16. Environmental implications of energy production

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1 INTRODUCTION

The assessment of the environmental implications of energy production is a wide and complex challenge. Many energy sources and technologies exist with very different environmental profiles and implications in the form of emissions to the environment, hazardous wastes, occupational risks, production of noise or visual intrusion or risks of accidents, etc. All of them impose risks on human beings, ecosystems and materials, producing damages that are *external* in the sense that they are not taken into account by the person or institution causing the effects. Such effects, known as externalities, are then not incorporated in the market price of the energy products they generate. The presence of externalities in the energy market is a market failure that results in the energy mix being inefficient from a social point of view.

When investment or operation decisions are made, e.g. about which power plant technology to use or where to locate a power plant, it would be beneficial for society to take environmental and health impacts into account and include the external effects into the decision making process. Quantifying these implications in a comparable manner would help energy policy makers in finding the energy mix which maximizes social welfare. In order to be able to assess and compare the external effects with each other and with private costs, it is convenient to express them in a common unit such as a monetary unit. Thus converting external effects into monetary units results in *external costs* that can be easily used in a cost-benefit analysis or be internalized through the appropriate environmental policy instruments.

In the first section of this chapter we will review the environmental implications of a wide variety of energy sources and technologies. In the case of fossil fuel technologies, as the previous chapter has examined the environmental impacts of fossil fuel extraction, this chapter will focus on those impacts produced during energy generation. However, in the case of renewable energies, the environmental implications of the energy generation stage of the fuel chain are in many cases negligible and most impacts are produced in either upstream or downstream stages. Therefore a discussion of these impacts will also be included.

In the second section of this chapter, the methodological options to quantify environmental implications and externalities of energy technologies will be briefly introduced, including the Life Cycle Assessment methodology and the ExternE methodology for externalities assessment. Finally, in the last section, some results of environmental impacts and externalities of different energy technologies will be presented.

2 ENVIRONMENTAL IMPLICATIONS OF DIFFERENT ENERGY SOURCES

2.1 Coal

Coal is the world's most abundant and widely distributed fossil fuel. Around 27 per cent of the world's total primary energy demand and 42 per cent of the world's electricity production is based on coal combustion (IEA, 2011). Several studies (MIT, 2007; IEA, 2011) conclude that coal will continue to have an important role meeting the world's energy needs in significant quantities.

The main use of coal nowadays is electricity generation although other uses include coking coal for steel manufacturing and industrial process heating whereas for electricity generation, pulverized coal fired is the most common installed technology nowadays (Bauer et al, 2008; IEA-ETSAP, 2010a). An average net thermal efficiency of 35–36 per cent is commonly assumed for large existing plants with subcritical steam burning relatively high quality coals.

Currently, supercritical pulverized coal (SCPC) power is the dominant option for new coal-fired power plants (IEA-ETSAP, 2010a). Super-critical pulverised coal (SCPC) power plants use supercritical steam as the process fluid to reach high temperatures and pressures and reach efficiencies up to 46 per cent. New ultrasupercritical (U-SCPC) power plants may even reach higher temperatures and pressure, with efficiency up to 50 per cent.

Integrated gasification combined cycles (IGCC) and Fluidized-bed combustion (FBC) are alternative coal-fired power technologies. IGCC can reach higher efficiencies varying from 39 per cent to 45 per cent while the primary driving force for the development of fluidized-bed combustion was the reduction in SO2 and NOx emissions at the combustor (Bauer et al, 2008).

Pulverised coal-fired power plants produce a considerable amount of airborne emissions. Emissions of SCPC and IGCC power plants are quite smaller and shown in Figure 16.1. Coal combustion produces also trace elements such as metals, including nickel, mercury, arsenic, chromium and cadmium (CATF, 2001).

Coal-fired power plants use large quantities of water for producing steam and for cooling. Pollutants build up in the water used in the power plant boiler, cooling system, ash handling plants and flue gas desulphurization (FGD) plants (EC, 1995a; US-EPA, 2012). If the water used in the power plant is discharged to a lake or river, pollutants in the water can harm fish and plants. Further, if rain falls on coal stored in piles outside the power plant, the water that runs off these piles can flush heavy metals from the coal, such as arsenic and lead, into nearby bodies of water.

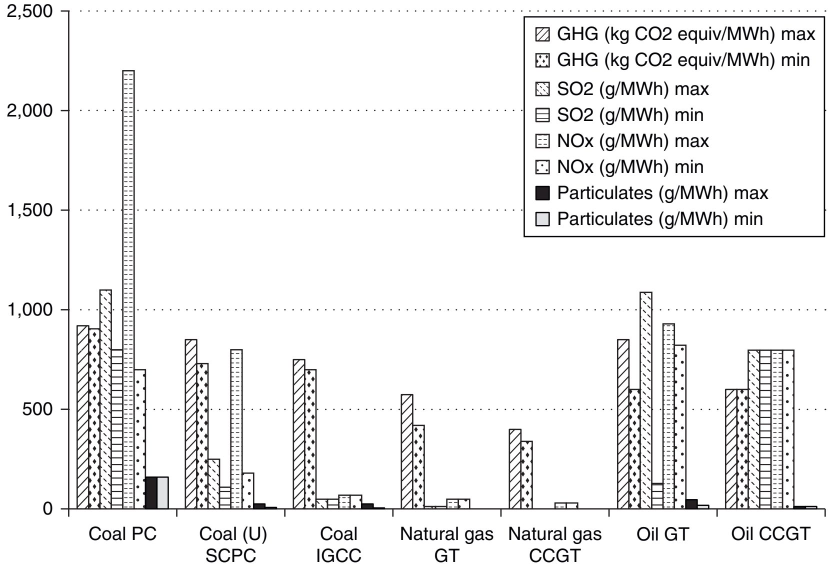
The burning of coal creates solid waste, called ash, which is composed primarily of metal oxides and alkali. On average, the ash content of coal is around 10 per cent (6–20 per cent). Solid waste is also created when air pollutants are removed from the stack gas. Much of this waste is deposited in landfills and abandoned mines, although some amounts are now being recycled into useful products, such as cement and building materials.

Finally, soil at coal-fired power plant sites can become contaminated with various pollutants from the coal and take a long time to recover, even after the power plant closes down.

2.2 Natural Gas

Natural gas is an extremely important source of energy that offers a number of environmental benefits over other sources of energy, particularly other fossil fuels. Natural gas is important in many sectors of the economy: for electricity generation, as an industrial heat source and chemical feedstock as well as for water and space heating in residential and commercial sectors. Moreover, natural gas is increasingly being used in the transportation sector.

Power plants use several methods to convert gas into electricity. The most common approach is to burn the gas in a combustion turbine to generate electricity in the so called open-cycle gas turbine (OCGT) plants, which offer a moderate electrical efficiency of between 35 per cent and 42 per cent at full load (IEA-ETSAP, 2010b). Another technology is to burn natural gas in a combustion turbine and use the hot combustion turbine exhaust to make steam to drive a steam turbine. This technology is called "combined cycle" (CCGT) and achieves a higher efficiency. This technology has been largely expanding in the last two decades (Bauer et al, 2008)



Sources: EC, 1995a; IEA-ETSAP, 2010; EC, 1995b; US-EPA, 2011a; EC, 1995b; US-EPA, 2011a; IEA-ETSAP, 2010b.

Figure 16.1 Airborne pollutant emissions from fossil fuel fired power plants

and its net electrical efficiency ranges from 50–58 per cent (Bauer et al, 2008).

There is a wide variety of environmental impacts generated by the use of natural as a source of energy.

Composed primarily of methane, the main products of the combustion of natural gas are carbon dioxide and water vapour, very small amounts of sulphur dioxide and nitrogen oxides, virtually no ash or particulate matter, and low levels of carbon monoxide as well as other reactive hydrocarbons as shown in Figure 16.1.

Compared to the average air emissions from conventional coal-fired generation, natural gas produces half as much carbon dioxide, lower quantities of nitrogen oxides and almost no sulphur oxides at the power plant.

The burning of natural gas in combustion turbines requires very little water. However, natural gas-fired boiler and combined cycle systems do require water for cooling purposes. Pollutants and heat build up in the water used in natural gas boilers and combined cycle systems. When these pollutants and heat reach certain levels, the water is often discharged into lakes or rivers affecting water bodies' ecosystems.

The use of natural gas to create electricity does not produce substantial amounts of solid waste (EC, 1995b).

Other burdens from the operation of natural gas power plants include noise and visual intrusion (EC, 1995b). The construction of natural gas power plants, as any large facility, can destroy natural habitat for animals and plants. Possible land resource impacts include erosion, loss of soil productivity, and landslides.

2.3 Crude Oil

Crude oil is a vital source of energy for the world and will likely remain so for many decades to come (IEA, 2011). The vast majority of petroleum consumed in the world is used for transportation. The remainder is used to create the many oil-based products used in industry and our houses such as lubricants and plastics, to generate electricity and to heat our homes.

The previous chapter analysed the environmental implications of extracting crude oil, and the environmental consequences of the use of oil products are analysed in a subsequent chapter. This chapter will focus on the stages of the oil fuel cycle after oil extraction and up to the production of fuels and electricity.

2.3.1 Petroleum refining

The petroleum refining industry converts crude oil into refined products, including liquefied petroleum gas, gasoline, kerosene, aviation fuel, diesel fuel, fuel oils, lubricating oils, and feedstocks for the petrochemical industry employing a wide variety of processes.

Potential environmental impacts associated with petroleum refining include the following (IFC, 2007):

- Air emissions
- Waste water
- Hazardous materials
- Wastes
- Noise.

Air emissions can be exhaust gases – carbon dioxide (CO2), nitrogen oxides (NOx) and carbon monoxide (CO) – from combustion of gas, fuel oil or diesel in turbines, boilers, compressors and other equipment for power and heat generation, venting and flaring emissions and fugitive emissions (hydrogen (H2), methane (CH4), volatile organic compounds(VOCs), polycyclic aromatic hydrocarbons (PAHs) and inorganic gases such as associated with leaks of hydrocarbon vapours from process equipment and evaporation of hydrocarbons from open areas (US-EPA, 2011b; IFC, 2007). Sulphur oxides (SOx) and hydrogen sulphide may also be emitted from boilers, heaters and other process equipment. Particulate emissions from refineries are associated with flue gas furnaces and catalyst based processes, handling of coke and incineration of sludge. Carbon dioxide is produced in significant amounts during petroleum refining from combustion processes, flares, hydrogen plants and catalyst regeneration (IFC, 2007).

Waste water from refineries includes "sour" water and alkaline waste water (IFC, 2007). Waste water is treated in treatment units before disposal. Oil refinery effluents contain many different chemicals at different concentrations including ammonia, sulphides, phenol and hydrocarbons. These effluents often have a toxic effect on the fauna, which is usually restricted to the area close to the outfall (Wake, 2005).

Petroleum refining facilities also use significant amounts of hazardous materials. Solid hazardous wastes from a refinery are spent catalysts, solvents, filters, used sweetening, spent aminas, activated carbon filters, sludge of several types, exhausted molecular sieves and exhausted alumina.

The main causes of noise in a refinery are the large rotation machines (compressors and turbines), pumps, air coolers and heaters.

2.3.2 Production of electricity from oil

Similarly to natural gas, oil is usually burnt in open cycle or combined cycle gas turbines to produce electricity with similar technological characteristics. Burning oil at power plants produces nitrogen oxides, sulphur dioxide, carbon dioxide, methane, and mercury compounds. The amount of sulphur dioxide and mercury compounds can vary greatly depending on the sulphur and mercury content of the oil that is burned. The average emissions are shown in Figure 16.1.

Oil-fired power plants use large quantities of water for steam production and cooling. When oil-fired power plants get the water from a lake or river, fish and other aquatic life can be killed, which affects those animals and people who depend on these aquatic resources. Moreover, power plants also release wastewater – which contains pollutants and is generally hotter than the water in nearby lakes and streams – that can harm fish and plants.

Also, when oil is burned at power plants, residues that are not completely burned can accumulate, forming another source of solid waste which, if not properly disposed, can cause land contamination.

2.4 Nuclear Energy

Nuclear power is the use of sustained nuclear fission to generate heat and electricity. Nowadays, nuclear power plants provide around 13 per cent of the world's electricity (IEA, 2011).

Most of the world's reactors are light water reactors (LWR) that use the so called "once-through" open fuel cycle in which the spent nuclear fuel (SNF) from the LWR is sent to interim storage and eventually to waste disposal. Other options are a partly closed fuel cycle that is currently used in countries such as France, Germany and Japan in which the SNF is sent to a reprocessing facility where plutonium is recycled back to LWRs as mixed oxide (MOX) fresh fuel. Finally, there is a specific fast reactor fuel cycle in which the plutonium in SNF is separated and reused to produce fast reactor (FR) fuel. This strategy has been demonstrated but not yet commercially deployed. (MIT, 2011).

The nuclear fuel cycle entails all the stages from the mining and milling of uranium through the manufacture of the fuel, electricity generation in the reactor, transport and reprocessing of the spent fuel and the management of the associated waste in all these steps. The environmental consequences of all these stages are briefly discussed below.

Uranium is mined in either open-pit or underground mines. Then, the ore is processed at mills and the uranium is separated from the rock to get uranium oxide (yellow cake).

Environmental impacts associated with uranium mining are related to impacts on land and water due to waste water arising from mine drainage and from water use in drilling. Also occupational health impacts due to radon exposure are produced in this stage (EC, 1995c).

In the milling process, a high percentage of the radioactivity contained in the ore remains in the mill tailings (fine sands released by the milling plant which contain insoluble radium). Their associated environmental releases are the movement of the contaminated leachate to rivers or groundwater as well as the atmospheric dispersion of fine particles by wind.

From the mill, the yellow cake is converted into uranium hexafluoride (UF6). To fabricate nuclear fuel, the UF6 must be further enriched in the fissile isotope U-235. Enriched UF6 is then transformed into uranium dioxide (UO2) powder and pressed into pellets that are inserted into thin zircaloy or stainless steel tubes which are then sealed and assembled to form fuel assemblies.

The main potential hazard in the conversion stage arises from the toxicity of hydrogen fluorine and fluoride used in the production of UF6. Gaseous and liquid releases of F- can be produced. Atmospheric and liquid releases of uranium isotopes are also produced in this stage (EC, 1995c).

The enrichment process uses a large amount of energy and atmospheric and liquid releases of uranium are produced. As the level of enrichment increases, the risk of criticality accidents also increases although this risk is considered to be very small (El-Hinnawi, 1978). The depleted uranium residue is stockpiled for possible future use. This material gradually produces nuclides such as 226Ra and 222Rn that can generate radiation hazard.

Fabrication of fuel elements is a non-hazardous process although some atmospheric and liquid releases of uranium isotopes and chemicals are produced. Manufacture of mixed oxide fuel is far more hazardous due to the higher toxicity of plutonium and its lower critical mass.

During normal operation of a nuclear reactor, radioactive fission and activation products are originated. Fuel elements retain most of the radioactive materials, but some are produced within or are diffused into the coolant which can later be removed by waste processing systems.

Nuclear power plants use large quantities of water for steam production and for cooling. As previously, some nuclear power plants obtain large quantities of water from a lake or river, and discharge waste heat to the cooling water which could affect fish and other aquatic life.

The solid waste from nuclear plants is mainly composed of spent fuel which is classified as high level waste and stored on site for some time and eventually taken to intermediate storage or reprocessing plants.

At the reprocessing plant the fuel is chemically dissolved and the residual fuel material – uranium and plutonium – can be recovered. Gaseous effluents from a reprocessing plant include gaseous fission products and also tritium, ^{14}C and some Pu isotopes. Liquid effluents from a reprocessing plant are mainly composed of tritium, ^{14}C and other minor radio nuclides. Intermediate and low level solid wastes produced by reprocessing plants are mainly structural elements of the fuel elements and can be contaminated with spent fuel.

High-level wastes from reprocessing plants comprise highly-radioactive fission products and some transuranic elements with long-lived radioactivity. They are later vitrified into borosilicate (Pyrex) glass, encapsulated into heavy stainless steel cylinders and stored for eventual disposal deep underground.

Long-term managed storage of the spent fuel preserves future options for its utilization at little relative cost (MIT, 2011). Managed storage can be done safely at operating reactor sites, centralized storage facilities, or geological repositories.

Public concern about reactor operation focuses on the possibility of accident occurrence leading to the release of a considerable amount of radioactivity to the surrounding environment. Various types of accidents are possible during the operation of a nuclear reactor and many safety devices are incorporated in the reactor design. In addition most power reactors are placed inside a containment building.

There have been three significant accidents in the 50-year history of civil nuclear power generation (WNA, 2012):

- Three Mile Island (USA 1979) where the reactor was severely damaged but radiation was contained and there were no adverse health or environmental consequences.
- Chernobyl (Ukraine 1986) where the destruction of the reactor by steam explosion and fire killed 31 people and had significant health and environmental consequences.
- Fukushima (Japan 2011) where three old reactors (together with a fourth) were damaged and the effects of loss of cooling due to a huge tsunami were inadequately contained. The fuel was badly damaged and there were significant off-site radiation releases.

The safety provisions in a nuclear plant include a series of physical barriers between the radioactive reactor core and the environment as well as the provision of multiple safety systems. These safety systems are "active" in the sense that they involve electrical or mechanical operation on command, but in some recent designs the passive or inherent features substitute for active systems. Such a design would have averted the Fukushima accident, where loss of electrical power resulted in a loss of the cooling function.

Another important aspect of the nuclear industry is the transport of radioactive materials. Spent fuel elements are transported in shielded cooled casks to prevent radiation exposure to transport workers. Accidents producing rupture of casks could have severe impacts on the environment. High level wastes are also transported to storage places in containers. Management, packaging, transport, and disposal of waste are strictly regulated and carefully controlled.

Plutonium-239, the isotope used in atom bombs, is produced in relatively high quantities in the nuclear fuel cycle. Environmental hazard of plutonium is related to the risk of the occurrence of a chain reaction if sufficient plutonium came together, with the subsequent emission and dispersion of plutonium to the environment.

2.5 Renewable Energies

2.5.1 Solar

Solar energy is the most abundant of all energy resources and there is a large family of different solar energy conversion technologies capable of meeting a variety of energy service demands.

Conversion of solar energy to heat (i.e., thermal conversion) is done by specialized techniques and devices such as optical coatings and mirrors. Generation of electricity can be achieved in two ways. Solar energy can be converted directly into electricity in a device called a photovoltaic (PV) cell. Solar thermal energy can also be used in a concentrating solar power (CSP) plant to produce high-temperature heat which is then converted to electricity via a heat engine and generator. Both approaches are currently in use. Furthermore, solar driven systems can deliver process heat and cooling, and other solar technologies are being developed that will deliver energy carriers such as hydrogen or hydrocarbon fuels – known as solar fuels. Large CSP plants may also prove effective for cogeneration to support water desalination (Arvizu et al, 2011; IEA-ETSAP, 2011).

Emissions associated with generating electricity from solar PV technologies are negligible because no fuels are combusted. PV systems do not generate any type of solid, liquid or gaseous byproducts when producing electricity. Also, they do not emit noise or use non-renewable resources during operation. However, two issues are of concern: the emission of pollutants and the use of energy during the full lifecycle of PV manufacturing, installation, operation and maintenance (O&M) and disposal; and the possibility of recycling the PV module materials when the systems are decommissioned.

Energy is required to manufacture and install solar PV components, and any fossil fuels used for this purpose will generate emissions. Most lifecycle GHG emission estimates range from about 30 to 80 g CO2eq/kWh (Arvizu et al, 2011).

Some PV cells make use of scarce and rare materials like indium and tellurium. Large use of these cells would lead to resource depletion (IEA, 1998). Moreover, in its production lines, PV industry uses some toxic, explosive gases, GHGs, as well as corrosive liquids.

Photovoltaic systems do not require the use of any water to create electricity. However, in certain locations, periodic cleaning of the PV panels is required to maintain performance, resulting in non-negligible water requirements.

Construction and operation of PV systems can cause land use impacts on natural ecosystems. Main impacts are produced during construction activities and can be mitigated by minimizing earth movements and helping to reestablish the previous biodiversity (IEA, 1998).

Visual impacts of PV installations depend on the type of scheme. Centralized large schemes would have significant visual impacts while small scale roof mounted schemes would have much lower visual impact.

Decommissioning of PV systems may also cause some environmental impacts especially in the case of CdTe modules due to the high toxicity of cadmium. Recycling the material in PV modules is already economically viable, mainly for concentrated and large-scale applications (McDonald and Pearce, 2010; Arvizu et al, 2011).

For CSP plants, the environmental consequences vary depending on the technology. Life cycle GHG emissions estimates fall between 14 and 32 g CO2eq/kWh (Arvizu et al, 2011). Main life cycle impacts are associated with the construction of the steel-intensive infrastructure for solar energy collection due to mineral and fossil resource consumption, as well as discharge of pollutants related to today's steel production technology (Lechón et al, 2009). However, most CSP solar field materials can be recycled and reused in new plants (SolarPACES, 2008).

The deployment of CSP can also cause some unintended environmental impacts. The main impacts are impacts on amenity and relate to the large area required for the technology. The main impacts identified are the following:

- Visual impacts: these impacts can be significant due to the large area occupied by the mirrors. Visual effects are most noticeable in tower CSP plants where very bright points appear in the rural landscape. An advantage is that CSP plants are often located in areas with limited amenity or aesthetic value (EASAC, 2011).
- Noise: noise will be generated from the steam generating plant (IEA, 1998).
- Ecological impacts due land use: CSP plants have large land use requirements. To date, most sites are in arid or semiarid areas which have fragile soil and plant communities. Consequently, there could be an important risk of soil erosion and habitat loss due to CSP plants installations that could be significant in ecologically important areas (IEA, 1998). Mortalities caused to vertebrates are the main concern in respect of the local environmental impact of CSP. Direct mortalities take place by collision with top mirrors and buildings (the tower in particular), and heat shock or burning damage in the concentrated light beams plants (EASAC, 2011). Massive establishment of solar plants in an area may affect regional animal

or plant populations by cutting dispersion routes and partially isolating populations from each other (EASAC, 2011).

- If a plant is built on former agricultural land, available nutrients in the soil may facilitate growth of vegetation up to 1 m in height below and between solar collectors. The vegetation can dry up and contribute to fire risk (EASAC, 2011).
- Water resources impacts: CSP plants using conventional steam plants to generate electricity have a requirement for cooling water. This could pose a strain in water resources in arid areas (IEA, 1998). Because solar abundance and fresh water constraints often coincide geographically, the cumulative impacts of installing numerous CSP plants in a region raises policy concerns. Consequently, the trend is towards more fresh water efficient cooling technologies (Carter and Campbell, 2009). Water is also used for cleaning the mirrors to maintain their high reflectivity, although water use for cleaning is typically a factor of a hundred lower than that used for water cooling. For areas with high irradiation and available land close to the sea, using salt water for cooling could be an attractive option (EASAC, 2011).

Most of these impacts are local and are therefore highly affected by the siting of the technology. Consequently some of them can be minimized by a sensitive siting choice.

2.5.2 Geothermal

Geothermal resources consist of thermal energy from the Earth's interior stored in both rock and trapped steam or liquid water. Accessible geothermal energy from the Earth's interior can supply heat for direct use, can be used in combined heat and power applications as well as to generate electric energy.

Geothermal resources include basically low-enthalpy fields, which have long been used for direct heating applications and high quality high-enthalpy, which are used for power generation. In general, high-enthalpy geothermal fields are only available in areas with volcanic activity, whereas the rest of the fields are low- or medium-enthalpy resources (IEA-ETSAP, 2010c).

Currently, the basic types of geothermal power plants in use are steam condensing turbines and binary cycle units. Steam condensing turbines can be used in steam plants operating at sites with intermediate- and high-temperature resources (≥150°C). Binary-cycle plants are commonly installed to extract heat from low- and intermediate-temperature geothermal fluids (generally from 70 to 170°C), from hydrothermal- and EGS-type reservoirs.

Newer geothermal plants in New Zealand and Hawaii are combined-cycle or hybrid plants that provide relatively high electric efficiency (IEA-ETSAP, 2010c).

Emissions associated with generating electricity from geothermal technologies are negligible because no fuels are combusted. However, geothermal fluids contain minerals leached from the reservoir rock and variable quantities of gas, mainly CO2 and a smaller amount of hydrogen sulphide (Goldstein et al, 2011).

CO2 emissions from geothermal power plants range from 4 to 740 g CO2/kWh with an average of 122 g CO2/kWh (Goldstein et al, 2011). According to the published LCA studies of geothermal electricity, life cycle GHG emissions, including the emission from constructing, operating and decommissioning the power plants, are lower than 80 gCO2equiv/kWh (Goldstein et al, 2011), value that compares very favorably to GHG emissions from fossil sources.

Apart from CO2, geothermal fluids can, depending on the site, contain a variety of other minor gases, such as hydrogen sulphide (H2S), hydrogen (H2), methane (CH4), ammonia (NH3) and nitrogen (N2). Mercury, arsenic, radon and boron may also be present. H2S is toxic, but rarely found in sufficient concentration to be harmful. CH4 is also present in small concentrations.

Geothermal energy applications can have also some detrimental environmental impacts. Concerns are related to impacts on water use and quality. Geothermal power plants usually re-inject the hot water that they remove from the ground back into wells. However, a small amount of water used by geothermal plants in the process of creating electricity may evaporate and therefore not be returned to the ground. Also, for those geothermal plants that rely on hot, dry rocks for energy, water from local resources is needed to extract the energy from the dry rocks (US-EPA, 2012).

Geothermal power plants can possibly cause groundwater contamination when drilling wells and extracting hot water or steam. However, this type of contamination can be prevented with proper management techniques. In addition, geothermal power plants often re-inject used water back into the ground (through separate wells) instead of discharging the used water into surface waters. This prevents underground minerals or pollutants (boron and arsenic) from being introduced into surface waters (US-EPA, 2012).

Scrubbers reduce air emissions but produce a watery sludge high in sulphur and vanadium, a heavy metal that can be toxic in high concentrations. Additional sludge is generated when hydrothermal steam is condensed, causing the dissolved solids to precipitate out. This sludge is generally high in silica compounds, chlorides, arsenic, mercury, nickel, and other toxic heavy metals). Usually the best disposal method is to inject liquid wastes or redissolved solids back into a porous stratum of a geothermal well.

Moreover, drilling activities, production and reinjection of fluids can produce pressure and temperature changes in the fields that can lead to geo-mechanical stress that can in turn cause micro earthquakes, subsidence and steam eruptions.

Despite geothermal power plants typically requiring less land use than fossil fuel power plants, this is still an issue since new projects or power plants are often located within or adjacent to national parks or tourist areas.

2.5.3 Bioenergy

Bioenergy includes different sets of technologies for applications in various sectors. In 2009, biomass provided about 10 per cent of the annual global primary energy supply (IEA, 2011) from low efficiency traditional biomass use to high-efficiency modern bioenergy uses.

There is a wide variety of commercial bioenergy routes that starting with feedstocks – such as forest or energy crops or industrial, commercial or municipal waste streams and by-products – deliver electricity or heat, biogas and liquid biofuels. Some of these routes are already commercial and other are still in development stage (Chum et al, 2011; IEA Bioenergy, 2009).

As far as power generation is concerned, there are different technological possibilities: biomass can be used in medium-size power plants by way of mono-combustion as well as by way of co-combustion together with fossil fuels such as hard coal in large power plants. Another option is the gasification of biomass with subsequent combustion technologies with gas and steam turbines (IGCC) which allows efficient power and heat production (Gärtner, 2008).

Sustainably managed bioenergy can provide a number of beneficial effects (IEA Bioenergy, 2009; Royal Society, 2008) depending on the former use of the land where bioenergy is implanted, such as:

- enhanced biodiversity;
- soil carbon increases and improved soil productivity;
- reduced shallow landslides and local flash floods;
- reduced wind and water erosion;
- reduced sediment volume and nutrients transported into rivers; and
- improvements in growth and productivity and reduction of wildfire risk in forests.

Some options for a sustainable bioenergy production have been identified (Bringezu et al, 2009; Tilman et al, 2009; Ravindranath et al, 2009) and include:

- increasing yields and optimizing agricultural production (including double crops and mixed cropping systems);
- restoring formerly degraded land;
- use perennial crops;
- use sustainably harvested wood and forest residues;
- use of waste and production residues;
- cascading use of biomass.

The main environmental advantage of bioenergy is the fact that it is a part of the terrestrial carbon cycle. The CO2 emitted due to bioenergy use was earlier sequestered from the atmosphere and will be sequestered again if the bioenergy system is managed sustainably. Thus, in a sustainable fuel cycle, there would be no net emissions of carbon dioxide, although some fossil-fuel inputs may be required for planting, harvesting, transporting, and processing biomass.

If biomass wastes such as crop residues or municipal solid wastes are used for energy, there should be few or no net greenhouse gas emissions. However, under some circumstances, GHG emissions from bioenergy can be very large. Drainage of peatlands or replacing tropical forests for growing energy crops can lead to big amounts of GHG emissions (Royal Society, 2008; Fargione et al, 2008; Page et al, 2011).

Diversion of crops or land into bioenergy can produce direct or indirect land use change (LUC or ILUC) mobilizing C stocks and emitting additional amounts of CO2 that can in some cases offset the expected GHG emissions savings (De Cara et al, 2012; Laborde, 2011; EEA, 2011; Tilman et al, 2009; Melillo et al, 2009; Fargione et al, 2008).

Agricultural practices and specially the production and application use of fertilizers, give rise to important life cycle GHG and other pollutant emissions. N2O emissions arising after application of N fertilizers and from the N present in crops residues are of special importance. These emissions vary considerably with environmental and management conditions, including soil water content, temperature, texture, carbon availability, and therefore are difficult to assess.

A global greenhouse gas emissions policy that protects forests and encourages best practices for nitrogen fertilizer use can dramatically reduce direct and indirect GHG emissions associated with biofuels production (Melillo et al, 2009).

Like conventional agriculture and forestry systems, bioenergy can exacerbate soil and vegetation degradation associated with overexploitation of forests, too intensive crop and forest residue removal as well as water overuse. Water requirements of energy derived from biomass are about 70 to 400 times more than other energy carriers such as fossil fuels, wind and solar (Gerbens-Leenes at al, 2009). Therefore, large scale expansion of energy crop production could lead to a large increase in water use and in some countries exacerbating an already existing stressed water situation. Possible consequences of water overuse could be lowered groundwater levels, river depletion, and reduced downstream water availability (IEA Bioenergy, 2009). Several options to reduce these impacts exist including using less water demanding crops, increase water use efficiency and manage water for multifunctionality (De Fraiture and Berndes. 2009). Bioenergy based on wastes and by-products of the food and forestry sector would also avoid these problems.

Feedstock cultivation can lead to leaching and emission of nutrients that increase eutrophication of aquatic ecosystems (Simpson, et al, 2009; Royal Society, 2008) and pesticide emissions to water bodies may also negatively impact aquatic life (Sala et al, 2009).

Increased biomass output for bioenergy can directly impact wild biodiversity through conversion of natural ecosystems into bioenergy plantations or through changed forest management (IEA Bioenergy, 2009; Royal Society, 2008). Habitat and biodiversity loss may also occur indirectly. Eikhout et al (2008) showed that, in most cases, the long-term positive effect of greenhouse gas reductions from biofuel production on biodiversity are not enough to compensate for biodiversity losses from land use change, at least not within a time frame of several decades. However, when crops are grown on degraded or abandoned land, such as previously deforested areas or degraded crop- and grasslands, the production of feedstocks for bioenergy could have positive impacts on biodiversity (Tilman et al, 2009).

Biodiversity impacts from the use of genetically modified energy crops could also arise (IEA Bioenergy, 2009; Firbank, 2008).

Several processes exist to convert feedstocks and raw materials into biofuels for use in transport. First-generation biofuels are produced through processes such as cold pressing/extraction, transesterification, hydrolysis and fermentation, and chemical synthesis, derived from sources such as starch, sugar, animal fats, and vegetable oil. Second-generation biofuels are produced through more advanced processes, including hydro treatment, advanced hydrolysis and fermentation as well as gasification and synthesis from ligno-cellulosic sources. Environmental burdens associated with these processes are related to the use of energy and chemicals.

Combustion of biomass and biomass-derived fuels to generate electricity and heat produces air pollution including carbon monoxide, nitrogen oxides, and particulates such as soot and ash. The amount of pollution emitted per unit of energy generated varies widely by technology. Compared to coal and oil stationary applications, sulphur dioxide (SO2), toxic metals (cadmium, mercury and others) and nitrous oxide (NOx) emissions from bioenergy applications are mostly lower. Pollutant formation may occur due to incomplete combustion that can lead to high emissions of unburnt pollutants such as CO, soot, and PAH. Although improvements to reduce these emissions have been achieved by optimized furnace design, there is still a relevant potential of further optimization. Pollutants such as NOX and particles are formed as a result of fuel constituents. Air staging or fuel staging technologies can reduce NOx emissions by 50–80 per cent. As for other combustion technologies, if combined with secondary abatement measures such as selective catalytic reduction, reductions of up to 95 per cent can be achieved (Nussbaumer, 2003). The most serious problem is their particulate emissions, which must be controlled with special devices in place.

Raw municipal waste often contains toxic metals, chlorinated compounds, and plastics, which generate harmful emissions.

Carbon capture and storage (CCS) from fossil-fuelled power plant flue gases is being considered as a measure to reduce greenhouse gas emissions. In this context, CCS can also be applied to co-firing plants, which would enable the capture of carbon from biomass (biotic CCS), resulting in a net negative carbon emission or carbon sink associated with biomass combustion (IEA Bioenergy, 2009).

Biomass power plants require the use of water, because the boilers burning the biomass need water for steam production and for cooling. Whenever any type of power plant removes water from a lake or river, fish and other aquatic life can be killed, which then affects those animals and people that depend on these aquatic resources.

As is the case with fossil fuel power plants, biomass power plants have pollutant build-up in the water used in the boiler and cooling system. Pollutants in the water and the higher temperature of the water can harm fish and plants in the lake or river where the power plant water is discharged.

Biomass burning in boilers creates a solid waste called ash, which despite having extremely low levels of hazardous elements, must be properly disposed.

2.5.4 Wind

The use of wind energy requires that the kinetic energy of moving air be converted to mechanical and then electrical energy using wind turbines.

On shore wind turbines have been increasingly installed around the world providing nowadays 1 per cent of the world electricity (IEA, 2011). Offshore wind energy technology is less mature than onshore being the primary motivation to its development to provide access to additional and high quality wind resources.

Emissions associated with generating electricity from wind technology are negligible because no fuels are combusted. However, emissions are produced in other parts of the life cycle both upstream and downstream. The most significant are those associated with the processing and manufacturing of materials and components of the wind turbine (IEA, 1998; EWEA, 2009).The majority of lifecycle GHG emission estimates cluster between about 8 and 20 g CO2eq/kWh (Wiser et al, 2011).

Wind power plants generally require the use of large areas of land, using space that might otherwise be used for other purposes. Special concern has been raised recently about wind farm installations in peat land (Nayak et al, 2010). Drainage of peat land produce the mobilization of the C stored in the soil and also other impacts such as erosion and mass movements.

Provided wind turbines are carefully located, away from scenic, tourism or highly populated areas, they tend to have low and localized impacts on the environment. However, sensitivity to some of these impacts may cause public opposition and make a project unacceptable (IEA, 1998).

Large wind farms pose aesthetic concerns. The dominant visual effect is the intrusion of the turbines and associated equipment. Wind turbines are highly visible structures often deployed in arrays of many machines on ridges or hilltops. Moreover, wind turbines and power plants have grown in size, making the turbines and related transmission infrastructure more visible (Wiser at al, 2011). Opposition to wind energy on the grounds of loss of visual amenity is one of the biggest problems in the wind industry (EC, 1995d) and concerns have risen for both on- and offshore wind energy (Ladenburg, 2009; Haggett, 2011).

Wind turbines that are improperly installed or landscaped may create soil erosion problems (US-EPA, 2012; NWCC, 1997). These problems can arise in deserts when the soil surface is disrupted during wind tower construction or in hilly environments when towers are located on ridgelines where soil-holding vegetation is removed. Access roads to wind turbine farms disrupt tracts of land and support equipment litters the surroundings.

Wind farms can also have noise impacts mostly due to the operating turbines (EC, 1995d). Possible impacts can be both audible and subaudible. Sub-audible sound may cause health effects but little evidence of this effect has yet been found (Wiser at al, 2011). Regarding audible noise from turbines, it can be mechanical noise (produced by the gear boxes and generators) and aerodynamic noise created by the rotation of the blades. This audible noise can impact sleep patterns and well-being (Wiser at al, 2011). New blade designs are being used to reduce the amount of noise.

Bird and bat mortality has been an issue at some wind farms. The types of risks that may affect birds are mainly collision with turbines, habitat disturbance and habitat loss as well as interference in birds' movements between feeding, wintering, breeding and moulting habitats (EWEA, 2009). As offshore wind energy has increased, concerns have also been raised about seabirds (Wiser at al, 2011). The impact of wind power plants on bat populations is of particular concern, because bats are long-lived and have low reproduction rates (Wiser at al, 2011). Nevertheless, the number of bird fatalities at existing wind power plants appears to be orders of magnitude lower than other anthropogenic causes of bird deaths (Erickson et al, 2005).

Wind power plants can also cause habitat and ecosystem modification impacts on flora and fauna including avoidance of or displacement from an area, habitat destruction and reduced reproduction (EWEA, 2009).

The impacts of wind power plants on marine environment are also an issue for offshore wind farms. Constriction and operation of offshore wind farms can affect marine mammals mainly due to stress and increased diseases vulnerability caused by noise (EWEA, 2009). Offshore wind turbines foundations can also affect benthos-organisms living in the sediments at the sea bottom- through changes in the substrate and subsequent changes in the species composition of the benthos and the existing biodiversity in the area (EWEA, 2009; Köller et al 2006).

Impacts of wind energy on water are not very significant. In areas with little rainfall, wind farms may require the use of a small amount of water. If rainfall is not sufficient to keep the turbine blades clean, water is used to clean dirt and insects off the blades so that turbine performance is not reduced. Wind turbines do not discharge any water while producing electricity.

Finally, the use of scarce raw materials may also be an issue if we consider the use of neodynium in high performance magnets used in wind turbines generators (Köller et al, 2011).

2.5.5 Hydro

Hydropower is generated from water moving in the hydrological cycle from higher to lower elevations. Hydropower plants are often classified in three main categories according to operation and type of flow: Run-of-river (RoR), storage (reservoir) and pumped storage HPPs. A RoR HPP draws the energy for electricity production mainly from the available flow of the river. In hydropower projects with a reservoir, the generating stations are located at the dam or further downstream connected to the reservoir through tunnels or pipelines. In pumped storage plants water is pumped from a lower reservoir into an upper reservoir during off-peak hours and the flow is reversed to generate electricity during the daily peak load period.

Dams are constructed for several purposes and have several benefits for society. While the main one is water supply for domestic or industrial uses, other key purposes and benefits include: irrigation for agriculture, flood control, inland navigation and recreation (ICOLD, 1999).

Most of the impacts of the hydro fuel cycle are direct burdens on aquatic and terrestrial ecosystems.

IEA (1998) has identified several sensitive issues that need to be carefully assessed and managed to achieve sustainable hydropower projects. Some of these aspects are:

- Hydrological regimes: a hydropower project may modify a river's flow regime if the project includes a reservoir which significantly affects natural aquatic and terrestrial habitats in the river and along the shore.
- Reservoir: the creation of a reservoir transforms a terrestrial ecosystem into an aquatic one and a fast-flowing water course into an artificial lake generating some impacts such as erosion in the reservoir shorelines, changes in fish habitats and species compositions, etc.
- Water quality in the reservoirs: in the deeper anaerobic layers of large reservoirs many biochemical reactions may take place leading to a change in the nutrient balance of the reservoir and eutrophization.
- Increased sedimentation due to reduction in the sediment carrying capacity of the water body.
- Biological diversity effects due to the permanent loss of habitats, fluctuating water levels, downstream floods, introduction of exotic species and obstacles to fish migration.
- Public health impacts trough increases in waterborne diseases.

Life cycle greenhouse gas emissions of hydropower plants are very variable depending on the technology and on the special characteristics of the location of the power plant. The main emissions of atmospheric pollutants associated with hydro schemes arise from the manufacturing and construction of the generation and transmission equipment including the dam (IEA, 1998). The majority of lifecycle GHG emission estimates for hydropower cluster between about 4 and 14 g CO2eq/kWh, but under certain scenarios there is the potential for much larger quantities (more than 160 g/kWh) of GHG emissions (Kumar et al, 2011).

Hydropower creates no direct atmospheric pollutants or waste during operation, and GHG emissions associated with most lifecycle stages are minor (EC, 1995d). However, under certain conditions, CO2 and methane (CH4) emissions from reservoirs from the degradation of flooded vegetation might be substantial. Research suggests that emission levels in cold and temperate climates are generally low, and that elevated emissions may be observed in some tropical systems with persistent anoxia (UNESCO/IHA,2009). Decommissioning of the power plant can cause also important GHG emissions from the silt collected over the life of the plant.

There is evidence that the presence of massive bodies of water has influenced the geological stability in the local region around dams increasing the occurrence of earthquakes (IEA, 1998). The presence of large water bodies will affect the local climate, with higher humidity and fog formation in temperate climates.

Lastly, large dams can also have visual intrusion impacts (IEA, 1998) which are site specific.

2.5.6 Ocean energy

The ocean energy resource comes from six distinct sources:

- Waves
- Tidal
- Tidal currents
- Ocean currents
- Ocean Thermal Energy Conversion (OTEC)
- Salinity gradients (osmotic power).

Due to the scarce deployment and operation of ocean energy technologies there is little information regarding their anticipated environmental impacts.

Ocean energy does not directly emit CO2 during operation. Life cycle emissions of GHG gases and other pollutants arise in the stages of construction, maintenance and decommissioning of the installation, including the emissions produced in the processes of manufacturing all the necessary components and in the extraction of all required raw materials. Lifecycle GHG emissions quantifications from wave and tidal energy systems are scarce but from the available studies (Sorensen and Naef, 2008; Lewis et al, 2011) they seem to be less than 23 g CO2eq/kWh, with a median estimate of 8 g CO2eq/kWh for wave energy.

A description of potential local environmental effects is given by Boehlert and Gill (2010) and Lewis et al (2011). Negative effects may include:

- reduction in visual amenity;
- loss of access to space for competing users;
- noise during construction;
- noise and vibration;
- electromagnetic fields;
- disruption to biota and habitats;
- water quality changes and possible pollution;
- water salinity and sediment movements in estuaries;
- moving parts may harm marine life;
- changes in the regional properties (temperature and nutrient characteristics) of seawater.

3 METHODS TO QUANTIFY ENVIRONMENTAL IMPACTS

3.1 Life Cycle Assessment

Life Cycle Assessment is a method for systematic analysis of environmental performance from a cradle to grave perspective. This analytic tool systematically describes and assesses all flows that enter into the studied systems from nature and all those flows that go out from the systems to nature, all over the life cycle.

The interest in LCA started in the 1990s and since then a strong development has occurred. The practice of LCA is regulated by the international standard ISO 14040 and 14044 (ISO, 2006a,2006b), and there are several introductions (Guinée et al., 2002; JRC IES, 2010) and databases (Ecoinvent, 2007) available.

LCA is a robust and mature methodology although some aspects are still under development. A thorough review of the recent advances of the methodology can be found in Finnveden et al (2009).

A complete LCA study consists of four steps:

1. Definition of the goal and scope of the study;
2. Life cycle inventory (LCI phase) where the collection of all the environmental inflows and outflows takes place;
3. Life cycle impact assessment (LCIA) phase where the emissions and resource data collected in the former phase are translated into indica-

tors that reflect environmental and health pressures as well as resource scarcity; and
4. Interpretation of the results.

However, it is quite common that some LCAs only perform the inventory analysis delivering a list of emissions or only evaluate some of the impacts (like global warming impacts).

The purpose of LCIA is to provide additional information to help assess the results of the LCI in order to better understand their environmental significance. LCIA translates the inventory into potential impacts on the "areas of protection" that are: human health, natural environment and the man made environment (Udo de Haes et al, 2002). LCIA attempts to model any impact from the product system that can be expected to damage one or more areas of protection. In this sense, LCIA addresses toxic impacts from air pollution and also other impacts associated with emissions (global warming, stratospheric ozone depletion, acidification, photochemical ozone and smog formation) and waterborne effluents (eutrophization) as well as the environmental impacts of land and water use, noise, radiation and depletion of resources (Finnveden et al (2009).

3.2 Externalities Assessment

As explained in the introductory section of this chapter, all power generation technologies have some associated externalities – costs imposed on individuals or the community that are not paid for by the producer or consumer of electricity.

The most relevant project dealing with the determination of the externalities of energy is the European ExternE project (www.externe.info, accessed February 2013) which was launched in 1991 by the European Commission and the US Department of Energy. Since then, the European Commission has continuously supported this research field through several projects. The latest of these projects is the NEEDS Project (New Energy Externalities Development for Sustainability, www.needs-project.org/, accessed February 2013).

The ExternE methodology is widely accepted and considered as the world reference in the field by the scientific community. The quantification of the external costs in based on the "impact pathway" (IPA) methodology which was developed in the series of ExternE projects, and has been further improved in the NEEDS projects and other related projects like the EU CASES project (www.feem-project.net/cases, accessed February 2013). The impact pathway methodology aims at modelling the causal relationships from the emission of a pollutant to the impacts produced on various receptors through the transport and chemical conversion of this pollutant in the atmosphere.

The principal steps of an IPA can be grouped as follows (EC, 2005):

- Emission: specification of the relevant technologies and pollutants, e.g. kg of oxides of nitrogen (NOx) per GWh emitted by a power plant at a specific site).
- Dispersion: calculation of increased pollutant concentrations in all affected regions, e.g. incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone formation due to NOx.
- Impact: calculation of the dose from the increased concentration, followed by calculation of impacts (damage in physical units) from this dose, using a dose response function, e.g. cases of asthma due to this increase in ozone.
- Cost: economic valuation of these impacts, e.g. multiplication by the cost of a case of asthma.

In practice, ExternE uses LCA in combination with IPA (impact pathway analysis) to get a complete assessment of external costs due to energy production, including impacts that occur upstream and downstream of the power plant itself.

Main receptors of the impacts are human health, crops, ecosystems and materials and welfare losses produced by these impacts are assessed using economic valuation methods.

Impacts categories, pollutants and effects considered in the ExternE methodology are summarized in Table 16.1.

Seven major types of damages have been considered in ExternE. The main categories are human health (mortality and morbidity effects), effects on crops and materials as well as global warming.

Global warming impacts assessment is subject to a very high degree of uncertainty. A good review of the literature on the economic impacts of climate change can be found in Tol (2009). Within NEEDS, the model FUND 3.0 was used to estimate the marginal external costs of GHG emissions (Anthoff, 2007). Results greatly differ depending on the assumptions regarding some very influencing parameters like discounting and equity weighting. Two sets of externals costs factors were used in NEEDS trying to reflect these uncertainty (Preiss and Friedrich, 2009).

Table 16.1 Impact categories, pollutants and effects considered in the ExternE methodology

Impact category	Pollutant	Effects
Human health: Mortality	PM_{10}, SO_2, NO_x, O_3	Reduction in life expectancy
	As, Cd, Cr, Ni	Cancer
	Accident risk	Fatality risk from traffic and workplace
Human health: Morbidity	PM_{10}, O_3, SO_2	Respiratory hospital admissions
	PM_{10}, O_3	Restricted activity days
	PM_{10}, CO	Congestive heart failure
	PM_{10}	Cerebro-vascular hospital admissions
		Cases of chronic bronchitis
		Cases of chronic cough in children
		Cough in asthmatics
		Lower respiratory symptoms
	Pb	Neurotoxicidad
	O_3	Asthma attacks
		Symptom days
	Benzene, Benzo-[a]-pyrene 1,3-butadiene	Cancer risk (non-fatal)
	Diesel particles	
	Noise	Myocardial infarction
		Angina pectoris
		Hypertension
		Sleep disturbance
	Accident risk	Risk of injuries from traffic and workplace accidents
Building materials	SO_2	Ageing of galvanized steel, limestone, mortar, sand-stone, paint, rendering, and zinc for utilitarian buildings
	Acid deposition	
	Combustion particles	Soiling of buildings
Crops	NO_x, SO_2	Yield change for wheat, barley, rye, oats, potato, sugar beet
	O_3	Yield change for wheat, barley, rye, oats, potato, rice, tobacco, sunflower seed
	Acid deposition	Acid deposition Increased need for liming

Table 16.1 (continued)

Impact category	Pollutant	Effects
Global warming	CO_2, CH_4, N_2O, N, S	Worldwide effects on mortality, morbidity, coastal impacts, agriculture, energy demand, and economic impacts due to temperature change and sea level rise
Ecosystems	Acid deposition Nitrogen deposition	Acidity and eutrophication (avoidance costs for reducing areas where critical loads are exceeded)

Source: EC, 2005.

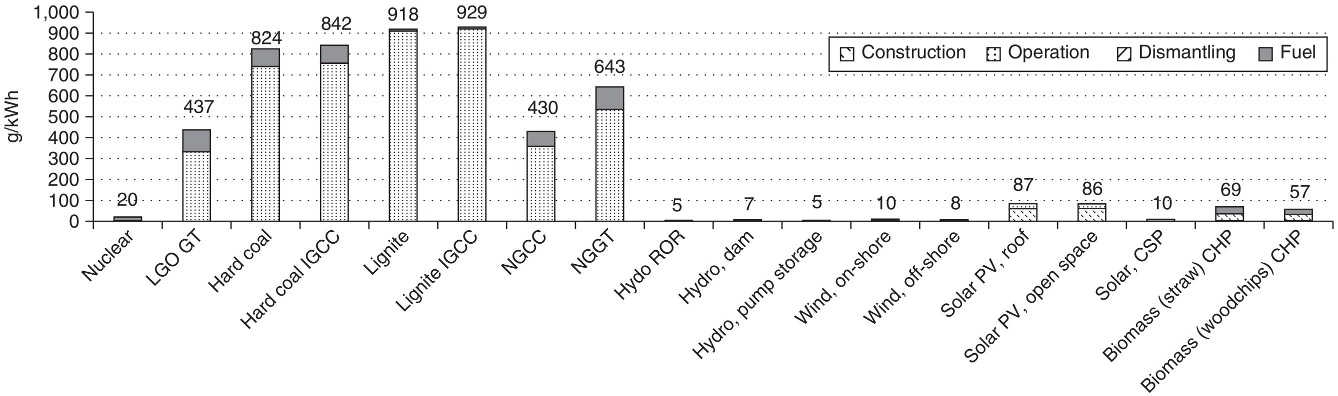
4 SOME RESULTS

In recent years, remarkable progress has taken place in analysing environmental impact and externalities of electricity generation thanks to several major projects (EC, 2005; NEEDS project www.needs-project.org/; www.feem-project.net/cases, accessed February 2013). LCA methodology has also been extensively used to assess mainly GHG emissions but also other emissions from the production and use of several biofuels of different origins compared to conventional fuels. A good review of published studies can be found in Menichetti and Otto (2009).

Some results on life cycle GHG emissions from several electricity generation technologies are shown in Figure 16.2. Results show that fossil technologies, especially coal and lignite fired power plants, produce the largest emissions. Results also show that non-combustion RE technologies and nuclear power cause comparatively minor emissions, only from upstream and downstream processes. Among these technologies solar PV power plants are the largest emitters.

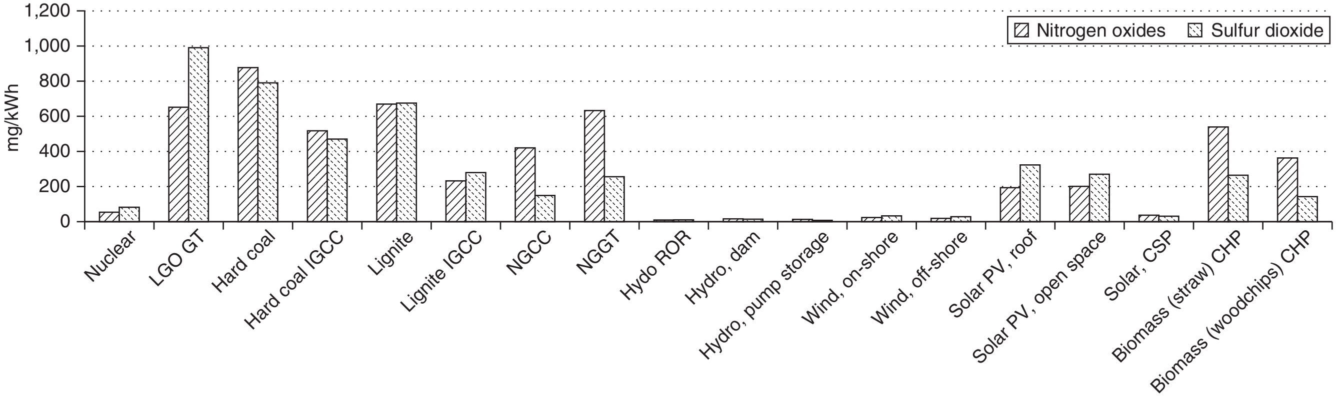
Figures 16.3 and 16.4 show other pollutants' life cycle emissions of electricity generation technologies. Fossil fuel technologies and also biomass technologies produce the highest emissions of NOx and SO2 followed by solar PV technologies. Oil and gas technologies produce the highest amounts of NMVOCs emissions, followed by biomass technologies. In the case of particulates, solar PV technologies show the worst results.

Results of GHG emissions from the production of biofuel – bioethanol



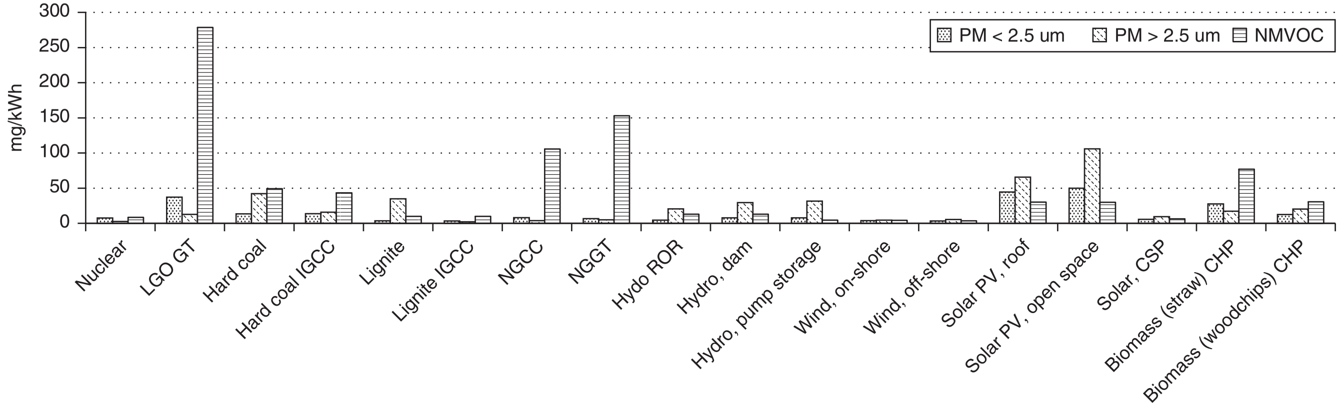
Source: CASES project (CASES, n.d.).

Figure 16.2 Lifecycle GHG emissions of electricity generation technologies disaggregated by life cycle stage



Source: CASES project.

Figure 16.3 Lifecycle NOx and SO2 emissions of electricity generation technologies



Source: CASES project.

Figure 16.4 Lifecycle particulate and NMVOC emissions of electricity generation technologies and biodiesel – obtained by different authors in the literature are shown in Figures 16.5 and 16.6. Dotted line on the graphs shows the reference emissions for fossil fuels. In general, results show GHG emissions savings for the vast majority of raw materials analysed, although some potentially important issues such as LUC or ILUC effects are not considered in the majority of the assessments. In the case of bioethanol production, sugar based raw materials are better than starch based ones with sugar cane showing the best results. In the case of biodiesel, the observed variability in the results is quite remarkable, especially in the case of palm oil biodiesel. Biodiesel from recycled oil followed by sunflower show the best results with a high emission saving potential. However, as mentioned before, the consideration of ILUC associated GHG emissions can have an important impact on these results (Laborde, 2011).

Results for damage costs per kWh obtained in the CASES project are shown in Figures 16.7 and 16.8 for various electricity generation technologies. As can be seen in those figures, results demonstrate that, compared to fossil fuel technologies – especially oil and coal fired generation – renewable energies have lower damages.

Fossil fuel technologies have external costs above 1.4 eurocent/kWh reaching more than 3 eurocent/kWh in the case of coal power plants. These costs are dominated by global warming impacts in the case of coal, lignite and natural gas and by health effects in the case of oil. Among fossil technologies, the ones with higher efficiencies have correspondingly less external costs per kWh.

Despite nuclear energy external costs appear very low in these calculations, it must be taken into account that they do not consider the effects of a possible nuclear accident or the effects on future environment and society of the possible accidental release of the nuclear waste that has been disposed of (Lecointe et al, 2007).

Among renewable technologies, biomass technologies show the highest external costs dominated by health and biodiversity effects while run of river hydro technologies show the lowest costs among all the technologies.

Among solar technologies, solar PV technologies have sensibly higher external costs than CSP and these costs are dominated by the health effects arising from the emissions originated by the energy requirements of the upstream processes related to the production of silicon and PV wafers (Frankl et al, 2006). Foreseen improvements in energy consumption and even better efficiencies for this technology would reduce the external costs significantly.

External costs of fossil fuel power plants are dominated by impacts produced during operation of the power plants while renewable energies have the most of their external costs associated with the construction stage of

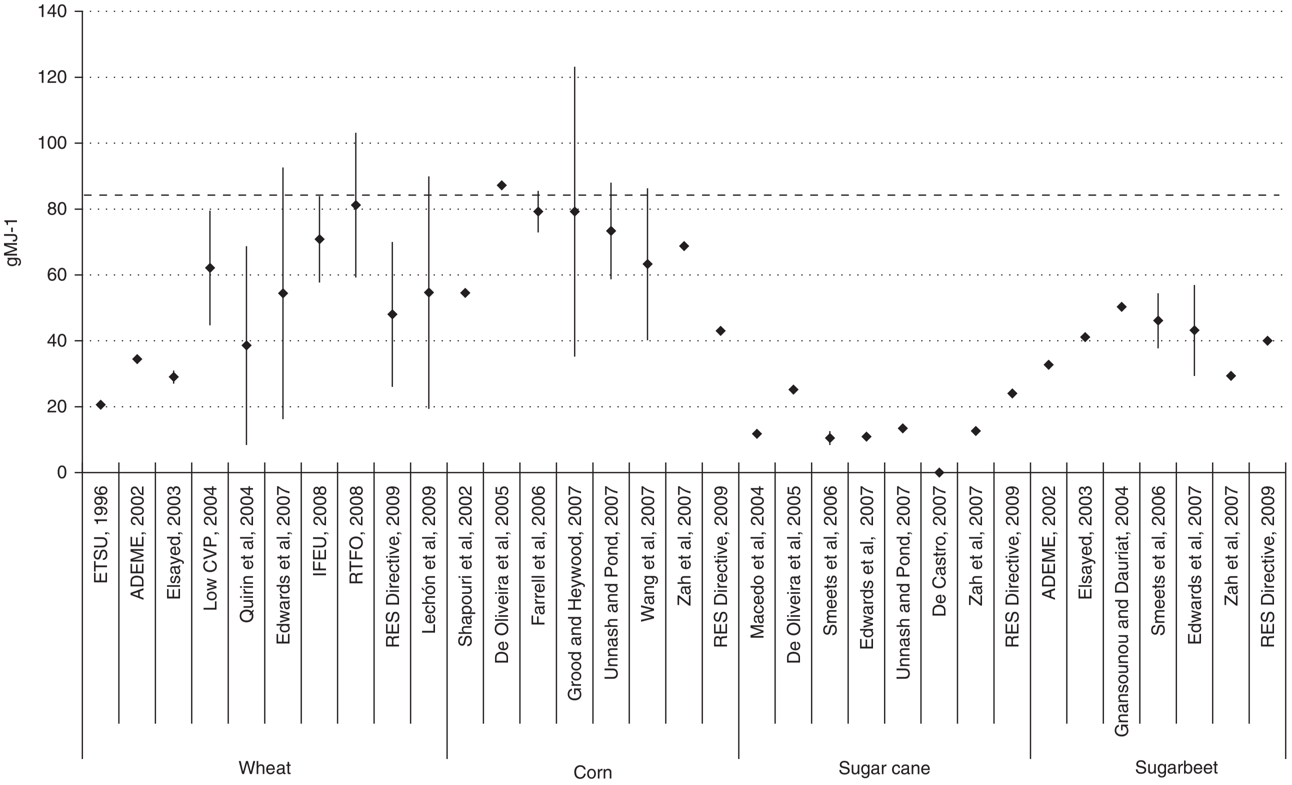
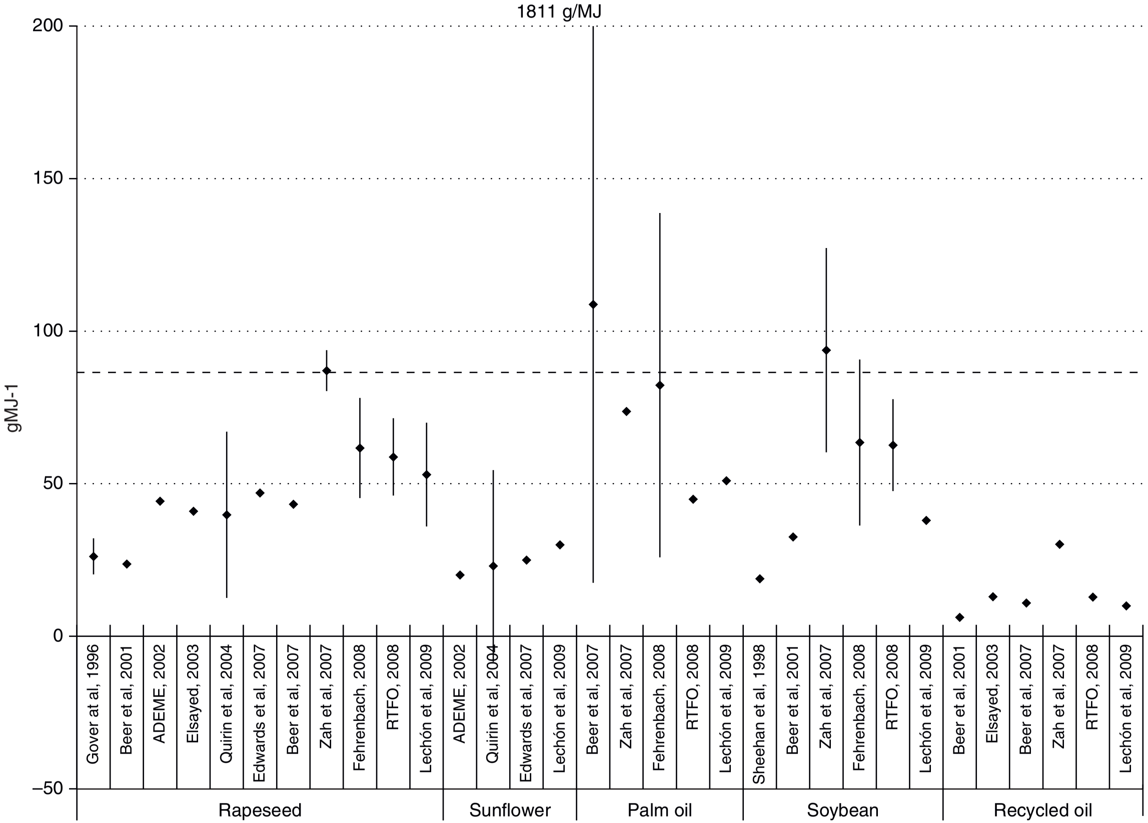
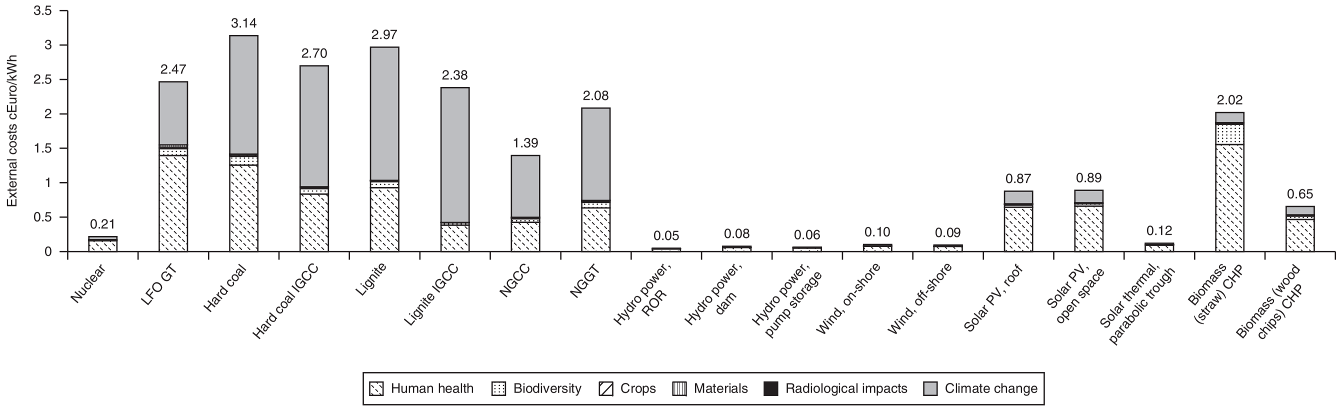


Figure 16.5 *Lifecycle GHG emissions of bioethanol production from different raw materials*



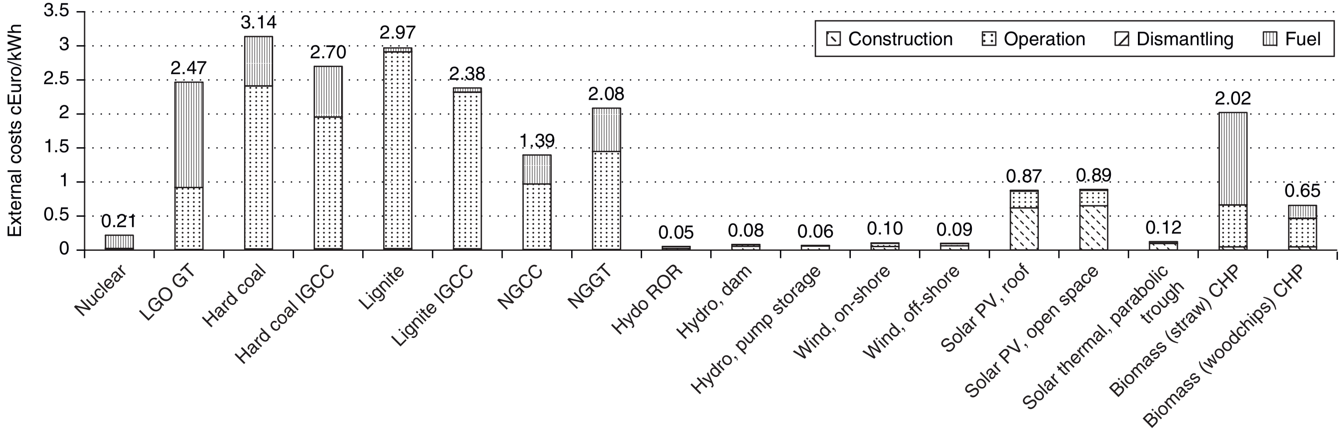
Note: The symbol ♦ represents the mean value of GHG emissions calculated by the authors in the references. Bars represent the highest and lowest values reported.

Figure 16.6 Lifecycle GHG emissions of biodiesel production from different raw materials



Source: CASES project.

Figure 16.7 External costs of electricity generation technologies disaggregated by impact category



Source: CASES project.

Figure 16.8 External costs of electricity generation technologies disaggregated by life cycle stage the fuel cycles. Fuel provision external costs are important in oil, coal and gas technologies but also in biomass power plants. The nuclear fuel cycle external costs are also dominated by fuel related activities.

5 CONCLUSIONS

This chapter has reviewed the environmental implications of a wide range of different energy production technologies showing results for different kinds of pollutant emissions, impacts as well as external costs calculations. One relevant conclusion emerging from this review is that renewable energies can play an important role in mitigating global warming emissions, a major concern in current environmental policy agendas. In terms of GHG mitigation potential, some renewable technologies seem to attain robust results in the reviewed studies, while others such as biomass derived electricity and biofuels show a more variable range of results. Of the latter technologies, some aspects of concern are related to the associated indirect effects produced by a large scale deployment. When mitigation of other impacts and pollutants are included in the picture, some renewable technologies show higher potential than others. Once more, biomass technologies but also solar PV technologies have a lesser potential to contribute to this mitigation.

When all of these effects are aggregated in a single indicator and are quantified in monetary units, the social welfare benefits of deploying renewable energy sources become clear. Consequently, if policy makers want to promote and pursue a sustainable energy system that maximizes social welfare, environmental externalities of all energy technologies must be taken into account. In order to do so, it is necessary to properly identify, quantify and later internalize the external costs in the price of energy through the various existing mechanisms.

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