Sustainable Asset Valuation Tool

ENERGY INFRASTRUCTURE

IISD
International Institute for
Sustainable Development

MAVA
FONDATION POUR LA NATURE

Andrea M. Bassi
Kieran McDougal
David Uzsoki

September 2017

Published by the International Institute for Sustainable Development.

International Institute for Sustainable Development

The International Institute for Sustainable Development (IISD) is one of the world's leading centres of research and innovation. The Institute provides practical solutions to the growing challenges and opportunities of integrating environmental and social priorities with economic development. We report on international negotiations and share knowledge gained through collaborative projects, resulting in more rigorous research, stronger global networks, and better engagement among researchers, citizens, businesses and policy-makers.

IISD is registered as a charitable organization in Canada and has 501(c)(3) status in the United States. IISD receives core operating support from the Government of Canada, provided through the International Development Research Centre (IDRC) and from the Province of Manitoba. The Institute receives project funding from numerous governments inside and outside Canada, United Nations agencies, foundations, the private sector, and individuals.

Head Office

111 Lombard Avenue, Suite 325
Winnipeg, Manitoba
Canada R3B 0T4

Tel: +1 (204) 958-7700
Fax: +1 (204) 958-7710
Website: www.iisd.org
Twitter: @IISD_news

MAVA Foundation

The MAVA Foundation is a Swiss-based philanthropic foundation with a focus on the conservation of biodiversity. Since its inception in 1994, it has supported more than 700 projects, implemented by over 280 different organisations. These include international and local NGOs, research institutions, universities and occasionally government bodies or individuals. The foundation operates four different programmes. Three are region-based: Switzerland, the Mediterranean Basin and West Africa. In each place it has strived to help build extensive conservation capacity, to create and support conservation institutions and influence policy. Its fourth programme, the Sustainable Economy programme, provides opportunities to affect global trends and have an impact that goes beyond the foundation's priority regions by focusing on valuing natural capital, green finance and resource efficiency.

Sustainable Asset Valuation Tool: Energy Infrastructure

September 2017

Written by Andrea M. Bassi, Kieran McDougal and David Uzsoki

This document is not meant to be an original contribution. Instead, it is a review that summarizes available knowledge in the literature for a given infrastructure type, including, for instance, the policy landscape and data availability. As a result, this document (both the light screening and in-depth review) were utilized to inform the creation of the SAVi model, a simulation tool that integrates knowledge from various disciplines and sectors for sustainable asset valuation.

TABLE OF CONTENTS

PART I: LIGHT SCREENING

Definition of sustainable infrastructure	At the international level, the main goals of green growth in the energy sector are defined as ensuring universal access to modern energy services, promoting renewable energy use, and achieving GHG emissions reductions (both in terms of carbon intensity and absolute reductions). The objective of ensuring universal access to affordable, reliable and modern energy services to all by 2030 is featured in Sustainable Development Goal 7. Concerning infrastructure, IISD defines sustainable infrastructure as assets that optimize value for money economy-wide, and hence for all taxpayers. With regards to sustainable energy infrastructure, this implies estimating and using the levelized cost of electricity generation (including the cost of externalities) and the contribution of this infrastructure to society (e.g., employment creation), as opposed to using exclusively the capital costs and the cost of electricity generation. In the case of electricity supply, the following technologies are considered: • Renewable: solar, wind, biomass, hydropower • Low-carbon: nuclear • Thermal: coal, natural gas, oil-derived (liquid) fuels
Indicators used to measure performance	The Sustainable Energy For All (SE4ALL) initiative was launched in September 2011 by UN Secretary-General Ban Ki-moon, and details how governments, business and civil society can work together to make sustainable energy for all a reality by 2030. As a supporting tool for the SE4ALL, the World Bank developed the Global Tracking Framework, which, tracks country-level indicators for energy access, renewable energy, and energy efficiency. The latest assessment available is the Global Tracking Framework 2015.
Shortcomings of business-as-usual investments	When seen as an enabler of economic growth, the energy supply is optimized to reduce energy generation costs. In this case, investments with the lowest initial capital cost are prioritized. As a result, thermal generation, which uses fossil fuels (e.g., coal), is often chosen. When fossil fuels are used, there are both upstream and downstream impacts: • Upstream: mining, leading to deforestation, water pollution, energy consumption and emissions (both from reduced sinks and increased sources), suboptimal labour standards. • Downstream: GHG emissions, leading to higher PM concentration and health impacts (e.g., sick leave taken and overall reduced labour productivity—mortality and morbidity). Further, large centralized electricity generation plants are more vulnerable to natural (e.g., climate-related) disasters, partly because these types of infrastructure require more infrastructure (e.g., for power distribution). The levelized costs of electricity generation (which consider the cost of generation over the lifetime of the plant, rather than only using upfront costs) are showing that renewable energy is gaining ground and it is often more economical than conventional thermal generation.
Advantages of green investments	The advantages of sustainable and renewable energy include: • Small-scale renewables provide decentralized supply, making it easier to reach remote communities and at a lower cost (e.g., islands, mountainous regions). • Renewable energy has a long lifetime and low operating and management costs, and no variable fuel costs. This allows the forecasting of generation costs with more certainty, lowering the investment risk. • With the use of renewable resources such as sunlight and wind, the overall costs of electricity generation are constant. With no use of fossil fuels, imports can be reduced, improving energy self-sufficiency and costs (e.g., in case the price of fossil fuels increases). • Renewable energy generates no emissions in operations and electricity generation. Emissions may be created during the installation (e.g., hydropower dams may lead to deforestation). • As a new technology, renewable energy is more labour-intensive than conventional thermal generation, often leading to the creation of local employment. • Balance of system costs generates more skilled and semi-skilled jobs in the domestic economy. This also provides opportunities for technology transfer.
Main roadblocks for the adoption of green infrastructure	Challenges arise for the adoption of green infrastructure in relation to the difficulty in pricing externalities (i.e., estimating the economic value of externalities) and the risk associated with the investment in relation to social and environmental (e.g., climate-driven) events. As a result, investors in the energy sector cannot price the entire spectrum of risks associated with investments in electricity supply. Further, some of the benefits sought by governments are accounted for as costs by investors and project developers (e.g., investment). And some of the actions/inaction of governments (e.g., on climate adaptation) can reduce/increase risks for investors and project developers. On the other hand, this brings even more uncertainty to project financing decisions, since policies are constantly evolving at the national level. Other more tangible roadblocks for the adoption of renewable energy include: - Higher capital cost relative to thermal capacity. - Intermittent supply (with the need for backup generation or batteries), leading to issues when small producers enter the market and large utilities are left with small revenues and old (inefficient) power supply. - Access to financing for smaller, distributed projects. - Uncertainties related to feed in tariffs and other policy uncertainties.

Policy interventions	**Grey infrastructure** • Regulatory: carbon pricing, air pollution laws. • Market: price volatility for inputs (e.g., coal, natural gas), cost of competing options (e.g., renewable energy), price volatility for output. • Technical: unexpected O&M costs, climate change impacts on capital (e.g., extreme weather events), volatility in the availability of inputs (e.g., droughts), cost of decommissioning. • Social pressure: fossil fuel divestment campaign, campaigns to reduce social and environmental impacts, changing consumer preferences, requirements for local employment and skills gap.
	Green Infrastructure • Regulatory: uncertainty in incentives, feed-in tariff, carbon pricing, air pollution laws; grid access. • Market: cost of competing options (e.g., cogeneration), uncertainty related to electricity generation. Capacity bottlenecks and price volatility (e.g., solar panels), lack of grid integration (for off-grid solutions). • Technical: potential failure due to climate change and extreme conditions (e.g., wind speed for wind farms, landslides), excessive wearing of mechanical parts (e.g., wind), side effects of human action (e.g., extra sedimentation in the case of hydropower due to a growing trend of deforestation), availability of inputs/feedstock (e.g., water for hydro). • Social pressure: cost minimization (e.g., to support economic growth), potential disruption of landscapes (e.g., wind farms).
	The main enabling conditions for achieving green growth in the energy sector relate to channelling investments into energy efficiency, renewable energy and well-designed infrastructure (e.g., for the production, delivery and distribution of electricity). Some of the policies that can accelerate the transition include pricing mechanisms (e.g., the phasing out of subsides for fossil fuels, a carbon tax or a cap and trade system), incentives (e.g., feed-in tariffs for distributed generation) and support for levering private investments (e.g., advantageous loans). Capacity building is also important, and the main elements to it are the identification of skill gaps, the establishment of demonstration projects, and investments in both R&D and training.
Actors involved	The main social actors involved in the energy sector are: • Government: to ensure reliable electricity supply (access and affordability). The government is also involved through parastatal or government-owned utilities. • The private sector: especially in the case of auctioning for large infrastructure projects, the private sector plays an important role in the design and construction (as well as operation at times) of electricity generation capacity. The private sector is also involved in decisions (and investments) for energy efficiency and the private sector category includes investors (debt and equity), constructors and private utilities. • Households: primarily involved in investments pertaining to decentralized and small-scale renewable energy supply (e.g., rooftop PV and solar heat water). - Bilateral and multilateral agencies: to direct investments toward (and co-finance) projects that meet specific sustainability standards. These include multilateral development banks and donors/sponsors.
Existing sustainability standards	Hydropower sustainability assessment protocol: http://www.hydrosustainability.org/ ISO: http://www.iso.org/iso/home/news_index/iso-in-action/energy.htm SASB: http://www.sasb.org/sectors/renewable-resources-alternative-energy/
Main organizations working on the assessment of infrastructure	- Sustainability: International Energy Agency (IEA), International Renewable Energy Agency (IRENA). - Data: IEA, World Development Indicators (WB) and SE4ALL. - Projections: IEA.

Table 1. **Assessment of selected green economy interventions in the energy sector**

		Market support			Multi-criteria analysis		
Goal	**Policy**	**Awareness**	**Demand**	**Supply**	**Investment**	**Avoided cost**	**Added benefit**
	Incentives for distributed capacity		x		Public incentive (G), Purchase of RE capacity (H)	Electricity bill (H), Public generation capacity (G), Reduced grid blackouts (H,P), Avoided water consumption (H,P), Reduced health spending (G,H)	Lower emissions (G,H), Employment creation (H), Avoided impact on soil and water quality (G, H), Increased access to electricity (H,P)
	Incentives for production and servicing			x	Public incentive (G), Purchase of machineries (P), Capacity building (P)	Import of RE capacity (P), Public generation capacity (G)	Improved balance of payments (G), Employment creation (H), Tax revenue (G), GDP growth (P,G), Skill creation (P,H)
Energy efficiency	Incentives for building retrofits and efficiency appliances		x		Public incentive (G), Purchase of products or retrofits (P,H)	Electricity and energy bill (H,P), Reduced fossil fuel use (H,P), Public generation capacity (G)	Lower emissions (G), Employment creation (H), Higher savings/ consumption (H,G)

Note: P – Private sector; G – Government; H - Households

PART II: IN-DEPTH REVIEW

1.0 DEFINITION OF SUSTAINABLE INFRASTRUCTURE

At the international level, the main goals of green growth in the energy sector are defined as ensuring universal access to modern energy services, promoting renewable energy use and achieving GHG emission reductions (in terms of both carbon intensity and absolute reductions). The objective of ensuring universal access to affordable, reliable and modern energy services to all by 2030 is featured in Sustainable Development Goal 7.

IISD defines sustainable infrastructure as assets that optimize value for money economy-wide, and hence for all taxpayers. With regards to sustainable energy infrastructure, this implies estimating and using the levelized cost of electricity generation (including the cost of externalities) and the contribution of this infrastructure to society (e.g., employment creation), as opposed to using exclusively the capital costs and the cost of electricity generation.

In the case of electricity supply the following technologies are considered:

- Renewable: solar, wind, biomass, hydropower
- Low-carbon: nuclear
- Thermal: coal, natural gas, oil-derived (liquid) fuels

Table 2. **Overview of required inputs and outputs generated by buildings**

Inputs	Outputs
• Construction o Capital o Labour o Raw materials (e.g., aluminum, steel) o Water o Energy • Operation o Labour o Energy input (e.g., coal)	• Electricity generation • Air emissions (CO_2, SO_2, NO_x, CH_4) o Human health (mortality and morbidity) o Crop yield reduction o Global warming • Water pollution • Water scarcity • Thermal pollution • Ecosystem (acid and nitrogen deposition) • Noise • Visual impact • Competition for land use

1.1 SHORTCOMINGS OF BUSINESS-AS-USUAL INVESTMENTS

When seen as an enabler of economic growth, the energy supply is optimized to reduce energy generation costs. In this case investments with the lowest initial capital cost are prioritized. As a result, thermal generation using fossil fuels such as coal is often chosen.

When fossil fuels are used, there are both upstream and downstream impacts:

- Upstream: mining, leading to deforestation, water pollution, energy consumption and emissions (both from reduced sinks and increased sources), suboptimal labour standards.

> ***Example:***
>
> In the scientific literature there is uncertainty over the relative contributions of various forest-exploiting sectors to forest losses across countries. The paper *Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest Loss in Indonesia* (Abood, 2015) compares the magnitudes of forest and carbon loss, and forest and carbon stocks remaining within oil palm plantation, logging, fiber plantation (pulp and paper), and coal mining concessions in Indonesia. Forest loss in all industrial concessions, including logging concessions, relate to the conversion of forest to non-forest land cover. The study found that, “the four industries accounted for 44.7 per cent (6.6 Mha) of forest loss in Kalimantan, Sumatra, Papua, Sulawesi, and Moluccas between 2000 and 2010. Fiber plantation and logging concessions accounted for the largest forest loss (1.9 Mha and 1.8 Mha, respectively). Although the oil palm industry is often highlighted as a major driver of deforestation, it was ranked third in terms of deforestation (1 Mha), and second in terms of carbon dioxide emissions (1,300–2,350 Mt CO2). Crucially, 34.6 per cent (26.8 Mha) of Indonesia’s remaining forests is located within industrial concessions, the majority of which is found within logging concessions (18.8 Mha). While the mining, and oil and gas exploration industries have also contributed to significant environmental damage, this has been documented to a lesser extent by remote sensing studies” (Abood, 2015).

- Downstream: GHG emissions, leading to higher PM concentration and health impacts (e.g., sick leave taken and overall reduced labour productivity – mortality and morbidity).

> ***Example:***
>
> The study *Air pollution and children’s respiratory symptoms in six cities of Northern China* (Pan, 2010) “evaluated the effects of outdoor air pollution on respiratory morbidity in children selected from multiple sites in a heavy industrial province of northeastern China… The study included 11,860 children aged 3-12 years selected from 18 districts of six cities in Liaoning province… There were wide gradients for TSP (188–689 mg/m^3), SO_2 (14–140 mg/m3) and NO_2 (29–94 mg/m^3) across the 18 districts of six cities. The three air pollutants significantly increased the prevalence of persistent cough (21–28 per cent), persistent phlegm (21–30 per cent) and current asthma (39–56 per cent) for each interquartile range increment (172 mg/m^3 for TSP, 69 mg/m^3 for SO_2 ,30 mg/m^3 for NO_2), showing larger between-city effects than within-city.” The findings of the study demonstrate that the “high levels of outdoor air pollution in north China are positively associated with children’s respiratory symptoms, the associations with TSP appear to be stronger than SO_2 and NO_2” (Pan, 2010). The correlation between air pollution and respiratory disease, especially among children, has led in the past to schools’ closings in China (Nuwer, 2013). For instance, pollution levels in Harbin, a city in northeast China, worsened dramatically over a few weeks in 2013, leading to schools being shut down, flights being cancelled and several highways being closed. “Air quality readings reached about 20 times the level considered safe by the World Health Organization, leading to a 30 per cent increase in patients reporting respiratory problems at Harbin’s hospitals” (Nuwer, 2013).

Further, large centralized electricity generation plants are more vulnerable to natural (e.g., climate-related) disasters, partly because these types of power generation technologies require more infrastructure (e.g., for power distribution).

> ***Example:***
>
> "The Fukushima Daiichi nuclear disaster was initiated primarily by the tsunami following the Tōhoku earthquake on 11 March 2011. Immediately after the earthquake, the active reactors automatically shut down their sustained fission reactions. However, the tsunami destroyed the emergency generators cooling the reactors, causing Reactor 4 to overheat from the decay heat from the fuel rods. The insufficient cooling led to three nuclear meltdowns and the release of radioactive material beginning on 12 March 2011" (Fukushima on the Globe, 2014).
>
> Heat waves in France as well as in the United States cause several nuclear reactors to shut down every summer. This is due to the lack of cooling water or to the temperature of available water being too high (preventing the discharge of water above 25 degrees in rivers). The same applies to coal power generation plants.

The levelized costs of electricity generation (which consider the cost of generation over the lifetime of the plant, rather than only using upfront costs) show that renewable energy is gaining ground, and it is often more economical than conventional thermal generation.

> ***Example:***
>
> "India has been heavily backing solar power for some years and it has recently unveiled a string of ambitious solar projects… One of the consequences of all this ongoing investment in infrastructure is that the cost of providing solar power in India is becoming increasingly affordable—to the point where the country's energy minister, Piyush Goyal, now says that solar power is a more cost-effective option than the old fossil fuel staple, coal" (Dockrill, 2016). The results of a reverse auction tender of 420MW of solar capacity conducted by the Rajasthan government revealed this week that Finnish group Fortum Energy bid the lowest price of 4.34 rupees/kWh for a 70MW solar PV plant. It is the lowest price obtained so far in India, which aims to install more than 100GW of solar by 2022. "And if the price keeps falling at a similar rate, it will soon drop significantly below coal, with some saying that by 2020, solar could be as much as 10 per cent cheaper than coal power" (Dockrill, 2016).
>
> The study *Levelized Cost Of Electricity Renewable Energy Technologies* (Fraunhofer Society, 2013) analyzed the levelized cost of electricity (LCOE) of renewable energy technologies in Germany in the third quarter of 2013.
>
> "PV power plants reached LCOE between 0.078 and 0.142 Euro/kWh in the third quarter of 2013, depending on the type of power plant (ground-mounted utility-scale or small rooftop power plant) and insolation (1,000 to 1,200 kWh/m²a GHI in Germany). The specific power plant costs ranged from 1,000 to 1,800 Euro/kWp. The LCOE for all PV power plant types reached parity with other power generation technologies and are even below the average end-customer price for electricity in Germany of 0.289 Euro/kWh (Fraunhofer Society, 2013).
>
> Wind power at very good onshore wind locations already has lower costs than new hard coal or CCGT power plants. Currently the LCOE for onshore wind power (spec. invest between 1,000 and 1,800 Euro/kW) is between 0.045 and 0.107 Euro/kWh. Despite the higher annual average full load hours (up to 4,000 hours), offshore wind power with just 0.119 to 0.194 Euro/kWh shows considerably higher LCOE than onshore wind power. The reasons for this are the expensive installation as well as higher operating and financing costs for offshore power plants (spec. invest between 3,400 and 4,500 Euro/kW) (Fraunhofer Society, 2013).
>
> The LCOE from biogas power plants (spec. invest between 3,000 and 5,000 Euro/kW) is between 0.135 Euro/kWh (substrate costs 0.025 Euro/kWhth, 8,000 full load hours) and 0.215 Euro/kWh (substrate costs 0.040 Euro/kWhth, 6,000 full load hours). A heat usage is not considered in the calculations (Fraunhofer Society, 2013).
>
> In the case of conventional power plants, brown coal profits the most from the low prices of CO_2 allowances. Depending on the assumed full load hours, the fuel costs and the price of CO_2 allowances, the LCOE for brown coal is at 0.038 to 0.053 Euro/kWh, from hard coal at 0.063 to 0.080 Euro/kWh and from CCGT power plants at 0.075 to 0.098 Euro/kWh. The full load hours of conventional power plants are integrated into the LCOE with a decreasing tendency corresponding to the forecasted increasing renewable energy share" (Fraunhofer Society, 2013).

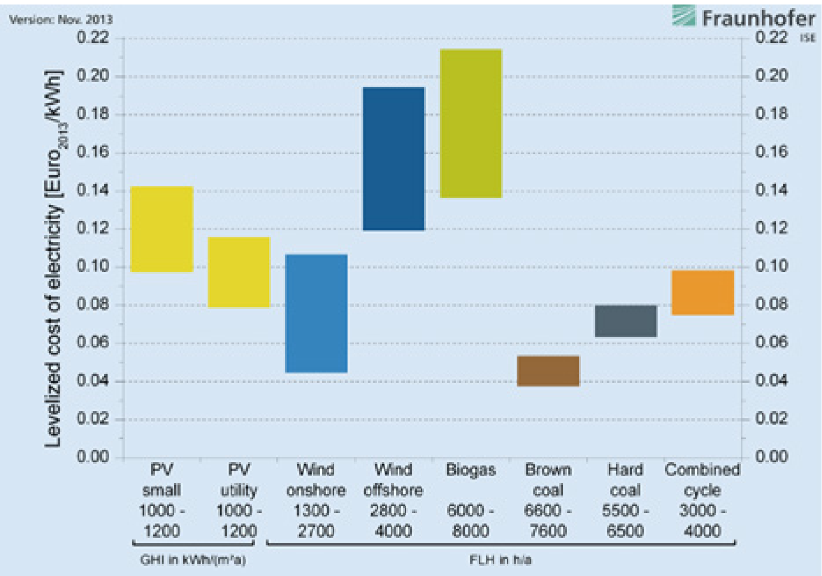


Figure 1. LCOE of renewable energy technologies and conventional power plants at locations in Germany in 2013

Source: Fraunhofer Society, 2013

1.2 ADVANTAGES OF GREEN INVESTMENTS

The advantages of sustainable and renewable energy include the following:

- Small-scale renewables provide decentralized supply, allowing for increased accessibility and interconnectedness of remote communities (e.g., islands, mountainous regions), as well as cheaper distribution costs.

  Example:

  In Aberdeen, the city council decided to use district heating to solve fuel poverty in some of their social housing stock. So far 1,500 flats have been connected as well as eight public buildings. Typical fuel costs to tenants in these multistorey blocks have been reduced by 50 per cent, and carbon emissions from connected buildings have been reduced by 45 per cent. There are plans to extend the award-winning scheme to connect even more buildings, further replicating the benefits realized so far (Carbon Trust, 2013).

  The Tunisian Solar Programme (PROSOL)—a joint initiative of the Tunisian National Agency for Energy Conservation (ANME), the state utility Société Tunisienne de l'Electricité et de Gaz (STEG), the United Nations Environment Programme and the Italian Ministry for the Environment, Land and Sea—provides an example of solar thermal market development. The government provides a subsidy of 20 per cent of the system cost or $75 per square metre, while customers are expected to finance a minimum of 10 per cent of the purchase and installation costs. Over 50,000 Tunisian families now get their hot water from the sun based on loans amounting to more than $5 million in 2005 and $7.8 million in 2006—a substantial leverage to PROSOL's initial cost of $2.5 million. With installed surface of the program reaching 400 000 m^2 in 2008, the government had set a more ambitious target of 750,000 m^2 for the period 2010–2014, a level comparable to much larger countries such as Spain or Italy. As of 2008, PROSOL helped avoid 214,000 tonnes of cumulative CO_2 emissions. Jobs have been created, as 42 technology suppliers were officially registered and at least 1,000 companies installed the systems. In conclusion, the experience in Tunisia demonstrates the potential returns on investing in renewable energy, creating new jobs and reducing dependency on fuel imports.

- Renewable energy has a long lifetime and low operation and management costs, and no variable fuel costs. This allows more accurate forecasting of generation costs, lowering the investment risk.

  Example:

  "In a time of fuel price fluctuation, the use of renewable energy may offer, along with environmental benefits, greater stabilization of electricity costs (Commission for Environmental Cooperation, 2008). The pricing volatility of fossil fuels, along with the difficulty of forecasting fossil fuel prices, puts energy

> customers and providers at risk from fluctuating energy rates. As an alternative, renewable energy can serve as a financial 'hedge,' reducing exposure to fuel price risk. Renewable energy generation brings with it the price stability benefits of free-fuel generation from emerging technologies such as solar, wind, small hydro, and geothermal sources. Renewable energy costs tend to be stable or to decrease over time, compared to rising or fluctuating costs for fossil fuel. With certain factors in place, it has been demonstrated that renewable energy can be effectively priced at or below the cost of conventional sources… Since renewable energy resources (with the exception of biomass) do not require purchased fuel, the operating costs over time are highly predictable, as opposed to fossil fuel markets" (Commission for Environmental Cooperation, 2008). Furthermore, renewable energy reduces the demand for non-renewable resources, potentially easing prices of fossil fuels.

- With the use of renewable resources (e.g., sunlight and wind), the overall costs of electricity generation are constant. Eliminating the use of fossil fuels can reduce imports and improve energy self-sufficiency and costs (e.g., in case the price of fossil fuels increases).

> ***Example:***
>
> "Levelized cost of electricity (LCOE) is often cited as a convenient summary measure of the overall competiveness of different generating technologies. It represents the per-kilowatt hour cost (in real dollars) of building and operating a generating plant over an assumed financial life and duty cycle (EIA, 2016). Key inputs to calculating LCOE include capital costs, fuel costs, fixed and variable operations and maintenance (O&M) costs, financing costs, and an assumed utilization rate for each plant type. The importance of the factors varies among the technologies. For technologies such as solar and wind generation that have no fuel costs and relatively small variable O&M costs, LCOE changes in rough proportion to the estimated capital cost of generation capacity. For technologies with significant fuel cost, both fuel cost and overnight cost estimates significantly affect LCOE" (EIA, 2016).
>
> "Austria depends on energy imports in the form of fossil energy, primarily oil and natural gas. But Austria has been working hard to reduce its dependency. In December 2008, under the initiative of Niki Berlakovich, the Federal Minister of Agriculture, Forestry, Environment and Water Management, Austria announced its goal of becoming energy independent by 2050. Nowhere is this effort, and its benefits, more evident than in the region of Güssing. It was in 1990 that the Mayor of Güssing, Peter Vadasz, recognized the potential of changing Güssing's energy consumption for improving its devastating economic conditions. He focused on improving the energy efficiency of the region, and using existing resources such as woody-biomass and municipal solid waste that contains organic combustible material, to transform his municipality to the first and biggest energy model for energy independence in the world. Within eleven years, Güssing became self-sufficient with regards to electricity, heating, and transportation. In addition, more than 60 new companies and over 1,500 new 'Green Jobs' were created and the share of commuters to other regions fell to 40 per cent. Since Güssing generates more "green" energy than the region needs, the value added to the region is over $28 million per year. Finally, greenhouse gas emissions were reduced by over 80 per cent" (Kordik, n.d.).
>
> "The cost competitiveness of renewable power generation technologies has reached historic levels. Biomass, hydropower, geothermal and onshore wind can all now provide electricity competitively compared to fossil fuel-fired power generation. Most impressively, the LCOE of solar PV has halved between 2010 and 2014, so that PV is also increasingly competitive at the utility scale.
>
> Installed costs for onshore wind power, solar PV and concentrating solar power (CSP) have continued to fall, while their performance has improved. Biomass for power, geothermal and hydropower have provided low-cost electricity—where untapped economic resources exist—for many years.
>
> Solar PV module prices in 2014 were around 75 per cent lower than their levels at the end of 2009. Between 2010 and 2014 the total installed costs of utility-scale PV systems have fallen by 29 per cent to 65 per cent, depending on the region. The LCOE of utility-scale solar PV has fallen by half in four years. The most competitive utility-scale solar PV projects are now regularly delivering electricity for just USD 0.08 per kilowatt-hour (kWh) without financial support, compared to a range of USD 0.045 to USD 0.14/kWh for fossil fuel power plants. Even lower costs for utility-scale solar PV, down to USD 0.06/kWh, are possible where excellent resources and low-cost finance are available.
>
> Onshore wind is now one of the most competitive sources of electricity available. Technology improvements, occurring at the same time as installed costs have continued to decline, mean that the LCOE of onshore wind is now within the same cost range, or even lower, than for fossil fuels. The best wind projects around the world are consistently delivering electricity for USD 0.05/kWh without financial support.
>
> LCOEs of the more mature renewable power generation technologies—biomass for power, geothermal and hydropower—have been broadly stable since 2010. However, where untapped economic resources remain, these mature technologies can provide some of the cheapest electricity of any source" (IRENA, 2015).

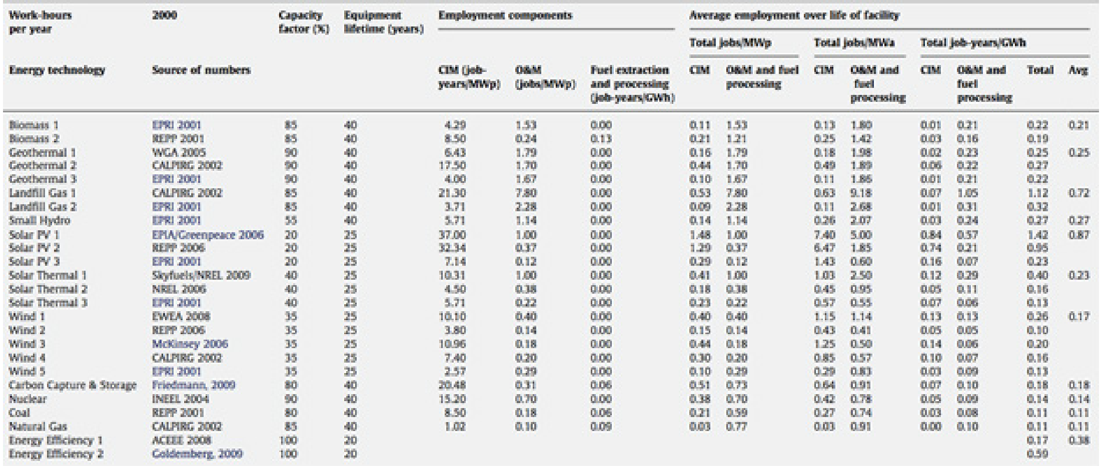
- Renewable energy generates no emissions in operations and electricity generation. Emissions may be created during the installation (e.g., hydropower dams may lead to deforestation).

> ***Example:***
>
> "While there are no emissions associated with generating electricity from solar energy, there are emissions associated with other stages of the solar life cycle, including manufacturing, materials transportation, installation, maintenance, and decommissioning and dismantlement. Most estimates of life cycle emissions for photovoltaic systems are between 0.07 and 0.18 pounds of carbon-dioxide-equivalent per kilowatt-hour. Most estimates for concentrating solar power range from 0.08 to 0.2 pounds of carbon-dioxide-equivalent per kilowatt-hour. In both cases, this is far less than the lifecycle emission rates for natural gas (0.6–2 lbs of CO_2E/kWh) and coal (1.4–3.6 lbs of CO_2E/kWh)" (Union of Concerned Scientists, 2016).

- As a new technology, renewable energy is more labour intensive than conventional thermal generation, often leading to the creation of local employment.

> ***Example:***
>
> While growth in employment slowed compared to previous years, the total number of jobs in renewables worldwide continued to rise, in stark contrast with depressed labour markets in the broader energy sector. In the United States, for example, renewable energy jobs increased by around 6 per cent, while employment in oil and gas extraction (and support activities) contracted by 18 per cent. In China, renewable energy employed around 3.5 million people, exceeding the 2.6 million employed in the country's oil and gas sector (IRENA, 2016).
>
> The study *Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US?* (Wei, 2009) found that "all non-fossil fuel technologies (renewable energy, EE, low-carbon) create more jobs per unit energy than coal and natural gas. Aggressive EE measures combined with a 30 per cent RPS target in 2030 can generate over 4 million full-time-equivalent job-years by 2030 while increasing nuclear power to 25 per cent and CCS to 10 per cent of overall generation in 2030 can yield an additional 500,000 job-years" (Wei et al., 2009, p. 919). "From a policy perspective, it is interesting to note that although the construction of turbines, solar panels, or other pieces of equipment can be easily done elsewhere, the installation of any technology necessarily creates local jobs. While coal and natural gas plants are typically centralized, large installations and renewable sources can be used for utility-scale developments, distributed renewable sources can provide local "distributed' employment with environmental and financial advantages such as shorter lead times and lower initial cost" (Wei et al., 2009, p. 928). The study found that "all renewable energy and low-carbon sources generate more jobs than the fossil fuel sector per unit of energy delivered while the type of employment differs between technologies (e.g., manufacturing vs. resource extraction) and the timing and location of employment may differ within a given country or geography. This information can be useful for policy makers who are designing long-range energy policies or short-term government programs to provide economic stimulus or incentives for direct employment" (Wei et al., 2010, p. 928).

Table 3. Comparison of jobs/MPw, jobs/MWa, and job-years/GWh across technologies



Work-hours per year	2000	Capacity factor (%)	Equipment lifetime (years)	Employment components			Average employment over life of facility							
							Total jobs/MWp		Total jobs/MWa		Total job-years/GWh			
Energy technology	Source of numbers			CIM (job-years/MWp)	O&M (jobs/MWp)	Fuel extraction and processing (job-years/GWh)	CIM	O&M and fuel processing	CIM	O&M and fuel processing	CIM	O&M and fuel processing	Total	Avg
Biomass 1	EPRI 2001	85	40	4.29	1.53	0.00	0.11	1.53	0.13	1.80	0.01	0.21	0.22	0.21
Biomass 2	REPP 2001	85	40	8.50	0.24	0.13	0.21	1.21	0.25	1.42	0.03	0.16	0.19	
Geothermal 1	WGA 2005	90	40	6.43	1.79	0.00	0.16	1.79	0.18	1.98	0.02	0.23	0.25	0.25
Geothermal 2	CALPIRG 2002	90	40	17.50	1.70	0.00	0.44	1.70	0.49	1.89	0.06	0.22	0.27	
Geothermal 3	EPRI 2001	90	40	4.00	1.67	0.00	0.10	1.67	0.11	1.86	0.01	0.21	0.22	
Landfill Gas 1	CALPIRG 2002	85	40	21.30	7.80	0.00	0.53	7.80	0.63	9.18	0.07	1.05	1.12	0.72
Landfill Gas 2	EPRI 2001	85	40	3.71	2.28	0.00	0.09	2.28	0.11	2.68	0.01	0.31	0.32	
Small Hydro	EPRI 2001	55	40	5.71	1.14	0.00	0.14	1.14	0.26	2.07	0.03	0.24	0.27	0.27
Solar PV 1	EPIA/Greenpeace 2006	20	25	37.00	1.00	0.00	1.48	1.00	7.40	5.00	0.84	0.57	1.42	0.87
Solar PV 2	REPP 2006	20	25	32.34	0.37	0.00	1.29	0.37	6.47	1.85	0.74	0.21	0.95	
Solar PV 3	EPRI 2001	20	25	7.14	0.12	0.00	0.29	0.12	1.43	0.60	0.16	0.07	0.23	
Solar Thermal 1	Skyfuels/NREL 2009	40	25	10.31	1.00	0.00	0.41	1.00	1.03	2.50	0.12	0.29	0.40	0.23
Solar Thermal 2	NREL 2006	40	25	4.50	0.38	0.00	0.18	0.38	0.45	0.95	0.05	0.11	0.16	
Solar Thermal 3	EPRI 2001	40	25	5.71	0.22	0.00	0.23	0.22	0.57	0.55	0.07	0.06	0.13	
Wind 1	EWEA 2008	35	25	10.10	0.40	0.00	0.40	0.40	1.15	1.14	0.13	0.13	0.26	0.17
Wind 2	REPP 2006	35	25	3.80	0.14	0.00	0.15	0.14	0.43	0.41	0.05	0.05	0.10	
Wind 3	McKinsey 2006	35	25	10.96	0.18	0.00	0.44	0.18	1.25	0.50	0.14	0.06	0.20	
Wind 4	CALPIRG 2002	35	25	7.40	0.20	0.00	0.30	0.20	0.85	0.57	0.10	0.07	0.16	
Wind 5	EPRI 2001	35	25	2.57	0.29	0.00	0.10	0.29	0.29	0.83	0.03	0.09	0.13	
Carbon Capture & Storage	Friedmann, 2009	80	40	20.48	0.31	0.06	0.51	0.73	0.64	0.91	0.07	0.10	0.18	0.18
Nuclear	INEEL 2004	90	40	15.20	0.70	0.00	0.38	0.70	0.42	0.78	0.05	0.09	0.14	0.14
Coal	REPP 2001	80	40	8.50	0.18	0.06	0.21	0.59	0.27	0.74	0.03	0.08	0.11	0.11
Natural Gas	CALPIRG 2002	85	40	1.02	0.10	0.09	0.03	0.77	0.03	0.91	0.00	0.10	0.11	0.11
Energy Efficiency 1	ACEEE 2008	100	20										0.17	0.38
Energy Efficiency 2	Goldemberg, 2009	100	20										0.59	

Source: Wei, 2009.

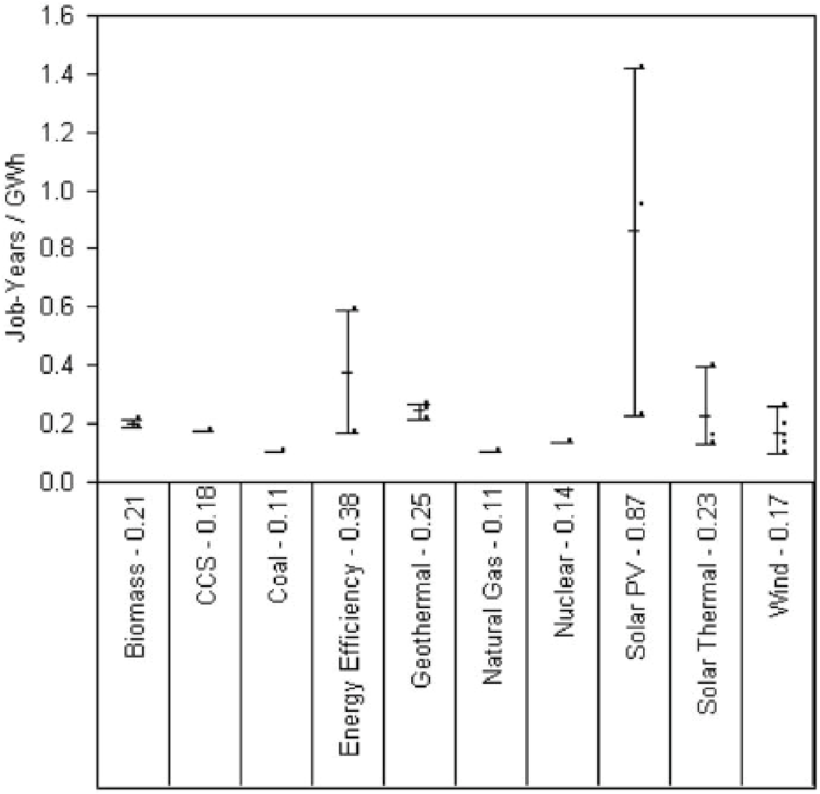


Figure 2. Average and range of direct employment multipliers for 10 different energy technologies

Source: Wei, 2009

- Balance of system costs generates more skilled and semi-skilled jobs in the domestic economy. Also provides opportunities for technology transfer.

> ***Example:***
>
> New skills will be needed by workers in many existing occupations and industries in the process of greening existing skills (ILO, 2011). "The analysis of countries' experience revealed that skill shortages already constrain the transition to a greener economy in terms of preparing for some new occupations and in terms of changing the skill profile of a large number of occupations. [ILO's research] also documented the need to provide opportunities for acquiring new skills to those who are at risk of losing jobs in high-emissions industries. Countries' experiences in adapting training provision to meet all of these needs vary. Some countries are developing innovative strategies and policies to proactively anticipate and address emerging skill needs; others adjust existing mechanisms and systems on a more ad hoc basis" (ILO, 2011, p. v). "Industry-level responses, through such bodies as industry skills councils or chambers of commerce, have already achieved considerable results in several countries. In France, for example, the main federations and business associations in the construction sector launched Qualit'ENR, a program to develop training standards for the installation of renewable energy equipment. Since the creation of the scheme in 2006, training provision has considerably improved" (ILO, 2011, p. xxii). "A number of examples of good practices demonstrate that public policy together with private initiatives can foster the green transformation and job growth. These policies focus on equipping young people entering the labour market and older workers mid-way through their careers with the ability to learn the skills required for adopting new technologies, meeting new environmental regulations, and shifting to renewable sources of energy" (ILO, 2011, p. v).

2.0 RISKS TO PROJECT FINANCING AND O&M

Table 3. **The impact of project risks on green/ grey infrastructure**

	Grey infrastructure	Green infrastructure
Regulatory		
Carbon pricing	-	+
Air pollution laws	-	+
Uncertainly in feed-in-tariff	+	-
Market		
Price volatility of inputs	-	+
Cost of competing options	-	-
Uncertainty related to electricity generation	-	+
Capacity bottlenecks and price volatility	-	-
Technical		
Potential failure	-	-
Cost of decommissioning	-	+
Social Pressure		
Fossil fuel divestment campaign	-	+
Changing consumer preferences	-	+
Requirements for local employment and skills gap	+	+
Cost minimization	+	-

2.1 GREY INFRASTRUCTURE

- Regulatory: Carbon pricing, air pollution laws, power purchase agreement in the context of rapidly changing technology costs.

> ***Example:***
>
> "The new carbon emissions rules from the Environmental Protection Agency in the United States will result in coal-fired power plant shutdowns potentially more than doubling. The new rules (which are being supported by the Obama administration) could result in a projected 90 GW of coal-fired power plants being retired by the year 2040. This compares against the roughly 40 GW of coal-fired power plants that would likely be shutdown anyway by 2040 in the absence of the new carbon emissions rules" (EPA, 2015).
>
> Canada's Prime Minister has stated that if provinces don't impose a price on carbon, the federal government will impose its own price by 2018 (The Winnipeg Chamber of Commerce, 2016)."If neither price nor cap-and-trade is in place by 2018," he said, "the government of Canada will implement a price in that jurisdiction." Manitoba's government recently held a workshop on carbon pricing, and considered opportunities for a "made-in-Manitoba" approach. Each jurisdiction has a unique carbon profile, and needs to govern its emissions accordingly. There has been some international momentum around carbon pricing, with many jurisdictions around the world having implemented or scheduled the implementation of a carbon price. In Canada, BC, Ontario, Quebec, and Alberta (representing the majority of the national population) have each implemented either a tax or a trading scheme, warranting consideration of a coordinated national strategy. A price on carbon has to be complemented with clear regulations and assistance for industry where necessary. There also exists a question of fairness, because a price on carbon will disproportionately affect vulnerable households and communities. Revenue recycling may therefore also need to include tax credits to society's most vulnerable (The Winnipeg Chamber of Commerce, 2016).

- Market: Price volatility for inputs (e.g., coal, natural gas), cost of competing options (e.g., renewable energy).

> ***Example:***
>
> "Australian power prices are likely to remain high and volatile as the market struggles with the withdrawal of base load coal-fired generation, higher gas prices and the growth in renewable capacity… The higher and more volatile price reflects the displacement of high-cost thermal base load power by intermittent renewable supply. Also, evolving generation mix, coupled with the network's limited interconnection capacity, will restrict the market's ability to respond to supply and demand shocks, leading to increased price volatility" (ABC News, 2016).

- Technical: Potential failure due to climate change and extreme conditions (e.g., heat waves, extreme rainfall, landslides), cost of decommissioning.

> ***Example:***
>
> "High water temperatures and diminished access to water caused by drought have forced a number of power plants to ramp down production or acquire waivers to operate with cooling water above regulated temperatures in the United States in the course of 2012" (National Geographic, 2012). For example, "one of two reactors at Millstone Power Station near New London, Connecticut, was shut down when temperatures in Long Island Sound, the source of the facility's cooling water, reached their highest sustained levels since the facility began monitoring in 1971. The outage had no immediate impact on power delivery, as New England was expected to have a buffer of 26 per cent more electricity supply than peak demand in the summer of 2012. But the Connecticut shutdown is a dramatic example of how U.S. power plant operators have had to struggle to keep power generation online through record-breaking weather, including the hottest July on record since 1895 and the most wide-reaching drought since 1956" (National Geographic, 2012).

- Social pressure: Fossil fuel divestment campaign, changing consumer preferences, requirements for local employment and skills gap.

> ***Example:***
>
> The NGO 350.org is carrying out campaigns in the UK, Norway, Sweden, Germany, the Netherlands, South Africa, Australia, and more (350.org, 2015). The NGO is now pressuring South African banks to divest, since the four main banks are all heavily invested in fossil fuel projects throughout Africa. They have also started organizing and mobilizing allies and partners to prepare for a full-blown divestment campaign in Japan to pressure coal funding banks to divest from coal and pressure universities and public institutional investors to divest (350.org, 2015).

2.2 GREEN INFRASTRUCTURE

- Regulatory: Uncertainly in feed-in tariff, carbon pricing, air pollution laws; grid access.

> ***Example:***
>
> An example of how political and regulatory risk can materialize is the move "by Spain and the Czech Republic in 2010 to introduce cuts to feed-in tariffs for existing solar projects of up to 45 per cent, clearly undercutting the rationale for having invested in those projects… Across Europe, according to Standard & Poor's, recent changes to renewable energy subsidy programs have led to cuts in solar feed-in tariffs for new projects ranging from 15 per cent in Germany to 70 per cent in the United Kingdom. It is therefore unsurprising that investors and project developers worry that some of the other 100 or so governments that support renewable energy investments will cut that support as part of austerity packages. While total worldwide investment in renewable energy projects grew strongly in 2010, investment slumped dramatically in some countries where government support lessened" (The Economist, 2015).

- Market: Cost of competing options (e.g., co-generation), uncertainty related to electricity generation; capacity bottlenecks and price volatility (e.g., solar panels).

> ***Example:***
>
> An example of capacity bottleneck is that China in 2007 deliberately idled nearly one-third of all its wind turbines because a saturated power grid lacked spare capacity to carry any electricity from remote wind farms (Forbes, 2011). "While China has largely resolved this issue by expanding the transmission system's capacity, it is not yet out of the woods entirely and still imposes rolling wind outages to avoid overwhelming the grid. Like China, the prodigious expansion of power production from renewable energy resources like wind, solar energy and geothermal has outpaced the ability of the transmission systems to move these new power supplies to centres of demand. As a result, transmission constraints in the United States and the European Union are threatening to table large-scale wind and solar energy projects under development. In some areas where the constraints are especially acute like Oregon and Washington State, the lack of spare transmission capacity could force wind farms that have already been built to shut down on a rolling basis in the near future" (Forbes, 2011).
>
> An instructive example on price volatility of raw materials used in manufacturing for renewable energy projects is represented by the historical trend of the price of polysilicon in China. In fact, a kilo of polysilicon sold for as little as $10 and as much as $500 between 2002 and 2008. Prices were peaking as the financial crisis broke and fell significantly as the global PV market contracted. The Chinese solar industry's long production chain, with its broad variety of polysilicon-related production companies, has expanded and contracted over the years as well. As a result, product supplies have ranged from extreme shortages to excess capacity.

- Technical: Potential failure due to climate change and extreme conditions (e.g., wind speed for wind farms, landslides), excessive wearing of mechanical parts (e.g., wind).

> ***Example:***
>
> In 2013 the South of England was swept by a windstorm. During dangerously high wind, the blades on turbines are supposed to be "feathered"—twisted so they no longer catch the wind and rotate. However, the high-speed wind in that instance destroyed one turbine in Devon (BBC, 2013). "One type of shutdown trigger would be wind over a certain average speed measured over 10 minutes. Another type of shutdown is triggered by gusts, although these would be more than 100 mph, much higher than the current storm" (BBC, 2013). "Variable renewable energy sources such as wind, solar, wave and tidal produce electricity only when the resource conditions are right" (Frankfurt School-UNEP Centre, 2016). The issue of how to make up for the lost generation when power stations are not producing electricity is also relevant, to a varying extent, to other technologies. But it is particularly pertinent for wind and solar, since these power sources are growing rapidly in the world electricity system and because there can be a lot of short-term variation in power output caused by fluctuations in wind speed or cloud cover in front of the sun (Frankfurt School-UNEP Centre, 2016).

- Social pressure: Cost minimization (e.g., to support economic growth).

> ***Example:***
>
> One of the biggest negatives of renewable energy is their capital intensive nature. Renewables have LCOE production than conventional energy. LCOE is the cost per unit of energy over the average lifetime of the technology, including costs for initial investments, fuel, maintenance and operations. An LCOE analysis does not factor in important costs such as environmental externalities, fluctuating fuel prices and high subsidies, therefore misrepresenting conventional energy as cheaper than renewables. If these factors were accounted for in the analysis, conventional energy such as coal or fossil power would be more expensive than renewables in many countries already (WWF, 2015).

3.0 CHALLENGES AND OPPORTUNITIES

3.1 MAIN ROADBLOCKS FOR THE ADOPTION OF SUSTAINABLE INFRASTRUCTURE

Challenges arise for the adoption of green infrastructure in relation to the difficulty in pricing externalities (i.e., estimating the economic value of externalities) and the risk associated with the investment in relation to social and environmental (e.g., climate-driven) events. As a result, investors in the energy sector cannot price the entire spectrum of risks associated with investments in electricity supply.

> ***Example:***
>
> "The impact of environmentally based market failure constraints the adoption of renewable energy technologies through the quantification in financial terms of the externalities of electric power generation, for a range of alternative commercial and almost-commercial technologies… It is shown that estimates of damage costs resulting from combustion of fossil fuels, if internalized into the price of the resulting output of electricity, could lead to a number of renewable technologies being financially competitive with generation from coal plants. However, combined-cycle natural gas technology would have a significant financial advantage over both coal and renewables under current technology options and market conditions. On the basis of cost projections made under the assumption of mature technologies and the existence of economies of scale, renewable technologies would possess a significant social cost advantage if the externalities of power production were to be 'internalised'" (Owen, 2006).

Further, some of the benefits sought by governments are accounted for as costs by investors and project developers (e.g., investment).

> ***Example:***
>
> Solar PV producer LDK in China grew massively between 2005 and 2014, before until filing for bankruptcy in 2015. When the company started losing money, local factories were shut down, resulting in thousands of lost jobs. To avoid shut downs, municipalities started contributing to pay back the companies debts (PV Magazine, 2015).

Finally, action or inaction of governments (e.g., on climate adaptation) can reduce/increase risks for investors and project developers. On the other hand, this brings even more uncertainty to project financing decisions, since policies are constantly evolving at the national level.

> ***Example:***
>
> In 2002 "the United Kingdom began in earnest to build renewable energy plants. The driver was one particular subsidy: the Renewables Obligation, or RO, introduced that year (Quartz, 2015). The money came from consumer bills, and was targeted at the construction of wind farms and other options to reduce carbon intensity in the power sector. This is what made the United Kingdom the third-largest producer of onshore wind energy" (Werber, 2015). However, as of April 2016 new onshore wind projects will no longer be able to access the RO.
>
> It's part of a move toward reforming the country's entire electricity market, and is in line with European guidelines designed to transition the industry off support. The problem, as the UK wind industry sees it, is the sudden change in policy. In the autumn of 2014—before the government won a new term in May's general election—it promised the RO subsidy would continue for new onshore wind until March 2017. More than money, the industry says it craves certainty. Because investment decisions on large infrastructure projects must be made far in advance, a stable regime—one in which the government keeps its promises—is vital to securing commercial investment: the very thing that will allow the subsidies to be removed without leading to a collapse" (Werber, 2015).

Other tangible roadblocks for the adoption of renewable energy include higher capital costs and intermittent supply.

Higher capital cost relative to thermal capacity: Centralized power generation generally has a lower cost per MW installed, and, "in addition to receiving subsidies for research and development as well as for extraction, conventional generating technologies have a lower tax burden. Fuel expenditures can be deducted from taxable income, but few renewables benefit from this deduction, since most do not use market-supplied fuels. Income and property taxes are higher for renewables, which require large capital investments but have low fuel and operating expenses" (Union of Concerned Scientists, 1999).

Intermittent supply (with the need for back up generation or batteries): The fact that wind and solar do not produce energy around the clock is certainly a major disadvantage (Scientific American, 2015). The difficulty associated with integrating variable sources of electricity stems from the fact that the power grid was designed around the concept of large, controllable electric generators. Because the grid has very little storage capacity, the balance between electricity supply and demand must be maintained at all times to avoid a blackout or other cascading problems. Intermittent renewables are challenging because they disrupt the conventional methods for planning the daily operation of the electric grid. Their power fluctuates over multiple time horizons, forcing the grid operator to adjust its day-ahead, hour-ahead and real-time operating procedures (Scientific American, 2015). Batteries are available, and their cost is rapidly declining, but they still represent an additional investment relative to conventional thermal power generation.

3.2 POLICY INTERVENTIONS

The main enabling conditions for achieving green growth in the energy sector relate to channelling investments into energy efficiency, renewable energy and well-designed infrastructure (e.g., for the production, delivery and distribution of electricity).

Some of the policies that can accelerate the transition include pricing mechanisms (e.g., the phasing out of subsides for fossil fuels, a carbon tax or a cap-and-trade system), incentives (e.g., feed-in tariffs for distributed generation) and support for private investments (e.g., concessional loans).

Capacity building is also important, and its main elements are the identification of skill gaps, the establishment of demonstration projects and investments in both R&D and training.

Table 5. **Policies to encourage deployment of renewable energy (RE) generation**

Policy	Definition
	Fiscal Incentives
Grant	Monetary assistance that does not have to be repaid and that is bestowed by a government for specified purposes to an eligible recipient. Usually conditional upon certain qualifications as to the use, maintenance of specified standards, or a proportional contribution by the grantee or other grantor(s). Grants (and rebates) help reduce system investment costs associated with preparation, purchase or construction of RE equipment or related infrastructure. In some cases, grants are used to create concessional financing instruments (e.g., allowing banks to offer low-interest loans for RE systems).
Energy Production payment	Direct payment from the government per unit of RE produced.
Rebate	One-time direct payment from the government to a private party to cover a percentage or specified amount of the investment cost of a RE system or service. Typically offered automatically to eligible projects after completion, not requiring detailed application procedures.
Tax credit (production or investment)	Provides the investor or owner of qualifying property with an annual income tax credit based on the amount of money invested in that facility or the amount of energy that it generates during the relevant year. Allows investments in RE to be fully or partially deducted from tax obligations or income.
Tax reduction/ exemption	Reduction in tax—including but not limited to sales, value-added, energy or carbon tax—applicable to the purchase (or production) of RE or RE technologies.
	Public Finance
Investment	Financing provided in return for an equity ownership interest in a RE company or project. Usually delivered as a government-managed fund that directly invests equity in projects and companies, or as a funder of privately managed funds (fund of funds).
Guarantee	Risk-sharing mechanism aimed at mobilizing domestic lending from commercial banks for RE companies and projects that have high perceived credit (i.e., repayment) risk. Typically a guarantee is partial, that is, it covers a portion of the outstanding loan principal with 50–80 per cent being common.
Loan	Financing provided to an RE company or project in return for a debt (i.e., repayment) obligation. Provided by government, development bank or investment authority usually on concessional terms (e.g., lower interest or with lower security requirements).
Public procurement	Public entities preferentially purchase RE services (such as electricity) and/or RE equipment.
	Regulations
Renewable Portfolio Standard/Quota obligation or mandate	Obligates designated parties (generators, suppliers, consumers) to meet minimum (often gradually increasing) RE targets, generally expressed as percentages of total supplies or as an amount of RE capacity, with costs borne by consumers. Building codes or obligations requiring installation of RE heat or power technologies, often combined with efficiency investments RE heating purchase mandates. Mandates for blending biofuels into total transportation fuel in percent or specific quantity.
Tendering/ Bidding	Public authorities organize tenders for given quota of RE supplies or supply capacities, and remunerate winning bids at prices mostly above standard market levels.
Fixed payment feed-in tariff (FIT)	Guarantees RE supplies with priority access and dispatch, and sets a fixed price varying by technology per unit delivered during a specified number of years.
Premium payment FIT	Guarantees RE supplies an additional payment on top of their energy market price or end-use value.
Green energy purchasing	Regulates the supply of voluntary RE purchases by consumers, beyond existing RE obligations.
Green labelling	Government-sponsored labelling (there are also some private sector labels) that guarantees that energy products meet certain sustainability criteria to facilitate voluntary green energy purchasing. Some governments require labelling on consumer bills, with full disclosure of the energy mix (or share of RE).
Net metering (also net billing)	Allows a two-way flow of electricity between the electricity distribution grid and customers with their own generation. The meter flows backwards when power is fed into the grid, with power compensated at the retail rate during the “netting” cycle regardless of whether instantaneous customer generation exceeds customer demand.
Priority or guaranteed access to network	Provides RE supplies with unhindered access to established energy networks.
Priority dispatch	Mandates that RE supplies are integrated into energy systems before supplies from other sources.

Source: IRENA, 2012

4.0 ACTORS INVOLVED

The main social actors involved in the energy sector are:

- Government: To ensure reliable electricity supply (access and affordability). The government is also involved through parastatal or government-owned utilities.

> ***Example:***
>
> "Renewable energy solutions often receive financial, institutional or educational support from the government… A significant challenge for the actors in the RES field is policy consistency. When investments are carried out, a prognosis for future policies must be made. If the future is uncertain, larger risk margins should be included in the investment appraisals. An example is represented by what happened in Ontario when feed-in tariffs were introduced in 2009 and resulted in a large uptake in the program. Then, in 2010, the subsidies were drastically cut, resulting in the renewable energy community losing confidence that the government would offer consistent support to the sector. By passing the Green Energy Act in 2009, Ontario became the first province to introduce a feed-in tariff to encourage renewable energy, which made them a green energy leader in Canada. The rates were considered generous when they were introduced. These rates were considered to be too generous by those who believed it could only result in increased taxes and higher tariffs for traditional energy sources. Adopters of new technology welcomed the rates and this resulted in a large uptake of the program. A total of 16,000 micro-feed-in tariff applications were received, with 80 per cent of the applications being for small ground-mount solar systems" (Nybakk, 2014).

- The private sector: Especially in the case of auctioning for large infrastructure projects, the private sector plays an important role in the design and construction (as well as operation at times) of electricity generation capacity. The private sector—including investors (debt and equity), constructors and private utilities—is also involved in decisions (and investments) for energy efficiency.

> ***Example:***
>
> "In order to encourage private sector actors to invest in renewable energy and get them mobilized, specific outreach activities should be carried out. This requires not only creating an enabling environment, but also highlighting the various ways that the private sector can achieve business value from sustainable energy actions" (UN, 2014, p. 8). "Business value can be created in the energy sector through brand enhancement. This refers to building a brand that associates positively in the minds of consumers because of the positive linkages to usage of sustainable energy sources. Over time, this can become a source of comparative advantage. [Futhermore, the] use of renewable energy sources can support private sector operators in making them less vulnerable to risks related to, for example, fluctuations in fuel price or regulatory changes issuing new carbon restrictions. Use of renewables can also secure the running of various operations during power cuts and thus reduce risks related to damage caused by temporary cuts in the supply of electricity" (UN, 2014, p. 9). Finally, "sustainable energy can create business value through cost reduction. This refers to mitigating energy costs, for example, by applying energy efficiency measures or switching to renewables" (UN, 2014).

- Households: Primarily involved in investments related to decentralized and small-scale renewable energy supply (e.g., rooftop PV and solar heat water).

> ***Example:***
>
> “Investment bank UBS recently produced a report on how a 50 per cent renewable energy target in Australia might be met. Most interesting was the report’s analysis of the critical role that households could play in knitting RE technologies together. UBS–like other analysts and observers, and some market operators—predicts a massive take-up of solar PV in the coming decade. The number of houses with rooftop solar is expected to jump at least four-fold within the next 10 to 15 years, and businesses will add solar too. Unlike the last few years, this will be accompanied by battery storage, which will be delivering attractive paybacks of 5–6 years by 2020, and quite possibly earlier. In its report, UBS suggests that if one million households—just over 15 per cent of the 6.6 million households in the National Electricity Market—had a battery of around 7kWh, then they would be capable of providing about 2–3 GW of power at any given time.
>
> ‘Household storage and utility storage should be sufficiently economic in 5–6 years to give some confidence that storage will be a “tool” to help deal with the volatility for higher renewable penetration,’ it notes. ‘Storage also helps to manage the swing in capacity as utility-scale PV output drops in the afternoon and prior to the pickup in wind generation.’ The attraction to this is that much of the investment would come from the households themselves, or it could be an incentive for the retailers and others to come in and provide services.
>
> ‘Unlike PV, household storage does not need a detached house,’ UBS writes. ‘If utility-scale solar was priced low enough in the middle of the day, we think households would be incentivized to charge the battery in the middle of the day and consume in the evening.’ UBS also notes that having storage widespread in the community does not mean large numbers disconnecting. But it will mean less investment in the grid in terms of peak and largely unused capacity, and more investment in the ‘intelligence’ of the grid” (RE New Economy, 2015).

- Bilateral and multilateral agencies: To direct investments toward (and co-finance) projects that meet specific sustainability standards. These include multilateral development banks and donors/sponsors.

> ***Example:***
>
> “Recent years have seen considerable growth in the number and variety of multilateral initiatives seeking to foster the deployment of low-carbon energy technologies, particularly since 2005, the year that the Kyoto Protocol to the UNFCCC entered into force. This trend has included: i) new cross-cutting technology initiatives; ii) new technology- and sector-specific initiatives; and iii) an increased focus on international energy technology collaboration within existing multilateral entities that have wider economic or political mandates. Multilateral collaboration for the development and deployment of low-carbon energy technologies is now widely recognized as a crucial component in providing the integrated solutions needed to constrain greenhouse gas emissions while also fostering economic growth and access to secure, affordable energy” (IEA, 2014).

5.0 MEASUREMENT STANDARDS AND DATA

5.1 EXISTING SUSTAINABILITY STANDARDS

Hydropower sustainability assessment protocol: http://www.hydrosustainability.org/

The Hydropower Sustainability Assessment Protocol is a tool that promotes and guides sustainable hydropower projects. It provides a common language that allows governments, civil society, financial institutions and the hydropower sector to talk about and evaluate sustainability issues. The Protocol offers a way to assess the performance of a hydropower project across more than 20 sustainability topics. Assessments are based on objective evidence and the results are presented in a standardized way, making it easy to see how existing facilities are performing and how well new projects are being developed. The Protocol has many uses, each with distinct value, such as i) independent review of sustainability issues; ii) guiding sustainability issues; iii) comparison with international best practice; iv) communication with stakeholders; v) facilitating access to finance; vi) preparing clients to meet bank requirements; vii) reducing risk of investment opportunities. The Protocol can be used at any stage of hydropower development, from the earliest planning stages right through to operation. It has also been designed to work on projects and facilities anywhere in the world.

ISO: http://www.iso.org/iso/home/news_index/iso-in-action/energy.htm

ISO International Standards can help solve the energy challenge by increasing energy efficiency and promoting the development of renewable energy technologies. Over 150 of the 21,000 ISO standards are related to energy efficiency and renewables. These range from the energy-management system standard ISO 50001 that can be used by any organization in any sector, to standards specific to certain sectors, such as building or transportation. For instance, ISO standards on emerging technologies such as solar power can help organizations share best practice and drive uptake. Out of a total of over 21,300 International Standards, ISO has more than 200 related to energy efficiency and renewables, with many more in development. ISO 50001 is based on the management system model of continual improvement also used for other well-known standards such as ISO 9001 or ISO 14001. This makes it easier for organizations to integrate energy management into their overall efforts to improve quality and environmental management. ISO 50001:2011 provides a framework of requirements for organizations to: i) develop a policy for more efficient use of energy; ii) fix targets and objectives to meet the policy; iii) use data to better understand and make decisions about energy use; iv) measure the results achieved; v) and continually improve energy management. In addition to ISO 50001 on energy-management systems, the most widely used energy-related standard, ISO has developed standards on energy performance indicators, the measurement, analysis and verification of energy performance, as well as methodologies for the calculation of energy savings in projects, organizations and regions directly and through fuel switching (e.g., by expanding renewable energy capacity) (ISO, 2016).

SASB: http://www.sasb.org/sectors/renewable-resources-alternative-energy/

SASB Sustainability Accounting Standards are comprised of (1) disclosure guidance and (2) accounting standards on sustainability topics for use by U.S. and foreign public companies in their annual filings (Form 10-K or 20-F) with the U.S. Securities and Exchange Commission (SEC). SASB Standards identify sustainability topics at an industry level, which may constitute material information—depending on a company's specific operating context—for a company within that industry (e.g., Yingly Green in the solar panel manufacturing sector). SASB Standards are intended to provide guidance to company management, which is ultimately responsible for determining which information is material and should therefore be included in its Form 10-K or 20-F and other periodic SEC filings. Indicators include energy consumption by source, air emission calculations, waste generated and recycled, and efforts to implement life cycle approaches. SASB Standards provide companies with standardized sustainability metrics designed to communicate performance on industry-level sustainability topics. When making disclosure on sustainability topics, companies can use SASB Standards to help ensure that disclosure is standardized and therefore decision-useful, relevant, comparable and complete.

5.2 DATA

Technology, Energy Demand and Production

- IEA, *World Energy Outlook*.
- IEA, *Energy Technology Perspectives*.
- IEA, *World Energy Outlook Power Generation Cost Assumptions*.
- BP, *Statistical Review of World Energy*.
- US Geological Survey, *World Petroleum Assessment 2000*.
- US Department of Energy and Energy Information Administration, *International Energy Statistics*.
- Intergovernmental Panel on Climate Change (IPCC). *Fifth Assessment Report* (AR5).
- McKinsey & Company (2009), *Pathways to a Low-Carbon Economy – Version 2 of the Global Greenhouse Gas Abatement Cost Curve*.

Energy Employment

- Wei M., S. Patadia, and M. Kammen (2010). Putting Renewables and Energy Efficiency to Work: How Many Jobs Can the Clean Energy Industry Generate in the US? *Energy Policy 38* (2010) 919-931;
- Greenpeace International (2009). *Energy Sector Jobs to 2030: A Global Analysis*.

The power supply employment consists of: (a) manufacturing, (b) construction and (c) operation and maintenance employment. Each power source has different employment factor for the three identified employment areas. The following are the type of power sources and its employment factors:

a. Hydropower:
   - hydro manufacturing employment factor (0.8 in 2010 to 0.6696 by 2030) per Mw
   - hydro construction employment factor (17.28 in 2010 to 14.46 by 2030) per Mw
   - hydro operating and maintenance employment factor (0.352 in 2010 to 0.2946 by 2030) per Mw

b. Wind power:
   - wind manufacturing employment factor (17.75 in 2010 to 8.771 by 2030) per Mw
   - wind construction employment factor (3.812 in 2010 to 1.902 by 2030) per Mw
   - wind operating and maintenance employment factor (0.63 in 2010 to 0.3156 by 2030) per Mw

c. Solar power:
   - Solar manufacturing employment factor (10.89 in 2010 to 3.474 by 2030) per Mw
   - Solar construction employment factor (35.06 in 2010 to 11.19 by 2030) per Mw
   - Solar operating and maintenance employment factor (0.756 in 2010 to 0.2412 by 2030) per Mw

d. Geothermal power:
   - Geothermal manufacturing employment factor (7.081 in 2010 to 3.43 by 2030) per Mw
   - Geothermal construction employment factor (6.651 in 2010 to 3.23 by 2030) per Mw
   - Geothermal operating and maintenance employment factor (2.36 in 2010 to 1.146 b y2030) per Mw

e. Landfill gas:
   - Landfill manufacturing employment factor (0.8479 in 2010 to 0.547 by 2030) per Mw
   - Landfill construction employment factor (8.267 in 2010 to 5.333 by 2030) per Mw
   - Landfill operating and maintenance employment factor (3.291 in 2010 to 2.123 by 2030) per Mw

f. Nuclear energy:
    - Nuclear manufacturing employment factor (0)
    - Nuclear construction employment factor (24.96 in 2010 to 18.72 by 2030) per Mw
    - Nuclear operating and maintenance employment factor (0.824 in 2010 to 0.618 by 2030) per Mw

g. Waste to energy:
    - Waste manufacturing employment factor (0.8479 in 2010 to 0.547 by 2030) per Mw
    - Waste construction employment factor (8.267 in 2010 to 5.333 by 2030) per Mw
    - Waste operating and maintenance employment factor (3.291 in 2010 to 2.123 by 2030) per Mw

h. Coal power:
    - Coal manufacturing employment factor (0.0038 in 2010 to 0.0025) per Mw
    - Coal construction employment factor (18.32 in 2010 to 12.18 by 2030) per Mw
    - Coal operating and maintenance employment factor (0.344 in 2010 to 0.2287 by 2030) per Mw

i. Co-generation power:
    - Co-generation manufacturing employment factor (0.8479 in 2010 to 0.547 by 2030) per Mw
    - Co-generation construction employment factor (8.267 in 2010 to 5.333 by 2030) per Mw
    - Co-generation operating and maintenance employment factor (3.291 in 2010 to 2.123 by 2030) per Mw

j. Diesel and fuel energy:
    - Diesel and fuel manufacturing employment factor (0.001 in 2010 to 0.0007) per Mw
    - Diesel and fuel construction employment factor (3.535 in 2010 to 2.422 by 2030) per Mw
    - Diesel and fuel operating and maintenance employment factor (0.456 in 2010 to 0.3125 by 2030) per Mw

- Oil extraction employment: oil employment factor ranges from 105 per Mb in 1970 to 111 per Mb in 2008, assumed at 85 Mb in 2050. Oil and gas employment (from ILO) is disaggregated based on the ratio between oil and gas production volume in Btu.
    - Oil and gas employment: International Labour Organization (ILO); Labour Statistics (LABORSTA).
- Natural gas extraction employment: this employment is anchored to the oil and gas data mentioned above. Natural gas employment factor ranges from 17.5 per Bcf in 1970 to 18.7 per Bcf in 2008, assumed at 14.2 in 2050.
    - Oil and gas employment: ILO; LABORSTA.
- Coal extraction employment: this employment relates to coal production. Coal employment factor is 1,400 per mst in 1990, 770 in 2010 and 200 in 2050.
    - Data sources for coal extraction employment: According to China's data, the factor is 1,785 per mst (from ILO, email), calculated as the fraction of coal production (2.8 billion mst in 2007) over employment (5 million). On the other hand, in the US, the employment for coal extraction and processing for power generation is only 1/17 of China's value (108 per mst; Wei et al. 2010). We calculated the share of world's coal production to get a weighted average that uses 60 per cent of US's value and 40 per cent of China's value (China produces 37.5 per cent of world's coal).

Technology Cost

Table 6. Technology capital and O&M cost (IEA, see Annex I for more detail).

Renewables - regional details	Capital cost ($2012 per kW)		Yearly O&M cost ($2012 per kW)		Efficiency (power generation %)		Capacity factor (%)		Construction Time (years)	
	2012	2035	2012	2035	2012	2035	2012	2035	2012	2035
Biomass Power plant										
Europe	2380	2170	83	76	35%	35%	70%	70%	3.0	3.0
United States	2500	2320	87	81	35%	35%	70%	70%	3.0	3.0
Africa	2160	1990	76	70	35%	35%	70%	70%	3.0	3.0
Geothermal										
Europe	2980	2820	60	56	15%	15%	70%	80%	4.0	4.0
United States	2090	1890	42	38	15%	15%	73%	80%	4.0	4.0
Africa	2620	2320	52	46	15%	15%	65%	75%	4.0	4.0
Hydropower - large-scale										
Europe	2270	2890	53	67	100%	100%	26%	26%	4.0	4.0
United States	2510	2500	62	61	100%	100%	33%	33%	4.0	4.0
Africa	1870	2030	45	49	100%	100%	50%	50%	4.0	4.0
Hydropower - small-scale										
Europe	4040	4030	70	70	100%	100%	30%	30%	4.0	4.0
United States	4010	3990	79	78	100%	100%	30%	30%	4.0	4.0
Africa	2990	2930	60	59	100%	100%	50%	50%	4.0	4.0
Solar photovoltaics - Buildings										
Europe	3250	1910	33	30	100%	100%	12%	14%	1.0	1.0
United States	4450	2620	45	42	100%	100%	16%	17%	1.0	1.0
Africa	3540	1950	35	31	100%	100%	16%	19%	1.0	1.0
Wind onshore										
Europe	1790	1630	46	41	100%	100%	22%	24%	1.5	1.5
United States	1890	1710	47	43	100%	100%	29%	30%	1.5	1.5
Africa	1540	1380	39	35	100%	100%	26%	27%	2.5	1.5
Wind offshore										
Europe	5180	3310	181	116	100%	100%	38%	46%	2.5	2.5
United States	5390	3320	189	116	100%	100%	37%	47%	2.5	2.5
Africa	4680	3030	164	106	100%	100%	39%	46%	4.0	2.5

Emissions per kWh (IEA – EPA)

It is possible to calculate the amount of carbon dioxide (CO_2) produced per kilowatt hour (kWh) for specific fuels and specific types of generators by multiplying the CO_2 emissions factor for the fuel (in pounds of CO_2 per million Btu) by the heat rate of a generator (in Btu per kWh generated), and dividing the result by 1,000,000.

Table 7. CO_2 emissions per kWh, by source

Fuel	Pounds of CO_2 per million Btu	Heat rate (Btu per kWh)	Pounds of CO_2 per kWh
Coal			
Bituminous	205.691	10,080	2.07
Subbituminous	214.289	10,080	2.16
Lignite	215.392	10,080	2.17
Natural gas	116.999	10,408	1.22
Distillate oil	161.290	10,156	1.64
Residual oil	173.702	10,156	1.76

Source IEA (available at https://www.eia.gov/tools/faqs/faq.cfm?id=74&t=11*)*

Although coal represented 29 per cent of the world's total primary energy supply (TPES) in 2013, it accounted for 46 per cent of global CO_2 emissions due to its heavy carbon content per unit of energy, and the fact that 19 per cent of TPES is derived from carbon-neutral fuels (IEA, 2015). Compared to gas, coal is nearly twice as emissive. From the late 1980s until the early 2000s, coal and oil were each responsible for approximately 40 per cent of global CO_2 emissions, with emissions from oil generally exceeding those from coal by a few percentage points. However, trends differed at a regional level. In Annex I countries, oil was the largest source of fuel combustion emissions, whereas, in non-Annex I countries emissions from coal ranked highest. Since 2002, due to the increasing influence of non-Annex I countries' energy consumption, coal has increased its share of CO_2 emissions from 40 per cent in 2002 to 46 per cent in 2013, while the share from oil has decreased from 39 per cent to 33 per cent, with the share of emissions from natural gas staying approximately stable at 20 per cent. In 2013, CO_2 emissions from the combustion of coal increased by 3.4 per cent to 14.8 $GtCO_2$. Currently, coal fills much of the growing energy demand of those developing countries (such as China and India), where energy-intensive industrial production is growing rapidly and large coal reserves exist with limited reserves of other energy sources (IEA, 2015).

Land Requirements per Energy Source

Each technology utilized to produce electricity requires land. This is particularly true for options that require feedstock as input for thermal power generation. While oil, gas and coal require land through mining, co-generation and biomass-based electricity generation require land directly to grow fibre.

Table 8. Land requirements by technology and energy source (power generation and feedstock energy)

Capacity type	Value	Unit	Source
Land requirement coefficients based on energy production			
Coal	1.6474 E-4	Ha/MWh	(Nace, 2010)
Gas	1.3 E-4	Ha/Year/MWh	(IEA, 2002)
Land requirement coefficients based on capacity			
Nuclear	1.27687	Ha/MW	(Cheng & Hammond, 2016)
Biomass	10,000[a]	Ha/MW	(PPCR, 2012)
Hydropower small scale	6.9337	Ha/MW	Average value from Hydro sustainability reports[b]
Hydropower large scale	49.0453	Ha/MW	Average value from Hydro sustainability reports[c]
Solar small scale	2.38765	Ha/MW	(NREL, 2013)
Solar large scale	2.91374	Ha/MW	(NREL, 2013)
Wind	34.5	Ha/MW	(NREL, 2013)

a. Land requirements for biomass supply included
b. http://www.hydrosustainability.org/
c. http://www.hydrosustainability.org/

Life-Cycle Resource Consumption of Capacity

In addition to requiring land, power generation capacity requires construction materials, such as cement and steel. Material intensity varies considerably across technologies and energy sources, as indicated by the life cycle utilization of cement and steel presented in Table 9.

Table 9. Life cycle cement and steel use by technology

Capacity type	Cement	Steel	Unit
Coal	4.19 E-3	2.26 E-3	tonne/mWh
Gas	7.04 E-4	1.58 E-3	tonne/mWh
Nuclear	2.41 E-4	9.52 E-5	tonne/mWh
Biomass			
Hydro power	6.7 E-3	9.63 E-5	tonne/mWh
Solar power			
Wind power	3.92 E-3	6.61 E-3	tonne/mWh

Emissions from Electricity Generation, by Technology (Tonne per MWh) and Economic Valuation

In addition to estimating emissions from the burning of fossil fuels, life-cycle emissions are considered capture processes that go beyond the production of electricity alone. This includes, for instance, emissions from the manufacturing on power generation capacity.

Table 10. Life-cycle missions per MWh in North America, by fuel input

Capacity type	SO_2	NO_x	$PM_{.5}$	PM_{10}	Source
Coal	3.53 E-3	1.24 E-3	3.18 E-4	4.46 E-4	(CEC, 2011)
Gas	-	3.78 E-7	2.7 E-4	3.4 E-4	(CEC, 2011)
Nuclear	1.29 E-5	1.66 E-5	-	-	(IEA, 2002)
Biogass	6.26 E-4	8.4 E-5	-	-	(IEA, 2002)

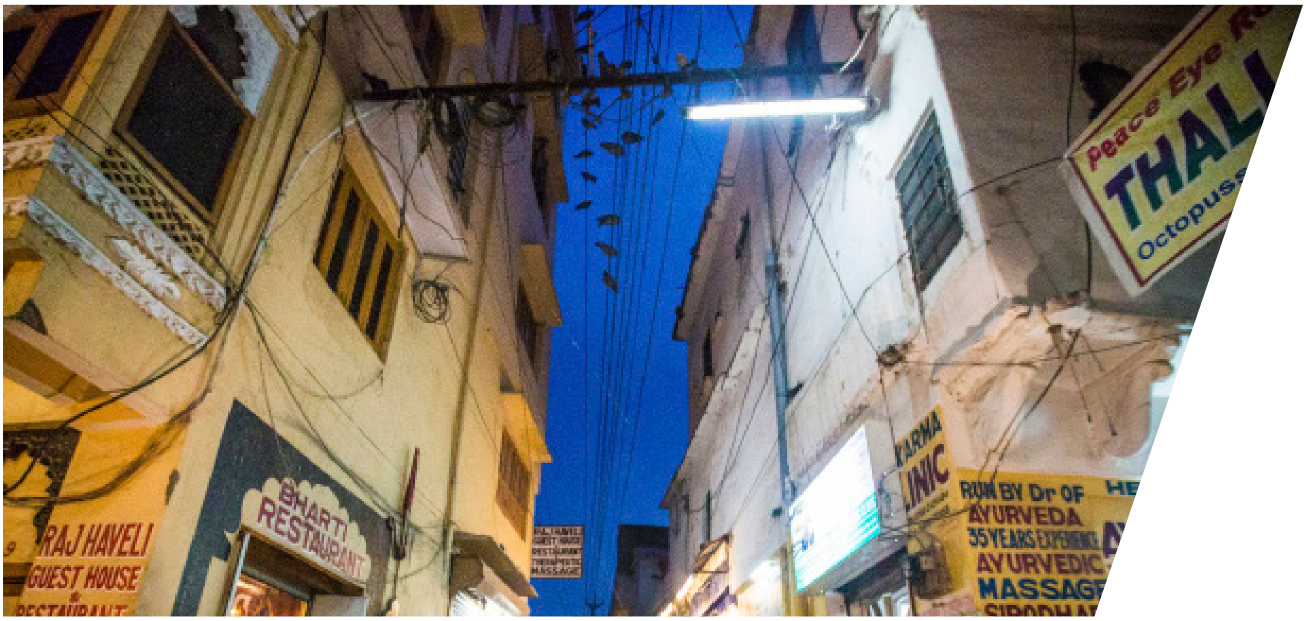
Source: Turconi, 2013

In addition to the envionmental impact that emissions may have, it is important to consider the health impacts and resulting economic valuation of morbidity and mortality. Table 11 presents estimations of avoided health costs for the reduction of a tonne of $PM_{2.5}$ SO_2 and NO_x. Values are presented considering 3 per cent and 7 per cent discount factors.

Table 11. Total dollar value (mortality and morbidity) per ton of directly emitted $PM_{2.5}$, SO_2 and NO_x

Valuation of $PM_{2.5}$, SO_2 and NO_x at a 3 per cent discount factor					
	Unit	**2016**	**2020**	**2025**	**2030**
dollar value of directly emitted $PM_{2.5}$	USD 2010/tonne	130,000	140,000	150,000	160,000
dollar value of directly emitted SO_2	USD 2010/tonne	35,000	37,000	40,000	43,000
dollar value of directly emitted NO_x	USD 2010/tonne	5,200	5,400	5,800	6,200
Valuation of $PM_{2.5}$, SO_2 and NO_x at a 7 per cent discount factor					
	Unit	**2016**	**2020**	**2025**	**2030**
dollar value of directly emitted $PM_{2.5}$	USD 2010/tonne	120,000	120,000	130,000	140,000
dollar value of directly emitted SO_2	USD 2010/tonne	31,000	33,000	36,000	39,000
dollar value of directly emitted NO_x	USD 2010/tonne	4,600	4,900	5,200	5,600

Source: EPA, 2013



7.0 MAIN ORGANIZATIONS WORKING ON THE ASSESSMENT OF INFRASTRUCTURE FOR SUSTAINABLE ROADS

- International Energy Agency (IEA)
- International Renewable Energy Agency (IRENA)
- World Development Indicators (WB)
- Sustainable Energy for All (SE4ALL),
- International Labour Organization (ILO)
- Fraunhofer Institute
- Environmental Protection Agency (EPA)
- Frankfurt School-UNEP
- International Institute for Sustainable Development (IISD)
- UN Committee on Climate Change

Table 12. Assessment of selected green economy interventions in the energy sector

		Market support			Multi-criteria analysis		
Goal	**Policy**	**Awareness**	**Demand**	**Supply**	**Investment**	**Avoided cost**	**Added benefit**
	Incentives for distributed capacity		x		Public incentive (G), Purchase of RE capacity (H)	Electricity bill (H), Public generation capacity (G), Reduced grid blackouts (H,P), Avoided water consumption (H,P), Reduced health spending (G,H)	Lower emissions (G,H), Employment creation (H), Avoided impact on soil and water quality (G, H), Increased access to electricity (H,P)
	Incentives for production and servicing			x	Public incentive (G), Purchase of machineries (P), Capacity building (P)	Import of RE capacity (P), Public generation capacity (G)	Improved balance of payments (G), Employment creation (H), Tax revenue (G), GDP growth (P,G), Skill creation (P,H)
Energy efficiency	Incentives for building retrofits and efficiency appliances		x		Public incentive (G), Purchase of products or retrofits (P,H)	Electricity and energy bill (H,P), Reduced fossil fuel use (H,P), Public generation capacity (G)	Lower emissions (G), Employment creation (H), Higher savings/ consumption (H,G)

Note: P – Private sector; G – Government; H - Households

BIBLIOGRAPHY

350.org. (2015). *350 Campaign Update: Divestment*.

ABC News. (2016). *Power prices set to remain high and volatile*. Retrieved from http://www.abc.net.au/news/2016-08-25/power-prices-set-to-remain-high-and-volatile/7785982

Abood, S. A. (2015). Relative Contributions of the Logging, Fiber, Oil Palm, and Mining Industries to Forest loss in Indonesia. *Conservation Letters*, Volume 8, Issue 1.

BBC. (2013). *Who, what, why: What happens to wind turbines in a storm?* Retrieved from http://www.bbc.com/news/blogs-magazine-monitor-24706238

Carbon Trust. (2013). *Decentralised energy: Powering a sustainable future*.

CEC. (2011). *North American power plant air emissions*. Montréal: Commission for Environmental Cooperation.

Chang, T. (2016). Air pollution is making office workers less productive. *Harward Business Review*.

Cheng, V., & Hammond, G. (2016). Life-cycle energy densities and land-take requirements of various power generators: A UK perspective. *Journal of Energy Institute, 90*,(2), 201–213.

Commission for Environmental Cooperation. (2008). *Renewable energy as a hedge against fuel price fluctuation: How to capture the benefits.* Retrieved from http://www.cec.org/islandora/en/item/2360-renewable-energy-hedge-against-fuel-price-fluctuation-en.pdf

Desaigues, B. (2011). Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY). *Ecological Indicators, 11*(3).

Eerden, V. d. (1988). Crop loss due to air pollution in The Netherlands. *Environmental Pollution, 53*, (1–4), 365–376.

EIA. (2016). *Levelized cost and levelized avoided cost resources in the annual energy outlook 2016.* Washington, D.C.

EPA. (2010). *Nutrient pollution*. Retrieved from https://www.epa.gov/nutrientpollution

EPA. (2013). *Estimating the benefit per ton of reducing pm2.5 - Precursors from 17 sectors*. North Carolina: U.S. Environmental Protection Agency.

EPA. (2015). *Analysis of the impacts of the clean power plan*. Washington D.C.

Fares, R. (2015). *Renewable energy intermittency explained: Challenges, solutions, and opportunities.*

Forbes. (2011). *Transmission bottlenecks bad news for renewable energy*. Retrieved from http://www.forbes.com/sites/williampentland/2011/05/03/transmission-bottlenecks-bad-news-for-renewable-energy/#306027b27db7

Frankfurt School-UNEP Centre. (2016). *Global trends in renewable energy investment 2016.* Frankfurt. Retrieved from http://fs-unep-centre.org/sites/default/files/publications/globaltrendsinrenewableenergyinvestment2016lowres_0.pdf.

Fraunhofer Society. (2013). *Levelized cost of electricity renewable energy technologies.* Munich. Retrieved from https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/Fraunhofer-ISE_LCOE_Renewable_Energy_technologies.pdf

Friends of the Earth. (2013). *Nuclear power and water consumption*.

Fukushima on the Globe. (2014). *The nuclear accident*.

IEA. (2002). *Environmental and health impacts of electricity generation*. Paris: International Energy Agency.

IEA. (2014). *Mapping multilateral collaboration on low-carbon energy technologies*. Paris: International Energy Agency.

IEA. (2015). *CO_2 emissions from fossil fuels combustion*. Paris: International Energy Agency.

IISD. (2015). *How green public procurement contributes to sustainable development in China*. Retrieved from http://www.iisd.org/sites/default/files/publications/how-gpp-contributes-sustainable-development-china.pdf

ILO. (2011). *Skills for green jobs: A global view.* Geneva.

IRENA. (2012). *Evaluating policies in support of the deployment of renewable power.* Masdar City. Retrieved from https://www.irena.org/DocumentDownloads/Publications/Evaluating_policies_in_support_of_the_deployment_of_renewable_power.pdf

IRENA. (2015). *Renewable power generation costs in 2014.* Masdar City. Retrieved from https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

IRENA. (2016). *Renewable energy and jobs - Annual review.* Masdar City. Retrieved from https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Jobs_Annual_Review_2016.pdf

ISO. (2016). *ISO and energy. Geneva.*

Lifset, R. (2012). Toward Meta-Analysis in Life Cycle Assessment. *Journal of Industrial Ecology, 16*(s1), S1-S2.

McCool, P. (1986). Determining crop yield losses from air pollution. *California Agriculture*.

Nace, T. (2010, 11 18). *Grist*. Retrieved from http://grist.org/article/2010-11-17-which-has-bigger-footprint-coal-plant-or-solar-farm/

National Geographic. (2012). *Record heat, drought pose problems for U.S. electric power.* Retrieved from http://news.nationalgeographic.com/news/energy/2012/08/120817-record-heat-drought-pose-problems-for-electric-power-grid/

NREL. (2009). *Land-use requirements of modern wind power plants in the United States*. Colorado: National Renewable Energy Lab.

NREL. (2013). *Land-use requirements for solar power plants in the United States*. Colorado: National Renewable Energy Lab.

Nuwer, R. (2013). Air pollution closed schools in China. *Smithsonian Magazine*.

Nybakk, E. (2014). The role of governments in renewable energy: The importance of policy consistency. *Biomass and Bioenergy, 57*: 97–105.

Owen, A. (2006). Renewable energy: Externality costs as market barriers. *Energy Policy, 34*(5): 632-642.

Pan, G. (2010). Air pollution and children's respiratory symptoms in six cities of Northern China. R*espiratory Medicine, 104*(12), 1903-1911.

PPCR. (2012). *Presentation of 25MW Biomass Power Plant in Kozani Area.* Kozani: PPC Renewables.

PV Magazine. (2015). *LDK solar emerges from bankruptcy.* Retrieved from https://www.pv-magazine.com/2015/02/20/ldk-solar-emerges-from-bankruptcy_100018292/

RE New Economy. (2015). *Households to play central role in high renewable energy system.* Retrieved from http://reneweconomy.com.au/households-to-play-central-role-in-high-renewable-energy-system-35577/

Regional Center for Renewable Energy and Energy Efficiency. (2013). *Environmental externalities from electric power generation.* Cairo: RCREEE.

Swarthmore College. (2010). *Comparison against other fossil fuels.* Retrieved from http://www.swarthmore.edu/environmental-studies-capstone/comparison-against-other-fossil-fuels

The Economist. (2015). *The growing importance of renewable energy risk*. Retrieved from http://www.economist.com/topics/alternative-energy-1

The Winnipeg Chamber of Commerce. (2016). *Carbon pricing and Manitoba*.

TranSafety. (1997). *Factors that determine the reduction in property values caused by traffic noise*. Retrieved from http://www.usroads.com/journals/p/rej/9710/re971004.htm

Tripathi, L. (2015). Water pollution through energy sector. *International Journal of Technology Enhancements and Emerging Engineering Research, 3*(3), 2347–4289.

Turconi, R. B. (2013). Life cycle assessment (LCA) of electricity generation technologies: overview, comparability and limitations. *Renewable and sustainable energy reviews, 28*, 555–565.

UK Committee on Climate Change. (2015). *Meeting carbon budgets - Progress in reducing the UK's emissions*. London.

UN. (2014). *Role of the private sector in advancing the implementation of the IPoA: Focus on sustainable energy.* Retrieved from http://unohrlls.org/custom-content/uploads/2014/01/Role-of-the-private-sector-in-advancing-the-implementation-of-the-IPoA.pdf

Union of Concerned Scientists. (1999). *Barriers to renewable energy technologies.* Retrieved from http://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/barriers-to-renewable-energy.html#.WbMOB9N97cM

Union of Concerned Scientists. (2016). *Environmental impacts of solar power.* Retrieved from http://www.ucsusa.org/clean_energy/our-energy-choices/renewable-energy/environmental-impacts-solar-power.html#.WbMOJdN97cM

US Department of Agriculture. (2000). *Ecosystem valuation.* Retrieved from http://www.ecosystemvaluation.org/

Weber, C. (2015). *The UK is scrapping one of its most successful renewable energy subsidies*. Retrieved from http://qz.com/431684/the-uk-is-scrapping-one-of-its-most-successful-renewable-energy-subsidies/

Wei M., S. Patadia, and M. Kammen (2010). Putting renewables and energy efficiency to work: How many jobs can the clean energy industry generate in the US? *Energy Policy, 38*(2), 919–931.

WWF. (2015). *Busting the myths on renewable energy.* Retrieved from http://awsassets.panda.org/downloads/myth_buster_brochure.pdf

ANNEX I – POWER GENERATION CAPACITY DATA

Renewables - regional details	Capital cost ($2012 per kW)		Yearly O&M cost ($2012 per kW)		Efficiency (power generation %)		Capacity factor (%)		Construction Time (years)	
	2012	**2035**	**2012**	**2035**	**2012**	**2035**	**2012**	**2035**	**2012**	**2035**
Biomass Power plant										
Europe	2380	2170	83	76	35%	35%	70%	70%	3.0	3.0
United States	2500	2320	87	81	35%	35%	70%	70%	3.0	3.0
Japan	2400	2220	84	78	35%	35%	70%	70%	3.0	3.0
Russia	2260	2160	79	76	35%	35%	70%	70%	3.0	3.0
China	1610	1540	56	54	35%	35%	70%	70%	3.0	3.0
India	2150	2030	75	71	35%	35%	70%	70%	3.0	3.0
Middle East	2240	2040	78	71	35%	35%	70%	70%	3.0	3.0
Africa	2160	1990	76	70	35%	35%	70%	70%	3.0	3.0
Brazil	2220	2090	78	73	35%	35%	70%	70%	3.0	3.0
Biomass - waste incineration - CHP										
Europe	8500	7820	323	297	50%	50%	65%	65%	3.0	3.0
United States	9210	8520	350	324	50%	50%	65%	65%	3.0	3.0
Japan	8400	7770	319	295	50%	50%	65%	65%	3.0	3.0
Russia	7600	7390	289	281	50%	50%	65%	65%	3.0	3.0
China	5580	5360	212	204	50%	50%	65%	65%	3.0	3.0
India	7260	6820	276	259	50%	50%	65%	65%	3.0	3.0
Middle East	7500	6920	285	263	50%	50%	65%	65%	3.0	3.0
Africa	7320	6790	278	258	50%	50%	65%	65%	3.0	3.0
Brazil	7750	7300	295	277	50%	50%	65%	65%	3.0	3.0
Geothermal										
Europe	2980	2820	60	56	15%	15%	70%	80%	4.0	4.0
United States	2090	1890	42	38	15%	15%	73%	80%	4.0	4.0
Japan	2850	2730	57	55	15%	15%	64%	64%	4.0	4.0
Russia	2320	2140	46	43	15%	15%	68%	78%	4.0	4.0
China	2110	1950	42	39	15%	15%	68%	78%	4.0	4.0
India	2070	1890	41	38	15%	15%	65%	75%	4.0	4.0
Middle East	2080	1910	41	38	15%	15%	65%	75%	4.0	4.0
Africa	2620	2320	52	46	15%	15%	65%	75%	4.0	4.0
Brazil	2660	2450	53	49	15%	15%	65%	75%	4.0	4.0
Hydropower - large-scale										
Europe	2270	2890	53	67	100%	100%	26%	26%	4.0	4.0
United States	2510	2500	62	61	100%	100%	33%	33%	4.0	4.0
Japan	2430	2400	59	58	100%	100%	24%	24%	4.0	4.0
Russia	2040	2150	51	54	100%	100%	43%	43%	4.0	4.0
China	1700	1760	39	39	100%	100%	38%	38%	4.0	4.0
India	1900	2320	45	54	100%	100%	37%	35%	4.0	4.0
Middle East	2070	2080	51	51	100%	100%	25%	25%	4.0	4.0
Africa	1870	2030	45	49	100%	100%	50%	50%	4.0	4.0
Brazil	2060	2560	48	60	100%	100%	54%	54%	4.0	4.0

Renewables - regional details	Capital cost ($2012 per kW)		Yearly O&M cost ($2012 per kW)		Efficiency (power generation %)		Capacity factor (%)		Construction Time (years)	
	2012	2035	2012	2035	2012	2035	2012	2035	2012	2035
Hydropower - small-scale										
Europe	4040	4030	70	70	100%	100%	30%	30%	4.0	4.0
United States	4010	3990	79	78	100%	100%	30%	30%	4.0	4.0
Japan	3920	3890	75	74	100%	100%	30%	30%	4.0	4.0
Russia	3260	3440	65	69	100%	100%	40%	40%	4.0	4.0
China	2120	2260	41	43	100%	100%	40%	40%	4.0	4.0
India	2980	3050	60	61	100%	100%	30%	30%	4.0	4.0
Middle East	3200	3180	64	64	100%	100%	30%	30%	4.0	4.0
Africa	2990	2930	60	59	100%	100%	50%	50%	4.0	4.0
Brazil	3410	3480	65	66	100%	100%	50%	50%	4.0	4.0
Solar photovoltaics - Large-scale										
Europe	2490	1440	25	22	100%	100%	13%	17%	1.5	1.5
United States	3000	1730	32	28	100%	100%	19%	20%	1.5	1.5
Japan	2950	1650	30	26	100%	100%	12%	15%	1.5	1.5
Russia	3200	1810	33	29	100%	100%	12%	12%	1.5	1.5
China	1850	1050	18	16	100%	100%	16%	19%	1.5	1.5
India	2120	1170	21	19	100%	100%	16%	20%	1.5	1.5
Middle East	2690	1440	27	24	100%	100%	20%	22%	1.5	1.5
Africa	2590	1440	26	23	100%	100%	20%	22%	1.5	1.5
Brazil	2550	1420	26	22	100%	100%	16%	19%	1.5	1.5
Solar photovoltaics - Buildings										
Europe	3250	1910	33	30	100%	100%	12%	14%	1.0	1.0
United States	4450	2620	45	42	100%	100%	16%	17%	1.0	1.0
Japan	5130	3060	53	37	100%	100%	13%	14%	1.0	1.0
Russia	3710	2090	37	33	100%	100%	9%	10%	1.0	1.0
China	2050	1170	21	18	100%	100%	14%	16%	1.0	1.0
India	2530	1550	25	23	100%	100%	15%	18%	1.0	1.0
Middle East	3670	1960	37	32	100%	100%	17%	21%	1.0	1.0
Africa	3540	1950	35	31	100%	100%	16%	19%	1.0	1.0
Brazil	3420	1860	34	30	100%	100%	14%	17%	1.0	1.0
Concentrating solar power										
Europe	7250	4580	290	183	40%	40%	37%	41%	2.0	2.0
United States	5980	3810	239	153	40%	40%	45%	45%	2.0	2.0
Japan	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Russia	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a	n.a
China	5310	3330	212	133	40%	40%	39%	46%	2.0	2.0
India	5200	3270	208	131	40%	40%	39%	41%	3.0	2.5
Middle East	5150	2980	205	119	40%	40%	39%	41%	3.0	2.5
Africa	5250	3010	210	120	40%	40%	34%	43%	3.0	2.5
Brazil	7450	4430	288	177	40%	40%	40%	46%	3.0	2.5
Wind onshore										
Europe	1790	1630	46	41	100%	100%	22%	24%	1.5	1.5
United States	1890	1710	47	43	100%	100%	29%	30%	1.5	1.5
Japan	1830	1630	46	41	100%	100%	24%	27%	1.8	1.5

Renewables - regional details	Capital cost ($2012 per kW)		Yearly O&M cost ($2012 per kW)		Efficiency (power generation %)		Capacity factor (%)		Construction Time (years)	
	2012	**2035**	**2012**	**2035**	**2012**	**2035**	**2012**	**2035**	**2012**	**2035**
Russia	1570	1430	39	36	100%	100%	24%	27%	2.5	1.5
China	1300	1240	35	33	100%	100%	23%	26%	1.8	1.5
India	1510	1420	39	36	100%	100%	21%	24%	1.8	1.5
Middle East	1580	1420	40	36	100%	100%	24%	26%	2.5	1.5
Africa	1540	1380	39	35	100%	100%	26%	27%	2.5	1.5
Brazil	1590	1470	41	37	100%	100%	41%	42%	2.5	1.5
Wind offshore										
Europe	5180	3310	181	116	100%	100%	38%	46%	2.5	2.5
United States	5390	3320	189	116	100%	100%	37%	47%	2.5	2.5
Japan	5190	3220	182	113	100%	100%	41%	48%	3.0	2.5
Russia	4930	3120	173	109	100%	100%	38%	45%	4.0	2.5
China	4440	2860	155	100	100%	100%	41%	46%	3.0	2.5
India	4670	2970	163	104	100%	100%	35%	47%	3.0	2.5
Middle East	4910	3100	172	109	100%	100%	40%	47%	4.0	2.5
Africa	4680	3030	164	106	100%	100%	39%	46%	4.0	2.5
Brazil	4810	3050	168	107	100%	100%	40%	50%	4.0	2.5

ANNEX II - METHODS TO ESTIMATE EXTERNALITIES

Externalities in power generation are considerable. Many studies are available that provide estimates on a per kWh basis (Figure A1, Figure A2). On the other hand, these estimates are heavily influenced by local conditions. As a result, an overview of the main methodologies available to estimate and value these externalities is provided.

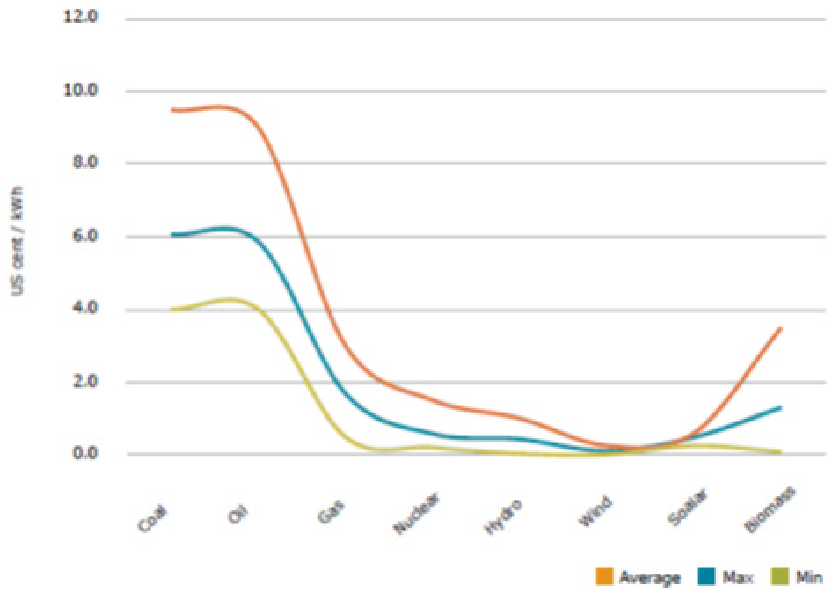


Figure A1. Range of external cost estimates (US c/kWh)

Source: Regional Center for Renewable Energy and Energy Efficiency, 2013

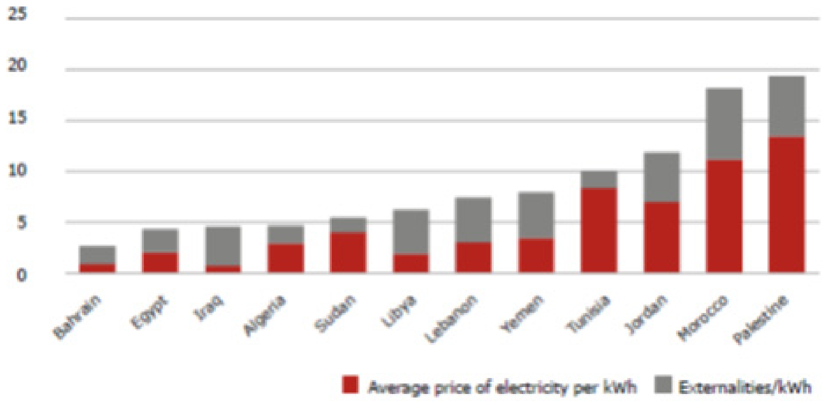


Figure A2. True price of electricity (2011) considering externalities

Source: Regional Center for Renewable Energy and Energy Efficiency, 2013

- Human health (mortality and morbidity): To calculate the damage costs of air pollution, the valuation of mortality is important because premature mortality makes, by far, the largest contribution (Desaigues, 2011). "While several studies try to quantify the cost of air pollution mortality by multiplying the number of deaths by the 'value of prevented fatality' (also known as 'value of statistical life'), others evaluate the change in life expectancy due to air pollution. To do this, an estimate for the monetary value of a life year (VOLY) is needed. The most appropriate method for determining VOLY is contingent valuation (CV). To determine VOLY for the European Union, the study has conducted a CV survey in nine European countries: based on the results from this CV survey the study recommends a VOLY estimate of 40,000 € for cost–benefit analysis of air pollution policies for the European Union. As for confidence intervals, the study argues that VOLY is at least 25,000 € and at the most 100,000 €" (Desaigues, 2011).

  "To estimate VOLY, surveys can be carried out where respondents are asked their willingness-to-pay (WTP) for life expectancy gains of three and six months achieved by corresponding air pollution reductions under realistic policy scenarios. As a validity test Desaigues et al. regressed the WTP of the pooled sample on income and other characteristics of the respondents. Income had a significant positive effect on WTP, as expected from economic theory. If respondents expressed concerns about health effects of air pollution, they also had significantly higher WTP than those who did not. Those who were sure about their stated WTP also gave significantly higher WTP than those who were not. WTP was also significantly higher for male respondents, and those with the highest education. Age, however, had no significant effect" (Desaigues, 2011).

  "Calculating the health cost of air pollutants requires concentration-response ratios, which link concentrations of pollution to health endpoints (IISD, 2015). Several health endpoints are valued for PM, SO_2, and NO_x, including death, chronic bronchitis, reduced activity days, respiratory hospital visits, and cardiovascular hospital visits. For instance, chronic bronchitis is valued as a fraction of the VSL. IISD in a study of green public procurement in China obtained the value of reduced activity days using a benefit-transfer approach. The value of respiratory and cardiovascular hospital visits were estimated using the cost of illness approach that sums direct expenses (medication etc.) and indirect expenses (lost wages etc.) (IISD, 2015). As an example, the social cost of carbon used in the model is 0.13242 CNY/kg CO_2 based on figures from the Interagency Working Group on Social Cost of Carbon, which uses $36 USD per metric ton of CO_2" (IISD, 2015).

- Crop yield reduction: "Dose-response equations are converted to a percentage of crop reduction relative to a specific dose... Pollutant dose levels from agricultural regions can be used with the loss equations to determine the estimated yield loss due to pollutants in that specific area. Yield-loss functions can also be used in each region for economic assessment, land-use planning, and development of appropriate air quality criteria (McCool, 1986). "The extent of yield reduction and economic loss caused by air pollution has been estimated for the Netherlands. Based on available data on direct effects only, each species was designated as sensitive, moderately sensitive or tolerant... On a nationwide scale, only ozone (O_3), sulphur dioxide (SO_2), and hydrogen fluoride (HF) exceeded effect thresholds. On the basis of these calculations, air pollution in the Netherlands reduces total crop volume by 5 per cent–3.4 per cent by O_3, 1.2 per cent by SO_2, and 0.4 per cent by HF. The slope of the nonlinear relationship between crop volume reduction and exposure level increases at higher concentrations" (Eerden, 1988).

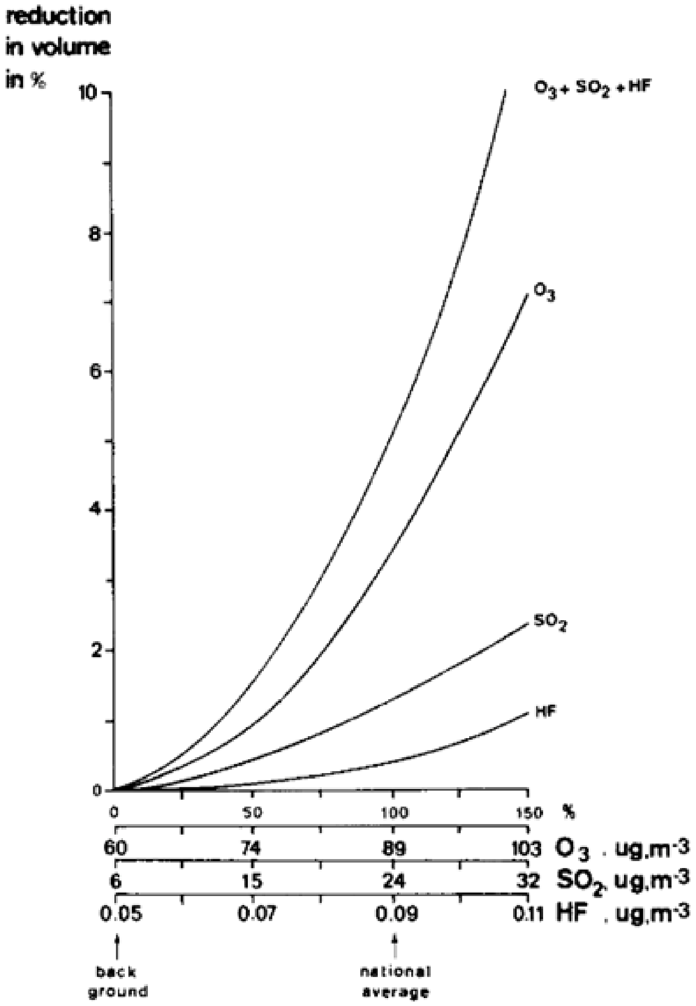


Figure A3. **Percentage reduction in crop volume, related to the levels of 03, S02 and HF**

Source: Eerden, 1988

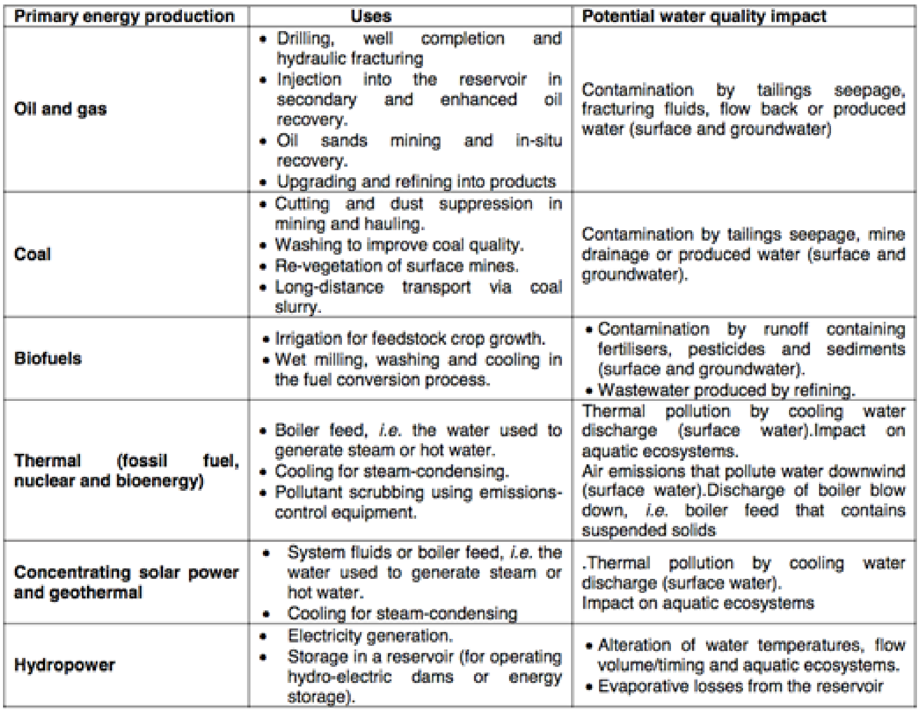
- Global warming: "The social value of carbon sequestration may be defined as the benefit in savings from damage avoidance" (UK Committee on Climate Change, 2015). This benefit can be estimated by observation of compensatory costs to society, or "the shadow price." That price should in theory be set at the marginal damage cost of a unit of emissions; in other words the present value of the economic cost caused by one extra unit of greenhouse gas while it is in the atmosphere. Estimating the social cost of carbon is, however, a profoundly difficult exercise. The difficulty arises because there are several deep uncertainties in estimating the present value of the economic damage from carbon dioxide while it is in the atmosphere, including uncertainties about the science (the warming resulting from emissions of carbon dioxide and other greenhouse gases and the environmental changes accompanying warming, such as precipitation changes and sea level rise) and uncertainties about the economic impact of climate change (UK Committee on Climate Change, 2015). The difficulties of assessing all these factors and agreeing on the ethical standpoints taken in so doing have given rise to a large range of estimates of the social cost of carbon and much methodological debate among economists. There have been many estimates of what price paths would incentivize a reduction in emissions big enough to keep the expected temperature increase to 2°C. In general, they have been based on aiming to stabilize the atmospheric concentration of greenhouse gases at or below around 450 parts per million (ppm) of carbon-dioxide-equivalent. Several models have been developed to estimate the appropriate price of carbon. In our study we will adopt the carbon price indicated by the UK Committee on Climate Change, which amounts to USD 43 per tonne of carbon dioxide for 2020 (UK Committee on Climate Change, 2015).

- Water pollution increasing input costs for water treatment: "The productivity method is used to estimate the economic value of ecosystem products or services that contribute to the production of commercially marketed goods" (US Department of Agriculture, 2000). For example, water quality affects the costs of purifying municipal drinking water. Thus, the economic benefits of improved water quality can be measured by the decreased costs of providing clean drinking water. In this example cleaner water is a direct substitute for other production inputs, such as water purification chemicals and filtration. Thus, the benefits of improved water quality can be easily related to reduced water purification costs (US Department of Agriculture, 2000). "Nitrates and algal blooms in drinking water sources can drastically increase treatment costs. Nitrate-removal systems in Minnesota caused supply costs to rise from 5–10 cents per 1,000 gallons to over $4 per 1,000 gallons" (EPA, 2010).

Coal extraction and burning contribute substantially to water pollution. Common contaminants of concern in power plant wastewater include arsenic, aluminum, boron, chromium, manganese, nickel, and lead (Swarthmore College, 2010). "Unlike natural gas, emissions from coal and oil can cause acid rain, which is formed when sulfur dioxide and nitrogen oxides react with hydroxyl radicals in the environment... Another impact of coal mining and extraction on regional water quality is the runoff—known as Acid Mine Drainage (AMD)—from active and retired coal mines. AMD is formed when pyrite reacts with air and water to form sulfuric acid and dissolved iron. This can cause red, yellow, or orange-coloured sediment in streambeds and dissolve other heavy metals that then are introduced into surface water and groundwater supplies" (Swarthmore College, 2010).

Energy and water are valuable resources and are to a large extent interdependent. Water is an integral element of energy resource development and utilization. It is used in energy resource extraction, refining & processing and transportation (Tripathi, 2015). "Thermal power plants that run on coal and other fossil fuels introduce a myriad of chemicals for maintenance or operational purposes, and, through combustion, liberate other chemicals from the fuel that is found in the power plant's discharge. Nuclear power plants consume even more water than fossil fuel facilities because of the additional cooling requirements of reactor cores and can have major impacts on marine environments. By contrast, many renewable energy technologies such as wind and solar photovoltaic technology produce electricity without generating any waste effluent released into waterways or without relying upon any cooling water" (Tripathi, 2015).

Table A2. **Energy production impacts on water quality**



Primary energy production	Uses	Potential water quality impact
Oil and gas	• Drilling, well completion and hydraulic fracturing • Injection into the reservoir in secondary and enhanced oil recovery. • Oil sands mining and in-situ recovery. • Upgrading and refining into products	Contamination by tailings seepage, fracturing fluids, flow back or produced water (surface and groundwater)
Coal	• Cutting and dust suppression in mining and hauling. • Washing to improve coal quality. • Re-vegetation of surface mines. • Long-distance transport via coal slurry.	Contamination by tailings seepage, mine drainage or produced water (surface and groundwater).
Biofuels	• Irrigation for feedstock crop growth. • Wet milling, washing and cooling in the fuel conversion process.	• Contamination by runoff containing fertilisers, pesticides and sediments (surface and groundwater). • Wastewater produced by refining.
Thermal (fossil fuel, nuclear and bioenergy)	• Boiler feed, *i.e.* the water used to generate steam or hot water. • Cooling for steam-condensing. • Pollutant scrubbing using emissions-control equipment.	Thermal pollution by cooling water discharge (surface water).Impact on aquatic ecosystems. Air emissions that pollute water downwind (surface water).Discharge of boiler blow down, *i.e.* boiler feed that contains suspended solids
Concentrating solar power and geothermal	• System fluids or boiler feed, *i.e.* the water used to generate steam or hot water. • Cooling for steam-condensing	.Thermal pollution by cooling water discharge (surface water). Impact on aquatic ecosystems
Hydropower	• Electricity generation. • Storage in a reservoir (for operating hydro-electric dams or energy storage).	• Alteration of water temperatures, flow volume/timing and aquatic ecosystems. • Evaporative losses from the reservoir

Source: (Tripathi, 2015)

- Loss of recreational value: In the United States, “the tourism industry loses close to $1 billion each year, mostly through losses in fishing and boating activities, as a result of water bodies that have been affected by nutrient pollution and harmful algal blooms. Airborne nutrient pollution can also affect visibility at popular outdoor destinations like national parks. This kind of pollution can also damage buildings and other structures, especially those made of marble and limestone” (EPA, 2015). “The travel cost method is used to estimate economic use values associated with ecosystems or sites that are used for recreation. The basic premise of the travel cost method is that the time and travel cost expenses that people incur to visit a site represent the “price” of access to the site. Thus, peoples’ willingness to pay to visit the site can be estimated based on the number of trips that they make at different travel costs. This is analogous to estimating peoples’ willingness to pay for a marketed good based on the quantity demanded at different prices. The basic premise of the travel cost method is that the time and travel cost expenses that people incur to visit a site represent the “price” of access to the site. Thus, peoples’ willingness to pay to visit the site can be estimated based on the number of trips that they make at different travel costs. This is analogous to estimating peoples’ willingness to pay for a marketed good based on the quantity demanded at different prices” (US Department of Agriculture, 2000).

- Decrease in real estate value: Environmental noise caused by traffic can reduce property values (TranSafety, 1997). The majority of sounds detected by human hearing are within the range of 0 to 140 decibels (dB). The effects of noise pollution are routinely measured using an A-weighted decibel scale (designated dBA), which is useful for measuring the noise impact of a single occurrence but not the impact of continuous noise. A frequently used measurement for continuous noise is the equivalent sound level (Leq), known also as the energy mean sound level. Leq includes both the intensity and length of all sounds occurring during a given period. In the US, the Environmental Protection Agency has developed a measurement for a community’s exposure to noise (the average energy sound level) for a 24-hour period from midnight to midnight. The measure of this day-night sound level, designated DNL or Ldn, is commonly used to evaluate noise impacts on communities and residential areas. Calculating the impact of noise on residential property values requires constructing a model for estimating the value of property that includes an estimate of traffic noise cost. It operates on the theories that people will pay to avoid high noise levels and that housing values reflect location relative to a noisy source (TranSafety, 1997).

- Loss of productivity: Recent research started to catalogue how pollution might affect people's productivity. Several studies have demonstrated that pollution reduces the output of both farm workers and factory workers (Chang, 2016). In analyzing the personnel working in a call center in China, a study found a surprisingly robust relationship between daily air pollution levels and worker productivity. On average, a 10-unit increase in the Air Quality Index (AQI) led to a 0.35 per cent decline in the number of calls handled by a worker. That finding suggests that workers are 5–6 per cent more productive when air pollution levels are rated as good by the Environmental Protection Agency (AQI of 0–50) versus when they are rated as unhealthy (AQI of 150–200). The reason for this is that particulate matter is small enough to be absorbed into the bloodstream, and even travels along the axons of the olfactory and trigeminal nerves into the central nervous system, where it can become embedded deep within the brain stem and diminish cognitive functions (Chang, 2016).

ANNEX III – Life Cycle Analysis, Emissions

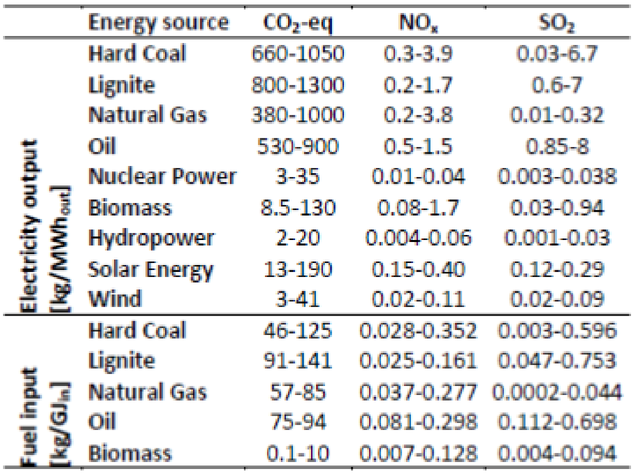
Excerpt from Turconi, 2013

Life cycle greenhouse gas (GHG) emissions from renewable electricity generation technologies are generally less than from those from fossil fuel-based technologies (Lifset, 2012). Comparisons also show that the proportion of GHG emissions from each life cycle stage differs by technology:

- For fossil-fuelled technologies, fuel combustion during operation of the facility emits the vast majority of GHGs.
- For nuclear power, fuel processing stages are most important, and a significant share of GHG emissions is associated with construction and decommissioning.
- Most emissions for biopower are generated during feedstock production, where agricultural practices play an important role.
- For other renewable technologies (solar, wind, hydropower, ocean and geothermal), most life cycle GHG emissions stem from component manufacturing and, to a lesser extent, facility construction.

Electricity generation is a key contributor to global emissions of greenhouse gases (GHG), NO_x and SO_2 and their related environmental impact. A critical review of 167 case studies involving the life cycle assessment (LCA) of electricity generation based on hard coal, lignite, natural gas, oil, nuclear, biomass, hydroelectric, solar photovoltaic (PV) and wind was carried out to identify ranges of emission data for GHG, NO_x and SO_2 related to individual technologies. It was shown that GHG emissions could not be used as a single indicator to represent the environmental performance of a system or technology. Emissions data were evaluated with respect to three life cycle phases (fuel provision, plant operation, and infrastructure). Direct emissions from plant operation represented the majority of the life cycle emissions for fossil fuel technologies, whereas fuel provision represented the largest contribution for biomass technologies (71 per cent for GHG, 54 per cent for NO_x and 61 per cent for SO_2) and nuclear power (60 per cent for GHG, 82 per cent for NO_x and 92 per cent for SO_2); infrastructures provided the highest impact for renewables. These data indicated that all three phases should be included for completeness and to avoid problem shifting. The most critical methodological aspects in relation to LCA studies were identified as follows: definition of the functional unit, the LCA method employed (e.g., IOA, PCA and hybrid), the emission allocation principle and/or system boundary expansion. The most important technological aspects were identified as follows: the energy recovery efficiency and the flue gas cleaning system for fossil fuel technologies; the electricity mix used during both the manufacturing and the construction phases for nuclear and renewable technologies; and the type, quality and origin of feedstock, as well as the amount and type of co-products, for biomass-based systems. This review demonstrates that the variability of existing LCA results for electricity generation can give rise to conflicting decisions regarding the environmental consequences of implementing new technologies.

Table A3. Life cycle emission factors for electricity generation from selected technologies. Factors at the top of the table refer to electricity output [kg/MWhout], while values at the bottom of the table refer to fuel input [kg/GJin].



	Energy source	CO_2-eq	NO_x	SO_2
Electricity output [kg/MWh_{out}]	Hard Coal	660-1050	0.3-3.9	0.03-6.7
	Lignite	800-1300	0.2-1.7	0.6-7
	Natural Gas	380-1000	0.2-3.8	0.01-0.32
	Oil	530-900	0.5-1.5	0.85-8
	Nuclear Power	3-35	0.01-0.04	0.003-0.038
	Biomass	8.5-130	0.08-1.7	0.03-0.94
	Hydropower	2-20	0.004-0.06	0.001-0.03
	Solar Energy	13-190	0.15-0.40	0.12-0.29
	Wind	3-41	0.02-0.11	0.02-0.09
Fuel input [kg/GJ_{in}]	Hard Coal	46-125	0.028-0.352	0.003-0.596
	Lignite	91-141	0.025-0.161	0.047-0.753
	Natural Gas	57-85	0.037-0.277	0.0002-0.044
	Oil	75-94	0.081-0.298	0.112-0.698
	Biomass	0.1-10	0.007-0.128	0.004-0.094

Hard Coal

The results showed that direct emissions represented the main contribution for GHG emissions from coal-based technologies. The key factors were found to be the type of technology and the process efficiency. For example, GHG emission factors for direct combustion (DC) were in the range of 750–1050 kg CO_2-eq/MWh for which the lowest and highest values corresponded to energy recovery efficiencies of 42 per cent and 33 per cent, respectively, calculated relative to the input energy. On the other hand, coal gasification (IGCC) could achieve higher efficiencies (up to 52 per cent), thus leading to lower GHG emission factors compared to direct combustion (660–800 kg CO_2-eq/MWh). These values were in agreement with previous review studies in which overall emission factors on the order of 800–1200 kg CO_2-eq/MWh were reported for electricity generation from hard coal.

Data for NO_x and SO_2 emissions from direct combustion showed large amounts of variability among individual studies, with a flue gas cleaning (FGC) system and the energy recovery efficiency being the two most important aspects affecting the magnitude of emission factors. Emissions on the order of 2–4kg NO_x/MWh and 2–7kg SO_2/MWh throughout the life cycle were typically found for old power plants equipped with no or low-tech FGC systems, whereas modern plants had emission factors one order of magnitude lower (0.3– 1kg NO_x/MWh and 0.1–1kgSO_2/MWh). For coal gasification, overall emission factors were found on the order of 0.2–0.7 kg NO_x/MWh and 0.1–1kgSO_2/MWh, with the process efficiency and an FGC system being the key aspects. Coal provision accounted for 0.9 per cent to 2.6 per cent of the overall GHG emissions from coal-based electricity generation, mainly as a consequence of methane emissions during mining. Emissions of NO_x and SO_2 were dominated by direct emissions for coal combustion, whereas fuel provision was more relevant for IGCC, due to the high efficiency and high removal via FGC and consequently lower emissions at the stack.

Natural gas

Two technologies for electricity generation based on natural gas were considered: a single cycle (SC) turbine with low energy efficiencies (26–35 per cent) and a combined-cycle (CC) turbine with high energy efficiencies (up to 60 per cent). This distinction was made because the first technology provides peak electricity (i.e., electricity produced to cover peaks in electricity demand), whereas the latter delivers mainly baseload power. Direct GHG emissions from CC plants were rather consistent among different studies (350–410 kg CO_2-eq/MWh), with fuel provision contributing relatively large additional impacts (10–180 kg CO^2-eq/MWh). Fuel provision represented up to 30 per cent of the overall GHG emissions, mainly due to fugitive methane emissions and energy consumption during gas extraction and transportation. LCA studies commonly assume that 1–2 per cent of gross natural gas is lost to the atmosphere as fugitive emissions during extraction. Furthermore, up to 10 per cent of the natural gas extracted is consumed to power fuel extraction and transportation. Liquefied natural gas has even higher emissions due to the liquefaction process itself and to the longer transportation distances (6 out of 8 studies reported emissions above 100 kg CO_2-eq/MWh for fuel provision). Single cycle plants produced higher and more variable direct emissions at the power plant (480–730 kg CO_2-eq/MWh) compared with CC plants, and consequently, also over the life cycle (610–850 kg CO_2-eq/MWh). These values were in agreement with previous studies estimating approximately 400–900 kg CO_2-eq/MWh for electricity generation from natural gas. For CC plants, overall NO_x emissions were on the order of 0.2–1.3 kg NO_x/MWh, with fuel provision (0.1–0.5 kg/MWh) playing an important role as a consequence of the energy used for extraction of natural gas. Compared to CC plants, emissions of NO_x from SC plants were much higher, approximately 1.8–3.8 kg NO_x/MWh: lower efficiencies and less efficient FGC systems were responsible for this difference. Emissions of SO_2 were similar for the two technologies, in the range of 0.01–0.32 kg/MWh. The data available for CC studies show that natural gas provision can contribute up to 80–90 per cent of the life cycle emissions of SO_2.

Oil

The results showed that GHG and NO_x emissions were mainly related to power plant operation, whereas fuel provision (exploration, extraction, refinery and transportation) represented up to 20 per cent of the SO_2 emissions occurring throughout the life cycle, which depends on the FGC system, the oil provision and the sulfur content of the fuel. The energy recovery efficiency is the key parameter for GHG emissions: in base load power plants, efficiencies can reach 58 per cent, corresponding to 530 kg CO_2-eq/MWh emitted throughout the life cycle. Conversely, peak load power plants have lower efficiencies (i.e., 30–40 per cent), with subsequent GHG emission factors between 750 and 900 kg CO_2-eq/MWh over the entire life cycle.

Emission factors for NO_x were in the range of 0.5–1.5 kg/MWh, mainly depending on the FGC system of the plant. In particular, emission factors varied from 0.8 kg/MWh for modern plants to up to 6–8 kg/MWh for old plants not equipped with SO_2 scrubbing systems. Data about the commissioning and decommissioning of oil power plants were quite limited, with only a single study reporting a contribution from infrastructure of 2.2 kg CO_2-eq/MWh. Such a contribution can be considered negligible compared to those from direct emissions.

Nuclear Power

The results showed that GHG emission factors varied greatly, with differences of up to one order of magnitude (i.e., 3.1–35 kg CO_2-eq/MWh). This variability was due both to the different technologies and to the methodological approaches used to assess them. In particular, the assumptions regarding the inclusion of uranium enrichment processes had a significant influence on the results. The gas diffusion method, for example, uses approximately 40 times more electricity than the gas centrifuge method. These processes, combined with the use of fossil fuel-based electricity, can explain the wide range of values found for fuel provision (1.5–18 kg CO_2-eq/MWh). When using IOA, emission factors were estimated as being 10–20 times larger than those calculated using PCA. Emissions of NO_x and SO_2 related to electricity generation from nuclear power were mainly due to energy consumption during uranium extraction and enrichment. Emission factors were in the range of 0.01–0.04 kg/MWh for NO_x and 0.003–0.038 kg/MWh for SO_2, depending on the input electricity mix. Emissions related to infrastructure were found to be relevant for GHG (20–30 per cent of the total), while being almost insignificant for both NO_x and SO_2.

Hydropower

Life cycle emissions of GHG were reported in the range of 2–5kgCO_2-eq/MWh for run-of-river systems and 11–20 kg CO_2-eq/MWh for dam-reservoirs. The highest emissions factors were found in a study using the IOA approach, again indicating that greater impacts are estimated when using IOA instead of PCA. An important aspect of hydropower with dam-reservoirs is methane emissions from the anaerobic decomposition of flooded organic matter. These emissions depend on the local climate, reservoir size, water depth, type and amount of flooded vegetation and soil type; thus, large variations in emission factors can be seen. For example, emission factors range from 0.35 kg CO_2-eq/MWh for alpine regions to 30 kg CO_2-eq/MWh in Finland and reach up to

340 kg CO_2-eq/MWh in Brazil. Emission factors reported in previous review studies were in the range of 2–40 kg CO_2-eq/MWh, but higher values were found when the reservoirs were located in tropical areas. Emission factors for NO_x and SO_2 were found in the range of 0.004–0.06 kg NO_x/MWh and 0.004–0.03 kg SO_2/MWh, respectively. Emissions of NO_x and SO_2 were mainly associated with dam construction (i.e., provision of materials) and are therefore related to the dam size and generation capacity.

Solar Photovoltaic (PV)

Emission factors for GHG showed high variability (one order of magnitude, 13–130 kg CO_2-eq/MWh), mainly due to local conditions, such as the source of the electricity used during manufacturing, the typology of panels and the climate conditions where the panels were installed. One study showed how GHG emissions of PV technology produced in different countries would differ from each other because of the electricity input to the manufacturing process. A similar occurrence can be explained for NOx and SO_2 emissions. For example, emission factors range from 0.15–0.18 kg NO_x/MWh and 0.12–0.15 kg SO_2/MWh in southern Europe to 0.34 kg NO_x/MWh and 0.29 kg SO_2/MWh in Germany, for NO_x and SO_2 emissions, respectively. Using IOA, it has been estimated emission factors in the range of 100–190 kg CO_2-eq/MWh, 0.20–0.40 kg NOx/MWh and 0.13–0.26 kg SO2/MWh. These emissions are slightly higher than those estimated using PCA, but the significant differences between IOA and PCA results that had previously been highlighted for nuclear energy were not observed in this case. Emission factors reported in previous studies were in the range of 40–160 kg CO_2-eq/MWh.

Wind

In this case, the main contributions were related to material provision and construction of the wind turbines. Hence, the local electricity mix where manufacturing and installation of the turbines occurred had a significant influence on the results. Onshore and offshore turbines can have similar emission factors because larger emissions during the construction phase can be compensated for by the higher productivity of offshore turbines. 1 One study accounted for GHG emissions, including an electricity storage device (i.e., hydrogen for fuel cells) that obtained higher overall emission factors (35–41 kg CO_2-eq/MWh). It should be noted, however, that such a study including electricity storage cannot be directly compared to a study of wind power without storage because of the different functional unit used. Based on IOA, emission factors were estimated on the order of 30–40 kg CO_2-eq/MWh, thus providing higher values than similar studies using PCA. Emission factors reported in previous review studies were in the range of 5–35 kg CO_2-eq/MWh. Most LCA studies provided emission factors for NO_x and SO_2, ranging from 0.02–0.06 kg NO_x/MWh and 0.02–0.04 kg SO_2/MWh with emissions mainly depending on the electricity mix used for manufacturing. When using IOA, emission factors of 0.11 kg NO_x/MWh and 0.05 kg SO_2/MWh were reported, which were higher than the previously mentioned emission factors estimated using PCA.

Biomass

The reported GHG emission factors showed high variability: 25–130 kg CO_2-eq/MWh (CO-COMB), 8.5–118 kg CO_2-eq/MWh and 17–117 kg CO_2-eq/MWh (IBGCC). These data do not include biogenic CO_2 emissions because it is common LCA practice to assume a global warming characterization factor for biogenic CO_2 of zero. However, when emission factors are used for GHG emission reporting within the IPCC framework, biogenic CO_2 is then included because the CO_2 uptake by biomass is accounted for within the AFOLU (i.e., Agriculture, Forestry, and Other Land Use) sector. Emission factors for NOx were in the range of 0.08–1.7 kg NO_x/MWh, with the highest values related to COMB and the lowest values associated with CO-COMB. In addition to the FGC system, NOx emissions were strongly related to the type of biomass. In the provision phase, emissions occurred from the use of machinery during cultivation and harvesting in the case of energy crops, whereas no emissions were typically associated with wood residues (adopting a zero burden approach). Combustion of furniture wood residues may result in larger emissions due to the nitrogen content of the fuel. Emissions of SO_2 also showed high variability for all three technologies assessed, ranging from 0.03 to 0.94 kg SO_2/MWh, with the largest contribution from fuel provision.

IISD