Subsidies and costs of EU energy

An interim report

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Summary

Introduction

The way energy markets function and the effect of government interventions in the European Union has been the subject of much debate in recent years. To date however, there has not been a complete dataset for the EU28 detailing the Government interventions in the energy market. This report presents the results of a study commissioned by DG Energy to quantify the extent of public interventions in energy markets in all 28 Member States for all energy use excluding transport. One of the reasons Governments have to intervene in energy markets is that the market does not adequately price external costs such as environmental damages. In this project we also estimate the monetary value of environmental impacts from the use of energy. Finally, the study gives an indication of energy costs and prices, which is useful to provide context to the quantifications of interventions and external costs.

More specifically we report:

1. Historical and current data on public interventions in the energy market in all EU Member States and the EU overall. These interventions may regard the production and consumption side of energy products and carriers, as well as the energy system. The focus is on those measures that impact energy costs and energy market prices paid by consumers in 2012. Recent developments in policy will have an impact on future prices but not retrospectively on 2012 prices.
2. Monetary values for environmental impacts from the energy system that are not internalised in the price. Apart from these negative impacts energy has many benefits such as employment and tax revenues. However, these benefits are private and are reflected in the prices, so unlike the impacts we consider, these are not external.
3. Energy cost data covering capital and operating costs of different electricity and heat technologies. The cost analysis is used to put the subsidies and external costs in context. The cost data on technologies is complemented by estimates of national energy transmission costs. Both costs and external costs will vary in future in response to changes in the energy system such as a higher proportion of renewable energy, unconventional fossil fuel sources such as shale gas and/or changing energy demand and demand patterns. However, these changes are not affecting prices now. This study explicitly does not unravel retail price compositions.

This study is the first to provide consistent data on energy costs and subsidies for all EU Member States and for all technologies.

Findings

This study shows that in 2012, the total value of public interventions in energy (excluding transport) in the EU-28 is €$_{2012}$ 122 billion (see Figure S - 1). This figure is composed of the value of public interventions in 2012 of €$_{2012}$ 113 billion and a central estimate of direct historic support of €$_{2012}$ 9 billion (direct historic support is between €$_{2012}$ 3 and 15 billion). The direct historic support still has a direct effect today.

The energy mix as it exists now has associated external costs of €$_{2012}$ 200 billion, with a range of €$_{2012}$ 150-310 billion (see Figure S - 1). To put these numbers into context: the total cost of this energy would be around €$_{2012}$ 500 billion, based on wholesale/spot prices[1]. The cost to consumers would be even higher than this because retail prices are higher than wholesale prices. Interventions to support renewable energy sources have the highest value (€$_{2012}$ 41 billion). Support for energy demand is significant (€$_{2012}$ 27 billion). Support to energy efficiency is €$_{2012}$ 9 billion.

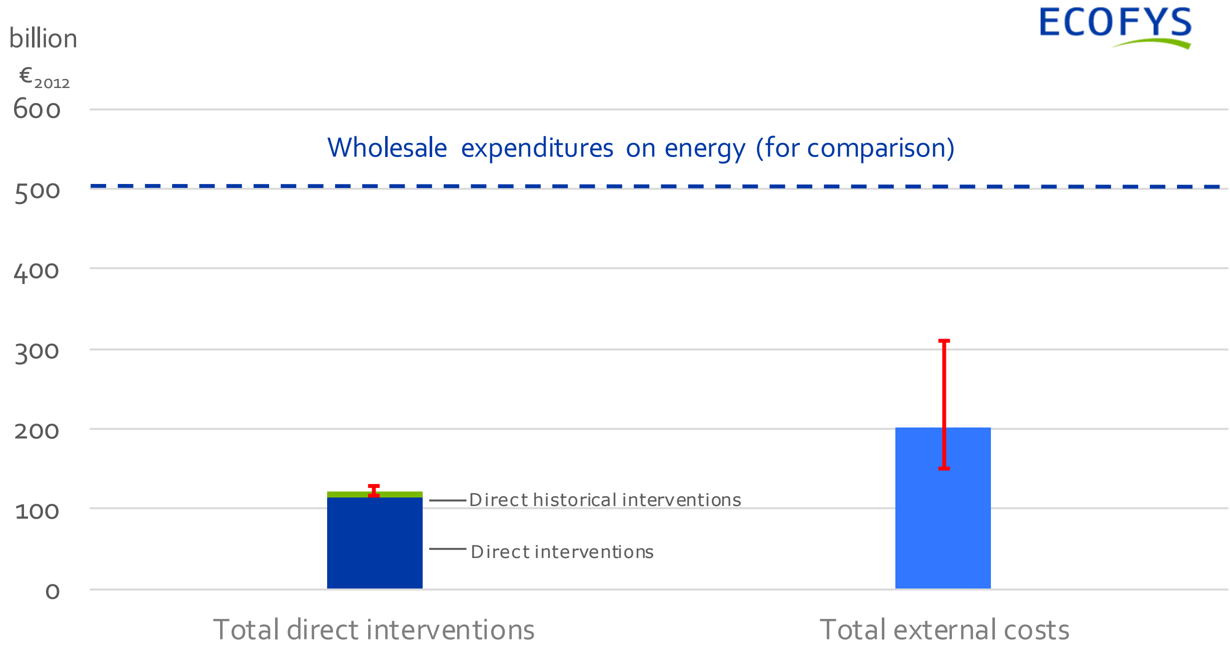

Figure S - 1 Total direct interventions, external costs and wholesale cost of energy in 2012 (in billion €$_{2012}$)

The direct historic interventions is shown as a range on top of the direct interventions in 2012. Direct interventions in 2012 include the EU ETS free allocations.

Interventions

In this study we monetised public interventions by Member States and the EU as a whole in the energy market. We present annual values of over 700 interventions in 2012. These regard payments made or revenues foregone as stipulated by all regulations in force, including regulations that were enacted in the past. The information on the specific interventions was collected by our partners in the Member States according to a tier system defined at the start of the project.

For most interventions, national sources of information such as national balance sheets were available. Where these sources were not available the intervention values were calculated according to a specified methodology.

Public interventions in the energy market have been occurring for decades and some still have an impact on energy prices in today's markets. Much of the current energy infrastructure was developed in a time when there was significant public (national or local government) ownership and central planning.

[1] The total wholesale costs are the product of the total volume of fossil fuels consumed in 2012 and the average spot prices (import prices) of coal, oil and natural gas plus the product of the volume of electricity consumed in 2012 and the average wholesale price of electricity in Europe. These cost represent the costs of energy without any taxes, transmission and distribution costs or costs of conversions (e.g. from crude oil to gasoline).

In addition to the monetisation of public interventions for the years 2008 - 2012 discussed above, we provide an estimate of historic interventions that are still having an effect on the energy market today. The approach to estimate these interventions is different to that for the years 2008 - 2012. The changing structure and priorities in the energy sector makes the definition of what was a subsidy very difficult for some categories. We have adopted an approach to estimate those subsidies but it must be recognised that this is subject to a high degree of uncertainty in both the methodology and data.

Figure S – 2 shows the total value of current interventions in 2012 for energy production of 14 different technology categories and separately for energy demand and energy savings. The largest single category of intervention is for energy demand which covers measures that would encourage the use of energy such as tax reductions for particular users. In general, support to energy demand tends to support individual fuels in proportion to their place in the fuel mix, which in the EU is still dominated by gas, coal and nuclear. Support to production of electricity or of primary fuels such as coal, gas and oil makes up almost 70% of the total support. Of this, most support is given to the renewable energy technologies, particularly solar, although significant support is also given to coal and nuclear, including decommissioning and waste disposal. Support to energy savings (i.e. for reducing energy use) is around 8% of the total.

We also present breakdowns of interventions by Member States and technology, both in absolute value (Figure S – 3) and divided by the total primary energy demand of the Member State (TPED) as a measure for domestic energy demand (Figure S – 4)[2].

[2] TPED refers to primary energy, i.e. the form of energy that first appears in the energy balance, before conversion processes and related losses (e.g. crude oil, coal, natural gas, biomass).

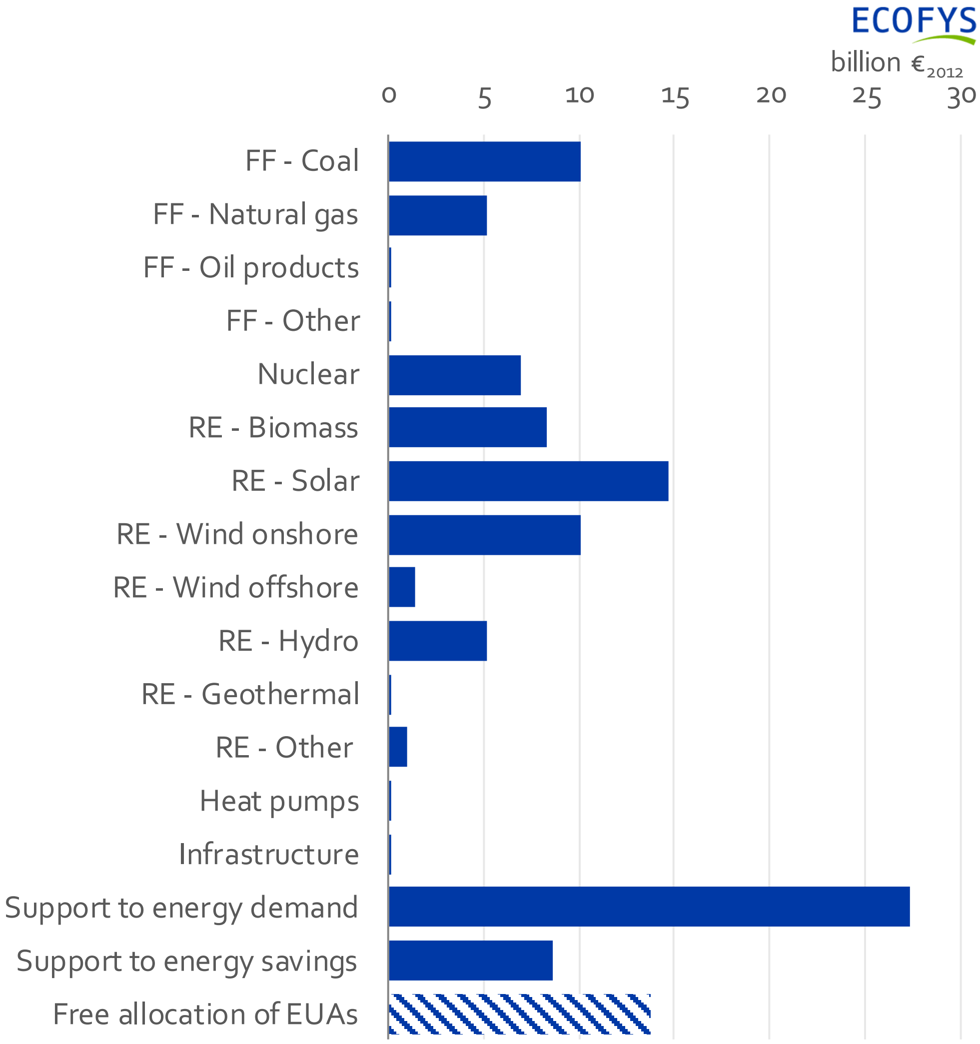

Figure S - 2 Total support provided in the 28 Member States (in billion €$_{2012}$), including EU level support. Historic support is not included

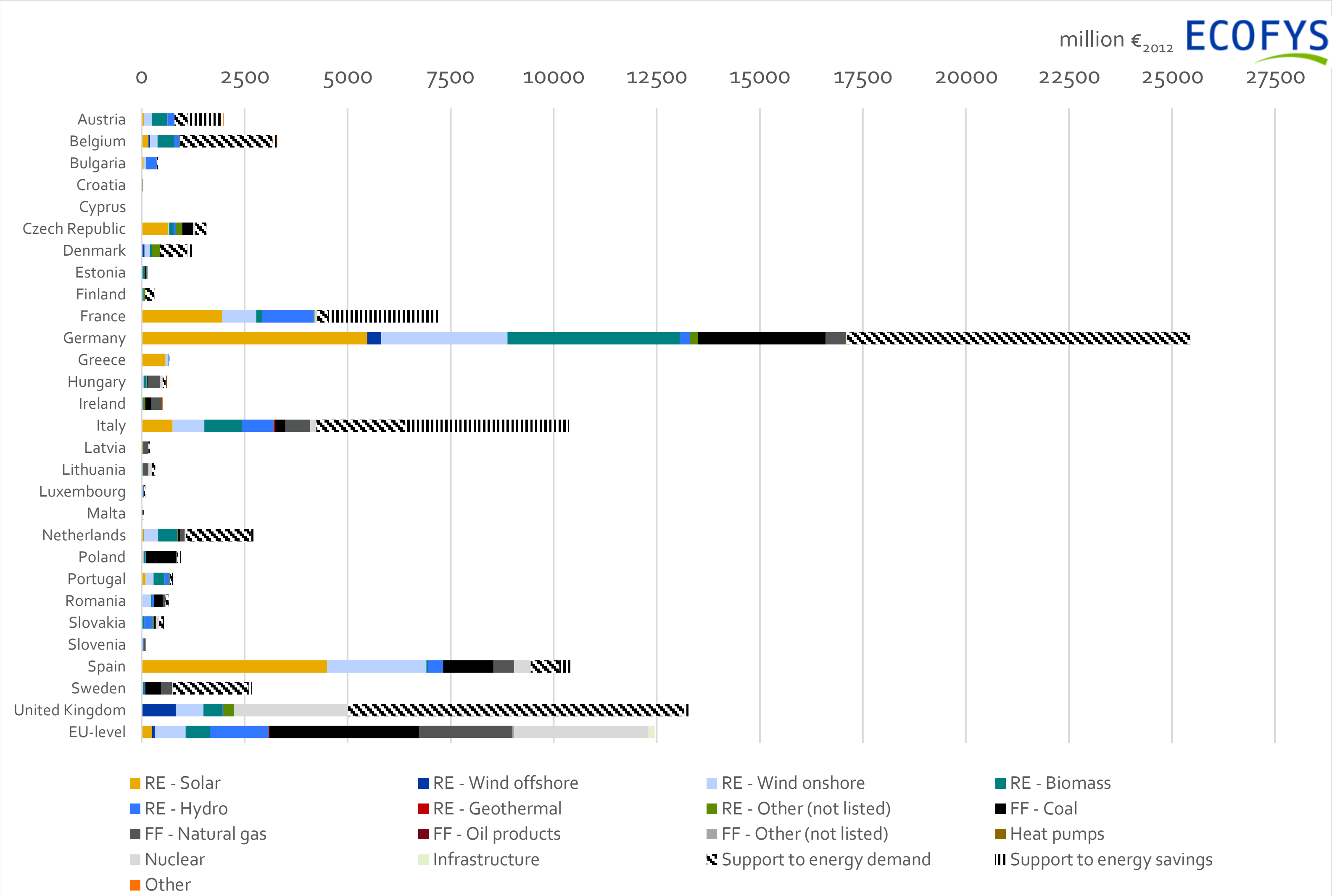

Figure S - 3 Interventions per Member State in 2012 (in million €$_{2012}$)

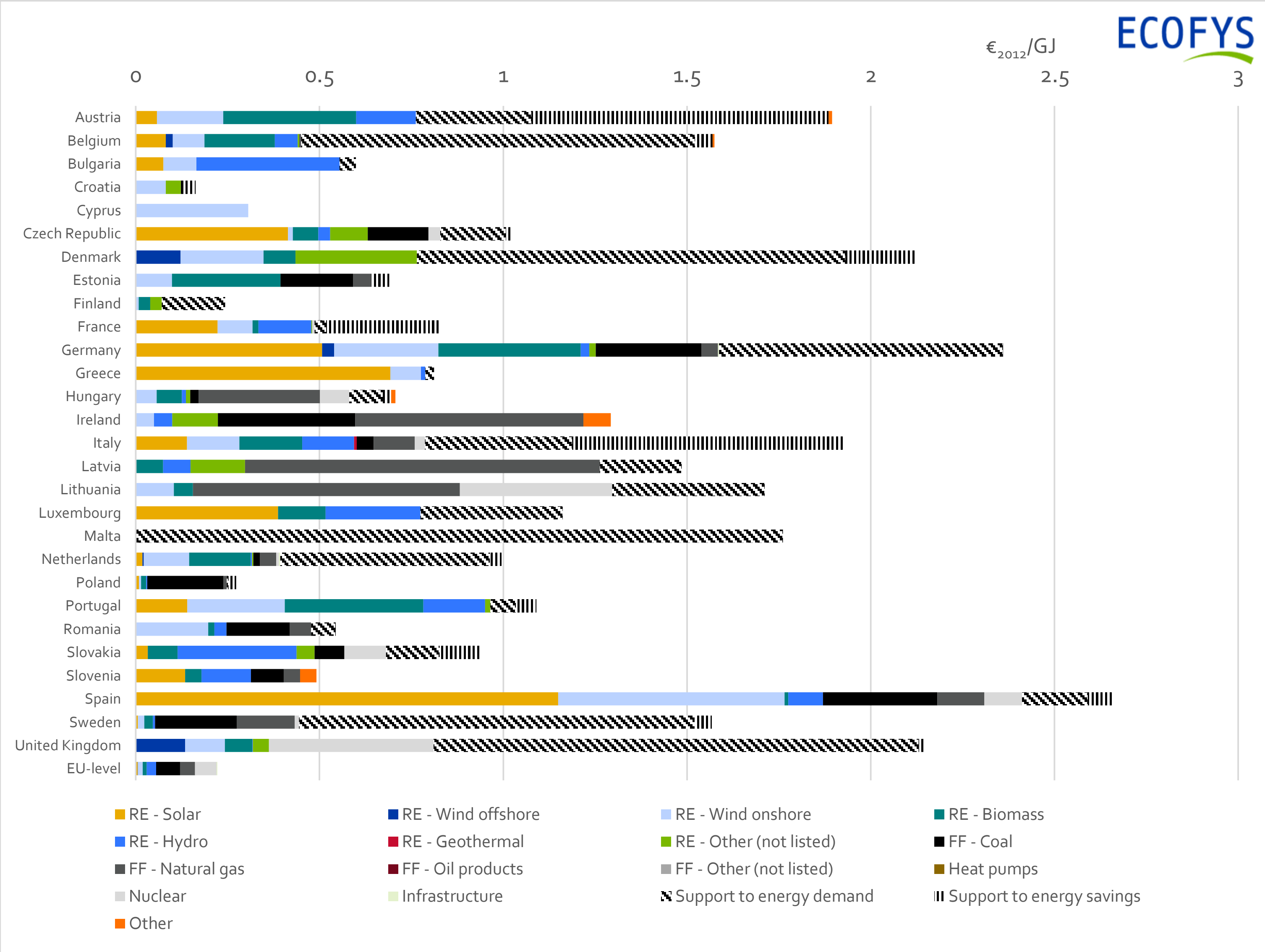

Figure S - 4 Interventions by Member State per unit of primary energy demand (GJ) in 2012[3]

[3] Total primary energy demand (TPED) represents domestic demand only and is broken down into power generation, other energy sector and total final consumption.

For historic subsidies, we distinguish three types of interventions: ones that relate directly to capacity that is still operating in the market today (*'direct historic support'*), ones that indirectly affect the development of capacity such as research and development (*'indirect historic support'*), and *'other historic support'* which does not have a direct impact on markets today, see Figure S – 5.

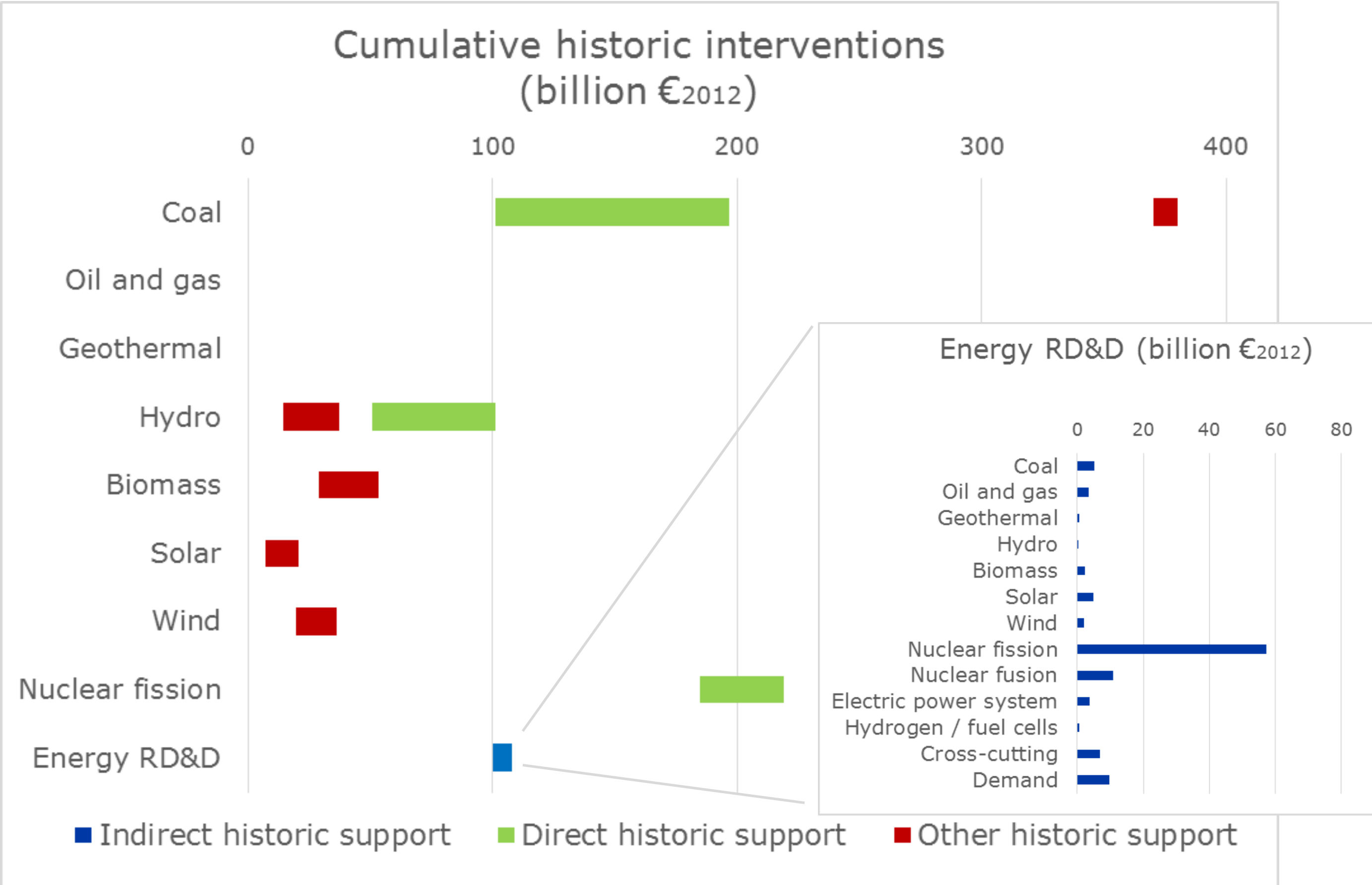

Figure S - 5 Cumulative historic interventions over the period 1970-2007 (in billion €$_{2012}$)

Direct historic support: Before liberalisation much of the infrastructure was built by Government or Government owned companies. It is plausible to argue that some of this infrastructure would not have been built without the implicit transfer of risk to Government. Typically, this would apply to the more capital intensive projects such as coal, hydro and nuclear. This transfer of risk can be classed as an intervention (although it is not a direct transfer of money). An estimate of the effect can be made by calculating the difference in levelised cost with the lower rate of capital for Government and with commercial rates of capital. This direct investment support results in cumulative interventions equalling almost €$_{2012}$ 200 billion for coal, €$_{2012}$ 100 billion for hydro, and €$_{2012}$ 220 billion for nuclear power plants. The contribution to the total level of interventions in 2012 is valued at €$_{2012}$ 15 billion at maximum (see Figure S – 1)[4]. Another area of support for nuclear has been soft loans for nuclear plants. It is assumed that the effect of these loans is also captured by this method.

Indirect historic support/Energy RD&D: Data from the IEA Research, Development and Demonstration (RD&D) Database shows historic expenditures made by 19 of the Member States on energy-related programmes. The reported cumulative RD&D expenditure by EU Member States in the period 1974–2007 was €$_{2012}$ 108 billion. For energy supply technologies this was €$_{2012}$ 87 billion (both including nuclear fusion).

[4] With a lower estimate of €$_{2012}$ 3 billion, the range coming from different methodologies for estimating the intervention; Figure S-5 shows the ranges for the cumulative support levels (1970-2007).

Historically the nuclear sector has received around 78% of the funding, of which the majority was on nuclear fission. The remaining RD&D expenditures were divided about equally over renewable energy (12%) and fossil fuels (10%). For energy efficiency the cumulative RD&D expenditures over the same period were almost $€_{2012}$ 10 billion, and $€_{2012}$ 11 billion was spent on a wider range of topics, including power conversion, transmission and distribution ($€_{2012}$ 4 billion), hydrogen and fuel cells ($€_{2012}$ 0.6 billion), and cross-cutting technologies/research ($€_{2012}$ 7 billion).

Other historic support: In addition to the above, the most significant interventions in the market has been production support to the European coal industry and more recently, the renewable industry. The coal interventions were designed to ensure that domestic coal remained competitive with imported coal. We have therefore estimated the magnitude of the intervention by assuming that the difference between cost of production for domestic coal and the price of imported coal has been covered by a Government intervention. Using this assumption, there is a cumulative value of interventions for coal of $€_{2012}$ 380 billion in the period 1970 - 2007, the majority of which was in Germany. For renewable energy, we estimate the level of the historic support based on a funding gap approach. We estimate that for the period 1990-2007 cumulative interventions totalled to about $€_{2012}$ 70-150 billion. Using our methodology around 40% of that intervention went to biomass and one 25% to wind and hydro, and 10% to solar.

External costs

We assessed external costs by integrating information from life cycle assessments (LCAs), actual power production data and monetisation methodologies to estimate and value total environmental impacts. The methods for valuing external costs necessarily come with higher uncertainties than for interventions as by definition there is no market value. Nevertheless, there is value in calculating external costs to identify their order of magnitude, to place different externalities into perspective by using units that relate to the real economy, to allow for prudent comparison and to identify areas for priority in mitigating externalities.

Total external costs are in the range of $€_{2012}$ 150-310 billion in 2012, with a central value of $€_{2012}$ 200 billion. The three biggest impacts are climate change, accounting for approximately half of the total, depletion of energy resources accounting for a further 22% and particulate matter formation, constituting 15% of the total. The remaining 13% of impacts include human toxicity, agricultural land occupation, water depletion, metal depletion, ecosystem toxicity, radiation, acidification and eutrophication. Among the power technologies, the fossil fuel technologies have the highest external costs, followed by nuclear and the renewable energy technologies (Figure S – 6).

How to read the range graphs (S – 6) and (S – 7) for external and levelised costs

The ranges depict the differences in outcome (external or levelised costs) across a variety of data points. For external costs these datapoints are for the 28 Member States. For levelised costs they relate to the variety of different sources for capital expenditures, operational expenditures and conversion efficiencies. The combination of these leading to the lowest outcome (external or levelised cost) represents the lowest extreme of the bar, while the opposite is valid for the maximum. The most solid area of the bar represents the median.

A solid line has been added to the range graphs at the EU weighted average for the external costs and the median for the levelised costs.

Domestic heat technologies show a spread in impacts, with the lowest for the renewable heat technologies. Industrial heat, sourced from a variety of fuels, typically has a highest environmental impact as coal is part of the fuel mix.

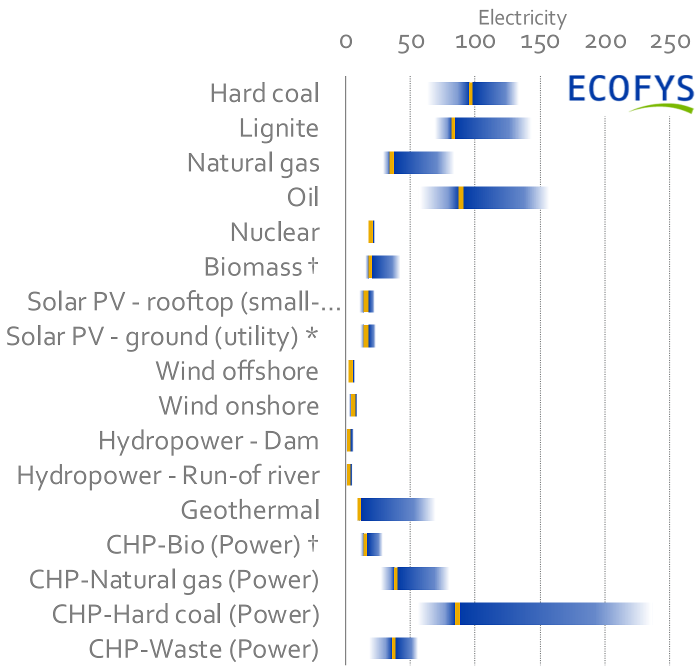

Figure S - 6: External cost ranges per technology for electricity technologies (blue bars), EU28 weighted averages (orange lines) (in €$_{2012}$/MWh$_e$)

*Note: The values presented here for solar PV are likely to be an overestimation of the current situation, because of the high pace of technological development for this technology improving efficiencies and reducing upstream impacts.

†Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Costs

To quantify the true 'cost' of energy is an extremely complex problem as it depends on the age and type of plant operating in a particular country as well as infrastructure and market connections with other countries. To do this analysis for 28 Member States would need extensive modelling and very large datasets. In this study, we therefore provided levelised costs of producing electricity (LCOE) and heat (LCOH). Levelised costs are used for comparing technologies for a variety of different purposes. In this study, they are used to set the size of the interventions and external costs in context of a measure of the cost of energy if the system was being newly developed, without Government intervention. These estimates are based on hypothetical new energy conversion projects. These hypothetical plants do not determine either current market revenues or consumer prices. In addition, we provide estimates of the total capital and operating costs for infrastructure based on information from the Member States.

Figure S – 7 presents levelised cost ranges per power generation technology. Levelised costs for electricity range from around 20 €$_{2012}$/MWh for hydropower running a full load to 200 €$_{2012}$/MWh for offshore wind and biomass plants running at realised loads[5]. Hard coal and natural gas have similar levelised costs (50 €$_{2012}$/MWh) if running at full load but in recent years the low price of coal and the increase in renewable electricity production has resulted in lower running hours for gas. Levelised costs at realised loads for gas are hence higher and comparable to onshore wind and nuclear. There have been significant reductions in capital costs for photovoltaics between 2008 and 2012, resulting in a fall in levelised costs from above 200 €$_{2012}$/MWh to around 100 €$_{2012}$/MWh.

[5] Full load hours are the hours that a plant could run in a year taking into account technical downtime. Realised or actual full load hours are the hours that plants actually ran on average in 2012. They are calculated from capacity and production.

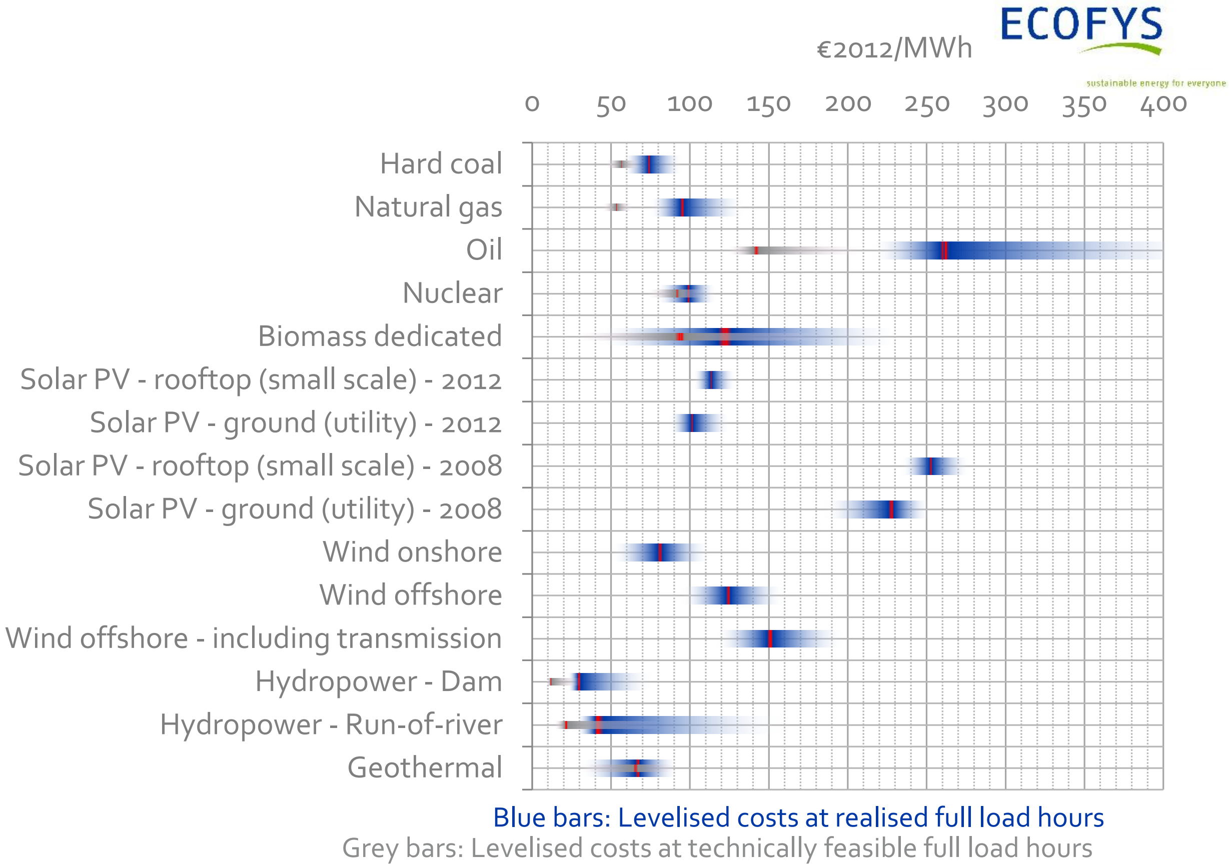

Figure S - 7: Levelised costs of energy in EU28 for electricity (in €$_{2012}$/MWh)

Note: The red lines in the figure above represent the median value for the range

The levelised cost of heat ranges from 20 €$_{2012}$/MWh for industrial gas boilers to 150 €$_{2012}$/MWh for heat pumps and wood pellet boilers in certain climate regions. In general, the cost of natural-gas based technology is largely driven by the cost of fuel, while for technologies running on other fuels (heat pumps, biomass boilers), capital expenditures play a larger role.

Electricity and heat technologies are part of the energy system. Transmission and distribution infrastructure is needed to deliver electricity and gas. Total annual expenditures (capital and operation & maintenance together) for the electricity transmission system across the EU28 are around €$_{2012}$ 20 billion. Total annual expenditures (capital and operation & maintenance) for the gas transmission network are of the order of €$_{2012}$ 15 billion in 2012. There were more data gaps in the reported expenditures for the gas transmission network.

Glossary

Accelerated depreciation: Accelerated depreciation is another measure that can be used to provide a tax advantage to firms, resulting in foregone income to the government. It works by changing the rate at which capital assets can be written off in firms accounts, allowing firms to write off more than would otherwise be allowed in the earliest years of the asset life.

Consumption side measures: Support measures to energy consumption relate to specific transfers of income to certain groups of energy consumers that may be exempt from taxes or allowed special deductions.

Costs: The cost of producing energy. The method followed aims at removing the effect of public interventions.

Direct transfer of funds: Also referred to as direct subsidies. Direct transfer of funds may include direct government payments such as capital grants, production support (e.g. feed-in tariffs and premiums), government spending on R&D and deficiency payments. Direct subsidies are most often 'visible', they can be quantified, and are usually included in annual government budget statements.

Energy efficiency obligation: In an energy efficiency obligation, an energy supplier or distributor (or other entity) is given an obligation by Government to achieve a certain level of savings (either in energy or in carbon).

Exemption from import duty: A project or firm is provided with an exemption from paying duties on capital equipment imported for a project. These exemptions are designed to make investments less costly and therefore more attractive.

External costs: All forms of energy have impacts that can result in cost to society. The most commonly discussed are environmental impacts. If these costs are not recovered by the market they are referred to as external costs.

Feed-in premiums: In a feed-in premium scheme, plant operators have to sell their renewable energy on the market and receive an additional payment on top of the market price. This payment may be either fixed or adapted to changing market prices to limit the price risks for plant operators.

Feed-in tariffs: In a feed-in tariff (FIT) system, power plant operators receive a fixed payment for each unit of electricity, heat and/or biogas generated, independent of the market price for these energy products.

Full load hours: The annual energy generation divided by the capacity. This represents the equivalent amount of hours a power unit would have been operating at full load to generate the total annual generation.

Government tax and other government revenue foregone: Tax revenue foregone refers to revenue foregone by the government (or other economic agents) due to a reduction in the tax liabilities of particular groups or of specific activities.

Hierarchist perspective: is based on the cultural perspectives theory of Thompson 1990. According to this theory consistent sets of subjective choices on time horizon, assumed manageability etc. can be grouped around three perspectives, identified by the names: individualist (I), hierarchist (H) and egalitarian (E). The hierarchist perspective is the middle perspective and is most often used as default option in life cycle analysis and valuation, reflection a 100 year time horizon and 3% social discount rate.

Income or price support: Also referred to as induced transfer of funds. Induced transfers refer to government support that is (indirectly) provided to consumers or producers to keep the end-price of an energy good or service lower or higher than its actual market price, often through some sort of price support or price regulation.

Levelised costs of energy: The levelised costs of energy (LCOE) represent the costs of production without interventions.

Life cycle analysis: Life cycle analysis (LCA) is a method for the environmental assessment of products and services, covering their entire life cycle from the cradle (raw material extraction) to the grave (waste treatment).

Life cycle impact assessment: During the life cycle impact assessment (LCIA) phase of an LCA, the environmental interventions defined in the LCI are translated into environmental impacts (e.g. climate change, ozone depletion) using an impact assessment method (e.g. ReCiPe).

Life cycle inventory analysis: During the life cycle inventory (LCI) analysis phase data are collected and the environmental interventions (i.e. resource use and pollutant emissions) of the product or service are calculated.

Marginal cost: The increase in the total cost of production as a result of producing one more unit of output.

Non-financial measures: Non-financial support measures relate to mandates, obligations and (voluntary) agreements between the government and producers and consumers of energy.

NPP: Nuclear power plant.

NPPO: Nuclear power plant operator.

OECD: Organisation for Economic Cooperation and Development.

Price guarantees: A policy measure providing producers with a guaranteed price for their products.

Prices: The price paid for a certain service (e.g. electricity, heat). The price that is paid includes market factors and the effect of public interventions.

Production side measures: Support measures on the production side aim at stimulating production of energy using some specific energy carriers or technologies of production.

Property tax abatement: A tax relief associated with property, resulting in foregone income to the government. It works by reducing the rate of tax which at which property, such as land, buildings or capital assets is taxed.

Public interventions: Any intervention in the energy market by public actors such as national and regional Governments that influences the market price.

Reference technology: A reference technology is a technology which reflects the average techno-economic characteristics of the installed capacity of a certain technology group.

Royalty exemption: A royalty exemption provides a project or a firm with an exemption from paying royalties on energy production.

Quota obligations: In countries with quota obligations, governments impose minimum shares of renewable energy on suppliers (or consumers and producers).

Soft loan: A soft loan is a loan with an interest rate below the commercial rate and/or a longer repayment period.

Stranded asset: A stranded asset is a financial term that describes an asset that has become obsolete or non-performing, but must be recorded on the balance sheet as a loss of profit.

Retail prices: Retail prices for electricity and heat are the cost of energy to the end-user set by the market and including the effect of all interventions.

Transfer of risk to government: The assumption of (some part of) the risk by governments that market players (e.g. energy producers) face.

WACC: Weighted Average Cost of Capital. For this study assumptions were made on the costs of capital per technology and per country, to reflect differences in risks.

Table of contents

1 Introduction

1.1 Background

On 22 January 2014 the European Commission presented a report on energy prices and costs together with the Communication on the policy framework to 2030[6]. The report includes an analysis of drivers and implications of changes, and presents a number of developments that point at governments intervening in the energy market.

Public interventions to support the energy sector are one way for governments to attain social, economic and environmental objectives. Significant support to conventional fossil fuel technologies was put in place over the last decades to accomplish specific policy goals such as reducing energy dependency on imported fuels, abating poverty by providing support to low-income households or to avoid competitive disadvantage of energy-intensive industries from increased energy prices. At the same time, there are reasons to support new renewable technologies including environmental considerations (climate change, but also air pollution and other environmental damages), improved security of supply through diversification and creation of new employment and export opportunities.

Against this background current public interventions in the energy market need to be reviewed, as they significantly affect costs and prices of energy. This can only be done if data on energy costs and subsidies in the EU and across the 28 Member States and the EU overall are consistent.

Currently, there are various studies that have addressed or are still investigating energy subsidies in the EU. These include a study for DG ECFIN in which PWC and Ecofys are investigating the cost-effectiveness of support to new electricity production technologies in five Member States and the EU overall, and a study undertaken by the European Environmental Agency (EEA) on energy subsidies in a selected number of countries. However, although relevant, these studies do not cover the whole of the EU and are limited in the extent to which they include and quantify subsidies and interventions.

In addition to these ongoing studies, there are two major studies that were published in recent years that have quantified the value of subsidies for fossil fuels in the EU. These include a study performed by the Organisation for Economic Co-operation and Development (OECD) in 2011[7] which was updated and extended in 2013, and a study by the International Monetary Fund in 2013[8]. Both studies cover (most) of the 28 Member States and the EU overall, but have certain limitations. Apart from the fact that they only include fossil fuels/energy and not nuclear and renewables, they are also limited in the extent to which they include indirect subsidies and government measures. Consequently, they provide only part of the picture.

To provide a more holistic picture, DG Energy commissioned a project to provide information on all costs of energy, including external costs, and to quantify the extent of public interventions in the energy market. This report gives the outcome of this project, which was led by Ecofys. KPMG, CASE and CE Delft provided data collection with regards to public interventions in the 28 Member States. The specific objectives for the project are defined below. Section 2 describes our methodological approach.

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[6] European Commission (2014) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Energy prices and costs in Europe. COM(2014) 21, 29 January 2014.
[7] OECD (2011) Inventory of estimated budgetary support and tax expenditures for fossil fuels.
[8] IMF (2013) Energy subsidy reform: lessons and implications. Overview of post-tax subsidies for petroleum products, electricity, natural gas, and coal.

Results are presented and put into context in Chapter 3. The annexes include details of the methodology and assumptions made and provide more detail on the results.

1.2 Objectives

As discussed above, the overall objective of this assignment is to provide the European Commission with a complete and consistent set of data on energy (electricity and heating), generation and system costs and the historical and current state of externalities and interventions in each Member State of the EU and for the EU overall.

More specifically the objectives are:

1. To assess different methodologies and definitions of costs and subsidies and to develop an objective and workable methodological framework.
2. To provide historical and current data on public interventions in the energy market in all EU Member States and the EU overall. These interventions may be on the production and consumption side of energy products and carriers, and on the energy system. The focus is on those measures that directly impact energy costs and energy market prices paid by consumers.
3. To monetise environmental impacts and related external costs from the energy system in all of the Member States (internalised or not).
4. To assess energy costs covering capital and operating costs of different electricity and heat generation technologies. The cost analysis is used to put the subsidies and external costs in context and are not intended to give any indication of the revenues for energy companies nor prices for consumers. The cost data on technologies is complemented by estimates of national energy transmission costs. This study explicitly does not assess energy (end) consumer price compositions.

There are many benefits to society from using energy and these have been drivers for Government interventions for decades. Apart from the fact that energy services are a critical requirement for virtually all human activities, the benefits include tax revenues raised by Government (in fact there are a number of energy sectors with higher rates of tax than comparable enterprises), employment, and economic activity. These benefits though are already reflected in market prices, are therefore unlike the external impacts we consider, and are not reported.

This project provides important information for the objectives above on the energy system up to the end of 2012. Inevitably some aspects that are part of the policy discussion now only have a limited effect in the period we examined. Important aspects are:

- Future development of the costs and external costs in the energy system. The drivers of policy in the energy system have changed in response to global concerns. In recent years, the need to tackle climate change and to ensure security of supply have been important drivers of energy policy. This has resulted in policies to encourage renewable energy but also unconventional fossil fuels such as shale gas. These factors will bring about changes to the costs and external costs in the system. For example, reduced use of conventional fossil fuels would bring lower external costs but unconventional fossils tend to have higher impacts and associated external costs. There are also potentially higher electricity system costs when the share of supply-driven renewable sources (like wind and solar PV) increases.
  Whether some of these costs should be associated with particular energy sources as external costs depends on the degree to which these costs are already reflected in the prices and on

the allocation methodology used. At current shares of renewable energy penetration these costs are considered to be negligible.

- Future policy changes in the energy system. The aim of this project is to obtain as complete a picture as possible of interventions in the energy system across the EU28. The latest year for which reliable information across all the countries was available when this project was carried out was 2012. Since then, there have been some significant changes in Government policies, for example reducing subsidies for renewables in many Member States, introducing production support in the UK for nuclear and introducing capacity markets. None of these policy changes affect the money paid out or foregone in 2012. Therefore, they are not described further.

1.3 Definitions

Support can take different forms, of which subsidies are most prominent. The OECD (2006) has concluded that 'there is no universally accepted definition of a subsidy' - a conclusion that is still valid today. Subsidies are commonly understood as the direct budgetary support of governments. In this context a subsidy is the direct payment of a government to an organisation, producer or consumer with the purpose of improving particular circumstances or to stimulate certain activities. This definition is however rather restrictive and excludes other forms of government support received by producers and paid by consumers. These may include tax measures, trade restrictions, purchase obligations and price conditions (EEA 2004).

The definition that is most widely used in the research community, probably because of its broad scope, is that of the OECD. The OECD (1998) uses a broad definition of subsidies as 'any measure that keeps prices for consumers below market levels, or for producers above market levels or that reduces costs for consumers and producers'. This definition is comparable to WTO (1994) that defines a subsidy as 'any financial contribution by a government, or agent of a government that confers a benefit on its recipients'.

For the purposes of this study we distinguish the following terms:

- Public interventions (see below for more detail): any intervention in the energy market by public actors such as national and regional Governments that influences market price.
- Prices – this is the price paid for a certain service (e.g. electricity, heat). The price that is paid includes market factors and the effect of public interventions.
- Costs – this is the cost of producing energy (see Section 2). The method followed aims at removing the effect of public interventions.
- External costs – all forms of energy have impacts that can result in cost to society. The most commonly discussed are environmental impacts. If these costs are not recovered by the market they are referred to as external costs.

We propose to use the term public interventions and use this throughout to reflect both direct subsidies and more indirect government subsidies, taxes, levies, regulations and measures. More details of subsidy types are given in Annex 1.

2 Overview methodology

In this chapter we present headlines of the methodological framework. We firstly describe our methodologies for estimating recent interventions (i.e. between 2008 and 2012) and historic interventions (before 2008). Next, we describe the reference technologies we use for the analyses of external and levelised cost. Finally, we describe the methodologies for calculating external costs, levelised costs of energy conversion, and costs of infrastructures. Details of the methodological framework are provided in the annexes to the report (see Table 2-1).

Table 2-1: Guidance for reading chapter 2

	Section	Annex
Interventions from 2008 - 2012	2.2	Annex 2 (A2.1 – A2.10)
Interventions before 2008	0	Annex 2 (A2.11)
External costs	2.5	Annex 3
Levelised costs	0	Annex 4
Grid infrastructure costs	2.7	-

2.1 Interventions

Public interventions in the energy market have been occurring for decades and some still have an impact on energy prices in today's markets. In addition to the monetisation for the years 2008 - 2012 discussed in the next section we provide an estimate of historic interventions that are still having an effect on the energy market today.

For a thorough understanding of the ways in which the EU's energy sector has been subsidised in past decades, it is not sufficient to merely present quantifications of state funding, but also to understand the structure of the energy industry and the drivers of intervention. This is set out in the text box below.

Box 2-1: Historic development of the energy industry in Europe

The energy sector before WWII

During the period of industrialisation in the 1800s, investments in both gas and electricity supply were mainly undertaken by emerging industries to grow and rationalise their production, i.e. this early period can theoretically be classified as an intervention free energy market.

However, as the energy system developed, national governments showed a strong interest in gaining political control. Investment decisions on energy supply and exploitation of certain energy carriers were therefore based on strategic political and often military considerations. In the 1920s, market interventions were influenced more by social aspects such as fixed prices.

The decades after WWII

The first supranational attempt to solve a root cause of Europe's political fragmentation was the European Coal and Steel Community (ECSC), ratified in 1951. The core part of the agreement was guaranteed customs-free access to coal and steel for its six member states. With the European Atomic Energy Community, a second institution of intra-European energy cooperation was created in 1957. Although supranational arrangements like ECSC had introduced some elements of liberalism, at least until the late 1960s energy policies of European countries were generally dominated by security of supply for national economies.

Developments after the 1973 oil crisis

Until 1997 most European Member States kept monopolistic structures in energy supply and distribution at least for their domestic energy carriers. In Eastern European countries, until 1989 the dominating principle was central planning in economy, which for energy supply meant increasing the absolute amount of energy generated, immaterial of the related cost[9]. Transparency on real cost of supply was in most cases not given, as both final energy prices, cost of labour, and mostly also investment cost were subject to political steering.
It is impossible to quantify or describe in qualitative terms how the European energy sector would have developed under merely market driven conditions. When looking at the role which certain energy carriers played in the historical setup in many European countries, it becomes evident that mainly hard coal and from the 1960s onwards also nuclear stood in the focus of policy induced strategies still ranking strategic security of supply higher than least cost options. Thus, it can be assumed that in a scenario without political influence on the sector both nuclear energy and hard coal, would have received less commercial attention and investment. International trade and energy efficiency might also have played an earlier role.

2.2 Interventions from 2008 through 2012

In this study we monetised public interventions in the energy market by Member States and the EU as a whole. We present annual values of interventions in Euros for the years 2008 - 2012. These regard payments made (or revenues foregone) in each of these five years as stipulated by all regulations in force, including regulations that were enacted in the past. As mentioned previously, retrospective changes in interventions do not affect annual values in past years only ones going forward from the date of those changes.

[9] Dietz, R (1984) Die Energiewirtschaft in Osteuropa und der UdSSR,. Springer-Verlag, Berlin, New York.

A wide variety of interventions has been monetised. For each intervention a three tier approach was adopted:

- Tier I National balance sheets or national reports
  The size of the intervention is taken directly from national balance sheets. This was the preferred option for all interventions as it provides the most robust figures for total expenditure in a year. However, this information was not always be available, as in the case of certain tax exemptions, or disaggregated insufficiently. In that case we used Tier II.
- Tier II Detailed methodology
  The size of the intervention is calculated in a detailed bottom-up manner using from other sources. In cases, where this is too complicated, we used Tier III.
- Tier III Alternative methodology
  For a selected number of interventions annual payments in the view period could not be calculated in the same manner for all countries and an alternative methodology was adopted.

To monetise any given intervention a reference scenario is needed. In most cases this represents the absence of the intervention. In some cases, in particular for tax measures, the reference scenario would be a different tax measure, or a higher tax burden. We have chosen as the benchmark the standard rate of tax in that Member State for similar categories of tax payers, for example comparing production tax allowances against the standard rate of corporate tax. We do not compare such tax allowances against any higher corporate rates that may apply for particular enterprises (such as gas producers or nuclear and renewable generation in some countries). VAT reductions are compared against the standard rate of VAT in a country.

In Annex 2, we describe the methodologies adopted for quantification of the interventions divided into support for R&D, support for investment for energy production, support to production, support to energy demand and support to energy savings (including grants for investments in energy saving). The quantification of energy price interventions presents some methodological challenges both in the definition of what is an intervention and the quantification of the value. These challenges are detailed in Box 2 - 2 together with our treatment in this study.

In addition, there are interventions that relate to the transfer of risk to Government. Examples include limits of liability for accidents and decommissioning and waste management. This transfer of risk, particularly on decommissioning and waste can apply in many industries, see for example the subsidies to lignite mine rehabilitation. However, in the nuclear industry the potential costs are much higher and therefore this is discussed in more detail in Annex 2 (Section A2.9). Based on our analysis, these interventions are insignificant compared to the results in Section 0 and are not included in the totals reported. These totals do include any direct interventions for decommissioning and waste management in the period 2008-2012.

Box 2-2: Challenges in quantifying energy price interventions.

Differences in payments per unit of energy consumed: For nearly every energy price component, there are different tariffs for different customers. These differences in tariffs per unit are not necessarily interventions, since they can be justified by characteristics of different customers. For example, industrial customers use the existing grid more efficiently than households due to the higher full load hours. Thus, the payments per unit can be lower. We define interventions in tariffs, if specific customers are exempted from tax payments although they have the same consumption characteristics as other customers that do pay a certain tax. If, for example, all households are exempted from specific taxes, this is not taken into account. If exemptions only apply to households with low income, they are included as interventions.

Reference tariff: If customers pay different tariffs for the same tax, levy or fee, it can be discussed which tariff should be the reference tariff. Often, there are specific tariffs for households, which are much higher than for companies. Some price components only apply to business customers like the Climate Change Levy in UK. When applicable, we used the general tariff for the same group of customers to estimate the value of a specific tax exemption.

Refunds: In several cases, consumers pay for a tax and receive a refund. These refunds are hard to quantify because total numbers are often not disclosed to public. They do not appear in subsidy reports, because customers do not receive more than they pay for a specific tax. We included information about refunds if possible. In some cases, the maximum value was calculated, if no detailed information or estimation was available.

Limits on payments: To avoid high energy costs for single customers, there are limits of total payments in several countries. One example is a payment up to a certain share of the value added, e.g. 0.5%. Tax payments that exceed this limit are either refunded or abolished. These interventions are covered in our analysis, but quantifications are hard. Like refunds they do not appear in subsidy reports, because customers do not receive more than they pay for a specific tax. We included information about the revenue foregone if available.

Overcompensation: Often, differences in payments are justified by estimated cost burdens. Some consumers pay less because they have high costs in related fields, e.g. to meet energy efficiency standards or because they provide certain services to the system, e.g. in interruptible load schemes. The exemptions from payments are determined on an average cost basis or as an estimation for the value of the service. If the particular exemptions are not well designed, specific parties might receive more generous payments than others which could be interpreted as a hidden subsidy. For example, two companies might receive similar payments for interruptible load with very different cost burdens. We have included interruptible load schemes where this data was provided by the Member State experts. There are other interruptible load schemes that we know exist but details of operation are not publically available.

Double taxation: Tax exemptions can be justified to avoid double taxation. If energy is used in production processes that are taxed for their energy content in a second step, the producer often does not have to pay taxes for the energy input. This regards mainly electricity production. In most of the EU Member States, electricity generators do not have to pay fuel taxes, but taxes are paid by the end consumer in form of electricity taxes on the final product. Another example are exemptions from electricity taxes for pumped storage power plants. Some countries exclude pumped storage power plants from electricity taxes, because the electricity is only stored and will be taxed in its end consumption. In these cases, we do not consider this an intervention.

Non energy use of fuels: In case there is a tax exemption for fuels used in industry that are likely to be used as feedstock use and not for energy purposes, we exclude these as interventions.

2.3 Interventions before 2008

The changing structure and priorities in the energy sector makes the definition of what was a subsidy very difficult for some categories. We have adopted an approach to estimate those subsidies but it must be recognised that this is subject to a high degree of uncertainty in both the methodology and data.

We distinguish three main types of intervention:

- Interventions that relate directly to infrastructure that is still operating in the market today (direct historic support);
- Interventions that indirectly affect the development of infrastructure and the market such as research and development (indirect historic support); and
- Historic (direct) interventions that no longer affect the energy markets today.

2.3.1 Direct historic support

'New' renewable energy technologies
For the direct support of renewable energy technologies (e.g. feed-in tariffs) we take the so-called funding gap in the first year of operation (cost minus reference energy price), multiplied by the energy production in the view year, as the measure for the intervention. Any new capacity that became operational in the period before 2008 hence adds to the total level of support in the years after 2008.

Investments under non-liberalised market conditions
Before liberalisation much of the power generation capacity was built by Government or Government owned companies. It is plausible to argue that some of this capacity would not have been built without the implicit transfer of risk to Government. Typically, this would apply to the more capital intensive projects such as coal, hydro and nuclear. This transfer of risk can be classed as an intervention (although not a direct transfer of money). An estimate of the effect can be made by calculating the difference in levelised cost with the lower rate of capital for Government and with commercial rates of capital. In a perfect market, the value of this intervention would have been included in the price paid for the assets at privatisation. It is difficult to demonstrate whether this was the case. We provide a sensitivity by looking at the difference in value if it is assumed that any intervention acts over the whole lifetime (base case), and the alternative that it acts only for the depreciation period of the asset. The motivation for the base case is that the impact of this intervention is not necessarily constrained to the depreciation period (which is basically a fiscal/accounting variable), or when a private party buys the power plant.

The transfer of ownership from public to private during the privatisation of the energy sector (either of the power plant, or of complete companies) does not significantly affect the calculation of the abovementioned level of intervention. We compare the *difference* between a power plant built by a public entity, and one built by a private entity, both being sold to a private entity. It is not the full transfer sum that should be treated as a negative subsidy, but only any differences between these cases. These differences are relatively small (and can be either positive or negative) and the total effect is considered to be negligible (especially compared to the other uncertainties in the approach). In the case of a transfer of the ownership of a full utility (i.e. from public to private), any benefits of lower initial cost of capital are 'inherited' by the new owner.

Due to its long lifetime past investments have long-lasting impact on the design and functioning of energy markets. For example, an urbanised area with an existing natural gas network makes the business case of waste heat utilisation through a district heating network much harder, and vice versa. As most investments have been made by Governments or Government owned infrastructure operators, a similar argument can hence be made for gas and electricity grid infrastructure. However, data on historic expenditures or physical build rates across the EU28 could not be identified, so no quantification could be made.

Support to nuclear energy through Government loans
Some governments provided loans to nuclear power plant operators in the past. The level of the intervention is assumed to be covered by the approach presented in the previous section (interventions under non-liberalised market conditions).

2.3.2 Indirect historic support

Research, development and demonstration (RD&D)
Data from the IEA Research, Demonstrating and Demonstration (RD&D) Database[10] were used to assess historic expenditures made by 19[11] Member States on energy-related programmes.

2.3.3 Historic support no longer affecting current energy markets

Some historic interventions, notably production support, have no direct impact on the energy markets today. This relates to support to coal production from European coal mines, and support given to renewable energy production. During several time intervals, some individual Member States have had particular interventions on some energy carriers, e.g. price support for natural gas.

Renewable energy sources
The interventions ion the period 1990-2007 have been estimated through application of the funding gap approach. The difference between levelised costs of energy and an average figure for the energy market prices was the measure for the intervention. This will result in an indicative figure. For the period 2008-2012, data have been collected (see section 2.2).

Coal production
Most significant indirect interventions have been support to the European coal industry, (soft) loans for new nuclear power plants and safety upgrades at existing nuclear plants (through Euratom and EIB). The coal interventions were designed to ensure that domestic coal remained competitive with imported coal. We have therefore estimated the magnitude of the intervention by assuming that the difference between cost of production for domestic coal and the price of imported coal has been covered by a Government intervention. Annexes 2.11 and 2.12 include a detailed description of the applied methodology and results.

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[10] Energy RD&D covers research, development and demonstration related to the production, storage, transportation, distribution and rational use of all forms of energy. The following is covered: basic research when it is clearly oriented towards the development of energy-related technologies, applied research, experimental development and demonstration.
[11] Austria, Belgium, Czech Republic, Denmark, Finland France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Spain, Sweden and the United Kingdom.

2.4 Technologies covered in external and levelised cost calculations

We calculated costs for a range of reference or typical technologies, covering the abundant majority of technologies deployed in the power, industrial and residential sector for supplying heat and/or power. The reference technologies are described briefly in this section and in more detail in Annex 3 and 4.

Table 2-2 Typical power and heat generating technologies for which in this analysis the levelised cost of electricity (LCOE), heat (LCOH) or of electricity or heat from CHP are determined (LCOE-CHP and LCOH-CHP respectively).

Category	Technology	Description
LCOE	Coal	Pulverised coal (excluding lignite) plant, typically ranging in size between 400 and 1000 MW.
	Natural gas	Natural gas combined-cycle gas turbine plants with a typical size between 100 and 400 MW.
	Oil	Fuel oil-fired power plant, typically sized between 50 and 200 MW, fuelled by fuel oil.
	Lignite	Lignite-fired power plants.
	Nuclear	New generation II nuclear plants†.
	Geothermal	High temperature conventional geothermal systems.
	Biomass	Dedicated biomass plant with feedstock ranging from (free) biomass waste to wood-pellets, typically sized between 1 and 50 MW.
	Hydropower – run-off-river	This category includes run-of-river plants and other smaller hydropower installations. The costs are based on small hydropower (<10s MW) and the full load hours on run-of-river plants.
	Hydropower – dam (reservoir)	This includes hydropower with large reservoirs with capacities ranging from ~50 MW to ~1000 MW). Costs are based on large hydropower costs and full load hours are based on estimates on reservoir plants.
	Solar PV – rooftop (household)	PV installed at roof tops in the residential sector.
	Solar PV – ground-mounted (utility)	PV installed ground-mounted by utilities or other commercial parties.
	Wind onshore	Onshore wind parks.
	Wind offshore	Offshore wind parks with and without the offshore transport and distribution infrastructure.
LCOE-CHP and LCOH-CHP	CHP biomass	Biomass CHP plant, sized between 1 and 100 MW, fuelled by biomass from waste streams††.
	CHP gas	Natural gas combined-cycle gas turbine CHP plants.
	CHP coal	Pulverised coal CHP plants.
	CHP waste-to-energy	Municipal waste-fired CHP plant.
	Industrial gas turbine with waste heat boiler	Gas turbine boiler with waste heat recovery boiler.
LCOH	Industrial gas-fired steam boiler	Steam boiler deployed to provide heat in the form of steam to industrial processes.
	Domestic gas-fired boiler (non-condensing)*	Household non-condensing boiler.
	Domestic gas-fired boiler (condensing)*	Condensing boiler.
	Domestic heat pump*	Air-water heat pump.

Category	Technology	Description
	Domestic wood-pellet-fired boiler*	Biomass boiler operating on wood-pellets.
	Domestic solar thermal*	Solar thermal boiler complemented by a gas-fired non-condensing boiler.

† As discussed, the technologies are hypothetical technologies that might have been built in in the period 2008 - 2012. In reality, no new nuclear plants projects have been initiated in recent years, although there have been life extensions on existing plants. Generation III nuclear plants are proposed for future developments, e.g. in the UK, but literature to derive robust estimates on the costs for these plants was not available, so Generation II costs were preferred.

†† There are other biomass fuels used but the biggest proportion are fuels from waste, including forestry and agricultural waste.

** For this analysis, all domestic heating technologies are deployed for supplying both space heat and domestic hot water. Investment costs are based on regions in Europe (North, East, West, South, Central) where peak demand as well as annual heat demand – taking into account average insulation levels - per region is taken into account.*

The data defining the technologies at EU level have been obtained from publically available sources: these data are project duration, construction period, capital cost, operation and maintenance cost, capacities and efficiencies (see Annex 4, section on literature sources). EU level data for technology costs are preferred for electricity generation as price differences for different countries can in part be driven by the interventions. For heating technologies, there is a differentiation between countries based on climate zone (Annex 4, detailed methodology). All EU level data is based on (one of the years in) the period 2008 - 2012, i.e. plants being constructed in the period 2008 - 2012. One exception is PV – for which more recent (2012) cost data has been used to account for the rapid decline in cost.

For the external cost calculation, the reference technologies were used to define the characteristics of the life cycle impact assessment. However, actual energy production and efficiencies, based on reported total fuel use and electricity or heat output, were used to calculate the impact for the fossil power and CHP technologies. Average national-level full load hours, relative to a reference, and actual production were used for the renewable power technologies.

2.5 External costs

This report presents a valuation of the external costs of energy. Box 2-3 briefly explains the theory behind externalities and what the external costs values should represent. In essence they help to provide an insight into the ‘true’ cost of energy, if all costs of production were to be included. Yet placing a value on these externalities is not straightforward, and a number of broad assumptions and value judgements are required.

Box 2-3: Theory of externalities

Economic externalities represent the impacts of production and consumption onto entities other than those producing and consuming, which are not reflected in prices. While externalities can be either positive or negative, the remit of this project was to quantify negative environmental externalities. The classic example is that of the private owner of a coal power plant paying for coal, labour and other inputs and charging for the energy sold, but not bearing a cost for the damages to health and nature caused by, for example, the air pollution the power plant emits. These costs are borne by society as a whole, so that the outcomes for private and social welfare differ.

In a perfect market, which maximises social welfare, private costs would be equal to societal costs, with no externalities to the price mechanism and all the costs and benefits to society of economic activity reflected in the price. Without policy intervention this is rarely the case, with the most common result of lower prices and higher consumption than is desirable for society as a whole (see Figure 2-1). It is necessary therefore to 'internalise' the externalities, through policy interventions such as taxes, regulations, subsidies and other measures. These modify the prices and incentives for private production and consumption decisions so that they better account for the full impact on social welfare. This is part of the polluter pays principle.

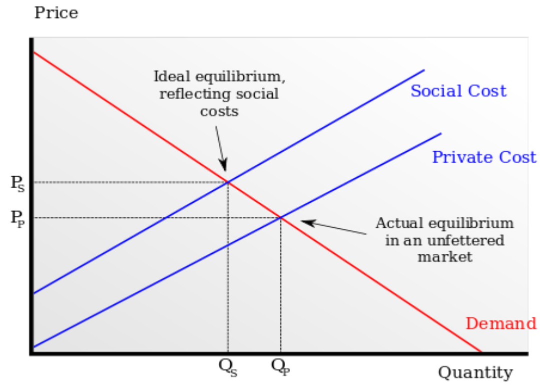

Figure 2-1: Externalities – result from the difference in private and social costs

This study has estimated the external cost of energy for the EU28, by energy generation technology and Member State. As discussed earlier, energy has many benefits as well as impacts but these benefits are most often private and are reflected in the prices, so unlike the impacts we consider, are not external.

A variety of EU and national policies and regulations have acted to reduce and/or attach prices (costs) to externalities, aiming to 'internalise' the costs. There remain significant discussions and considerable debate over which externalities are relevant, how these can be quantified and how a monetary value can be attached. Where there is a clearly identified link between an intervention and the external costs such as with the carbon price delivered by the ETS, it is appropriate to consider only net external costs. Net external costs are the difference between total external costs and the cost that has been internalized. Where there is no causal link between taxes or other interventions and external costs, for example where they are revenue raising, or where the taxes were already introduced before the externality became a political topic, it is not appropriate to net them from external costs. In this project we have internalised only the most directly relevant climate interventions.

We assess external costs using the External-E tool. This calculation tool integrates life cycle assessment (LCA), actual power production data and monetisation methodologies to estimate and value total environmental impacts.

The aggregation of external costs of the energy system at EU28 or Member State level presents a challenge. While we can make a clear cross-technology comparison of total life cycle impacts, a simple aggregation of these results will result in double counting of some of the electricity in upstream impacts. We have resolved this by using two sets of LCIA data, one including upstream electricity use and a second one excluding all upstream electricity use occurring within the EU. To ensure a fair comparison between technologies, the first LCIA dataset is used for all results per MWh (i.e. impacts per technology). To prevent double counting of impact, the second LCIA dataset is used for all aggregated results (i.e. impacts per member state).

Figure 2-2 provides a basic summary of the tool, which is based upon:

- Life cycle assessments of the key reference energy technologies based on the Ecoinvent database, and the impact assessment method ReCiPe[12], producing midpoint (or in some cases endpoint[13]) values across 18 environmental impact categories.
- Modification of life cycle impacts based on appropriate national characteristics, i.e. relative efficiency or load hours of the power park compared to the reference technology dataset.
- Monetisation methodologies from a range of work into external costs, but heavily based on leading EU level methodologies from NEEDS[14] and CASES[15].
- Actual power and heat production data are from 2012 (Eurostat data0.

A full description of the tool methodology is presented in Annex 3.

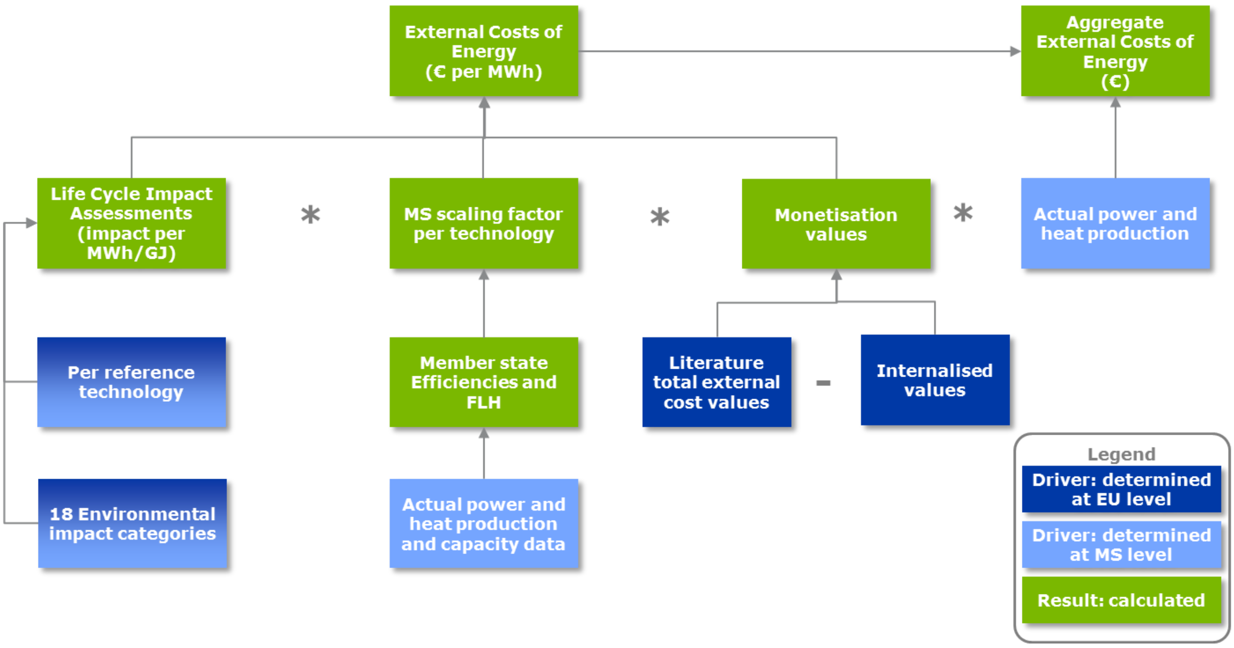

Figure 2-2: External-E tool overview of calculation and inputs

We attach a value to the 18 environmental impact categories of the life cycle impact assessment method ReCiPe as listed in Table 2-3.

Calculating external costs for a wide variety of technologies and countries has required dealing with a variety of uncertainties and making certain assumptions and simplifications. Some of these are explained in the remainder of this section. They are elaborated more fully in Annex 3.

There are a few approaches to valuation that include looking at damage (or social) costs or market prices to reach a specified emission target (e.g. EU-ETS). Others are based on mitigation, abatement and/or restoration cost.

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[12] Goedkoop, M, Heijungs, R., Huijbregts, M., De Schrijver, A., Struijs, J., Van Zelm, R. (2009) ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First edition Report I: Characterisation. http://www.pre-sustainability.com/download/misc/ReCiPe_main_report_final_27-02-2009_web.pdf"

[13] Environmental impact can typically be measured at three different levels: inventory, midpoint and endpoint: (1) Inventory - an inventory indicator is the expression of the physical flow of a single substance, for example SO_2 emissions or m^3 of water consumed; (2) Midpoint - a midpoint indicator, is where inventory indicators are expressed in a single common denominator of impact, e.g. GHG emissions expressed in CO_2 equivalents. (3) Endpoint - an endpoint indicator expresses the actual damage/effects of the impact. Please also see annex 3.

[14] NEEDS – the New Energy Externalities Development for Sustainability project (2005 - 2009) http://www.needs-project.org/.

[15] CASES – Cost Assessment for Sustainable Energy Systems (2006 - 2009) http://www.feem-project.net/cases/project_plan.php.

We have selected a damage cost approach to monetise the impacts. Damage (or social, as in societal) cost approaches attempt to take all societal costs into account and take a long-term perspective. Methodologies to value the environmental impacts focus on the translation of impacts to the damages they represent. In monetising impacts we first characterise the impacts into a small number of substances (called midpoint). For example the CO_2 equivalent unit for climate change will also include all LCI impacts from other greenhouse gases, converted to CO_2 equivalents.

The valuations are in almost every case based on a modelled relationship between the midpoint and the damage it causes (called the endpoint). We use three main endpoints:

- Human health damages;
- Ecosystems and biodiversity;
- Resources and depletion, primarily water, metals and fuels but also including crops, buildings and other assets.

In general, the methodology for valuing the resource depletion endpoints is in an earlier stage of development than the other two categories. A brief explanation of the monetisation of the three largest impacts is given below. Fuller explanation of the method and selection of these values, and the values for the other 15 impact categories, is provided in Annexes 3.1.5. to 3.1.10.

Table 2-3: Summary of impact categories, monetisation values and source

Impact categories	Unit	External costs (€$_{2012}$/ unit)	Approach/Method
Climate change[1)]	kg CO_2 eq	0.043	Literature
Ozone depletion	kg CFC-11 eq	107	NEEDS-based, ReCiPe endpoint, CE Delft
Terrestrial acidification	kg SO_2 eq	0.2	NEEDS-based, ReCiPe endpoint, CE Delft
Freshwater eutrophication	kg P eq	0.2	NEEDS-based, ReCiPe endpoint, CE Delft
Marine eutrophication	kg N eq	1.8	NEEDS-based, ReCiPe endpoint, CE Delft
Human toxicity	kg 1.4-DB eq	0.04	NEEDS-based, ReCiPe endpoint, CE Delft
Photochemical oxidant formation	kg NMVOC	0.0023	NEEDS-based, ReCiPe endpoint, CE Delft
Particulate matter formation	kg PM_{10} eq	15	NEEDS-based, ReCiPe endpoint, CE Delft
Terrestrial ecotoxicity[2)]	species.yr.m^2	1.04E-09	NEEDS-based, ReCiPe endpoint
Freshwater ecotoxicity[2)]	species.yr.m^3	2.95E-12	NEEDS-based, ReCiPe endpoint
Marine ecotoxicity[2)]	species.yr.m^3	5.68E-17	NEEDS-based, ReCiPe endpoint
Ionising radiation	kg U235 eq kBq	0.001	NEEDS-based, ReCiPe endpoint, CE Delft
Agricultural land occupation[3]	m^2a	0.09	NEEDS-based, ReCiPe endpoint
Urban land occupation	m^2a	0.1	NEEDS-based, ReCiPe endpoint
Natural land transformation	m^2	3.6	NEEDS-based, ReCiPe endpoint
Water depletion	m^3	0.2	Derived method from literature
Metal depletion	kg Fe eq	0.07	ReCiPe endpoint (adapted)
Depletion of energy resources[4)]	kg oil eq	0.05	ReCiPe endpoint (adapted)

1) Part of the damage costs of climate change are internalised by the EU ETS. Therefore, the average EU-ETS price of €2012 6.67 per tCO_2e in 2012 is subtracted from our monetisation value for climate change of €2012 50 per tCO_2e. See Annex 3 for more information.
2) These categories are represented at endpoint to enable monetisation.
3) Agricultural land occupation values loss of biodiversity on land used for agriculture rather than being left in its natural state.
4) This impact category is named 'Fossil depletion' in the ReCiPe methodology. We have renamed this to 'Depletion of energy resources', because we also include uranium depletion in this category, moved from the metal depletion category it is categorised within ReCiPe. See Annex 3 for more information.

Climate change
The valuation of climate change is based on estimates of the damage done in the future by emissions now. Various policies such as EU ETS and carbon taxes aim to internalise the damages by setting a market price for carbon. The consensus in literature is that the value of damages is much higher than the market carbon price today, which to a large extent has been affected by the economic crisis. Our approach to valuation of climate damages is based on literature review and expert judgement. CE Delft[16] developed estimates of the damage costs of climate change. Their values were 25 $€_{2008}/tCO_2e$ for 2010, increasing over time to $€_{2012}$ 45 in 2010, and $€_{2012}$ 70 in 2020. The Stern Review SCC values equivalent to $€_{2012}$ 25, €30 and €85 /tCO_2e, depending on the climate scenario, with a business as usual scenario attracting the highest values. A paper by Dietz and Stern published in June 2014[17] recommended the use of a current price of $\$US_{2012}$ 32-103/tCO_2e or 25-80 $€_{2012}$/ tCO_2e .

The US government produced estimates of the SCC in 2010[18], which placed values on carbon ranging from $\$_{2007}$ 4.7-64.9 in 2010. This work was updated in 2013 and the values revised upwards, resulting in a range of $\$_{2007}$ 11-90 in 2010, with the central 3% estimate of $ 33 ($€_{2012}$ 28), rising to $ 43 in 2020.

Taking into account these estimates, further estimates listed in Annex 3, continuing growth in global emissions and the most recent work such as that by Dietz and Stern, we arrive at a value of 50 $€_{2012}/tCO_2e$. This estimate is consistent with the expectation of being on a mid-high global warming pathway at present.

For the sectors covered by the ETS we subtract from this value, the average value of 1 tonne of CO_2 in the EU ETS in 2012 (6.67 $€_{2012}/CO_2$), to account for the partial internalisation of these costs. Therefore we arrive at a final value for the net external cost of climate change of **43.33 $€_{2012}/tCO_2e$**. We have also internalised the revenues from carbon taxes as applied in some EU Member States[19]. These are subtracted from the total climate impact for that country. In our analysis we carry out a sensitivity analysis around this value, testing the impact of a higher value, i.e. 100 $€_{2012}/tCO_2e$ and a lower value, 30 $€_{2012}/tCO_2e$ (section 3.2.3).

Depletion of energy resources
The value placed on energy resource depletion reflects the increased marginal cost to society of the consumption of finite (fossil and nuclear) fuel resources now, rather than in the future. Due to current extraction, future marginal costs of extraction are likely to increase if a finite resource becomes scarcer. Under assumptions of imperfect information and a too high discount rate of the owners of the resource stock (e.g. due to rent-seeking behaviour), this could be regarded as an externality. The current market price of these resources is then too low compared to the generation-equitable societal price.

The indicator is based on the approach in the ReCiPe set. The fossil fuel depletion indicator from ReCiPe has been extended to include nuclear energy resources to form a new indicator ‘Depletion of energy resources’. This indicator aims to capture the external costs based on a discounted surplus cost of the production of energy resources.

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[16] CE Delft (2010) Shadow Prices Handbook: Valuation and weighting of emissions and environmental impacts.
[17] Dietz and Stern (2014) Endogenous growth, convexity of damages and climate risk: how Nordhaus’ framework supports deep cuts in carbon emissions, Simon Dietz and Nicholas Stern, June 2014, Centre for Climate Change Economics and Policy Working Paper No. 180, Grantham Research Institute on Climate Change and the Environment Working Paper No. 159.
[18] United States Government, Working Group on Social Cost of Carbon (2013) Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 Interagency.
[19] Denmark, Ireland, Luxembourg, United Kingdom

Establishing a well-accepted methodology to estimate the societal cost of finite energy resource depletion has proven to be a very challenging research endeavour. Since the ExternE research programme various efforts have been attempted, the ReCiPe method being one of them. We reviewed work from other studies, but found no significant new updates, with the ReCiPe method still forming the basis of the recommended approach, therefore the ReCiPe methodology is used. However, this should be considered as an area still in development and indicators used to measure these external costs should be interpreted carefully (see also Annex 3).

A value of **0.05 $€_{2012}$ /kg oil eq**. is used to value depletion of energy resources. This value represents the individualist perspective of the ReCiPe approach, rather than the heirarchist perspective we use elsewhere (see also Annex 3). The individualist perspective encompasses a more optimistic view of total reserves and technological development which we judge more realistic in light of recent advances in extraction technologies. We also carried out a sensitivity analysis around this value (see section 3.2.3), using approaches which aimed to differentiate different degrees of scarcity or production costs for different fuels.

Particulate matter formation

We draw upon the ReCiPe method and characterisation, as well as work by CE Delft[20] and NEEDS[21] for our monetisation value for particulate matter formation. The impact of particulate matter is characterised using the ReCiPe method in PM_{10} equivalents, with the contributions of PM_{10}, NH_3, SO_2 and NO_x included. Endpoint damages in DALYs/PM_{10} are taken from the ReCiPe method.

The value we propose is updated from the CE Delft work and is based on direct valuation of the endpoint impacts on human health, in DALYs. A value of 14.30 $€_{2008}$ /kg PM_{10} for the EU was identified in the work by CE Delft. We then use an updated value **15 $€_{2012}$ /kg PM_{10}** for this work, based on the DALY valuation method explained in Annex 3.1.4.

Box 2-4: Electricity system costs

As discussed in the introduction, there are also potentially higher electricity system costs when the share of supply-driven renewable sources (like wind and solar PV) increases. Whether, or how much of, these costs should be associated with particular energy sources depends on defining a counterfactual or business as usual scenario for system costs and has high uncertainty. Several studies have been carried out to estimate these costs and also discuss the issue of allocation (see below for examples). These studies tend to be for scenarios for higher penetration of supply-driven renewable resources than was the case in the EU in 2012, for example NEA considered penetrations of 10-30% for both wind and solar. Even if system costs might increase in future, the contribution from energy supplied in 2012 is considered to be negligible. In addition, most of these costs should be reflected in the market in future, for example through imbalance costs for plant operators. As such they would not be defined as external costs.

References

NEA 2012 Nuclear energy & renewables: System effects in low carbon electricity systems

Hirth, Ueckerdt, Edenhofer (2012) Integration Costs and the Value of Wind http://ssrn.com/abstract=233568

Larsson et al (2014) Reviewing electricity production cost assessments. Renewable and Sustainable Energy Reviews 30 (2014) 170-183

[20] CE Delft (2010) Shadow Prices Handbook: Valuation and weighting of emissions and environmental impacts.

[21] NEEDS (2008) Deliverable n° 1.1 - RS 3a: Report on the procedure and data to generate averaged/aggregated data.

2.6 Levelised costs

To quantify the true 'cost' of energy is an extremely complex matter. It depends on the age and type of plant operating in a particular country as well as physical and market connections. To perform this analysis for 28 Member States would need extensive modelling and very large datasets. In this study, we therefore provide levelised costs of producing electricity (LCOE) and heat (LCOH). In addition, we assessed the levelised cost of energy from CHP-based technologies - LCOE-CHP and LCOH-CHP for electricity and heat respectively.

In this study, levelised costs are used to set the size of the interventions and external costs in context of a measure of the cost of energy if the system was being newly developed, without government intervention. The objective is to represent the costs of production without interventions for technologies if they would have been installed in the period of 2008 - 2012. These estimates will be based on hypothetical new energy conversion projects represented by the technologies detailed in Section 2.4. These hypothetical plants do not determine either current market revenues or consumer prices. In addition, we provide estimates of the total capital and operating costs for infrastructure based on information from Member States. The main approach to calculate levelised costs and results are outlined in this section, while more details on the approach and results are given in Annex 4.

The calculation of Levelised Cost of Energy (LCOE) of a technology requires data on all cash flows that occur during its lifetime as well as on production data.
The cost of energy can be broken down into several components:

1. Capital expenditure (which includes decommissioning and waste costs where applicable)
2. Operational expenditure
3. Fuel cost
4. (If relevant) revenues from the sales of by-products.

Figure 2-3 provides a comprehensive overview of the determining factors of each of these components for calculating levelised cost of electricity, heat and CHP.

For all of the factors driving energy costs, data has been collected from publicly available literature at two levels:

1. *EU level*: project duration, construction period, capital cost, operation and maintenance cost, capacities and efficiencies. EU level data for technology costs are preferred for electricity generation as price differences for different countries can in part be driven by the interventions. For heating technologies, there is a differentiation between countries based on climate zone (Annex II, detailed methodology). All EU level data is based on (one of the years in the) period 2008 - 2012, i.e. plants being constructed in the period 2008 - 2012. One exception is PV – for which more recent (2012, 2013) cost data has been used, to account for the rapid decline in cost.
2. *Member State level*: fuel prices, full load hours and weighted average cost of capital (WACC)[22]. Fuel prices represent average 2008 - 2012 prices. WACCs, which represent values post corporate taxation cost, are in the range of 5-11% for utility-scale technologies, while set at 4% for all domestic technologies. More information is in Annex 4, section on Member State level input values. For Member State information we use sources that as much as possible remove the effect of interventions.

An overview of assumptions is provided at the end of this section.

[22] The weighted average cost of capital are based on public literature and Ecofys expertise.

The amount of full load hours influences the capital expenditure and fixed operation and maintenance cost per unit of electricity produced. Therefore, a lower amount of full load hours leads to higher capital cost and fixed operation and maintenance per unit of electricity produced and thus a higher LCOE and vice versa.

There is considerable uncertainty in the level of WACC that is appropriate for different technologies and countries and it is commercially sensitive information which is not generally available. The WACCs used in this study and the reasoning used to derive them is described in detail in Annex 4. Higher levels of WACCs would increase levelised costs, with the biggest effect being on more capital intensive technologies.

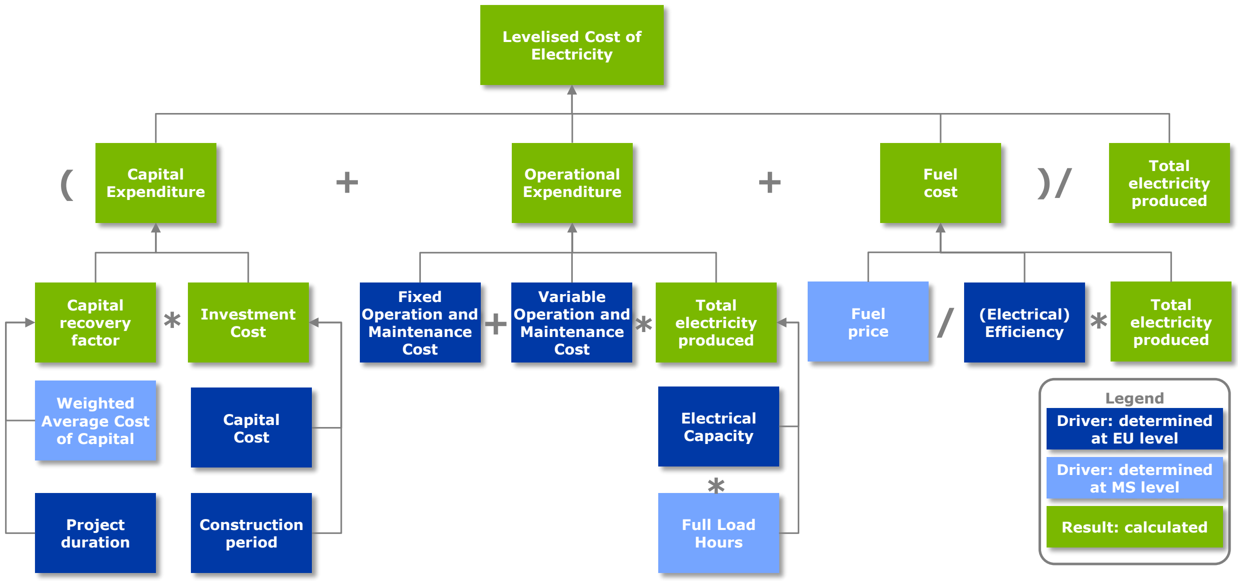

Figure 2-3: Simplified overview of approach followed and drivers determining the LCOE

The approach for determining LCOH is analogous to the approach followed for determining LCOE. In contrast to the LCOE calculations, for all domestic heating technologies, capital cost are differentiated based on five climate zones defined for Europe[23]. More information is provided in Annex 4. For the industrial steam boiler however, EU-wide capital cost are used as installed capacities are much less driven by the climate but rather by industrial heat demand.

In case of CHP electricity, generation costs are similar to the calculation for plants that only produce electricity or heat. The only difference is that potential revenues from heat sales are subtracted from the electricity generation costs. Analogous to the calculation of the electricity CHP, where heat sales are treated as revenues, we will also calculate the cost of heat production, where electricity sales is treated as revenue. As there is no market price for heat, we assumed a heat price based on the natural gas price, divided by a typical boiler efficiency of 90%. The average wholesale price of electricity (over 2008 - 2012) is used to calculate the revenues from electricity production.

An overview of key assumptions for calculating levelised costs is presented in Annex 4.

[23] Capital cost for domestic heating technologies are often driven by heat peak demands, which can differ substantially per climate zone.

2.7 Grid infrastructure capital and operating costs

The data for grid infrastructure (electricity and gas) was obtained by the Member State experts, generally from the regulator or reports to the regulator from transmission system operators. The information requested was electricity and gas transmission and distribution capital, operating and for electricity, balancing costs. The data was requested for period 2008-2012 and for historic periods before that (by decade). A summary of the data is provided in Section 3.4.

3 Results on interventions, external costs and costs

3.1 Interventions

Over the past decades, energy systems in the EU have gradually moved from a system based entirely on fossil fuels, nuclear and hydro energy to a system with an increasing share of solar, bio and wind energy. This trend reflects changing policy objectives. After WWII there was a need to expand and strengthen energy conversion and transmission infrastructures to keep up with an increasing energy demand. In the 1970s energy security rose high on the agenda, and political interest for nuclear energy as an affordable and clean source of energy increased. Since the late 1990s and in particular in recent years, the contribution of different forms renewable energy has increased considerably.

Interventions in the energy sector have followed these trends. While historically the public interest was with the development of energy infrastructures and ample fossil fuel and nuclear generation capacity, in the past decade public interventions were increasingly targeted at different forms of renewable energy, energy efficiency, and (to a smaller extent) clean fossil fuels.

In this study we considered interventions in the energy sector both in recent years (2008 - 2012) and in the more remote past (i.e. before 2008). For recent interventions we inventoried support to R&D, investment support, support to production, support to energy savings and support to energy demand.

As to the historic (pre 2008) interventions, we distinguished historic investment support, and support that indirectly affected energy markets in the view period (2008-2012).

3.1.1 Interventions in 2012

3.1.1.1 Support in the Member States and at EU level

The results from aggregation of the detailed Member State interventions are presented in the tables and figures below. The results are a snap shot of the interventions given, details from 2008-2012 are given in Annex 2. Key findings include:

- Total energy support in the EU28 (including EU level support) was €$_{2012}$ 99 billion in 2012 (Table 3-1). This excludes the free allocation of emission allowance units (EAUs) under the EU ETS. Inclusion of freely allocated EAUs would result in a total support level of €$_{2012}$ 113 billion.
- Most energy support in 2012 was provided in Germany (€$_{2012}$ 25 billion), followed by United Kingdom (€$_{2012}$ 13 billion) and Italy and Spain. EU level support to energy in 2012 added up to €$_{2012}$ 12 billion[24] (Table 3-2).
- In 2012 roughly 70% of all support was provided to the production of energy, and almost a third to energy demand (Table 3-3). Support to energy demand is typically provided in the form of tax exemptions (energy taxes, VAT, other taxes and levies) on the consumption of energy, or as price guarantees. Demand support benefits the use of energy, which is currently dominated by gas, coal, nuclear and oil.

[24] The greater part of this (€$_{2012}$ 11.7 billion) was focused at Convergence and Regional Competitiveness and Employment, half of which was allocated to energy efficiency projects (see Annex 2, section A2.7.3).

- Support to energy savings is reported at a low level around $€_{2012}$ 9 billion in 2012.
- The largest part of support is for production of electricity or primary fuels. The largest support to production is for renewable energy, although there is significant support to nuclear and coal (largely for primary coal production, but also includes nuclear decommissioning and waste disposal)[25].
- From all renewable energy sources solar energy received most support in 2012 ($€_{2012}$ 15 billion), followed by wind ($€_{2012}$ 11 billion) and biomass ($€_{2012}$ 8 billion). Changes in policy since 2012 mean that 2012 probably represents a peak for support to solar, certainly in terms of support per unit of energy produced.
- Support to energy transmission and distribution infrastructure for electricity, natural gas and heat is small compared to most other categories, at $€_{2012}$ 200 million.
- Around $€_{2012}$ 40 billion of the interventions are paid directly by energy consumers in the form of levies.
- We counted the number of interventions per Member State and targeted technology. Interventions that are used most frequently include investment grants (130 times) and feed-in tariffs (107, Table 3-3 and Figure 3-2). Also energy saving grants and subsidies, exemptions from energy taxes and R&D grants are widely used.
- The largest volumes of support are channelled through feed-in tariffs ($€_{2012}$ 26 billion), followed by investment grants ($€_{2012}$ 13 billion), and exemptions from energy taxes ($€_{2012}$ 12 billion). These amounts are on the same order of magnitude as the value of freely allocated GHG credits under the EU ETS ($€_{2012}$ 14 billion).

[25] Nuclear related interventions are mainly RD&D grants for nuclear research (6 out of 21 interventions) as well as support to decommissioning and waste disposal (also 6 out of 21 interventions). Other and fewer interventions are related to production support, support to stranded assets and a few related to investments. In total, we found data for 11 EU Member State on nuclear related interventions.

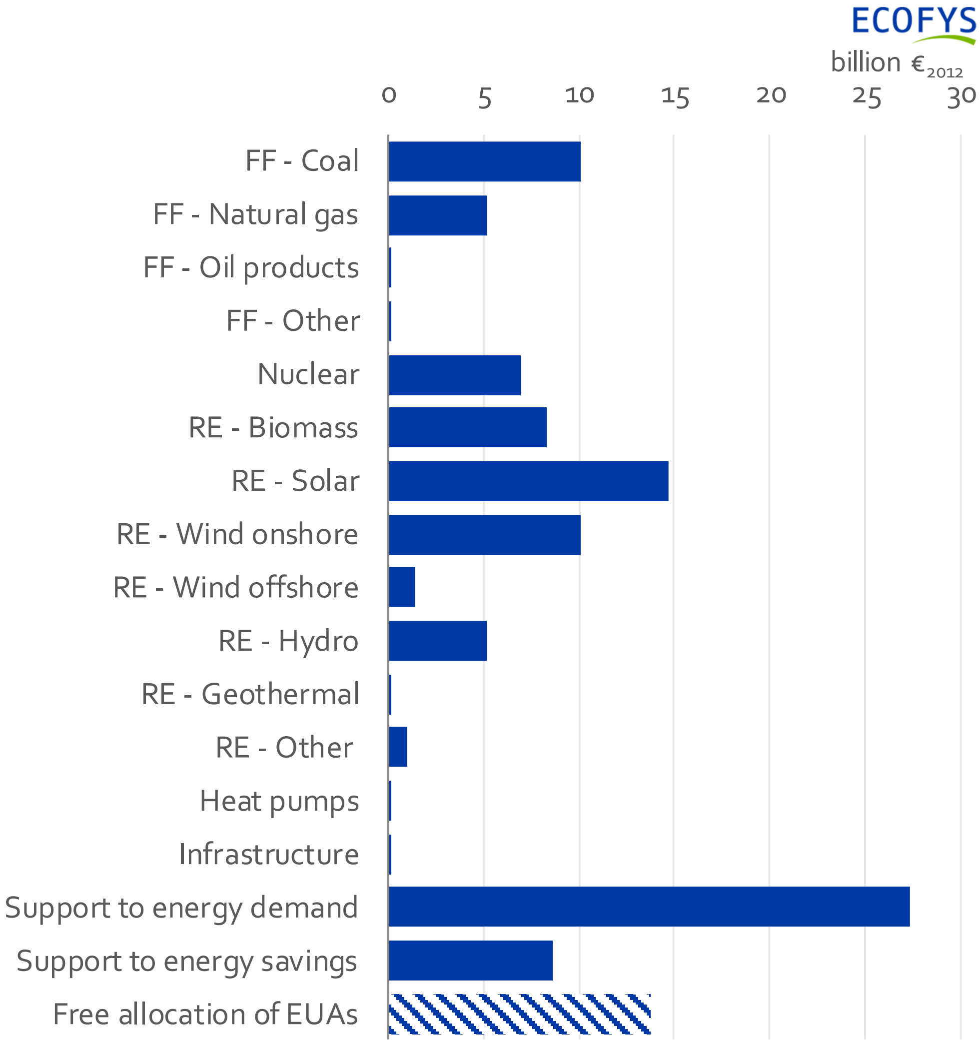

Figure 3-1: Total support provided in the 28 Member States in 2012 (in billion €$_{2012}$), including EU support. Free allocation of GHG credits and support for unspecified or undefined technologies is not presented.

Note: For interventions in energy supply, the size of the intervention could be calculated for specific fuels or technologies e.g. coal, gas, solar. For others, only the total size of the intervention could be determined. In this case, the intervention was allocated to the individual fuels/technologies according to the country energy supply mix.

Table 3-1 Support per technology and year, including the free allocation of GHG credits (in million €$_{2012}$)

Technologies	2012 (M€ 2012)
RE – Solar	14,730
RE – Wind	11,480
o.w. offshore	1,360
o.w. onshore	10,120
RE - Biomass	8,340
RE - Hydro	5,180
RE – Geothermal	70
RE – Other	1,020
RE – Total	**40,810**
FF – Coal	10,120
FF – Natural gas	5,190
FF – Oil products	0*
FF – Other	40
FF - Total	**15,350**
Heat pumps	0*
Nuclear	6,960
Infrastructure	200
Support to energy demand	27,360
Support to energy savings	8,590
Total	**99,270**
Not specified	60
Grand Total	**99,330**
Free allocation of EUAs	13,700
Direct historic support	9,000

Notes: 0* indicates that there is a value but it is below the level of rounding.

Table 3-2: Total energy support for 28 Member States for 2008 – 2012 (in million €$_{2012}$). Member State support levels do not include the free allocation of GHG credits.

Country	2012 (million €$_{2012}$)
Austria	2,000
Belgium	3,280
Bulgaria	410
Croatia	30
Cyprus	20
Czech Republic	1,600
Denmark	1,210
Estonia	150
Finland	300
France	7,250
Germany	25,470
Greece	680
Hungary	620
Ireland	510
Italy	10,360
Latvia	220
Lithuania	330
Luxembourg	90
Malta	50
Netherlands	2,740
Poland	970
Portugal	790
Romania	680
Slovenia	590
Slovakia	100
Spain	10,430
Sweden	2,690
United Kingdom	13,280
EU level†	12,460
Total Member States (28) + EU level support	**99,330**
Free allocation of allowances in the EU28	13,700
Direct historic support	9,000

†The main elements of EU level interventions are the EU structural and cohesion funds, the European Energy Programme for Recovery and R&DD funding

Table 3-3 Support per sub-intervention in 2012[26], excluding free allocation of GHG credits.

Support type	Interventions	Number of interventions	Amount (mln €$_{2012}$)
Support for investment	Accelerated depreciation	5	10
	Differentiated grid connection charges	3	20
	Exemption from import duty	0	-
	Grants (investment)	130	13,050
	Investment tax allowance	14	1,500
	Investment tax credits	0	-
	Property tax abatement	1	0 *
	Soft loans (investment)	26	70
	Other investment support (not listed)	7	20
Support to energy demand	Exemptions from energy taxes	60	12,100
	Exemptions other taxes and levies	9	3,430
	Exemptions value added taxes (VAT)	16	7,090
	Interruptible load schemes	3	1,260
	Price guarantees for electricity	4	80
	Other demand support (not listed)	26	3,390
Support to energy savings	Energy efficiency obligation	5	1,940
	Energy saving grants and subsidies	63	6,560
	Loan guarantees	0	-
	Soft loans (energy savings)	10	0 *
	Other support to energy savings (not listed)	11	90
Support to production	Capacity payments in electricity markets	1	30
	Exemptions from fuel taxes	13	3,060
	Feed-in premiums	47	6,650
	Feed-in tariffs	107	26,960
	Price guarantees for district heating	0	-
	Production tax allowance	7	50
	Production tax credits	4	0 *
	Renewable energy quotas with tradable certificates	25	3,930
	Royalty exemption	1	0 *
	Subsidised cooling water	0	-
	Direct support to decommissioning and waste disposal	13	4,330
	Support to fossil or nuclear electricity production	12	1,590
	Support to social costs of industry restructuring	8	360
	Support to stranded assets	4	200
	Tax allowances for decommissioning and remediation	0	-
	Tax credits for decommissioning and remediation	0	-
	Underwriting insurance nuclear	1	10
	Other production support (not listed)	16	840
Support to R&D	Government provided R&D facilities and transfer of IP	3	30
	Grants (R&D)	50	690
	Tax allowance for R&D	3	0 *
	Tax credits for R&D	4	10
	Other R&D support (not listed)	1	-

[26] Asterisk indicates non-zero figures rounded to zero.

Support type	Interventions	Number of interventions	Amount (mln €$_{2012}$)
	Total Member States (28) + EU level support	**713**	**99,330**
	Free allocation of allowances in the EU28		13,700
Historic support to investment	Historic direct support		9,000

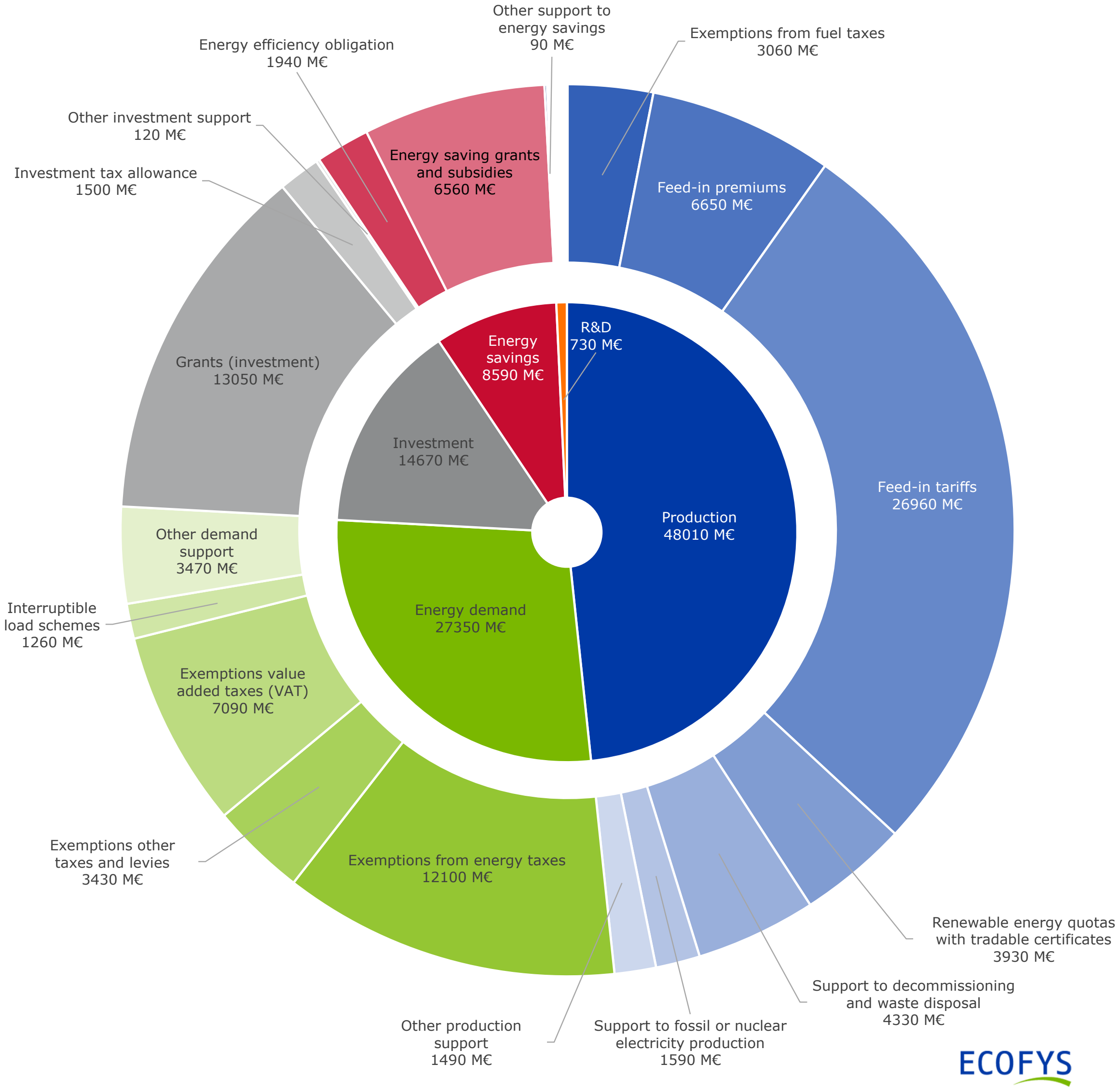

Figure 3-2 Breakdown of 2012 support by type of intervention (million €$_{2012}$). Free allocation of allowances is not shown.

3.1.1.2 Free allocation of GHG credits

The estimates of interventions provided above do not include the value of emissions allowances allocated freely under the EU ETS. The free allocation of these credits across the Member States was valued at €$_{2012}$ 14 billion in 2012. This is expected to decrease as free allocation from 2013 is mainly limited to sectors with risk of carbon leakage.

3.1.2 Interventions before 2008

In addition to the monetisation for the years 2008 - 2012 discussed above, we also provide an estimate of historic interventions before 2008 with a focus on those that are still having an effect on the energy market today. As discussed in section 2.3, three categories are distinguished:

- *Direct historic support,* which can be linked directly to the production of today. Examples include: renewable energy projects that still receive production support (e.g. feed-in tariffs) from pre-2008 support schemes, or government investment in production capacity under non-liberalised market circumstances;
- *Indirect historic support*, which has influenced the development of the energy system significantly but cannot be linked directly to production today: support for research, development, and demonstration (RD&D) and provision of government loans to nuclear power facilities; and
- Historic (direct) interventions that no longer affect the energy markets today (production support to renewable energy before 2008, support for European coal mining).

Direct historic support

'New' renewable energy technologies

The direct support for renewable energy (mainly production support, but partially investment and fiscal support) is already included in the interventions by Member State, or derived from the 'funding gap' approach (see section 2.3).

Investments under non-liberalised market conditions

As discussed in Section 2.3, historic investment support is estimated for high capital, low marginal cost generating capacity (coal, nuclear, hydro). This was done by calculating the difference between the cost of capital for governments and for commercial companies. Figure 3-3 shows the breakdown of historic investment support for power plants that have not been fully depreciated in the year 2012. The figure is based on the value of historic support that is still having an effect in 2012 based on undepreciated plants still operating in 2012. The longest depreciation period assumed is 25 years for hydro and nuclear generating capacity; 1988 is thus the first year for which government investments in these technologies will affect electricity prices in 2012. The first year for which government investments in coal generating capacity effects 2012 electricity prices is 1993.

Due to the uncertainty on depreciation period of power plants EU wide we provide a range in total support effective in 2012. The top value is based on the assumption that a depreciated power plant built historically still influences electricity prices today (base case). Figure 3-3 (left table) shows the average support weighted to capacity (corrected for liberalisation status) and historic investment support for 2012 and gives the breakdown of the historic investment support per technology.

The value of the **historic direct investment support for coal, nuclear and hydropower capacity in 2012 is estimated to between €$_{2012}$ 3 and 15 billion.** Mostly, government investments in nuclear generation capacity account for historic investment support in 2012 (79%), which has two main reasons:

- Most hydropower and coal fired power plants had already been through their depreciation period in 2012; most generating capacity was installed before 1988 and 1993 respectively.
- The weighted average historic investment support for nuclear generation capacity is higher than that of coal fired and hydro generation capacity (about 200%), which is caused by the high CAPEX for nuclear generation capacity during the years under consideration.

	Coal	Hydro	Nuclear
Weighted average support through the years [€/MWh]	6	5 – 6	8 - 11
Total support 2012 [B€$_{2012}$/ y]	**0.4–5**	**0.2-2**	**2-8**

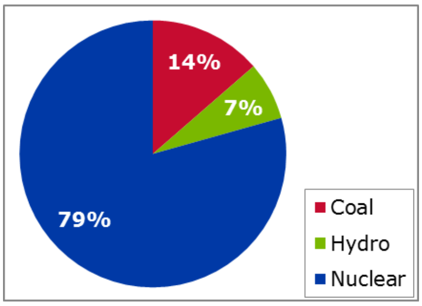

Figure 3-3: EU28 historic investment support to coal, hydro and nuclear production capacity (still effective in 2012). Breakdown of EU28 historic investment support effective in 2012.

(Weighted average support: weighted by installed capacity, corrected for liberalisation status over time)

Indirect historic support

Research, development and demonstration (RD&D)

Data from the IEA Research, Development and Demonstration (RD&D) Database[27] shows historic expenditures made by 19[28] Member States on energy-related programmes. For the energy supply technologies, the cumulative RD&D expenditure by EU Member State reported was €$_{2012}$ 87 billion in the period 1974 - 2007, which is on average €$_{2012}$ 2.6 billion per year. Around 78% of the funding has benefitted the nuclear sector, of which the majority is on nuclear fission. The remaining RD&D expenditures were divided about equally over renewables (12%) and fossil fuel technologies (10%).

Most of the RD&D funding occurred before 1990. However, nuclear fission continued to receive most RD&D funding up to 2007. Of the non-nuclear energy sources, coal received most funding until 1989. Since (and also before) then, RD&D support for coal has declined until around the beginning of this century, after which is has slightly increased again with an emphasis on clean coal technologies. Funding of renewables started from 1974 onwards. In 2007, RD&D for solar and bioenergy was the most prominent among the renewable sources.

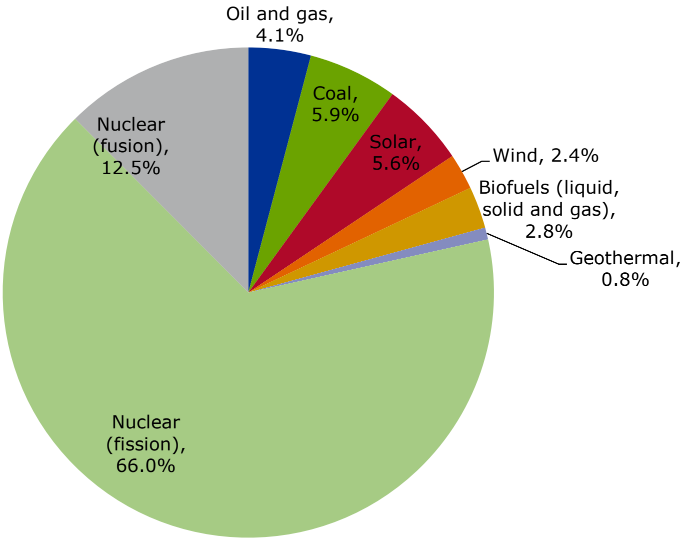

Figure 3-4 Breakdown of total EU Member State RD&D expenditure on energy supply side technologies (€$_{2012}$ 87 billion) in 1974 - 2007

[27] Energy RD&D covers research, development and demonstration related to the production, storage, transportation, distribution and rational use of all forms of energy. The following is covered: basic research when it is clearly oriented towards the development of energy-related technologies, applied research, experimental development and demonstration.

[28] Austria, Belgium, Czech Republic, Denmark, Finland France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Spain, Sweden and the United Kingdom.

For energy efficiency the cumulative RD&D expenditures over the same period were almost $€_{2012}$ 10 billion, on average $€_{2012}$ 0.3 billion per year. And $€_{2012}$ 11 billion was spent on a wider range of topics, including power conversion, transmission and distribution ($€_{2012}$ 4 billion), hydrogen and fuel cells ($€_{2012}$ 0.6 billion), and cross-cutting technologies/research ($€_{2012}$ 7 billion).

Note that not all countries have reported RD&D data and some have provided only data for certain years.

Support to nuclear energy through Government loans

Governments have supported nuclear energy by providing loans to the construction of nuclear facilities. National governments, the Euratom Loan Facility, the European Investment Bank (EIB) and the European Bank for Reconstruction and Development (EBRD) have enabled the deployment of nuclear energy in Europe. The effect of this intervention is believed to be included in the approach described above under 'direct investment support'. Euratom provided loans worth 3.4 billion $€_{2012}$ in the period 1977-2004, whereas for EIB this figure was 2.9 billion $€_{2012}$ in the period 1977-1987 (GHK/Pöyry, 2011)[29]. The size of the Member State loans is not known.

In EU Member States Euratom co-financed in the period 1977-1987 the construction of nine nuclear power plants (2.7 million $€_{2012}$ in five Member States[30]), a uranium enrichment facility (128 million $€_{2012}$ to the facility in Tricastin, France), and a uranium reprocessing facility (112 $M€_{2012}$, to the Thorp facility in the UK). Loans to safety upgrades to projects in Bulgaria (2000) and Romania (2004) (at those times not EU Member States) totalled about 450 million $€_{2012}$. Figure 3-5 and Figure 3-6 show the distribution of the Euratom loans over time and per Member State.

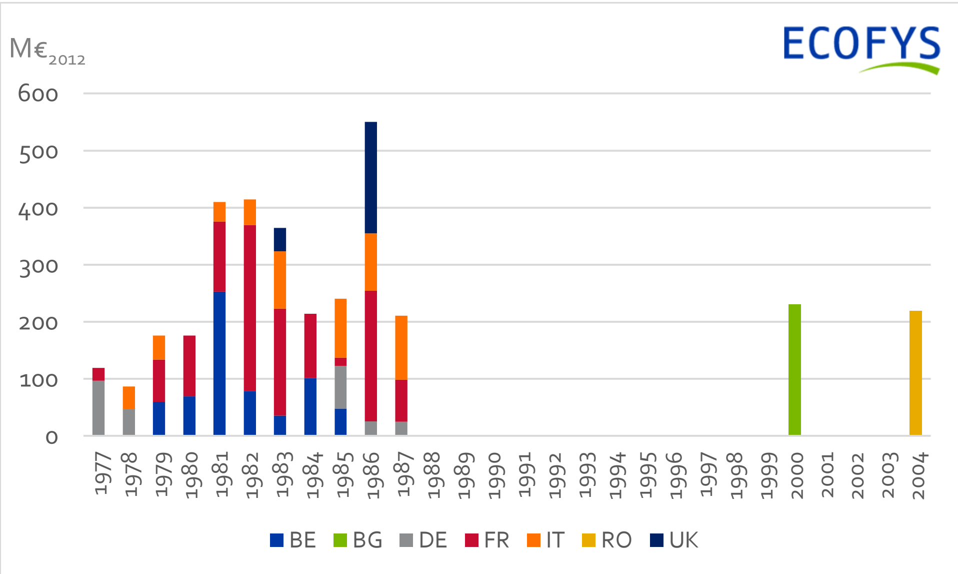

Figure 3-5 Euratom loans per year in the period 1977 - 2004 (in million $€_{2012}$)

[29] GHK/Pöyry (2011) Ex-post evaluation of the Euratom Loan Facility, Report for the European Commission, DG Economic and Financial Affairs, 3 June 2011.

[30] Belgium, Germany, France, Italy, United Kingdom

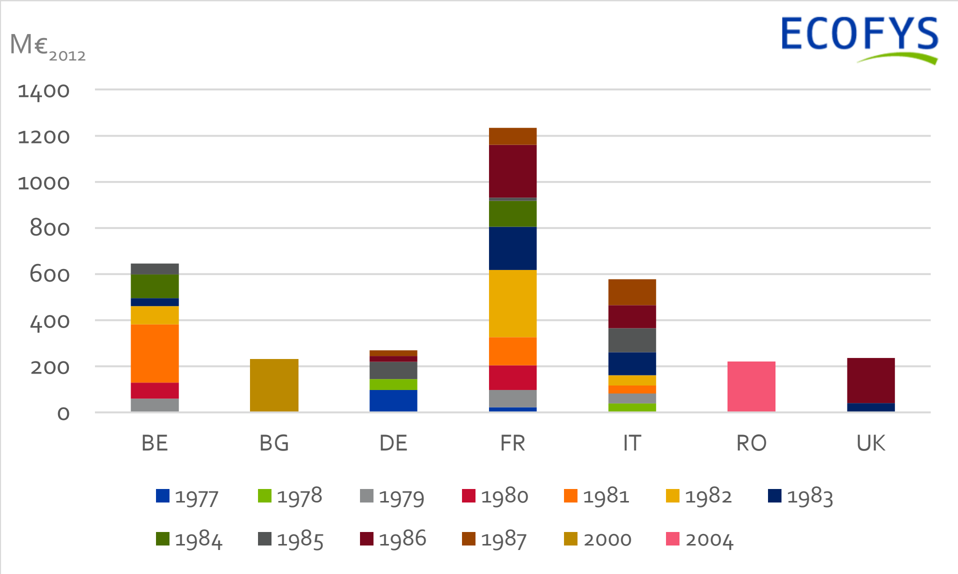

Figure 3-6 Euratom loans per country in the period 1977 - 2004 (in million €$_{2012}$)

Historic support no longer affecting current energy markets

Renewable energy sources

For the period 2008-2012 total subsidies for renewable energy equalled about €$_{2012}$ 157 billion (of which €$_{2012}$ 40.8 billion in 2012). For the period before 2008 no complete and consistent datasets are available, and we derive the level of the historic support based on a funding gap approach and energy statistics from 1990-2007 for hydro and 2000-2007 for solar, wind and biomass as support to these sources was limited before 2000, with some very generic assumptions. We estimate that for the period 1990-2007 cumulative interventions totalled to about €$_{2012}$ 70-150 billion. Using our methodology around half that intervention went to biomass and one third to wind, with solar and hydro receiving smaller amounts.

Support to coal production

In literature, typically data on other types of historic investment support than RD&D is scarce. If available, data tends to be rather anecdotal in terms of country and time coverage. From literature research it is clear however that most other types of support regard subsidies to coal production in the main coal producing countries. Prices of domestic coal have not been competitive to imported coal for many EU Member States and different types of subsidies are allocated to coal production, structured in several ways within each Member State. These can be through tax breaks, direct support to coal mines, support to salaries or pensions, or aid for reduction of production activity.

As many different types of subsidies are used to support coal production, we adopted a method to estimate coal support that can be used consistently for each Member State. We calculate the difference in price of domestic production and import of coal, multiplied by the total coal production within the Member State per year. Using such technique we assume that the full price difference of coal needs to be compensated for the industry to invest in domestic coal. Coal production per Member State is taken from the IEA. The main coal producing countries are ordered below, showing cumulative production in ktoe from 1970 to 2007. Figure 3-7 shows the estimated cumulative support in billion euro. There are a couple of points important to note when interpreting these numbers:

- Historic support to coal production for the EU28 is estimated at about €$_{2012}$ 10 billion per year in the years 1970 – 2007, but has been decreasing from 2000 onward. Most support was provided in Germany, which accounted for 71% of the total cumulative support in the years 1970 – 2012.

- Domestic prices for coal increased for all Member States relative to import prices throughout the years, which means that production in later years account to higher support estimates. This explains for instance the difference in support between Spain and France. Even though their cumulative production is similar, Spain has been producing more coal in recent years, whereas France has brought production down to almost zero.
- Domestic prices of coal production are much higher for Western European countries than for Eastern European countries. For example, Poland produced a similar amount of coal compared to Germany. However, Poland was able to produce coal at very similar prices to the import price up to recent years, leading to a relatively low estimate of cumulative required support. On the other hand, Germany has seen a sharp increase in domestic coal prices throughout the 1970's, up to almost three times the import price, which led to high estimates of required subsidy.

When we compare the values above to literature sources, they are very much in line.

- OECD (1998, 1999, 2005) documents a coal support for Germany from 1982 to 2000 increasing to about 8 Billion USD (about € 10 billion) in the first years and decreasing to about 5 Billion USD (about 6 Billion €) in 2000; for the UK diminishing from an average of 3-4 Billion USD (4-5 Billion €) to almost 0; and for Spain averaging to about 1 Billion (about 1 Billion €) per year.
- IEA (1987) documents increasing subsidies up to 5.8 billion USD in 1987 for Germany, 3.4 billion USD in 1987 for the UK and about 0.4 billion USD in 1987 for Belgium.
- Greenpeace (2014) estimates average support to coal production in Poland at about 0.45 billion Euro per year.

	EU28
Coal production (Gtoe)	13
Cumulative support 1970 – 2007 (billion $€_{2012}$)	380
Average annual cumulative support (billion $€_{2012}$/year)	10

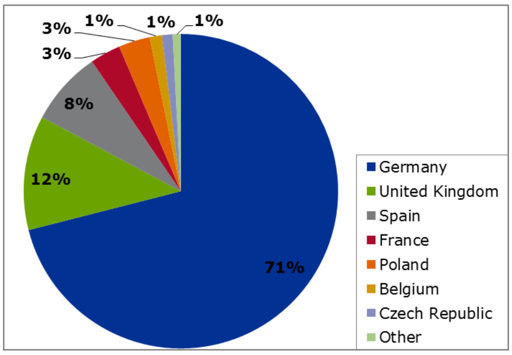

Figure 3-7 : EU28 cumulative and average historic support to coal production. A breakdown for selected Member States is given on the figure to the right.

3.1.3 Comparison with other literature

Renewable energy

- A study by the Council of European Energy Regulators (CEER 2011) is one of the few comprehensive studies that has mapped support for renewable energy in the EU. The scope of this study is restricted to electricity from renewable energy sources and 15 EU Member States[31]. It focuses on the major support schemes in countries (feed-in tariffs and premiums, and quota systems).
- In Table 3-4 the total monetary value of the support for the individual renewable electricity technologies and the total support estimates in the CEER (2011) study are compared to results from this study. All figures presented include only renewable electricity related production support and are for the year 2009.
- The table shows that the results from the CEER study are largely in line with results from this study. While Ecofys estimates the total value of monetary production support for renewable electricity for the 15 EU countries on the order of €$_{2012}$ 16 billion, CEER estimates this to be slightly higher, at a little over €$_{2012}$ 17 billion.
- In both studies figures were largely collected bottom-up. Differences are likely the result of different assumptions in full load hours and the use of different information sources.

Table 3-4: Total monetary value of support for renewable electricity in 2009. Results from this study compared to CEER (2011) (in billion €$_{2012}$)

EU15 in 2009	This study (billion €$_{2012}$)	CEER, 2011 (billion €$_{2012}$)
Wind	5.7	4.9
Solar	5.3	5.8
Hydro	1.5	0.6
Biomass	3.9	5.9
Total support for renewable energy	**16.4**	**17.2**

Fossil fuels

- The OECD has thus far published two major reports that cover fossil fuel subsidies in the EU (OECD 2011, 2013). While the 2011 version of the study included only 10 EU Member States, in 2013 the results of the study were updated and the scope extended to also include other Member States. In IVM (2013) an additional 6 EU Member States have been investigated that are not part of the OECD using a similar methodology as in OECD (2011, 2013).
- The OECD distinguishes between subsidies that are related to energy consumption and those that are related to energy production[32]. The 2013 study includes 2011 data.
- The majority of support mechanisms identified in the OECD inventory are tax expenditures, and are measured with reference to a benchmark tax treatment that is specific to the country in question.

[31] Austria, Belgium, Czech Republic, Denmark, France, Germany, Great Britain, Hungary, Italy, Lithuania, Luxembourg, Norway, Portugal, Spain, Sweden and the Netherlands.

[32] In total the study covers the following products/categories: petroleum, natural gas, coal and so-called general services support. The latter measures the value of transfers provided through policies that support producers or consumers collectively rather than as individuals (e.g. support for research, development, training, inspection, marketing and sectoral promotion).

- The OECD values the total of fossil fuel subsidies for the EU at €$_{2012}$ 39 billion. By far the largest subsidies are related to the consumption of petroleum, in total valued at €$_{2012}$ 25 billion, followed by subsidies related to the consumption of natural gas, nearly €$_{2012}$ 5 billion. An amount of €$_{2012}$ 3.5 billion related to subsidies for the production of coal and €$_{2012}$ 2.6 billion to the consumption of coal. Subsidies related to the production of petroleum are estimated to be worth a little over €$_{2012}$ 1 billion, the subsidies related to the production of natural gas are small, estimated at €$_{2012}$ 0.1 billion.
- Table 3-5 shows that the total monetary value of production support for fossil fuels and demand from OECD (2013) are compared to results from this study. All figures presented include only fossil fuel related production and demand support in the EU-28 and are for the year 2011 in order to make the comparison.
- The table shows that the results from both studies are largely in line with each other. While Ecofys estimates the total value of monetary production support for fossil fuel in the order of €$_{2012}$ 4.3 billion, OECD arrives at 5.6 €$_{2012}$ billion. Regarding energy demand, the OECD estimates demand related support to be €$_{2012}$ 2 billion higher.
- Differences are largely explained due to the use of different methodologies and to a lesser extent by the fact that OECD also includes transport related measures. The latter has a strong effect on the total support for energy demand, in particular in relation to oil and petroleum (see table).

Table 3-5: Total monetary value of support for fossil fuels differentiated by production and consumption support. Results from this study are compared to OECD (2013) (in billion €$_{2012}$).

EU28 in 2011	Production support (€$_{2012}$ billion)		Demand support (€$_{2012}$ billion)	
	This study	OECD, 2013	This study	OECD, 2013
Coal/lignite	2.2	3.5	..	2.6
Natural gas	0.4	0.1	..	4.8
Oil/petroleum	0.8	1.1	..	24.7
Other fossil fuels	0.9	0.9	..	0.9
Total support for fossil fuels	**4.3**	**5.6**	**30.1**	**33.0**

3.2 External costs

This section presents the headline results of our external costs analysis. More detailed discussion of the method, monetisation and limitations of our work and more detailed Member State results are presented in Annex 3.

3.2.1 External costs per technology

We present our results per power and heat technology measured in €$_{2012}$ total external cost per MWh. The results show the five biggest monetised impacts individually, and the remaining 13 impacts that we valued are combined into a category 'other'. In each case the full life cycle impacts are valued, therefore in addition to direct impacts at conversion the results also include impacts associated with upstream fuel extraction, processing and transport, construction and end-of-life impacts. Upstream energy use is also included. Part of these impacts occur outside the EU, particularly those for upstream activities. The values presented here are a weighted average of the results per Member State, based on the actual electricity and heat production in the Member States in 2012. Therefore, the values do not only reflect differences between technologies, but also country variations within technologies.

Power technologies

Figure 3-8 summarises external costs for electricity technologies at the EU level. Among the power generation technologies, fossil fuel technologies have the highest external costs, followed by nuclear and renewable energy technologies.

The external costs of CHP power are generally close to the external costs of a dedicated power plant using the same fuel. CHP based on hard coal has the highest impact, followed by CHP running on natural gas, waste and biomass. Although the overall efficiencies of CHPs are higher compared to their dedicated counterparts, this is not reflected in the external costs of CHP power. This is partly the result of the Eurostat statistics we use for production and efficiency, which sometimes show lower efficiencies for CHP than their dedicated counterparts. This most likely relates to the fact that for CHP a wide range of technologies are in use and CHP plants are often not run under optimal conditions. As a result the external costs for CHP differ from what the result would have been for new fully optimised CHP plants (see Annex 3 for more information).

The higher value for hard coal compared to lignite is explained in large part by the higher particulates and human toxicity impacts (see below). This difference arises primarily because lignite use in Europe is dominated by Germany, which has relatively high standards of emission control. Hard coal use is more mixed across Member States, resulting in higher average emissions and therefore also external costs.

As shown in Figure 3-8 the five biggest impacts across all technologies are climate change, depletion of energy resources, human toxicity, particulate matter and agricultural land occupation[33].

Climate change impacts are highest for the coal, oil and gas technologies at around 20-50$€_{2012}$/MWh, and lower for the other technologies. Part of the cost of climate change is internalised in the market through the carbon price set by the ETS. The values shown in Figure 3-8 are therefore based on the monetary value for climate change (50 $€_{2012}/tCO_2e$) minus the CO_2 price in 2012 (6.67 $€_{2012}/tCO_2$)[34]. The climate change value represents the estimated non-internalised damage costs to society of greenhouse gas emissions, including the impact on human health and the quality of ecosystems.

[33] This varies from the executive summary due to the inclusion of CHP technologies, leading to agricultural land occupation displacing metal depletion as the fifth largest impact.

[34] It should be noted that the ETS carbon price observed in the period under study is not representative for the degree of abatement cost internalisation inherent in the ETS, but reflect to a significant extent the impacts of the financial crisis.

Box 3-1: External costs of nuclear accidents

External costs related to negative environmental impacts of nuclear power are 18 $€_{2012}$/MWh. Following a literature review[35] we estimate that the external cost due to a nuclear accident ranges from 0.5-4 $€_{2012}$/MWh. We have therefore added a box up to this range to Figure 3-8 which then leads to total external costs in the range of 18-22 $€_{2012}$/MWh. This additional external cost of nuclear energy is, except for Figure 3-8, not shown in any of the graphs and aggregated figures presented in this report. Further detail on how we arrived at this estimate is provided in Annex 3.

Box 3-2: How to interpret the external costs results?

The methods for valuing external costs necessarily come with higher uncertainties than for interventions as by definition there is no market value to external effects. Nevertheless, there is value in calculating external costs to identity their order of magnitude, to place different externalities into perspective by using units that relate to the real economy, to allow for prudent comparison and to identify areas for priority in mitigating externalities.

However, the sheer scale and complexity of each energy technology, its supply chain and role in national power system, combined with the different demographic, resource and geographic characteristics of Member States, means that the results produced by our External-E tool are an approximation based on a set of general assumptions rather than a precise estimate of actual external costs.

> "It is important to acknowledge both the inherent limitations of the concept of externalities, and the partial character of the information conveyed in the highly aggregated external cost estimates in order to use external costs in environmental policy decisions in an appropriate way." [36]

Nevertheless the results provide insight into the best currently available information and gives an indication of the order of magnitude of specific impacts per technology and Member State on which further, more detailed research should be directed. Underlying assumptions, uncertainties and limitations of the study are discussed in more detail in Annex 3.

[35] Greenpeace (2014) Lifetime extension of ageing nuclear power plants: Entering a new era of risk, Report commissioned by Greenpeace. Available online at: http://www.greenpeace.nl/Global/nederland/2014/Documenten/Rapport%20Lifetime%20extension%20of%20ageing%20nuclear%20power%20plants.pdf;
IRSN (2012) Les rejets radiologiques massifs diffèrent profondément des rejets contrôlés. Working paper. Available online at : http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/FR_Cosafe-2012_Rejets-radioactifs-massifs-vs-rejets-controles_Cout_IRSN-Momal.pdf;
Institut für Energiewirtschaft und Rationelle Energieanwendung (IER; 2013) Die Risiken der Kernenergie in Deutschland im Vergleich mit Risiken anderer Stromerzeugungstechnologien;
OECD (2003) Nuclear Electricity Generation: What are the External Costs? Available online at: https://www.oecd-nea.org/ndd/reports/2003/nea4372-generation.pdf;
Rabl, A et al (2013) External costs of nuclear: Greater or less than the alternatives? Energy Policy Vol 57;
William D. D'haeseleer (2013) Synthesis on the Economics of Nuclear Energy, a Study for the European Commission, DG Energy,
Francoise Leveque (2013) The risk of a major nuclear accident: calculation and perception of probabilities, Interdisciplinary Institute for Innovation Working Paper 13-ME-02 (July 2013).
[36] Krewitt (2002) External Costs of Energy – do the Answers Match the Questions? Looking back at ten years of ExternE, Energy Policy 30:839–848.

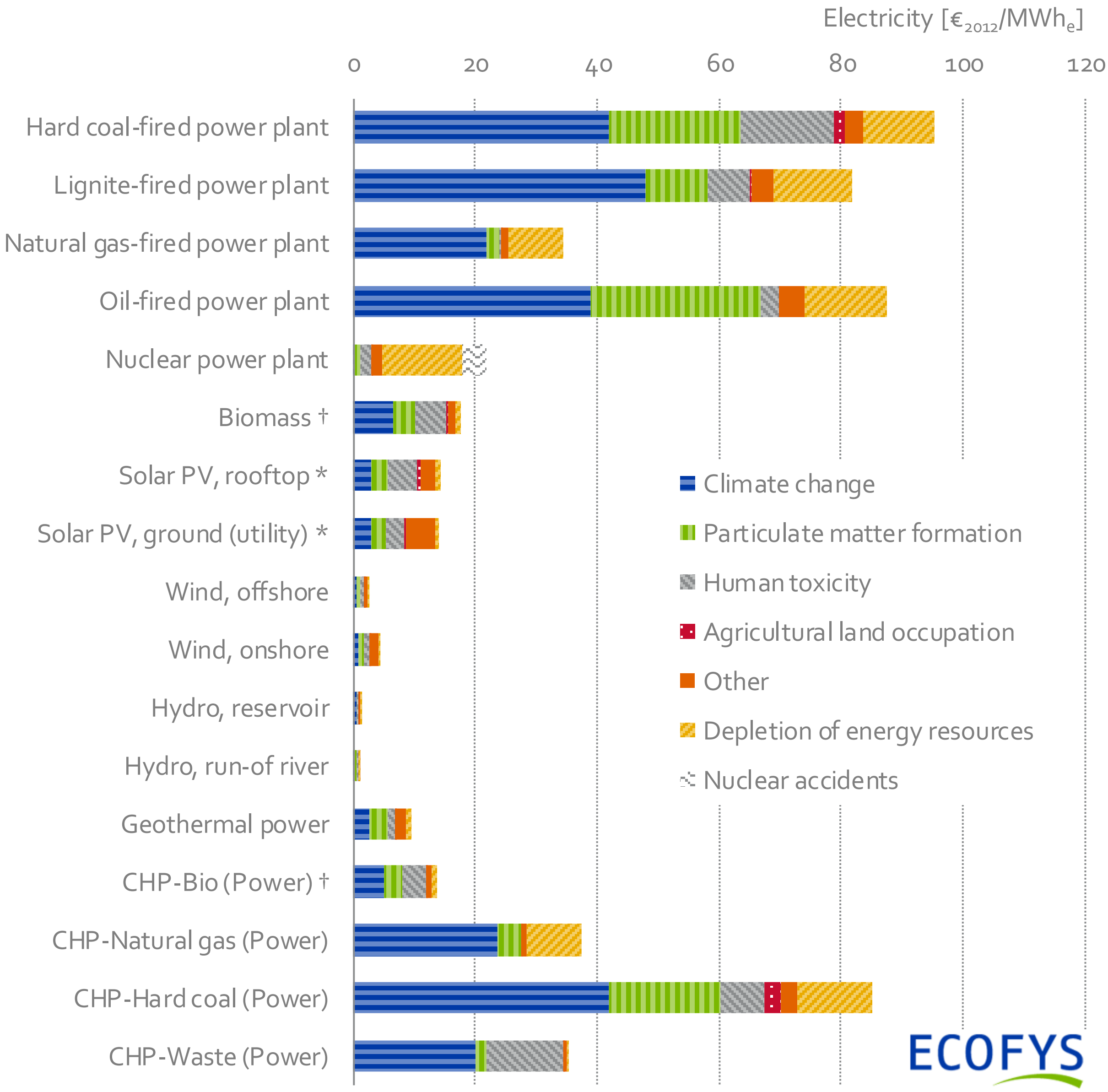

Figure 3-8: External costs per technology for electricity technologies, EU28 weighted averages (in €$_{2012}$/MWh$_e$).

*Note: The values presented here for solar PV are likely to be an overestimation of the current situation, because of the high pace of technological development for this technology.

†Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Depletion of energy resources are the highest for the nuclear, gas, oil and coal technologies, in the range of 9-14 €$_{2012}$/MWh for each. Some renewable energy technologies, such as geothermal, solar PV and biomass[37], also have impacts in this category resulting from their upstream energy use (e.g. fuels for transport, electricity in production). The value placed on energy resource depletion reflects the increased marginal cost to society of the consumption of finite (fossil and nuclear) fuel resources now, rather than in the future.

[37] In the case of biomass a significant part of the fossil depletion impact is caused by the natural gas used during ammonia production. Ammonia is used in the removal of NOx from the flue gas treatment by selective non-catalytic reduction (SNCR).

This externality arises if the increase marginal cost of extraction is not well enough captured by the present prices because, for example, owners of finite stocks of natural resources have higher discount rates than socially optimal. Given the scale of global fuel subsidies, it is unlikely that current prices are socially optimal.

Particulate matter formation[38], air pollution which damages human health, is the fourth largest impact. It is also highest for fossil fuel based power technologies, particularly oil power plants, but also hard coal and lignite[39]. The exception to this is natural gas based electricity which has very low particulate matter emissions.

Human toxicity impacts are highest for coal-based technologies, where emissions to air and waste and spoil from mining causes pollution, which as it is inhaled or ingested causes damages to human health. The totals for lignite have been adjusted to assume no emissions of manganese and arsenic from European mines[40], on the basis that regulations in Europe minimise or prevent the release of these substances (see Annex 3). For lignite this removes a large contribution to the score for impact on human toxicity. For hard coal, sourced predominantly from outside the EU, emission estimates for upstream activities are based on global and general estimates derived from the Ecoinvent database[41]. Therefore, some impacts from manganese and arsenic remain.

Agricultural land occupation, representing the value of the loss of biodiversity on lands used for agricultural production (for example production of biomass) rather than left in its natural state, is the fifth highest impact.

The other costs are relatively minor in general, but are significant for some technologies, for example nuclear energy, for which ionising radiation represents a quarter of the external costs. The external cost of metal depletion reflects reflecting increased marginal cost to society of the consumption of these finite resources now, rather than in the future and has significance for solar PV because of the metals used in solar panels.

Heat technologies

In Figure 3-9 weighted average external costs are shown for the heat technologies in the EU28. Domestic heat technologies show a spread in impacts, with the lowest for the renewable heat technologies. Industrial heat, sourced from a variety of fuels, has the highest per MWh impact as a variety of fuels including coal are used.

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[38] Note that the score for particulate matter formation includes both primary and secondary particulate formation. For example, important precursors for particulate matter formation are NOx, SO_2 and NH_3 which are highly relevant emissions from the energy sector.

[39] The figure shows that particular impacts are higher for hard coal than for lignite, which may be considered a surprising result. However, when interpreting these results it has to be kept in mind that this figure shows an EU28 weighted average. Therefore, the values do not only reflect differences between technologies, but also differences between member states. So while on average lignite would be more polluting than coal for particulates, the differences in average Member State power generation efficiencies, as well as differences in end-of-pipe technologies in the different member states, help explain the difference. In the case of lignite, the majority (>60%) of lignite power generation in our dataset is in Germany, one of the countries with relatively high plant efficiency and stringent emission abatement, this therefore brings the weighted average down compared to hard coal use which is more evenly spread across the EU (33% United Kingdom, 25% Germany, 13% Spain, 12% Italy), with a wider range of efficiencies and abatement technologies.

[40] Arsenic and manganese emissions from coal mining are the dominant substances contributing to the score for human toxicity.

[41] Doka (2009) Life Cycle Inventory of the disposal of lignite spoil, coal spoil and coal tailings. Available at http://www.doka.ch/DokaCoalTailings.pdf

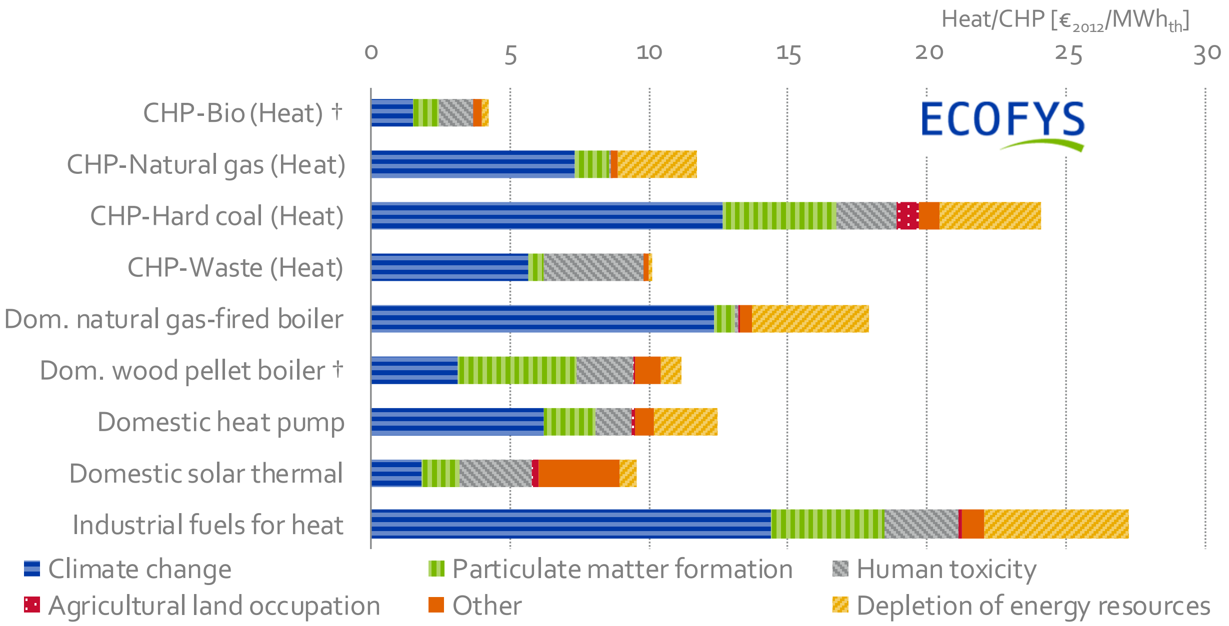

Figure 3-9: External costs per technology for heat and CHP technologies, EU28 weighted averages (in €2012/MWhth).

†Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Similar to the power technologies, climate change and depletion of energy resources are the largest impacts. These are closely linked to each other and are highest for the fossil fuel based technologies. A notable exception to this link is waste-fired CHP. This has very little depletion of energy resources because no impacts are associated with the fuel use. Instead, these impacts are allocated to former life of the waste. However, significant climate impacts occur as a result of the emissions from waste incineration. Human toxicity is a significant impact for waste due to the toxic emissions (e.g. manganese, barium, lead) resulting from waste incineration, and for domestic solar thermal due to mining of raw materials for components. The impact is somewhat less for other technologies. Particulate matter formation is most significant for coal CHP and to a lesser extent for the domestic wood pellet boiler. Impacts for solar thermal and heat pumps are largely found in their upstream phase, although some impacts are also associated with their electricity use, for which an EU28 average calculated within the External-E tool is used.

Range of Member State level results

Figure 3-10 shows the range of calculated external costs per technology for the different Member States. The spread in the results are caused by differences on the country level. For fossil technologies the differences in external costs are due to differences in efficiencies of power plants across countries and differences in operation. For instance, the type of end-of-pipe technologies may differ per countray, as well as the origin of the fuel. For renewables the differences are mainly caused by differences in full load hours and in some cases also by differences in operation. No range is shown for the domestic wood pellet boiler as no differentiation on the country level was made. The range for CHP based on hard coal (power) is significant and reflects the wide range of CHP types, from modern high efficiency units, to old low efficiency systems, and actual operating efficiencies in practice.

Box 3-3: How to read the range graphs for external and levelised costs

The ranges depict the differences in outcome (external or levelised costs) across a variety of data points. For external costs these datapoints are for the 28 Member States. For levelised costs they relate to the variety of different sources for capital expenditures, operational expenditures and conversion efficiencies. The combination of these leading to the lowest outcome (external or levelised cost) represents the lowest extreme of the bar, while the opposite is valid for the maximum. The most solid area of the bar represents the median.

A solid line has been added to the range graphs at the EU weighted average for the external costs and the median for the levelised costs.

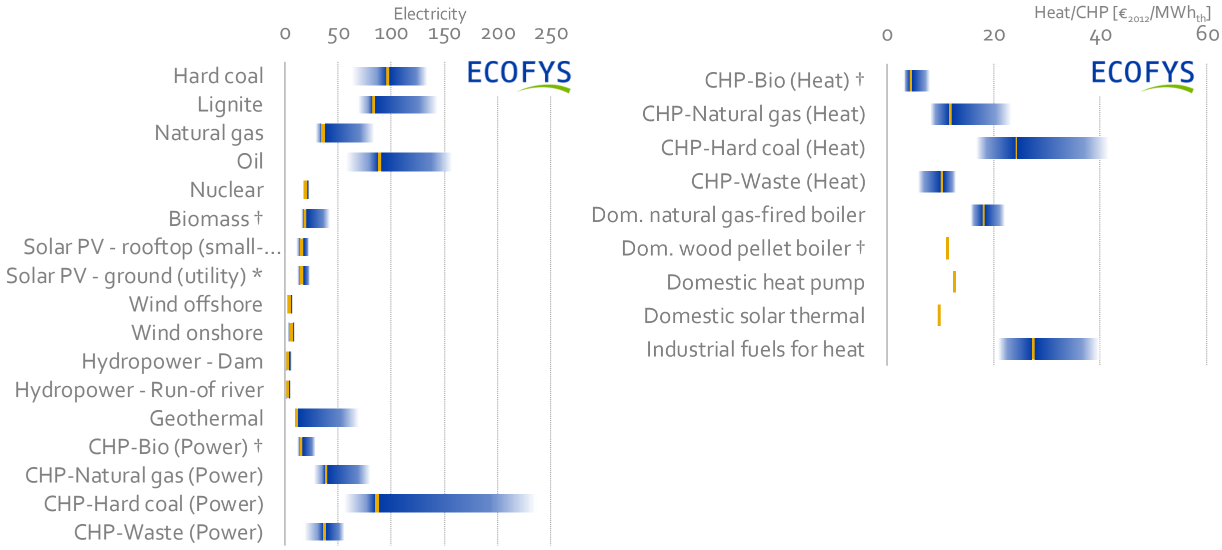

Figure 3-10: Range of external costs across different Member States per technology (in €$_{2012}$/MWh). The blue bars represent the range of values, the yellow line represents the weighted average.

Left graph: *Note: The values presented here for solar PV are likely to be an overestimation of the current situation, because of the high pace of technological development for this technology. †Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Right graph: †Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Note that the width of the bars does not necessarily represent a larger uncertainty in the actual external costs, but can be due to a higher number of available country specific datasets or more variation in the country specific modifications made (e.g. efficiency). For some technologies only generic datasets were used. These do not fully reflect or exaggerate the actual variations across countries. Although the weighted average is at the centre of the shading in the range, the overall range is unweighted and therefore can be skewed by outliers.

Finally, it should be noted that in any case the actual uncertainty associated with the results is likely to be significant. Therefore, even for technologies where there is no discernible range from our calculated results above, i.e. nuclear power or offshore wind, in reality there is uncertainty. This uncertainty may be significant, i.e. in the range of 25-50%.

Technology results in context

When comparing with existing literature on external costs, such as the ExternE, NEEDS, CASES outputs and other studies[42] our estimates are consistent with the external cost ranges (inflation adjusted) previously estimated in these studies, although in some cases towards the higher end of the ranges. It is to be expected that our estimates would be at the higher end of the range as more impacts are included. Most other studies did not include valuations for energy and mineral resource depletion. Furthermore, underlying assumptions for valuation, for example estimates being based on a lower value for climate impact (i.e. CASES used a value of $€_{2000}$ 19/tCO_2e) are highly significant. Inflation also has a significant impact with our values relating to 2012, while previous estimates relate to 2000, 2005 or 2008, accounting for changes of 5-30% in value, increasing over time. This is particularly true for impacts with human health aspects where not only inflation is relevant, but an additional annual uplift value of 0.85% is also applied due to positive income elasticities of demand for good health (see Annex 3). The external costs for nuclear are higher than the recent review by DG Energy (2013)[43]. The difference is entirely explained by the inclusion of energy resource depletion.

3.2.2 Aggregated external costs of energy for EU28

We also aggregated the total external costs of energy (electricity and heat) of the EU28 energy system based on 2012 production data. External costs of domestic solar thermal and domestic heat pumps are excluded from this analysis due to lack of production data for these technologies. The method is described in more detail in Annex 3. The results show total external costs in 2012 for the EU28 of approximately $€_{2012}$ 199 billion. These are broken down into the five biggest impacts of which climate change is the largest impact, accounting for approximately half of the total, while depletion of energy resources accounts for a further 22%. Particulate matter formation, constitutes 15% of the total. Human toxicity accounts a further 8%, while the agricultural land occupation takes a further 1%. Other impacts, such as water and metal depletion, ecosystem toxicity, radiation, acidification and eutrophication make up the remaining 4% of the total cost.

[42] i.e. UBA (2012) Best-practice-kostensätze für luftschadstoffe, Verkehr, Strom- und Wärmeerzeugung: Anhang der „Methodenkonvention 2.0 Zur Schätzung von Umweltkosten".

[43] DGEnergy (2013). Synthesis on the economics of nuclear energy. Prepared by W. D. D'haeseleer, KU Leuven. European Commission, DG Energy, Brussels

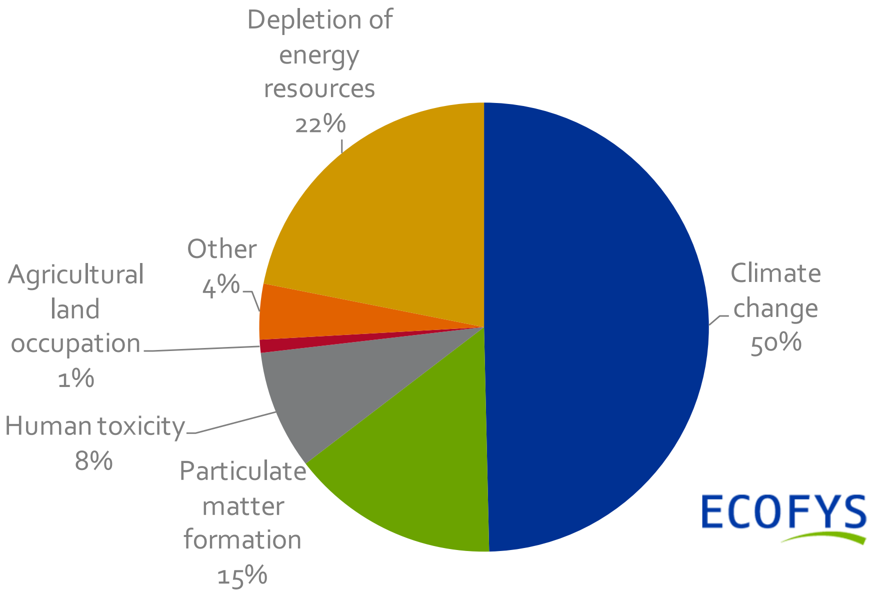

Figure 3-11: Breakdown of total aggregate external costs energy of €$_{2012}$ 199 billion in 2012.

Note: the impact of domestic heat pumps and domestic solar thermal are not included in this total.

Figure 3-12 shows how these total environmental impacts of €$_{2012}$ 199 billion are divided over the Member States. These are the environmental costs associated with energy production within these countries, although these environmental impacts do not necessarily occur within that country (e.g. impact of extraction of imported fuel) or even within the EU28. They are rather the estimated global costs attributable to the energy generated in that country.

The differences between countries reflect both differences in impact intensity and differences in the amount of energy production between countries. Total external costs are highest for Germany, the UK, Italy and France, because of both high energy production within these countries and a significant share of fossil energy within the energy mix. France, despite a similar population and economy size, is notably much lower than the UK, and also a little lower than Italy, because of the high share of relatively low external impact nuclear energy in the electricity mix. As noted in section 2.5 carbon tax revenues have been subtracted from the total as they represent internalisation of the climate impacts. These reduce the climate impact by approximately €2 billion and are relevant for 4 Member States[44]. Tables including more detailed results on the Member State level are included in Annex 3.

[44] Denmark, Ireland, Luxembourg, United Kingdom

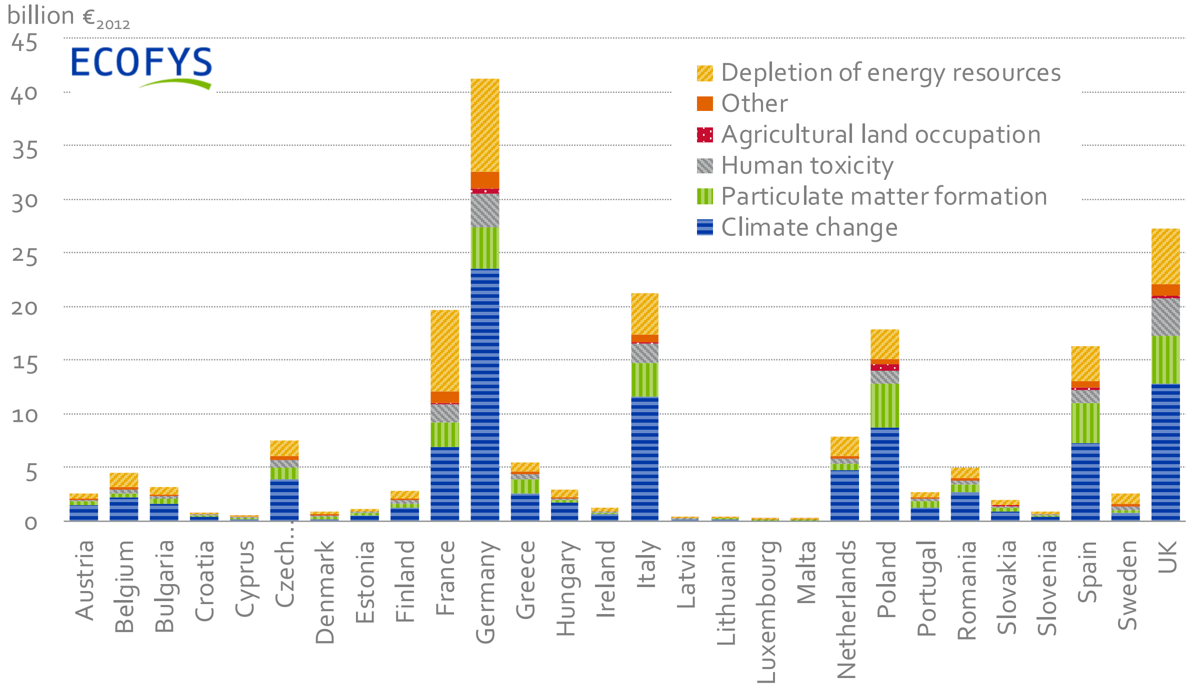

Figure 3-12: Total external cost per Member State in 2012 (in billion €$_{2012}$)

3.2.3 Sensitivity analysis

We have carried out two sensitivity analyses for the total external costs for EU28, one on climate change and one on depletion of energy resources, as these two impact categories have the highest external costs. The method used to derive the central values for climate change (50 €$_{2012}$/tCO_2e) and energy resource depletion (48 €$_{2012}$/tonne oil eq.) is presented briefly in section 2.5, while a fuller explanation of the sources and rationale is given in Annex 3.

Climate change

For climate change, from the central value of 50 €$_{2012/}$tCO_2e we performed sensitivity checks at 30 €$_{2012}$/tCO_2e and 100 €$_{2012}$/tCO_2e. The lower value represents a value typically used in analyses of the EU ETS. The latter values reflect the €$_{2012}$ 80-100 range of higher bound estimates from literature. For all technologies, except the domestic heating technologies, the carbon price for 2012 (6.67 €$_{2012}$/tCO_2) was deducted from the value so that net external costs are shown.

Figure 3-13 shows the results of the sensitivity analysis for the value for climate change on the EU28 aggregate external cost, with the different climate change values leading to total aggregate impacts falling to approximately €2012 150 billion at the lower value of 30 €$_{2012}$/tCO_2e and increasing to €$_{2012}$ 310 billion at the higher value of 100 €$_{2012}$/tCO_2e.

Figure 3-14 shows the sensitivity of results for the electricity technologies to different valuations of climate change. This shows a significant range in impact for the fossil fuel technologies, representing a large variety in operating conditions, although it is clear that at any of the values their external costs remain higher than nuclear power and renewables.

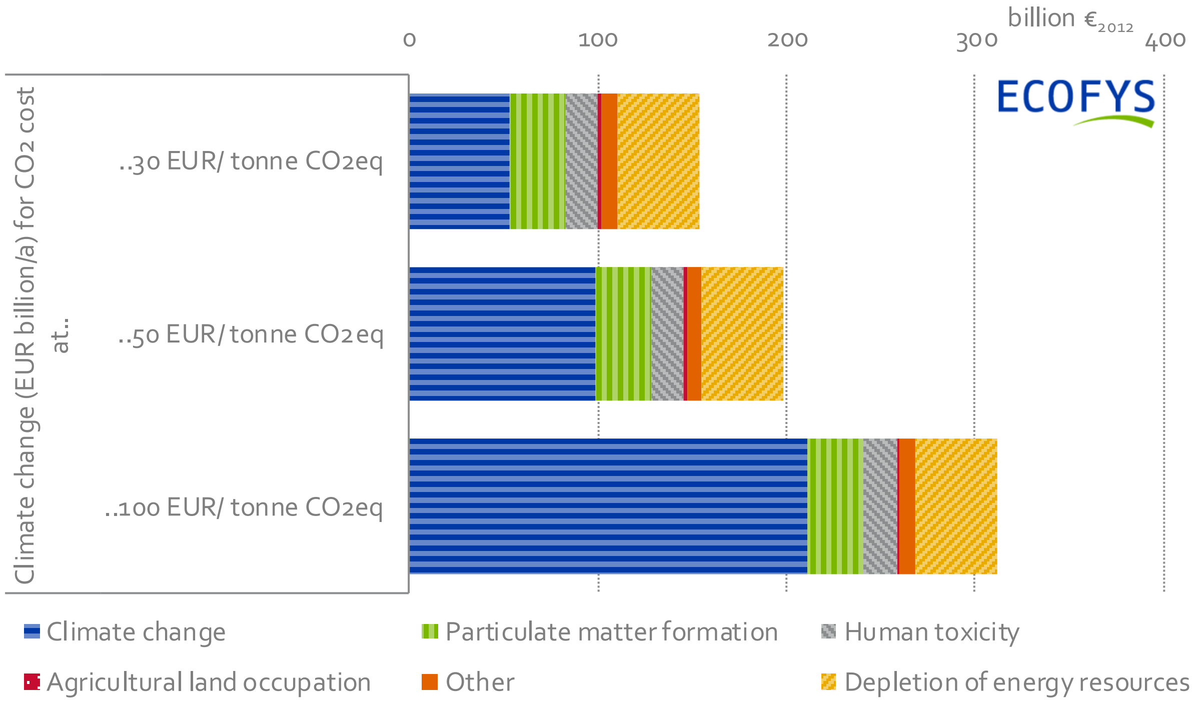

Figure 3-13: Sensitivity analysis of monetary values for climate change (in billion €$_{2012}$)

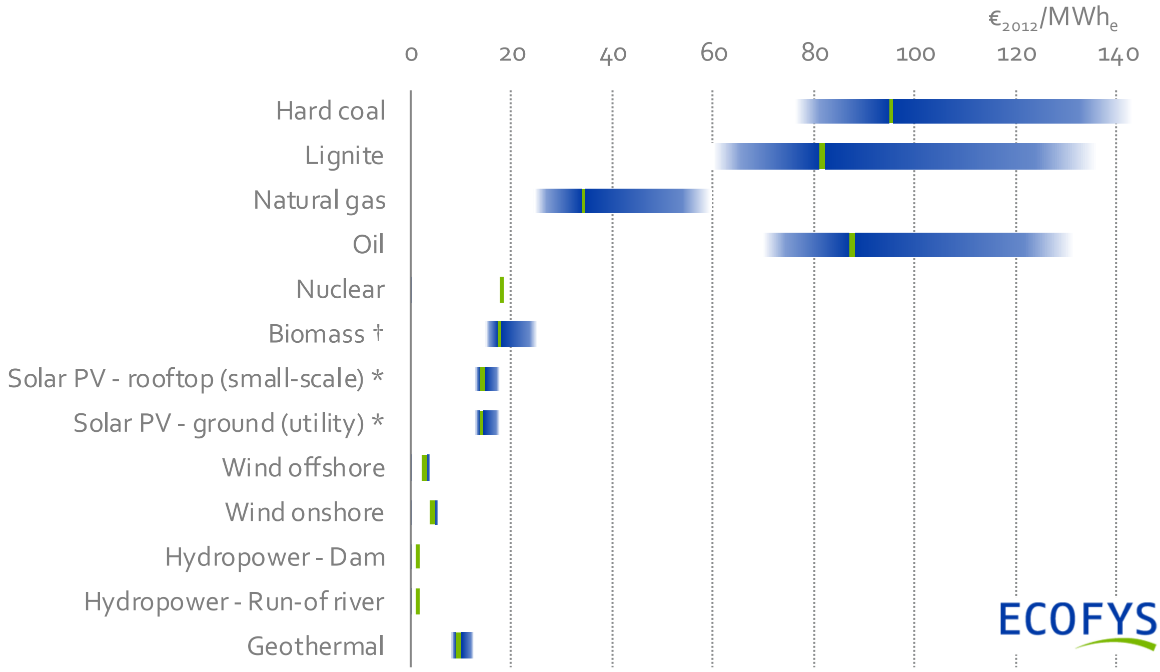

Figure 3-14: Total external costs of electricity technologies following from the sensitivity analysis of monetary values for climate change for (EU28 average) (in €2012/MWh$_e$). The blue bars indicate the range of external costs found in the sensitivity analysis; the green line indicates the results for the central assumption of 50 €$_{2012}$/tCO_2e.

*Note: The values presented here for solar PV are likely to be an overestimation of the current situation, because of the high pace of technological development for this technology.

†Note: biomass is assumed to be sourced from agricultural/waste wood residues only, i.e. biomass from dedicated energy crops is not included (see also Annex 3).

Depletion of energy resources

For depletion of energy resources we have used the monetary value of 48 €$_{2012}$/toe in the base case. We tested two variations on our value for energy resource depletion, to address concerns related to how the valuation approach takes into account differences in resource scarcity and production costs. The first variation applies adjusted values to technologies using gas, coal and uranium as fuels, with values adjusted for the resource scarcity of these fuels in comparison to oil. The second method also adjusts values relative to oil, but for the production cost per GJ for each fuel. These sensitivities are presented only as separate alternatives, not combined, as resource scarcity will already be (partially) reflected in production costs. The methods and results are as follows:

Method 1: Resource scarcity adjustment

From the Global Energy Assessment[45] we derived an estimate of the scarcity of the four main energy carriers. The scarcity is defined as the number of production years that are still left considering the current production rate and estimated reserves. A scarcity ratio is determined by assuming the number of oil production years left as a reference. The relative number of production years left compared to that of oil is then the scarcity ratio.

In our base analysis we use a value of €0.05 (48 €/toe), reflecting the individualist perspective. For this sensitivity analysis we adjust not from this value, but from the higher hierarchist ERD valuation factor of €0.15. We use the hierarchist value, rather than the individualist value, to reflect that the individualist approach we applied was already an adjustment to account for increases in economic unconventional energy reserves since the original method, and the scarcity and price issues identified here (see also section 2.5 and Annex 3).

Table 3-6: Scarcity adjusted values for energy resource depletion (ERD)

Fuel	Annual production	Reserves	Resources	Sum of reserves and resources	Years of production left as of 2005	Scarcity ratio (oil set at 1)	Adjusted ERD impact value
	EJ/yr	EJ	EJ	EJ	Years		€$_{2012}$ /kg oil equivalent
Oil	168.1	10930	18200	29130	173	1.00	0.15
Gas	99.4	49650	89100	138750	1 396	0.12	0.02
Coal	123.8	19150	363000	382150	3 087	0.06	0.01
Uranium	24.7	2400	7400	9800	397	0.44	0.07

Compared to the value of 0.05 used in the base analysis presented in Section 3.2.1, the contribution from the energy resource depletion category would be 60% lower for gas and industrial heat and 80% lower for coal. For oil, it would be 3 times higher and for uranium 1.4 times higher. This would not impact the order of impacts from different technologies but would bring nuclear power to close that of gas. In combination there would be a 36% decrease in total energy resource depletion impacts, corresponding to 7% lower aggregate total impacts.

45 GEA, 2012: *Global Energy Assessment - Toward a Sustainable Future*, Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria

Table 3-7: Impact of resource scarcity adjustment

	Base	New	Change	
	€$_{2012}$ billion	€$_{2012}$ billion	€$_{2012}$ billion	%
Aggregate impacts	199	185	-14	-7%
Energy resource depletion impacts	43	28	-16	-36%
ERD / aggregate impacts	22%	15%		

Method 2: Production cost adjustment

The second aspect covered is the difference in historical and future trends in production cost. We use the current market price as a proxy for the future increase in production cost. This is a rough assumption, but allows us to take into account differences in production costs (prices) between energy carriers and also differences in potential societal costs of depletion. The production cost ratio is shown in the table below and is defined as the relative production cost of an energy carrier compared to that of oil, as oil is the reference energy carrier in the ERD method. A single value is used here for the production cost.

Table 3-8: Scarcity adjusted values for energy resource depletion

	Price primary energy carrier	Price ratio (oil set at 1)	Adjusted ERD impact value
	€$_{2012}$/GJ		€$_{2012}$/kg oil equivalent
Oil	13.42	1.00	0.15
Gas	4.63	0.34	0.05
Coal	3.20	0.24	0.04
Uranium	0.29	0.02	0.00

Applying these new values to the relevant power and heat technologies results would lead to significantly decreased energy resource depletion impacts per MWh for nuclear power, lower impacts for coal power and heat, similar impacts for gas and industrial fuels as the base case, and significantly increased impacts for oil. The overall impact of this change, was decrease in total energy resource depletion impacts of 22%, corresponding to 4% lower aggregate total impacts.

Table 3-9: Impact of production cost scarcity adjustment (in billion €$_{2012}$)

	Base	New	Change	
	€$_{2012}$ billion	€$_{2012}$ billion	€$_{2012}$ billion	%
Aggregate impacts	199	192	-7	-4%
Energy resource depletion impacts	44	34	-9	-21%
ERD / aggregate impacts	22%	18%		

Overall, this alternative sensitivity analysis demonstrates that the approach to energy resource depletion may over or understate impacts for specific fuels and technologies, but that this varies by assumption. Overall, there is a suggestion that alternative methods could lower total impact values by 4-7%. As the methodology for valuing this impact is still under development, further research is suggested beyond this project to yield more robust and specific values for energy resource depletion impacts.

3.3 Levelised cost

This section provides levelised cost ranges for electricity, heat and CHP for the EU-28. Results at technology level indicating the differences among Member States, are given in Annex 4.

Box 3-4: How to interpret the levelised cost charts?

The levelised costs presented are valid for newly constructed plants in the period 2008 - 2012 in the EU28.

To provide insight in the impact of the degree of utilisation of each technology, levelised cost as a function of maximum operating hours (taking into account resource and technical constraints) as well as under actual average operating hours are shown. A difference between the technical and realized (or actual) full load hours is a consequence of market demand being lower than the supply capacity. The former is given in grey while the latter is shown in blue.

It is important to note that levelised costs cannot be used to estimate the market price of electricity. Levelised costs involve both capital, operational and fuel costs, while the market price of electricity is derived from a merit order of technologies that is based on marginal costs and availability of technologies at specific times. Marginal cost comprise variable cost only. As such, the marginal cost are by definition lower than levelised cost. Furthermore, system costs are not included (unless stated otherwise). These are, for example, grid investments needed to transmit energy production from a technology in the electricity grid.

3.3.1 Electricity

Figure 3-15 gives an overview of LCOEs. The red bars indicate LCOEs if technologies would operate at the technically possible amount of full load hours (FLH). The blue bars indicate the LCOEs when taking into the FLH that were realised in the European Union (based on generated electricity and installed capacities, see Annex 4, section on full load hours).

In a real-life electricity system that operates under market conditions, the technically feasible FLH will not be realised as it is a function of demand. For example: back-up capacity only runs in times of extreme demands or outages of other plants (see for instance the costs of oil-fired plants), renewable power generation partly replaces the marginal fossil thermal power production (see for instance the cost of natural gas-fired plants) and utilities do not have a perfect foresight and operate in competition.

Cost of lignite has also been studied, while investment and operational costs are available, consistent and intervention free fuel prices for all Member States that use lignite generation are not. The main reason is that domestic lignite production is directly integrated in the power production process: a lignite mine produces for neighbouring power plants and lignite is not traded. Furthermore, data on production costs of lignite are not publicly available. Therefore, levelised cost of lignite power production are not presented here.

Over the period 2008 - 2012, PV system prices have dropped substantially by about 60% [46], which is reflected in the significant lower PV prices in 2012 compared to 2008. For offshore wind, analogous to all other technologies, cost without (offshore) transmission and distribution cost are shown as well as the costs including offshore transmission infrastructure. The large range for oil reflects its use largely as a back-up power in most Member States, with a consequent range of full load hours[47].

[46] Fraunhofer Institute for Solar Energy Systems ISE. Photovoltaics Report Freiburg (November 7, 2013). Available online at: http://www.ise.fraunhofer.de/en/downloads-englisch/pdf-files-englisch/photovoltaics-report-slides.pdf.

[47] Investments are divided by the full load hours to obtain levelized costs. Low full load hours thus tend to inflate the levelised cost range.

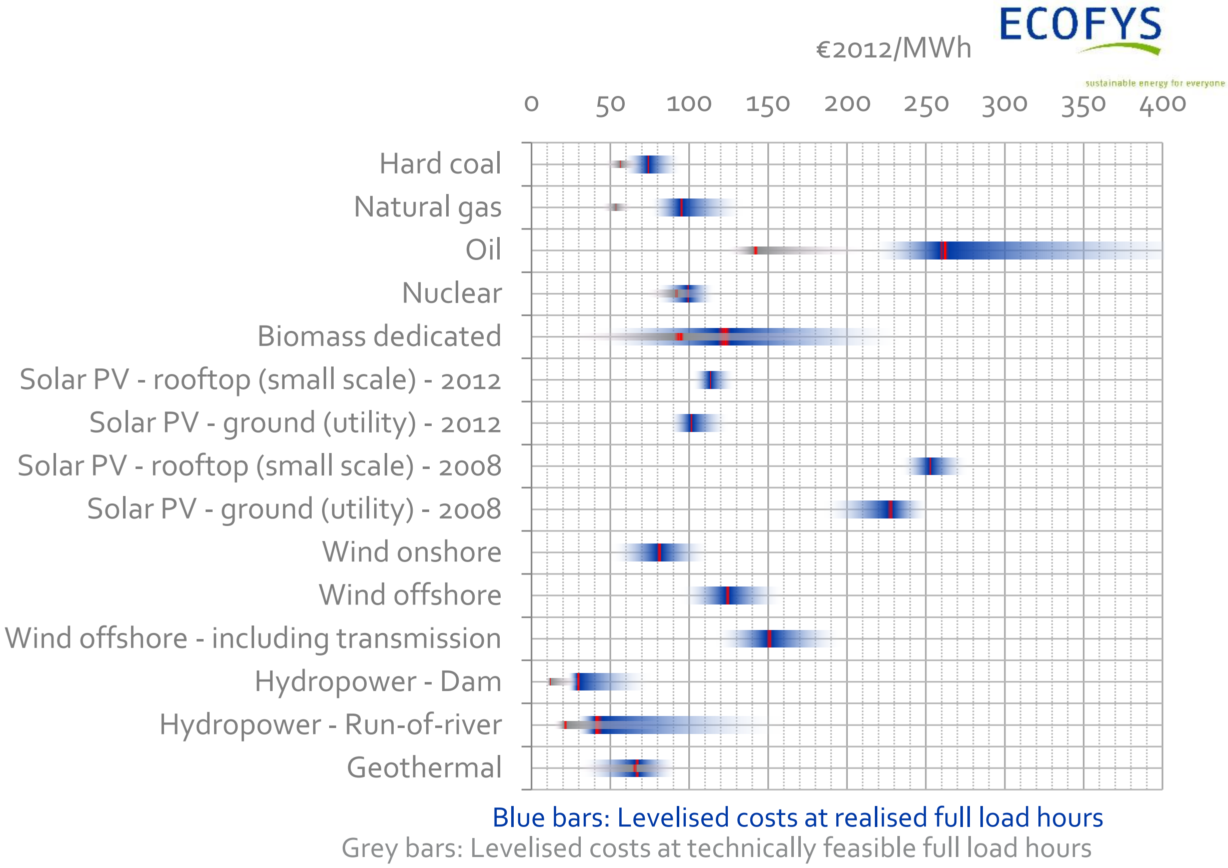

Figure 3-15: Levelised cost of electricity in the EU28 for various technologies in the EU28. The blue bars indicate the levelised cost at full load hours estimated from energy production and capacity statistics and the grey bars indicate levelised cost at technically feasible full load hours. The red vertical lines represent the median of the range.

We compared the outcomes to a similar analysis from the Fraunhofer Institute[48]. The levelised cost of electricity of wind, solar and coal-based and gas-based technologies resulting from this analysis are very similar both in terms of absolute cost and the cost-ranking of the technologies. DG Energy (2013) estimated the LCOE from a new "nth-of-a-kind" nuclear installation to range between €$_{2012}$ 69/MWh and €$_{2012}$ 84/MWh at a discount rate of 10%. The costs presented in this work (EU28 average) ranges between €$_{2012}$ 79/MWh and €$_{2012}$ 116/MWh at a discount rate of 10%. DG Energy (2013) applied 7446 full load hours, while in this study 6785 hours are used, based on Eurostat statistics. More detail on the comparison and comparability of the assumptions can be found in Annex 4.

3.3.2 Heat

Figure 3-16 shows LCOH of different technologies. For domestic technologies we distinguish different regions. More information of the defined regions is provided in Annex 4.

[48] Fraunhofer Institut for Solar Energy Systems ISE (2013). Levelised cost of electricity renewable energy technologies. November 2013.

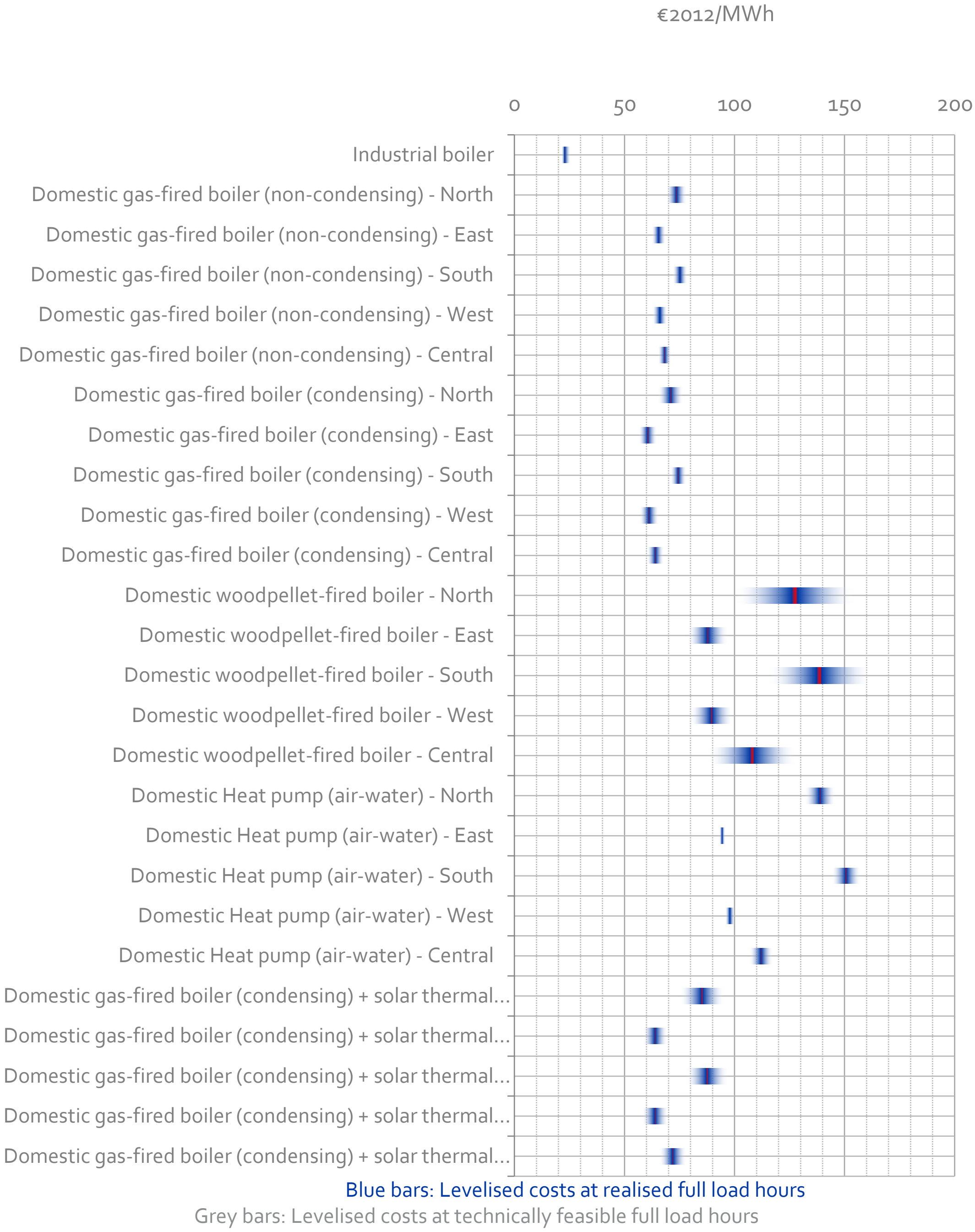

Figure 3-16: Levelised cost of heat in the EU28 for various technologies in the EU28

The large cost gap between industrial boiler and domestic heating technologies is almost entirely caused by much lower natural gas prices for industry. In general the cost of the natural-gas based technology is largely driven by the cost of fuel, while for technologies running on other fuels (heat pumps, biomass boilers), capital expenditures cost play a larger role. In Northern and Southern EU countries, the capital costs of domestic wood pellet-fired boilers are high and have a large impact on the levelised cost compared to gas-fired boilers[49].

[49] Compared to total heat supply a large capacity is needed to meet peak demand in these regions.

3.3.3 Combined Heat and Power

Figure 3-17 shows LCOHs and LCOEs for CHP. Here, the revenues reduce generating costs. The high cost of CHP running on waste are induced by high investment and operational costs. CHP is typically used in industry to fulfil the (part of) the heat demand of the industrial processes. Therefore, for CHP gas – industry, only the LCOH are shown.

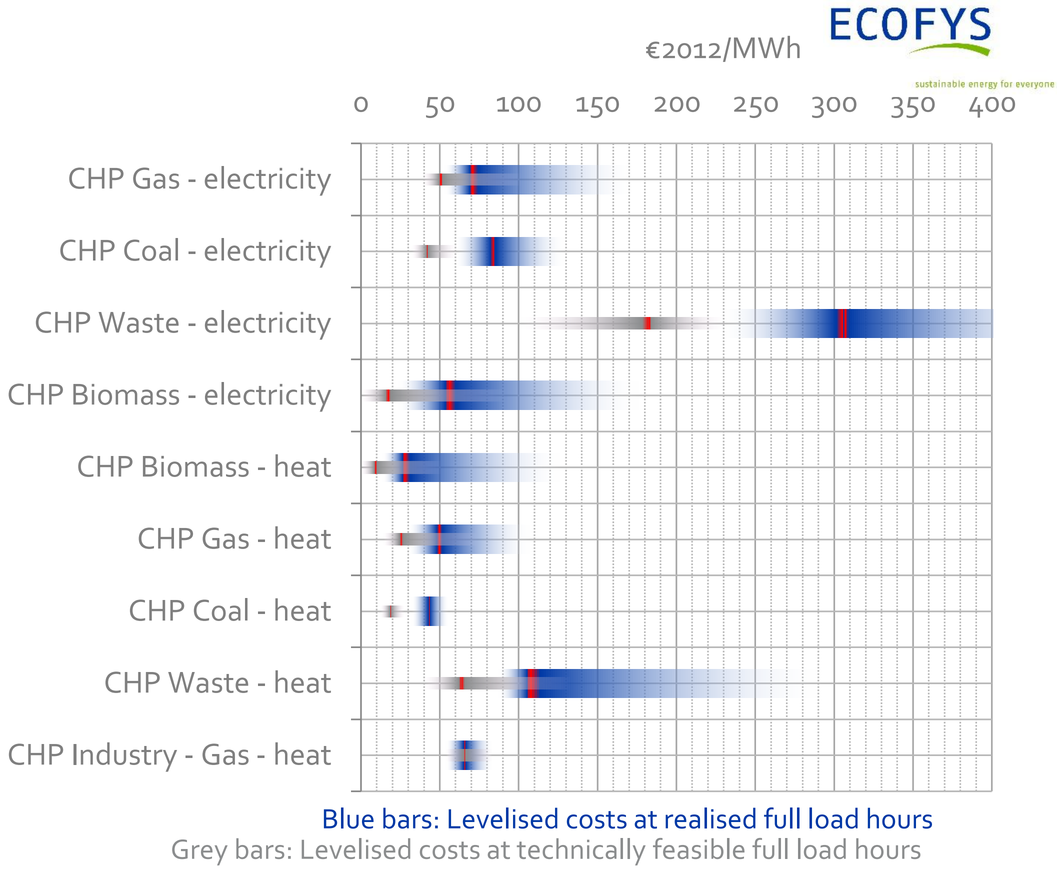

Figure 3-17: Levelised cost of various CHP technologies in the EU28

3.4 Cost of transmission infrastructure

Electricity and heat technologies are part of the energy system. Transmission and distribution are regulated industries and in most countries data on the transmission system, particularly for electricity, are available from energy regulators. For the distribution side, typically a much larger number of companies and/or municipalities' is involved and obtaining data for most Member States has been impossible. Total annual expenditures (capital and operation & maintenance together) for the electricity transmission system across the EU 28 are around €$_{2012}$ 20 billion. It was not always possible to separate out costs for distribution, so some countries include both transmission and distribution. There are also some data gaps, but the total given should be of the right order of magnitude.

Total annual expenditures (capital and operation & maintenance) for the gas transmission network are on the order of €$_{2012}$ 15 billion in 2012. There were more data gaps in the reported expenditures for the gas transmission network. More details of the expenditures are provided in Annex 4.5.

4 Conclusions

The results of this study show that in 2012, the total monetary value of public interventions in energy (excluding transport) in the EU28 are €$_{2012}$ 113 billion (see Figure 4-1). This value includes over 700 interventions that have been identified at the Member State and EU level. In this study, the majority of these interventions have been monetised, the remaining data gaps are small compared to the total. On top of the value of total interventions the historic support that has a direct effect today (hereafter referred to as 'direct historic support') is added. Direct historic support ranges from €$_{2012}$ 3 to 15 billion, with a central value of 9 billion.

Total aggregate external costs of energy add up to €$_{2012}$ 200 billion. The range for the external costs is €$_{2012}$ 150-310 billion. This is based on the sensitivity analysis for the economic valuation of climate change impacts.

The total amount of interventions is significant in relation to the total wholesale costs of energy in the European Union (€$_{2012}$ 500 billion)[50]. This is depicted in the figure below.

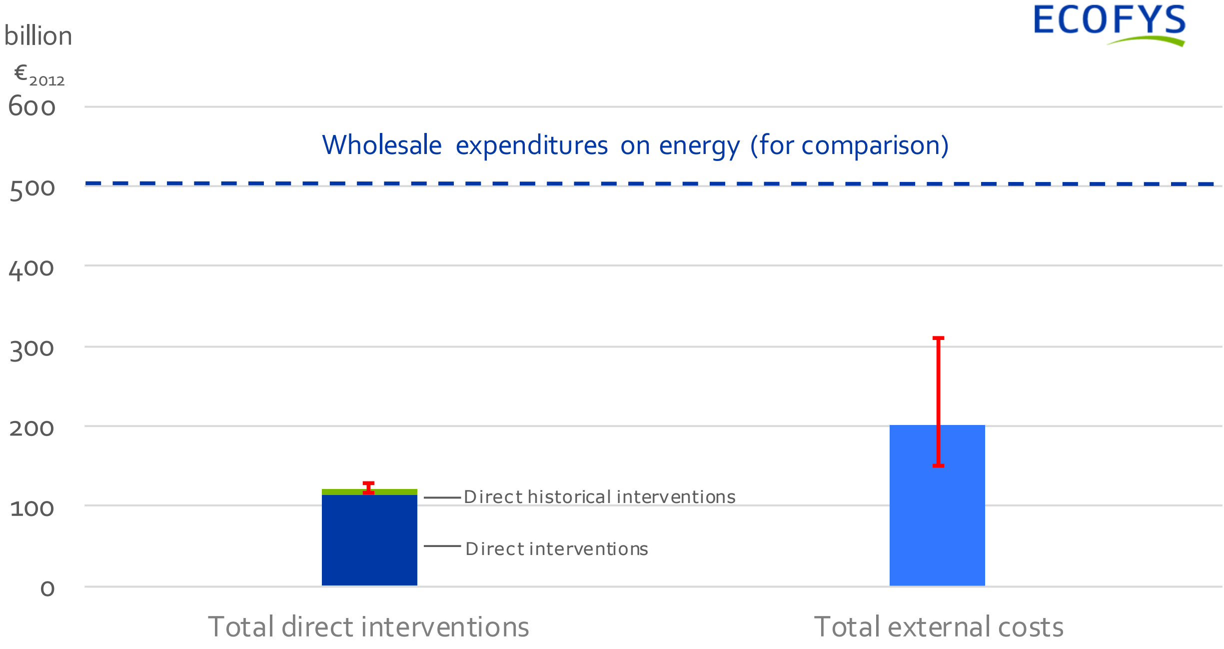

Figure 4-1: Total interventions, external costs and wholesale cost of energy 2012 (in billion €$_{2012}$)

The direct historic support is shown as a range on top of the total interventions. Total interventions include the EU ETS free allocations.

A further interpretation of the results requires a breakdown of the costs and subsidies by technology. Such a breakdown is presented in Figure 4-2.

[50] The total wholesale costs are the product of the total volume of fossil fuels and the average spot prices (import prices) of coal, oil and natural gas plus the product of the volume of electricity consumed and the average wholesale price of electricity in Europe. These cost represent the costs of energy without any taxes, transport/transmission costs or costs of conversions (e.g. from crude oil to gasoline).

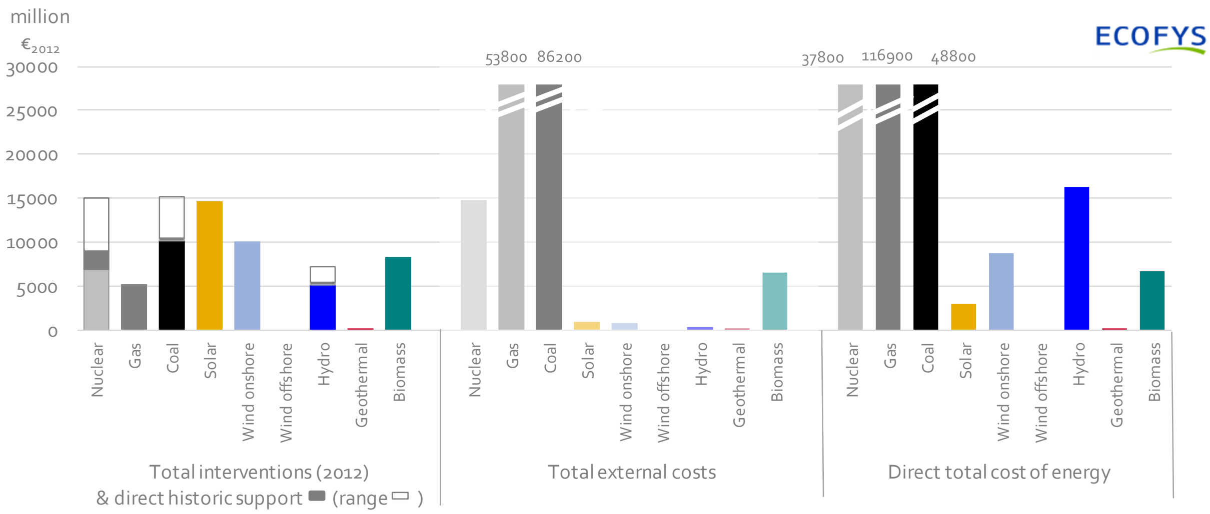

Figure 4-2: Total interventions, external costs and costs of energy split by technology 2012 (in million €2012)

Note: In this figure, total interventions exclude those not allocated to technologies i.e. infrastructure, energy demand, energy saving and free allocation of EU ETS allowances. Direct historic support is shown as ranges at the top of the interventions bar (marked by a gap in the bar). External costs have a higher level of uncertainty than the other components.

Interventions to support renewable energy sources have the highest value (€$_{2012}$ 41 billion). The effect of direct historic support at the high end of the range is to bring the intervention level for nuclear to similar levels as solar. The range is derived from different methodologies to estimate direct historic support. As well as this direct support, all technologies have received some indirect support mainly in the form of R&D, which historically, was largely for nuclear energy. In addition, coal and, more recently, renewable technologies have received production support.

Support of new technology is one reason why governments intervene in the costs or prices of energy. Besides this, a variety of social and economic objectives also form the background to support the production (e.g. coal) or the consumption of energy (energy-intensive industries, low-income households).

Interventions with the objective to save energy are valued at also significant at €$_{2012}$ 10 billion. Subsidies for energy demand (which in the end stimulate higher consumption) are significant at €$_{2012}$ 30 billion.

Figure 4-3 breaks down the value of intervention per MWh of electricity production by technology and compares it to the levelised costs, the external cost range per MWh (presented as columns) and the retail price range for electricity (excluding taxes and levies; presented by horizontal lines). The retail cost includes the effect of interventions. The levelised costs are a good proxy of the cost of energy without interventions, if the energy system would be newly developed. It can be seen clearly from the figure that retail prices are not determined by the levelised costs of new technologies, but rather by the whole energy system and its legacy.

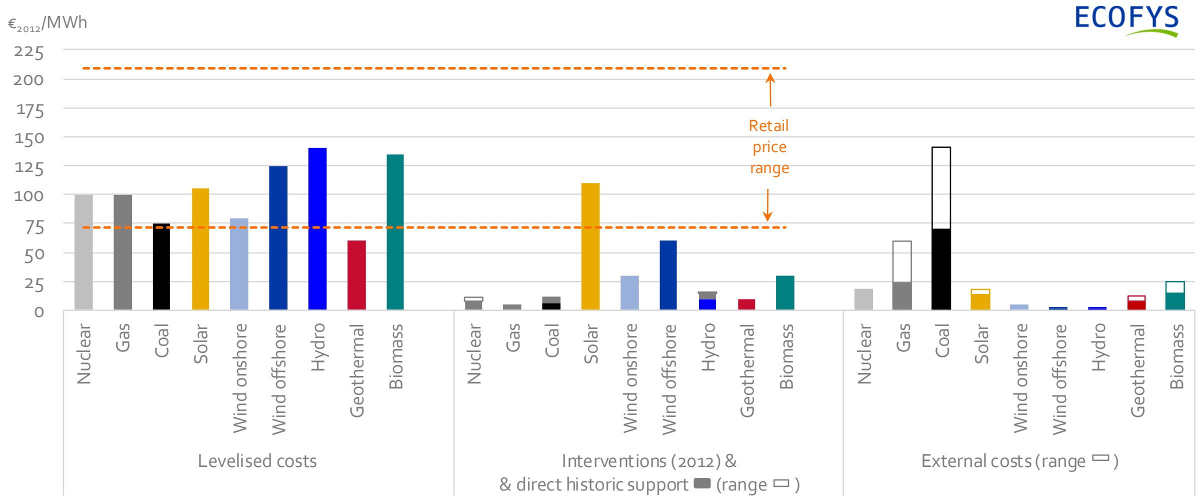

Figure 4-3: Levelised costs, total interventions, external costs split by technology 2012 and divided by production (in €$_{2012}$/MWh).

N.B.: In this figure, total interventions exclude those not allocated to technologies i.e. infrastructure, energy demand, energy saving and free allocation of EU ETS allowances. The historic direct support is again shown as a range. Some of the interventions shown here for gas and biomass may be heat related – it was not possible to separate this out. The range for external costs of coal is based on the weighted average for hard coal and lignite.

Figure 4-3 shows that the highest level of support is given to solar, approximately equal to the 2012 levelised costs of solar utility scale PV (which has lower costs than roof top PV per unit of output). Production support in 2012 includes support still being paid on systems installed in previous years when the costs, and consequently the support was at much higher levels. Even in 2008, costs were around twice the costs in 2012.

Another observation is that total levels of support for nuclear and coal are close to solar and higher than wind. Levels of support per unit of generation are much lower, as the share of these generation technologies in total generation of electricity and heat is much higher than the share of solar or wind. Levelised costs for offshore wind are higher than for onshore wind, and most related interventions are aimed at bringing costs down.