %
Ireland	23,2 %	2,1 %	59,4 %	0,0 %	2,4 %	9,6 %	0,7 %	0,0 %	0,0 %	0,0 %
Italy	12,3 %	6,5 %	46,9 %	0,0 %	15,1 %	2,4 %	3,2 %	0,4 %	1,5 %	0,0 %
Luxembourg	13,6 %	0,6 %	39,8 %	8,9 %	23,7 %	2,9 %	3,2 %	0,6 %	0,0 %	0,0 %
Netherland	23,1 %	1,3 %	69,2 %	3,7 %	0,0 %	0,3 %	0,6 %	0,0 %	0,0 %	0,0 %
Norway	13,9 %	0,8 %	16,9 %	16,5 %	36,2 %	2,1 %	3,1 %	0,5 %	0,0 %	0,0 %
Poland	88,5 %	1,8 %	3,0 %	0,0 %	2,2 %	1,1 %	4,2 %	0,0 %	0,0 %	0,0 %
Portugal	12,5 %	4,1 %	26,5 %	0,0 %	28,5 %	15,7 %	4,7 %	0,3 %	0,3 %	0,0 %
Slovak Rep	13,8 %	2,1 %	7,3 %	48,1 %	18,5 %	0,0 %	1,6 %	0,0 %	0,0 %	0,0 %
Slovenia	33,6 %	0,0 %	3,1 %	36,2 %	29,6 %	0,0 %	1,3 %	0,0 %	0,0 %	0,0 %
Spain	8,9 %	5,6 %	31,5 %	20,8 %	15,4 %	14,3 %	1,6 %	2,2 %	0,0 %	0,0 %
Sweden	2,3 %	1,9 %	3,4 %	37,4 %	40,6 %	2,0 %	5,6 %	0,0 %	0,0 %	0,0 %
Switzerland	0,0 %	0,1 %	1,2 %	39,2 %	55,4 %	0,0 %	4,1 %	0,1 %	0,0 %	0,0 %
UK	28,7 %	0,9 %	45,9 %	16,2 %	1,7 %	2,6 %	3,6 %	0,0 %	0,0 %	0,0 %

Table 18: Attribute residual electricity mix for the 23 European countries

	Coal	Oil	Gas	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	9,00%	0,00%	20,71%	0,00%	55,27%	2,85%	12,2%	0,00%	0,00%	0,00%
Belgium	6,61%	0,25%	26,34%	40,57%	14,81%	1,73%	9,01%	0,68%	0,00%	0,00%
Czech Rep	58,37%	0,23%	1,28%	32,56%	3,95%	0,35%	2,56%	0,70%	0,00%	0,00%
Denmark	43,60%	2,05%	21,47%	2,67%	4,53%	15,22%	10,4%	0,04%	0,00%	0,00%
Estonia	89,92%	0,00%	2,33%	0,00%	0,00%	2,33%	5,43%	0,00%	0,00%	0,00%
Finland	27,80%	0,85%	17,20%	31,69%	15,95%	1,14%	5,27%	0,10%	0,01%	0,00%
France	4,62%	1,10%	4,56%	74,66%	12,05%	1,68%	1,12%	0,12%	0,00%	0,0%
Germany	41,49%	1,15%	12,96%	21,57%	9,16%	5,61%	6,24%	1,83%	0,00%	0,00%
Greece	44,55%	12,52%	26,83%	0,16%	12,2%	3,41%	0,33%	0,00%	0,00%	0,00%
Hungary	19,05%	1,36%	27,82%	42,06%	2,22%	1,56%	6,19 %	0,11%	0,00%	0,00%
Ireland	24,12%	2,08%	59,44%	1,22%	2,69%	9,64%	0,79%	0,02%	0,00%	0,00%
Italy	15,96%	6,41%	46,09%	5,38%	17,41%	2,79%	3,84%	0,5%	1,57%	0,00%
Luxembourg	12,96%	0,52%	36,71%	17,94%	25,25%	2,82%	3,31%	0,48%	0,00%	0,01%
Netherland	19,72%	1,02%	55,68%	3,18%	7,82%	3,57%	8,93%	0,09%	0,00%	0,00%
Norway	13,27%	0,68%	13,76%	16,05%	47,91%	3,14%	4,66%	0,52%	0,01%	0,00%
Poland	87,70%	1,84%	3,04%	0,00%	2,22%	1,08%	4,12%	0,00%	0,00%	0,00%
Portugal	14,91%	4,08%	26,48%	3,41%	29,44%	15,96%	4,97%	0,40%	0,35%	0,00%
Slovak Rep	16,66%	2,10%	7,27%	52,14%	19,53%	0,25%	1,99%	0,07%	0,00%	0,00%
Slovenia	32,30%	0,00%	3,05%	34,73%	28,70%	0,00%	1,22%	0,00%	0,00%	0,00%
Spain	8,77%	5,54%	31,38%	20,77%	15,15%	14,61%	1,57%	2,21%	0,00%	0,00%
Sweden	3,45%	1,61%	2,98%	35,11%	49,36%	2,06%	5,38%	0,05%	0,00%	0,00%
Switzerland	0,00%	0,14%	1,13%	37,84%	56,46%	0,10%	4,17%	0,16%	0,00%	0,00%
UK	28,66%	0,89%	45,64%	16,33%	2,28%	2,61%	3,58%	0,00%	0,00%	0,00%

Table 19: Attribute consumption electricity mix for the 23 European countries

9.4.2 Environmental characteristics

	Coal	Gas	Oil	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	1,43	3,29	0,00	0,00	8,77	0,45	1,86	0,00	0,00	0,00
Belgium	2,22	8,84	0,09	13,62	0,48	0,37	1,54	0,23	0,00	0,00
Czech Rep	32,31	0,71	0,13	18,02	2,19	0,19	1,42	0,39	0,00	0,00
Denmark	10,48	4,90	0,50	0,00	0,00	4,84	3,16	0,00	0,00	0,00
Estonia	11,41	0,29	0,00	0,00	0,00	0,29	0,69	0,00	0,00	0,00
Finland	8,24	4,30	0,23	8,82	4,99	0,12	4,26	0,00	0,00	0,00
France	2,62	2,59	0,62	42,33	6,72	0,95	0,63	0,07	0,00	0,05
Germany	153,97	48,10	4,27	80,03	14,74	20,78	23,00	6,83	0,00	0,00
Greece	20,48	12,33	5,76	0,07	5,61	1,57	0,15	0,00	0,00	0,00
Hungary	2,39	4,40	0,19	6,00	0,08	0,19	0,95	0,00	0,00	0,00
Ireland	4,23	10,76	0,37	0,00	0,44	1,74	0,12	0,00	0,00	0,00
Italy	21,38	79,04	11,05	0,00	27,65	4,32	5,81	0,82	2,78	0,00
Luxembourg	0,00	1,04	0,00	0,00	0,54	0,04	0,04	0,00	0,00	0,00
Netherland	15,22	43,05	0,78	2,42	0,06	2,42	5,19	0,06	0,00	0,00
Norway	0,00	0,14	0,00	0,00	3,33	0,03	0,01	0,00	0,00	0,00
Poland	135,45	4,70	2,84	0,00	3,43	1,67	6,37	0,00	0,00	0,00
Portugal	2,54	5,21	0,81	0,00	5,81	3,20	0,95	0,07	0,07	0,00
Slovak Rep	0,98	0,45	0,14	3,42	1,31	0,00	0,12	0,00	0,00	0,00
Slovenia	1,97	0,19	0,00	2,12	1,75	0,00	0,07	0,00	0,00	0,00
Spain	8,63	30,88	5,46	20,43	14,98	14,45	1,55	2,18	0,00	0,00
Sweden	0,25	0,30	0,19	4,05	5,03	0,25	0,70	0,00	0,00	0,00
Switzerland	0,00	0,02	0,00	0,53	0,76	0,00	0,06	0,00	0,00	0,00
UK	63,94	102,21	1,98	36,17	3,90	5,82	7,98	0,00	0,00	0,00

Table 20: Total CO_2 emissions for each technology based on physical production electricity mix, in Mt CO_2-eq.

	Coal	Gas	Oil	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	3,27	2,75	0,04	1,26	6,38	0,50	1,54	0,07	0,00	0,00
Belgium	2,39	9,36	0,10	12,71	0,68	0,41	1,52	0,21	0,00	0,00
Czech Republic	33,58	1,13	0,21	16,11	2,28	0,23	1,47	0,34	0,00	0,00
Denmark	8,51	3,96	0,42	1,35	3,35	3,66	2,56	0,04	0,00	0,00
Estonia	9,78	1,03	0,00	0,55	0,54	0,23	0,56	0,00	0,00	0,00
Finland	8,59	4,79	0,20	8,37	5,27	0,13	3,62	0,00	0,00	0,00
France	2,78	3,01	0,63	41,55	6,80	0,98	0,69	0,08	0,00	0,05
Germany	149,18	48,20	4,17	81,75	18,62	20,44	22,94	6,41	0,00	0,01
Greece	19,68	12,54	5,12	1,07	6,01	1,40	0,14	0,00	0,00	0,00
Hungary	2,47	3,93	0,19	5,79	0,86	0,16	0,81	0,00	0,00	0,00
Ireland	4,25	10,67	0,37	0,09	0,43	1,70	0,14	0,00	0,00	0,00
Italy	20,15	69,03	9,73	9,38	31,93	3,86	5,63	0,73	2,39	0,00
Luxembourg	0,44	0,51	0,01	0,30	0,21	0,07	0,08	0,02	0,00	0,00
Netherland	15,67	38,96	0,75	4,36	1,85	2,45	4,98	0,17	0,00	0,00
Norway	0,03	0,17	0,00	0,03	3,21	0,04	0,03	0,00	0,00	0,00
Poland	131,62	5,35	2,80	1,91	4,20	1,95	6,52	0,11	0,00	0,00
Portugal	2,42	5,30	0,84	0,51	5,42	3,14	0,86	0,12	0,06	0,00
Slovak Republic	1,94	0,35	0,11	2,86	0,99	0,01	0,14	0,01	0,00	0,00
Slovenia	1,61	0,72	0,00	1,47	2,04	0,04	0,21	0,00	0,00	0,00
Spain	9,17	30,47	5,24	20,92	15,20	13,92	1,54	2,08	0,00	0,00
Sweden	0,40	0,37	0,18	3,77	5,09	0,27	0,69	0,00	0,00	0,00
Switzerland	0,15	0,10	0,01	0,48	0,54	0,02	0,07	0,01	0,00	0,00
United Kingdom	63,03	100,65	1,99	38,37	4,28	5,79	7,88	0,00	0,00	0,00

Table 21: Total CO_2 emissions for each technology based on physical consumption electricity mix, in Mt CO_2-eq.

	Coal	Gas	Oil	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	1,47	3,37	0,00	0,00	8,67	0,45	1,84	0,00	0,00	0,00
Belgium	2,22	8,84	0,09	13,62	0,48	0,37	1,54	0,23	0,00	0,00
Czech Rep	32,31	0,71	0,13	18,02	2,19	0,19	1,42	0,39	0,00	0,00
Denmark	10,92	5,38	0,51	0,67	0,35	3,61	2,41	0,01	0,00	0,00
Estonia	11,41	0,29	0,00	0,00	0,00	0,29	0,69	0,00	0,00	0,00
Finland	10,01	6,19	0,31	11,41	1,69	0,14	1,18	0,03	0,00	0,00
France	2,64	2,61	0,63	42,66	6,42	0,91	0,60	0,07	0,00	0,05
Germany	154,82	48,36	4,29	80,47	14,38	20,27	22,43	6,66	0,00	0,00
Greece	20,48	12,33	5,76	0,07	5,61	1,57	0,15	0,00	0,00	0,00
Hungary	2,70	3,95	0,19	5,97	0,32	0,22	0,88	0,02	0,00	0,00
Ireland	4,26	10,49	0,37	0,22	0,48	1,70	0,14	0,00	0,00	0,00
Italy	24,81	71,63	9,96	8,35	25,24	4,13	5,57	0,83	2,31	0,01
Luxembourg	0,23	0,66	0,01	0,32	0,34	0,04	0,05	0,01	0,00	0,00
Netherland	16,97	47,91	0,87	2,74	0,02	0,21	0,46	0,01	0,00	0,00
Norway	0,57	0,59	0,03	0,69	1,40	0,08	0,12	0,02	0,00	0,00
Poland	135,45	4,70	2,84	0,00	3,43	1,67	6,37	0,00	0,00	0,00
Portugal	2,78	4,94	0,76	0,64	5,49	2,98	0,93	0,08	0,06	0,00
Slovak Rep	1,07	0,47	0,13	3,35	1,25	0,02	0,13	0,00	0,00	0,00
Slovenia	1,97	0,19	0,00	2,12	1,74	0,00	0,07	0,00	0,00	0,00
Spain	8,68	31,04	5,48	20,54	14,82	14,29	1,54	2,16	0,00	0,00
Sweden	0,43	0,37	0,20	4,37	4,53	0,23	0,64	0,00	0,00	0,00
Switzerland	0,00	0,02	0,00	0,53	0,76	0,00	0,06	0,00	0,00	0,00
UK	63,95	101,82	1,98	36,44	4,00	5,82	7,98	0,01	0,00	0,00

Table 22: Total CO_2 emissions for each technology based on attribute residual electricity mix, in Mt CO_2-eq.

	Coal	Gas	Oil	Nuclear	Hydro	Wind	Bio & waste	Solar	Geo-thermal	Tide, wave, ocean
Austria	1,42	3,27	0,00	0,00	8,74	0,45	1,92	0,00	0,00	0,00
Belgium	1,81	7,21	0,07	11,11	4,05	0,47	2,47	0,19	0,00	0,00
Czech Rep	32,31	0,71	0,13	18,02	2,19	0,19	1,42	0,39	0,00	0,00
Denmark	10,41	5,12	0,49	0,64	1,08	3,63	2,48	0,01	0,00	0,00
Estonia	11,41	0,29	0,00	0,00	0,00	0,29	0,69	0,00	0,00	0,00
Finland	8,61	5,33	0,26	9,81	4,94	0,35	1,63	0,03	0,00	0,00
France	2,61	2,58	0,62	42,24	6,82	0,95	0,63	0,07	0,00	0,05
Germany	145,93	45,59	4,05	75,85	32,20	19,72	21,95	6,42	0,00	0,00
Greece	20,48	12,33	5,76	0,07	5,61	1,57	0,15	0,00	0,00	0,00
Hungary	2,70	3,95	0,19	5,97	0,32	0,22	0,88	0,02	0,00	0,00
Ireland	4,26	10,49	0,37	0,22	0,48	1,70	0,14	0,00	0,00	0,00
Italy	24,40	70,45	9,79	8,22	26,60	4,26	5,87	0,85	2,40	0,01
Luxembourg	0,21	0,61	0,01	0,30	0,42	0,05	0,05	0,01	0,00	0,00
Netherland	13,64	38,53	0,70	2,20	5,41	2,47	6,18	0,06	0,00	0,00
Norway	0,47	0,48	0,02	0,56	1,68	0,11	0,16	0,02	0,00	0,00
Poland	135,45	4,70	2,84	0,00	3,43	1,67	6,37	0,00	0,00	0,00
Portugal	2,78	4,94	0,76	0,64	5,49	2,98	0,93	0,08	0,06	0,00
Slovak Rep	1,07	0,47	0,13	3,35	1,25	0,02	0,13	0,00	0,00	0,00
Slovenia	1,97	0,19	0,00	2,12	1,75	0,00	0,07	0,00	0,00	0,00
Spain	8,64	30,93	5,46	20,47	14,93	14,40	1,55	2,17	0,00	0,00
Sweden	0,37	0,32	0,17	3,78	5,32	0,22	0,58	0,01	0,00	0,00
Switzerland	0,00	0,02	0,00	0,52	0,77	0,00	0,06	0,00	0,00	0,00
UK	63,64	101,31	1,97	36,26	5,07	5,80	7,94	0,01	0,00	0,00

Table 23: Total CO_2 emissions for each technology based on attribute consumption electricity mix, in Mt CO_2-eq.