MEASUREMENT OF EXTERNALITIES FOR RENEWABLE ENERGY INVESTMENT

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Abstract

Climate change and cleaner environment have been some of the growing concerns in the 21st century. Electricity production has been a major contributor to the emission of greenhouse gases and several other harmful pollutants into land, air and water. Hence, an understanding of the externalities created by the different fuels over their life cycle can aid in better engagement of an honest policy discussion about a 'level playing field' of different electricity generation technologies. The idea of internalization of the externalities favours the deployment of renewable energy technologies over the fossil fuels. In an attempt to internalize the externalities, countries have employed several policy incentives promoting renewable energy systems. However, the large and recent penetration of these renewable systems have raised the concern of policy makers on the cost of the policy incentives over the benefits. In order to gain a perspective on the policy costs, an economic analysis is performed comparing the benefits of avoided external costs and the fossil fuel savings through the penetration of renewables in the electricity mix with the cost incurred in the policy incentives promoting renewables. Knowing well that the results vary for each and every country and each technology significantly, on a broader picture, the results show that the benefits are higher than the policy costs for hydro power and wind energy while solar and biomass energy have exhibited higher costs over the benefits in many countries.

Keywords: Externalities, Renewable energy, European Policy Incentives, Fossil Fuel Savings.

INTRODUCTION

For the past decades, sustainable growth and energy policy have been a major concern for many developed and emerging countries. Reducing fossil fuel emissions, improving the clean combustion and promoting renewable energy technologies had been on focus amongst the policy makers. With growing environmental concerns and increasing public awareness, the decision making process of identifying and promoting both environmentally and economically efficient technologies has become very crucial. It is a challenge put forth to the decision makers in choosing the appropriate energy mix for the countries because fossil-fired power plants are generally economically advantageous and ecologically disadvantageous on the other hand renewable energy technologies tend to be ecologically advantageous and economically disadvantageous. As any economic activity can have externalities involved. While the externalities of any energy technology can be positive or negative depending on their impact in the society, it is important to assess them and include them in the utility (internalize the externalities) to have better understanding and comparison of the technologies. The difficulty is that economic and ecological criteria cannot be compared directly as the economic factors are measured in monetary units (internal costs such as production cost) whereas ecological advantages are usually not. Hence, renewable energy technologies which have good ecological benefits are at a disadvantage. To encourage and level the playing field the benefits of renewable technologies have to be internalized in their cost. Thus, several attempts are made to calculate ecological aspects in monetary terms (external costs) in order to provide a comparison of various technologies with a holistic assessment including both economic and ecological criteria. This gave rise to the monetary valuation of the externalities of the energy systems which are discussed further in this dissertation. The objective of the thesis is review three externality studies for renewable energy systems: ExternE, NEEDS and CASES and then to presents the benefits and cost involved in the policy incentives implemented by EU nations to promote renewable energy systems. This is done by comparing the cost of the renewable policy incentives with the benefits achieved by avoided external costs and fossil fuel savings through renewable penetration.

FUNDAMENTALS OF EXTERNALITY

An externality exists if two conditions exist. First, an impact (which can be negative or positive) is generated by an economic activity and it is imposed on third parties. Secondly, that impact must not be priced in the market place, for an example, if the effect is negative, no compensation is paid by the generator of the externality to the victim. If the effect is positive, the generator of the externality does not receive any gains from the benefiter. The externalities can exist an as external cost or an external benefit based on whether the welfare is lost or gained by the third party. In the perfect market conditions, the cost of producing a good is compensated by the money paid for the good by the consumer. Similarly, a compensation for the change in welfare of the third party (which can be an external cost or external benefit) can help in removing the market imperfection created by the externalities. This process of compensating the externality is called as the internalisation of the externality. In such a situation in which all externalities are internalised, the compensation corresponds to the same utility as the change of welfare so that there is no unaccounted externality anymore.

EXTERNALITIES IN THE ENERGY SYSTEMS

The externalities are measured along the fuel chain of the energy technology rather than just during the operation phase of the life cycle. The externalities of the energy systems accounted in this thesis are as follows,

Environmental Impact: The emission of pollutants such as SOx, NOx and particulate matters cause various health impacts, loss of habitat by the means of the environmental media into which the pollution is released such as air, soil and water. Apart from that, there are noise pollution, radiation released during the entire fuel chain. These impacts are measured.

Global Warming Impact: The greenhouse gases emitted cause the global warming each GHG based on their global warming potential. These impacts are measured in this sector. It has to be noted that while the studies on the damage cost of climate change is increasingly significant, there is still a huge degree of uncertainties on the possible consequences.

Accidents: The fuel chain includes various activities starting from mining the minerals, (fuels in case of fossil plants) required to build the components, manufacturing processes, transportation, commissioning, operation and maintenance. There are risky tasks involved along the fuel chain path. The public risks and unwanted accidents cause an inconvenience. These impacts because of the accidents are measured for each fuel chain.

UNCERTAINITIES IN THE EXTERNALITIES MEASUREMENT

When it comes to the measurement of externalities, the nature of uncertainties are not greatly due to the scientific nature of the data or the model uncertainty. It is rather the ethical dilemma such as the value of the lost life years in different regions of the world, uncertainty about the future. One approach to reduce the range of results arising from different assumptions on discount rates, valuation of mortality, etc. is to reach agreement on (ranges of) key values. (ExternE, 2005)Damage cost estimates are usually accompanied by large degree of uncertainties. It is very difficult to determine the current level of emissions. In order to achieve exact numbers, every emission source should be under permanent measurement. This is economically not feasible. Therefore, estimations of the emissions about similar sources are based on a representative source. While considering the dispersion of the emission of analyse the impact of the pollutants, meteorological conditions are estimated to understand the direction, distance of dispersion. The weather forecast with which the meteorological conditions are modelled are always accompanied with huge degree of uncertainty because of the complex behaviour of regional and local weather.

Besides all the uncertainties, efforts have been made by many organizations to calculate the external costs of the energy systems, be it for market or non-market values. This is because an uncertainty by a factor of three is better than infinite uncertainty. Second, in many cases the benefits are either so much larger or so much smaller than the costs that the implication for a decision is clear even with the uncertainty (ExternE, 2005). With two and half decades of research, the knowledge on externalities of energy have been quite developed. It is only with time and continuous improvement of the studies, we can reduce the degree of uncertainties involved in the calculation.

REVIEW OF EXTERNALITY STUDIES

EXTERNE: EXTERNAL COSTS OF ENERGY

Originally begun in 1991, the most recent ExternE studies were published between 2003 and 2005. ExternE includes a life cycle analysis and not only includes the externalities during the operation of the power plant but the whole life cycle. The ExternE methodology provides a framework for transforming impacts that are expressed in different units into a common unit – monetary values. (ExternE, 2005)

The ExternE studies utilize a bottom-up damage cost methodology to determine the social and environmental impacts of various pollutants emitted during the entire power generation lifecycle. The damages assessed include the particulate matter—both PM_{10}, $PM_{2.5}$; SO2; NOx; Volatile Organic Compounds (VOC); ammonia; heavy metals; and radionuclides as well as damages related to greenhouse gas (GHG) emissions and accidents. ExternE uses the Impact Pathway Approach. The impact pathway approach (IPA) is used to quantify environmental impacts and the principal steps can be grouped as follows, Emission: specification of the relevant technologies and pollutants, e.g. kg of oxides of nitrogen (NOx) per GWh emitted by a power plant at specific site; Dispersion: calculation of increased pollutant concentrations in all affected regions, e.g. incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone (O3) formation due to NOx ; Impact: calculation of the cumulated exposure from the increased concentration, followed by calculation of impacts (damage in physical units) from this exposure using an exposure-response function, e.g. cases of asthma due to this increase in O3; Cost: valuation of these impacts in monetary terms, e.g. multiplication by the monetary value of a case

The external cost of damages related to the emission of GHGs are determined to be between €18-46 per metric tonne CO2 equivalent (tCO2-eq), and for the ExternE central assessment a value of €19/tCO2-eq is used (ExternE-Pol, 2005)

NEEDS: NEW ENERGY EXTERNALITIES DEVELOPMENT FOR SUSTAINABILITY

NEEDS is an extension of the ExternE project. Funded by the European Commission, the NEEDS project is developed by the joint work of several researchers and universities along different European countries. The quantification of external costs in NEEDS is based on the 'impact pathway' methodology which has been developed in the ExternE projects. The methodology is further improved within NEEDS such as improving the dispersion and modelling of pollutants in the environment, improvising the exposure-response relationships that are used to describe the response of receptors to an increased level of exposure, and to improve monetary valuation. The NEEDS also employs the bottom-up damage cost methodology as in ExternE, where the external costs from lifecycle pollutant emissions are calculated through the EcoSense model.

The damages assessed include lifecycle emissions of particulate matter including both $PM_{2.5}$ and PM_{10}, SO2, NOx, VOC, ammonia, heavy metals and radionuclides, GHG emissions, biodiversity loss due to land use changes and accidents (NEEDS, 2009). One important aspect of the NEEDS project is that it estimates the future external costs for different energy generation sources. The FUND climate impact module is used in the NEEDS project for evaluating the damage costs. This module covers the agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, and unmanaged ecosystems (Tol, 2002).

CASES: COST ASSESSMENT OF SUSTAINABLE ENERGY SYSTEMS

Similar to NEEDS, the CASES study is a one-time extension of the ExternE assessment funded by the European Commission. The CASES study is developed in several countries over the years by multidisciplinary research teams at various universities and institutes across Europe. The CASES analysis was performed separately and in parallel to the NEEDS study.

However, in CASES, the social cost of the electricity generation by various sources is evaluated. This is done by calculating both the external and the internal cost of the European generation. Similar to ExternE, Impact pathway methodology is employed by the CASES for the estimation of external costs of generation technologies over the entire fuel life cycle. By fuel cycle, the entire lifecycle emissions and damages from material extraction to plant decommissioning are compiled. Then the marginal costs of emissions from different electricity generation are calculated through the EcoSense model. Finally, the lifecycle emissions per quantity of electricity generated are multiplied by the marginal cost of emissions to calculate the external cost of the emission released. The external impacts to human health, agriculture, the built environment, and ecology are considered. The damage of GHG emissions are monetized through the FUND and PAGE (a similar model to FUND) models. The lower bound GHG marginal cost from the FUND and PAGE models is estimated to be €4/tCO2-eq and the upper bound is 53 € /tCO2-eq. The central value is taken to be the average of the median runs of the FUND and PAGE models as 23€/tCO2-eq. (Anil Markandya et al, 2012).

RESULTS OF EXTERNALITY STUDY

The results of the three studies discussed above are summarized in the table 1. The table of different external cost for each energy technology is also graphically figured in the graph of figure 1.

TECHNOLOGY	EXTERNE	NEEDS	CASES
Unit	€c2000/KWh	€c2000/KWh	€c2005/KWh
Source	(ExternE-Pol, 2005)	(NEEDS, 2009)	(CASES, 2008)
Coal	4.07	3.06	3.1352
oil	4.83	Not Studied	2.4654
gas	1.55	1.31	2.0845
Solar PV	0.41	0.63	0.888
Wind	0.09	0.09	0.1025
Biomass	0.18	2.5	0.6537
Hydro	0.02	Not Studied	0.0763
Nuclear	0.19	0.09	0.2141

Table 1: Externality values from the studies. Sources: (ExternE, 2005), (NEEDS, 2009), (Anil Markandya, 2012)

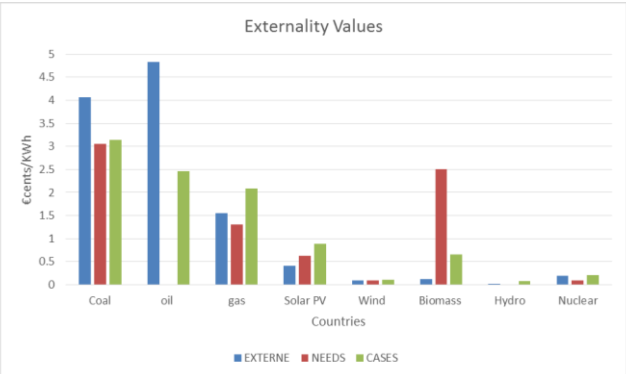

Figure 1: Externality values from the three studies for each technology.

The results vary considerably among the studies. However, in all the studies, the fossil fuels have very high externalities compared to the renewables. Among the renewables, solar holds the maximum amount of externalities compared to other renewable technologies. These externalities are primarily from the upstream process of solar manufacturing. It has to be noted that, solar has higher rate of technical growth and hence, with improvement in the material and efficiency, the externalities associated with solar will fall over time. The comparison may not be, however, so straightforward. In spite of the objective of comparing technologies, every nation has its own broad range of technologies, fuels, and abatement options. Therefore, due to the site- and technology-specificity of results, these will be sometimes very different. Among all the renewable technologies, differences are more prominent among countries in the case of nuclear and biomass technologies, since upstream process for these cycles (the extraction of the fuel, its transport, pre-processing) are highly variable among countries, and therefore their impacts will vary to a large extent. Hence, it is only appropriate to take site and technology specific case studies into consideration while assessing the externalities of energy systems. In general, it may be concluded that fossil fuels have significantly high external costs, while renewable energies have small amount of external costs. The nuclear fuel cycle has small external costs, although it has to be noted that not all the significant impacts of this fuel cycle have been quantified. It can be well noticed that the external costs of fuel cycles are high enough to affect energy policy decisions. The methodology has a large number of uncertainties and impacts measured varies for each study. For an example, it the NEEDS estimate for biomass is higher than the other two studies because NEEDS include the impact of land use change while the other two studies don't. Especially with biomass, the CO2 impact is very low owing to its carbon neutrality. Major proportion of the impact is from the nitrogen emission.

These uncertainties create some difficulties for using the results directly for policy-making. Several aspects should be taken a serious note, mainly the estimation of global warming damages. Atmospheric dispersion models, which, at least for some countries, should account for the complex topographic conditions are also a controversial aspect. Another important issue which should also be noted is the relationship between atmospheric pollution and chronic mortality, and the valuation of the deaths produced by atmospheric pollution. The table 2 gives the values of above mentioned parameters such as Value of Life per Year Lost (VSL), Total Value of Life (VSLY), damages assessed and the damage cost of CO2 for each study, thereby, addressing the differences in the values.

Study	CO2 value	(VSL)	(VSLY)
ExternE	€18-46	€1,000,000	€ 50,000
NEEDS	€7-98	€3,000,000	€ 40,000
CASES	€7-99	€3,000,000	€ 40,000

Table 2: Overview of the methodology implemented in the externality studies. Sources: (ExternE, 2005), (NEEDS, 2009), (Anil Markandya, 2012).

All these uncertainties affect the individual fuel cycles studied. For the aggregation of results to the whole electricity sector, there are plenty of issues to be faced such as the transferability of results from one site to another or accounting the effects for which there is a threshold. The differences in damages per tons of pollutant emitted between different sites are quite large, so the direct transfer of results from one site to another is not reasonable. Hence, it is recommended by the studies to use the results provided only as background information. This background information might be very useful for establishing economic incentive tools, such as environmental taxes, or subsidies for renewable energies and for energy planning. However, it is advised that the results are better not used directly, until the methodology is refined. (ExternE, 2008)

In the further part of the thesis, externality costs from the CASES study is used owing to the facts that the country data for each technology is available clearly explaining the impacts and the damage cost used.

INTERNALIZATION OF EXTERNALITIES

The main objective of numerous studies in estimating the external costs is to create policies that alter the price of energy in such a way to take into account both the private and the external cost, thereby, "level the playing field." Generally, renewable forms of energy have high private costs as most of the technologies are not mature but they have far lower external costs than energy generated from fossil fuels, but the market, which doesn't take this fact into account, would feature a huge price gap between the fossil fuel–derived energy and renewables-derived energy. It is through the policies, that the external costs can be "internalized" for the energy systems, making renewables competitive with fossil fuels on an economically justified basis (PSG AG, 2014). Several political instruments have been proposed to achieve internalization of external costs. "The optimal instrument for internalization creates no distortions on the market. Furthermore it should be efficient and fair, minimize costs and uncertainty and have low administrative costs" (CASES, 2008). There are several economic instruments employed to directly or indirectly internalize the external costs since early 19th century. The main purpose of these support instruments is to encourage the large scale deployment of the renewable energy generation and energy efficiency among the consumers. Large scale take-up of RES would help technologies to mature, learning rates to improve and integration of RES within traditional market arrangements to be tested and refined. (CEER, 2015)

RENEWABLE POLICY SUPPORT SCHEMES IN EUROPE

Policy supports for investment in renewable energy are usually based on a combination of different policy types. The policies can be differentiated according to their characteristics such as regulatory or voluntary, direct or indirect, investment-focused or generation- based, and more. The following policy types are distinguished into major and secondary instruments as follows; Major support instruments: Feed-in tariffs (FIT), Feed-in premiums (FIP), Tenders (TN), Quota obligations with trade-able green certificates (QO). Secondary support instruments: Investment Incentives (II), Tax Exemptions (TE), Net Metering (NM), Financial Incentives (FI) (Lena Kitzing et al, 2012).

ANALYSIS OF BENEFITS AND COSTS OF RENEWABLE POLICY SUPPORT COSTS

Almost all the EU nations have enacted support schemes in order to promote renewable electricity, correct the market failure and achieve desired level of renewable penetration into the electricity generation mix. However, concerns have been raised in many studies on the cost of promotion of these renewable energy systems. While promotion of renewable aids to indirect reduction of the externalities generated, it is also being well noted that the support costs have increased significantly in the recent years. The support cost for renewable electricity have increased by 144% from 2009 to 2012 (CEER, 2015). It has to be noted that the costs are borne by the consumers of the electricity in the end through the electricity bills. The growing penetration of the renewable systems and their increasing support costs has raised concerns of the policy makers of the EU nations about the cost of the promotion of renewable systems and their usefulness. A quantification of the cost and the benefit of the support costs of the renewable energy promotion can helping in gaining a perspective of the usefulness of these policy support costs. This analysis could contribute to the debate on the renewable energy targets and their promotion. The studies addressing the benefits and costs of the different technologies among the EU nations are scarce with few exception such as work by Garcia-Redondo et al (2014), European Commission (2014), Marcantonini et al (2014) and Margarita Ortega-Izquierdo et al (2016). Among the studies, Garcia-Redondo et al (2014) compares benefits associated with carbon dioxide emissions avoided with the cost of FIT systems in Spain. Margarita Ortega-Izquierdo et al (2016) extends the study and performs the analysis of the benefits of avoided carbon dioxide cost and the fossil fuel savings with the policy support costs for all the EU member states. As it is noted, GHG emissions are one of the several externalities in the energy generation. Hence, in this thesis, an analysis of the benefits of the avoided external costs by the renewable penetration and the benefits of fossil fuel savings are compared with the support costs of the renewable promotion schemes. It has to be noted that this cannot be considered as a cost-benefit analysis of the renewable technology, as performing a thorough cost benefit analysis will require the system costs.

This aim of this analysis is to understand the usefulness of the policy support costs by comparing them with the quantifiable benefits achieved through the renewable deployment

BENEFITS & COSTS CONSIDERED

Two main benefits from the promotion of renewable energy is discussed in this thesis. The externality reduction and fossil fuel savings.

Externality Reduction: The studies prove that the externalities generated from renewable energy is far lesser than the externalities generated by the fossil fuels. This avoided external cost by the renewable energy penetration is considered.

Fossil Fuel Savings: The current energy demand in the EU is 55% covered by imported energy sources. Energy dependence renders the EU vulnerable, particularly in terms of the potential loss of energy supply. While pollution represents mainly an environmental risk, the energy dependence represents predominantly economic and socio-political risk as well as a challenge to restructure the EU energy sector (Matevž Obrecht 2014). Penetration of renewables into the electricity generation mix of the nations have significantly increased the fossil fuel consumption and hence this fossil fuel savings are considered as one of the benefits.

Policy Support Cost: For a clear definition, support costs are the incentives paid for the renewable energy generation through different schemes as discussed earlier. Since this is an analysis to identify the usefulness of the policy support costs, only the policy instrument costs of the EU nations are considered and not the system costs which would involve the plant construction cost, operation, maintenance costs. As argued by Claudio Marcantonini et al (2014). The support costs are taken from the Council of European Energy Regulators (CEER, 2015) and for the year 2012. Hence, the benefits are also calculated for the year 2012.

Apart from the system costs, other costs related to the electricity system such as cycling costs, balancing costs are not considered in this analysis. The Cycling costs are the extra operation costs incurred due to the varying load due to the intermittent nature of the renewable systems. Balancing costs are costs incurred to meet the demand with the varying supply because of the non-predictable nature of the renewable systems. These costs are not considered as the studies show that such costs are negligible with low percentage mix of renewable energy systems. As mentioned by Claudio Marcantonini et al (2014), the balancing costs represent only a tiny average of 2% of the net remuneration costs. Hence, these costs are neglected for the analysis because of the following reasons as mentioned by Margarita Ortega-Izquierdo et al (2016). The aim of the analysis is to compare the costs and the benefits of policy support costs and not a holistic cost-benefit analysis. System costs and cycling costs for all the EU nations are not available as they are difficult to calculate. As studies have shown that these costs are very low for low penetration levels of renewable energy into the nation's electricity generation mix, they are ignored at this period of time.

METHODOLOGY

The costs and benefits are calculated for the year 2012. Literature data from (CEER, 2015) are taken for the policy costs while the avoided external costs are calculated from the CASES study. The fossil Fuel savings are adapted from the calculation devised by (Margarita Ortega-Izquierdo et al, 2016).

Fossil fuel saving: Near-zero variable costs of generation of renewables indicate that it displaces conventional fossil fuel generation from coal, natural gas or oil. The displaced cost of the fossil fuel required to generate the electricity is a cost saving. Consequently, it must be subtracted from the payment to generators to isolate the additional cost for abating externalities generated. This cost saving depends on the quantity and prices of the coal or natural gas imported, but figuring out what is displaced precisely when a technology like wind or solar generation is injected into the grid is not easy. Hence, some approximations are adapted. The quantities of each fuel displaced are indicated by the difference between the scenario calculated to replicate observed load for the year 2012 with and without renewables in the generation mix. The quantities calculated form the difference are multiplied by the fuel prices, to determine the fuel cost savings. Since natural gas prices are higher than coal, cost savings are greater per MWh of displaced natural gas generation than for coal generation. However, it should be noted that the efficiency of conversion of the primary energy to electricity by the plant also comes into role in deciding the amount of fuel used to produce the unit MWh (Claudio Marcantonini et al, 2014). Thus, in order to calculate the fossil fuel savings as a result of renewable penetration, the electricity is converted to primary energy using the respective efficiency rates (η) for the fossil fuels derived from (European Commission, 2011). The primary energy consumption is given by,

Primary Energy (MWh) = (1/η)*Final Energy (MWh).

The following conversion rates are followed. Coal – 1 MWh = 0.21 tons; Oil – 1 MWHh = 0.61 barrels; Natural gas – 1MWh = 3.44*106 BTU (Margarita Ortega-Izquierdo et al, 2016).

Avoided External Cost: The external cost per unit electricity production is taken from the aforementioned CASES study. Among the three studies discussed in the thesis, CASES study is the latest study inclusive of the final improvisations to ExternE. The electricity generation mix for each European country is taken from the database of (EUROSTAT, 2016). The avoided external cost for each KWh of electricity generated from the renewable technology is given by,

Avoided external $\text{cost}_{\text{renewable}}$ = Weighted $\text{Average}_{\text{fossil}}$ - External $\text{Cost}_{\text{renewable}}$

Weighted Average Cost (F)=(∑{El (F)*Ex(F)})/El

Where,

Weighted Average Cost (F) = Weighted Average External Cost of Fossil Fuels generation in a country (€ cent /KWh); El (F) = Electricity generated by each fossil fuel in the year 2012; Ex (F) = External cost per unit electricity generated from each fossil fuel at 2012; El = Net electricity generated from all the fossil fuels at 2012.

Applying the above, the Avoided external costs for each renewable technology for the year 2012 was calculated as,

Avoided External cost for a renewable = (avoided external cost /KWh) * (electricity generated by the renewable).

RESULTS

An analysis of the costs associated with the public support for renewables and the benefits from fossil fuel savings and the avoided external costs is presented in the tables below for the renewable technologies solar, wind, biomass and hydro separately.

	Solar (Million €)			
country	Av.External Cost	Fossil Fuel Saving	sum of benefits	Policy Cost
AT	5.85	11.00	16.85	34.00
BE	28.28	79.00	107.28	802.00
CZ	54.75	77.00	131.75	965.00
DE	610.30	993.00	1603.30	8118.00
DK	1.88	4.00	5.88	0.00
EE	0.00	0.00	0.00	0.00
ES	175.21	300.00	475.21	2614.00
FI	0.09	0.00	0.09	0.00
FR	74.09	118.00	192.09	1709.00
UK	22.08	55.00	77.08	377.00
HU	0.16	0.00	0.16	0.00
IE	0.01	0.00	0.01	0.00
IT	295.50	830.00	1125.50	6161.00
LT	0.02	0.00	0.02	1.00
NL	3.36	12.00	15.36	12.00
PL	0.02	0.00	0.02	0.00
PT	5.27	16.00	21.27	66.00
RO	0.22	0.00	0.22	0.00
SE	0.27	0.00	0.27	0.00

Table 3: Summary of benefits and cost for solar deployment at 2012

	Wind (Million €)			
country	Av.External Cost	Fossil Fuel Saving	Sum of Benefits	**Policy Cost**
AT	67.10	79.00	146.10	74.00
BE	64.95	101.00	165.95	257.00
CZ	14.51	15.00	29.51	27.00
DE	1706.93	1901.00	3607.93	3108.00
DK	246.12	378.00	624.12	202.00
EE	10.05	18.00	28.05	4.00
ES	1004.60	1818.00	2822.60	2053.00
FI	9.61	16.00	25.61	9.00
FR	411.44	443.00	854.44	550.00
UK	469.34	793.00	1262.34	1418.00
HU	23.61	29.00	52.61	43.00
IE	82.57	177.00	259.57	42.00
IT	329.00	594.00	923.00	1018.00
LT	9.79	25.00	34.79	28.00
NL	130.46	227.00	357.46	324.00
PL	145.84	196.00	341.84	315.00
PT	189.30	406.00	595.30	508.00
RO	107.94	95.00	202.94	148.00
SE	137.64	177.00	314.64	165.00

Table 4: Summary of benefits and cost for wind deployment at 2012

	Biomass (Million €)			
country	Av.External Cost	Fossil Fuel Saving	Sum of Benefits	Policy Cost
AT	88.69	147.00	235.69	248.00
BE	89.00	187.00	276.00	417.00
CZ	93.41	111.00	204.41	221.00
DE	1155.78	1556.00	2711.78	4827.00
DK	88.76	152.00	240.76	86.00
EE	20.25	35.00	55.25	13.00
ES	83.87	180.00	263.87	385.00

FI	189.28	341.00	530.28	37.00
FR	102.62	137.00	239.62	143.00
UK	282.98	576.00	858.98	783.00
HU	36.47	61.00	97.47	52.00
IE	7.35	19.00	26.35	11.00
IT	226.82	530.00	756.82	1612.00
LT	3.06	9.00	12.06	17.00
NL	138.26	316.00	454.26	343.00
PL	252.94	381.00	633.94	583.00
PT	47.25	113.00	160.25	177.00
RO	6.26	7.00	13.26	7.00
SE	194.05	292.00	486.05	258.00

Table 5: Summary of benefits and cost for biomass deployment at 2012.

	Hydro (Million €)			
country	Avoided External Cost	Fossil Fuel Saving	Sum of Benefits	Policy Support Cost
AT	1316.00	1527.00	2843.00	5.00
BE	39.44	61.00	100.44	14.00
CZ	100.75	103.00	203.75	54.00
DE	945.49	1027.00	1972.49	231.00
DK	0.41	1.00	1.41	0.00
EE	0.98	2.00	2.98	1.00
ES	496.61	894.00	1390.61	187.00
FI	332.20	536.00	868.20	0.00
FR	1774.37	1850.00	3624.37	86.00
UK	196.84	332.00	528.84	164.00
HU	6.60	8.00	14.60	3.00
IE	21.16	44.00	65.16	1.00
IT	1087.69	1925.00	3012.69	681.00
LT	17.27	42.00	59.27	3.00
NL	2.74	5.00	7.74	7.00
PL	76.42	101.00	177.42	139.00
PT	124.04	264.00	388.04	30.00
RO	509.88	438.00	947.88	31.00
SE	1539.09	1935.00	3474.09	72.00

Table 6: Summary of benefits and hydro for wind deployment at 2012.

The results show that the benefits are lower than the support costs for solar and biomass while wind and hydro have higher benefits to cost of policy incentives, on an EU wide. When noticed in detail, it widely varying among the countries and among each technology. The graphical representation of the results of each technology are presented below.

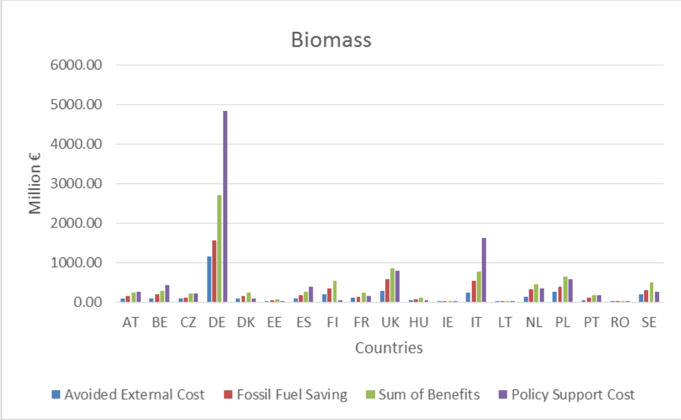

Figure 2: Comparison of benefits and costs of policy support for biomass

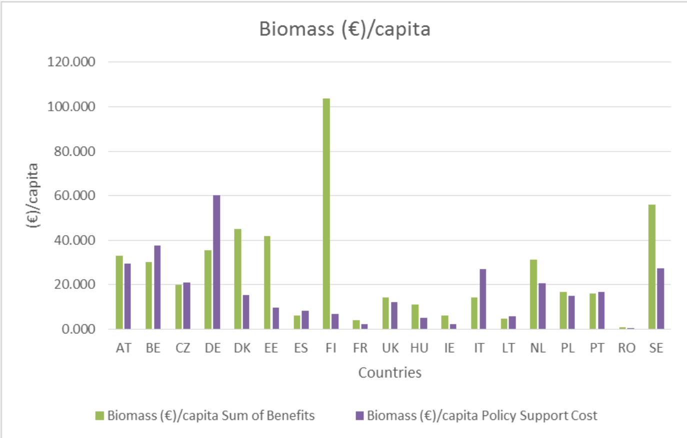

Figure 3: Per capita benefits and costs of policy support for biomass energy

Biomass has a mixed result to the benefit and cost comparison. Germany, Belgium, Italy, Estonia and Portugal have higher policy costs to the benefits obtained with Germany and Italy exhibiting huge difference. It has to be noted that for biomass, an assumption on the fuel is made. Woodchips is considered as the fuel for the calculation of the avoided external costs. This could considerable affect the results presented.

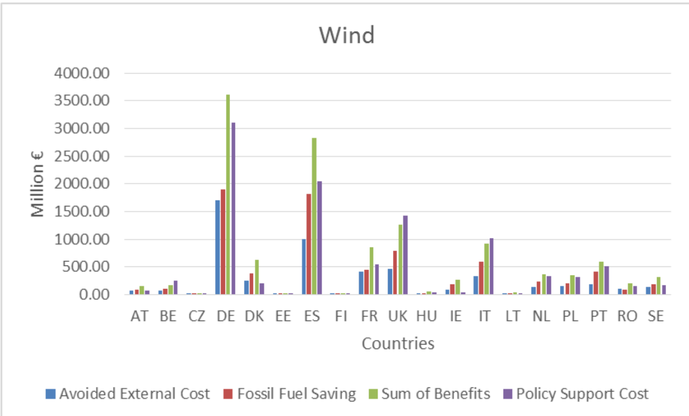

Figure 4: Comparison of benefits and costs of policy support for wind

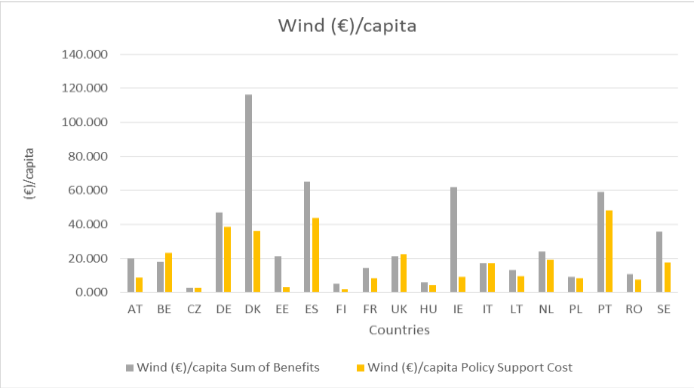

Figure 5: Per capita benefits and costs of policy support for solar energy

The benefits obtained from the wind energy is higher than the policy support costs in most of the countries with an exception of UK, Belgium and Italy. In Denmark, the benefits are threefold higher than the costs involved. Denmark has employed FIP, tendering ad both financial and investment incentives to promote wind energy.

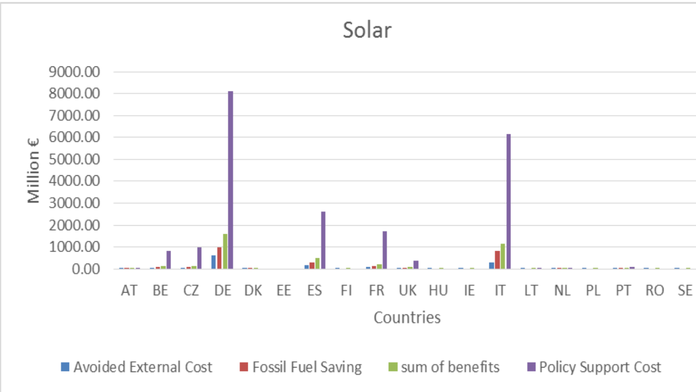

Figure 6: Comparison of benefits and costs of policy support for solar

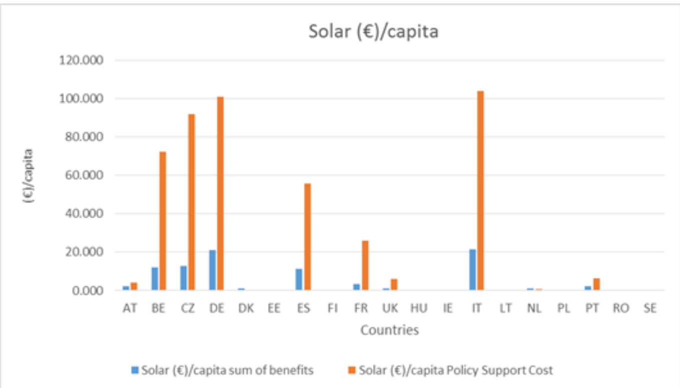

Figure 7: Per capita benefits and costs of policy support for solar energy

Solar has very high policy support cost compared to the benefits obtained from the avoided external costs and fossil fuel savings. Several countries such as do not have significant policy support instruments actively employed. Solar, besides being a mature technology, has high cost to the benefits. However, considering the high technology growth in solar industry, with considerable increase in the efficiency of the technology, the externalities may still come down, thereby increasing the possibility of benefits from the avoided external costs.

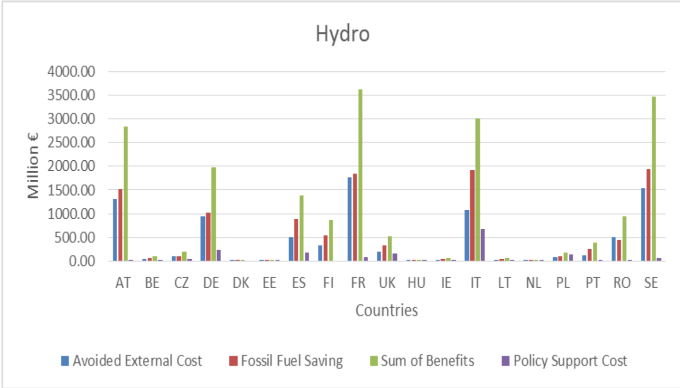

Figure 8: Comparison of benefits and costs of policy support for hydro

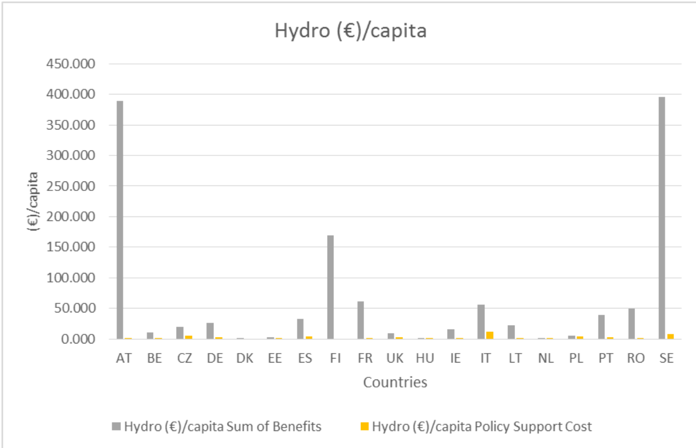

Figure 9: Per capita benefits and costs of policy support for hydro

The benefits from hydro outweigh the support costs in all the countries. This is also because, hydro is a very mature technology prevalent for decades. In countries like Sweden, Austria, Germany, France and Italy, the benefits are at least threefold than the policy costs. With the pumped storage system, the hydro is also used to meet the demand fluctuations in the day. Among all the four renewables, hydro has a steady high benefits to cost.

This analysis shows the summary of benefits and costs from the policy support for renewable penetration in the Europe. These support cost, which are paid by the electricity consumers ultimately, have led to the benefits of externality reduction and fossil fuel savings, thereby, contributing to energy security. While Solar has higher policy costs compared to the benefits on an average, other renewables have a mixed results with hydro mainly holding higher benefits than the policy costs. Hence, it is only reasonable to do a country wise research of their resource availability and the policy schemes to understand the usefulness of promoting the renewable technologies in each nation. It should also be noted that, with increasing renewable penetration in the energy mix, the cycling and balancing costs have to be taken into account.

Margarita Ortega-Izquierdo et al (2016) have performed similar analysis comparing the policy costs with fossil fuel savings and the Externality avoided from GHG emissions (during the operation of the power plant alone). The results are considerably different compared to the analysis performed in this thesis. While in the above mentioned study, on an average, benefits are more relevant to the policy costs for hydro and wind and they are below the policy costs for bioenergy and solar PV. Taking a closer look, the country level values differed in certain cases. For an example, Netherlands had higher policy costs for hydro compared to their benefits in the study Margarita Ortega-Izquierdo et al (2016). However, in the analysis above, Netherlands have higher benefits to the policy cost for hydro. Such difference in the results between the two studies can be explained primarily because of taking into account the entire fuel cycle externalities into account in this case.

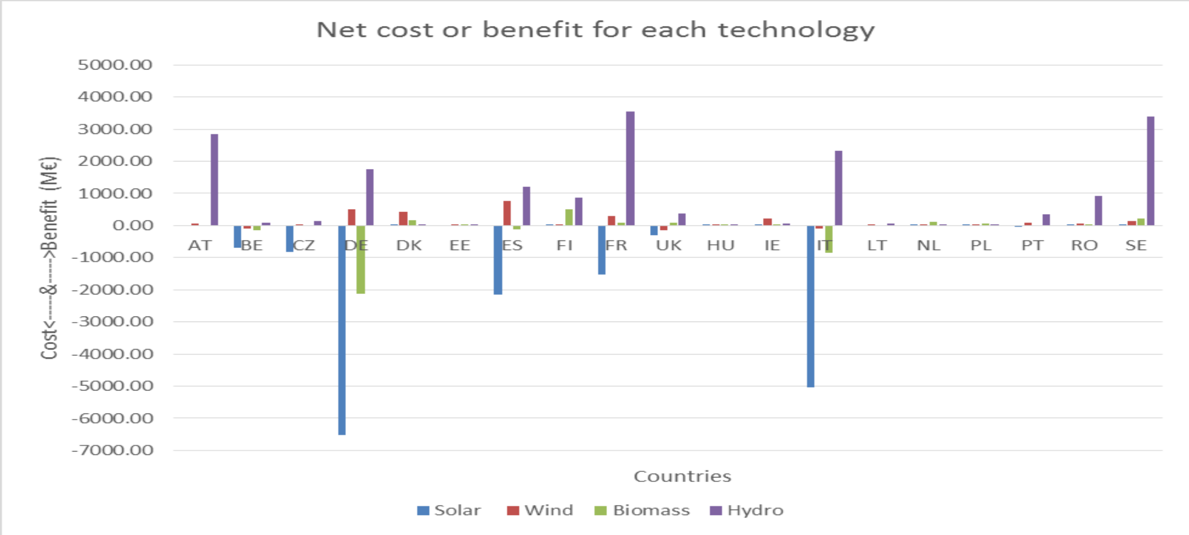

Figure 6: Comparison of the net costs and benefits by the renewable energy promotion. The Positive axis shows the benefits over the costs and the negative axis vice versa

The figure above, shows that mostly, promotion of solar energy has been costly. Hydro energy has well stabilized establishing more benefits over the policy support costs followed by wind. Biomass has mixed results. On the whole, except solar, the benefits have been on the higher value to the policy incentives employed to boast the renewable energy into the electricity market. While the results give an overview of the costs and benefits, separate analysis has to be done for each country considering their availability of fuel resources to obtain a sustainable electricity generation mix.

The empirical findings bring out some policy implications,

• Considerable social benefit is induced by every cent of renewable support aided by the electricity consumers in their bills.

• The costs of support have increased significantly for some countries and technologies over the years, leading to the implementation of cost-containment measures in FIPs and FITs (including capacity caps, generation caps) which in some cases may have come too late to limit those costs.

• While FITs certainly have issues on their own as discussed by many studies, the results show that, at least in the EU, they have also brought significant social benefits. Despite the criticism, FITs continue to be widely recognised as a bench-mark for effective policy design in support of renewable energy expansion (Margarita Ortega-Izquierdo et al, 2016).

• The valuation of externality plays a pivotal role is in affecting the estimation of the benefits obtained from each the renewable energy technology.

• The fossil fuel savings from each technology signifies the political benefits attained in its contribution to the security of energy supply of the nation.

CONCLUSION

This thesis work aims at identifying the externalities of the renewable energy technologies from various studies and from the externalities of each technology, the benefits and the costs involved in the public promotion of renewables was discussed. In this respect, this study can be regarded as confirming the climate benefits of replacing the fossil fuel power plants with the cleaner renewable technologies.

With respect to the externalities studies chapter, the study attempts to identify the external costs of various power generation technologies in order to support the decision-making process of future power plant investments under the framework of a sustainability. Along with the external costs, the uncertainties involved in the monetary valuation and hence the need for a site specific and technology specific study is stressed.

In order to level the economic playing field between several energy technologies, the external costs should be internalized and the existing subsidies on conventional and mature technologies have to be gradually reduced. From the policy perspective, there are several ways to achieve this goal with their own benefits and demerits. In this thesis, with the established external costs, the socio-economic effectiveness of promoting renewable energy through the policy incentives was discussed. With the exception of solar and biomass in certain countries, the EU wide average of the promotion of renewables have proven to be beneficial in terms of the avoided external costs and the fossil fuel savings. Behind the broader picture, significant differences between each country and technology emerge which has to be taken into account for the nation-wide decision making. Continuous assessment of the policy support tools to create cost effective and market based incentives are important.

The chief short coming of the thesis and hence an area for future research is the inclusion of private cost, cycling cost and balancing costs in the net cost of renewable penetration especially in the future when the penetration of renewable in the electricity mix increases. System cost are highly dependent on technology, location, size of project and cost of capital and it is extremely difficult to assess as a single figure. Furthermore, private costs, especially those of developing technologies such as solar PV and offshore wind, are not static, as they are subject to market forces and technological advancement. Hence, it is important to continuously update the studies and use market and site specific data for the analysis of cost and benefits of policy.

However, the current empirical findings and the analysis bring out the political and social benefits attained by the renewable energy technologies compared to the fossil fuel technologies in terms of the health and environmental benefits, climate change mitigation, social well-being and energy supply security.

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