Higher initial costs for renewables electricity: Emission, water and job-creation benefits offset the higher costs

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Abstract

The environmental consequences and depleting trends of fossil fuel reserves has made an earnest requirement of wider dissemination of renewable energy resources for power generation. Energy costs from renewables are generally higher due to their high initial capital investments. Wind and solar are the two major renewable energy resources accounted for 65% of the global total electricity generated from renewables (excluding hydro). Despite these two renewable energy resources are relatively evenly distributed over the world and have capabilities to counteract environmental challenges, their commercial deployment is limited due to the lack of inclusion of their indirect benefits. This study examines three major indirect benefits from the solar and wind based electricity, i.e. emissions, water saving and job creation benefits and figures out how these benefits offset their higher cost per unit of electricity. We have found that solar and wind electricity create these benefits in the range of 930–950 gCO_2e/kWh, 0.80–3.12 L/kWh, and 0.10–1.21 person-years/GWh in compare to most common fossil fuel (coal). While valuing these benefits, an emission saving of 925 gCO_2e/kWh, for example, could offset 2.6 US¢/kWh of electricity price for an emission pricing of 40 US$/tonne. Water and job creation benefits also offset further costs.

Keywords
Water saving, Emission, Job creation, Solar, Wind and Renewable.

1. Introduction

Major fossil fuel resources such as coal, oil and natural gas account for about 85% of the global total primary energy supply (Shafiee and Topal 2009). In the current consumption trends, major fossil fuel reserves will be diminished within this twenty-first century (Table 1) (Balat and Balat 2009; Shafiee and Topal 2009; WEC 2013). The burning of fossil fuels for energy generation also releases GHG (greenhouse gases) emissions and enhances climate change. Electricity generation from fossil fuels alone accounted for 50 % of the energy related CO_2 emissions (Bravi et al. 2007). The depleting trends and release of emissions from fossil fuels are pressing for alternative sources for electricity generation. In this context, renewable resources appear as potential alternative to counteract the above challenges (Table 2). Wind, photovoltaic, and biomass are the three predominant renewable energy resources in the world accounted for 95% of the renewable based electricity (excluding hydro) (REN21 2015). Among these three major sources, interests in wind and solar are particularly high owing to their availability and environmental cleanliness nature (Dolan and Heath 2012). Although solar and wind resources are relatively evenly distributed all over the world and have capabilities to counteract environmental and fossil fuel depletion challenges, their dissemination is still limited due to lack of inclusion of their indirect benefits. Emission, water saving, and job creation are the three major indirect benefits for renewable-based electricity that are often ignored while comparing with fossil-based energy. Assessing and inclusion of these benefits are essential while we make a comparison for economic competitiveness of different fossil and renewable sources.

Several studies assessed life cycle emissions and water consumptions for different fossil and renewable energy sources for power generation (Amponsah et al. 2014; Burnham et al. 2012; Chang et al. 2015; Chirinos et al. 2006; Dolan and Heath 2012; Fthenakis and Kim 2007; Najafpour et al. 2010; NEI 2014; Uddin and Kumar 2014; Whitaker et al. 2012; WNA 2011; Zeller-Powell 2011; Zhang et al. 2010; Zuwala and Ziebik 2011). These above studies compared emission and water savings for electricity generation from renewable sources in comparing to coal and natural gas. A few studies also determined water intensity (i.e. water consumption rate per unit electricity generation) and water footprint for the major life cycle stages of power generation (Ali and Kumar 2015; Grubert et al. 2012; Harto et al. 2014; Johst and Rothstein 2014; Li et al. 2012; Spang et al. 2014; Staples et al. 2013). Apart from emission and water savings, renewable energy uptake also has produced positive economic benefit through job creation (Cameron and van der Zwaan 2015; Dalton and Lewis 2011). Benefit through job creation for different renewable and fossil based electricity has been appeared in the literature (Cameron and van der Zwaan 2015; Dalton and Lewis 2011; Frondel et al. 2010; Simas and Pacca 2014; Warlick 2009; Lambert and Silva 2012; GEAR 2008).
Although indirect benefits for wind and solar sources for electricity generation have been reported by many studies, they are still perceived as an expensive and uncompetitive fuel sources (Saidur et al. 2011). In this regard, there is a clear lack of accumulating and emphasizing these three major benefits while comparing with fossil based energy. In this work, we assess emission, water saving and job creation benefits for solar and wind power generation in life cycle basis and determine to what extent the valuing of indirect benefits offset higher costs in comparing to a fossil fuel i.e. coal (because coal was responsible for around 41% of the global total power generation) (IEA 2015).

Table 1. Global reserve of fossil fuels

Fossil fuel resources	Reserves (2013)	Annual consumption rate	Estimated lifetime (y)
Natural Gas	209 trillion cubic meter	3.5 trillion cubic meter/y	60
Oil	223 Gt	3.973 Gt/y	56
Coal	891 Gt	7.5 Gt/y	100

Table 2. Global renewable energy potential

Renewable resources	Potential (TW)
Solar	23000
Tidal	0.3
Wave	0.2–2
Geothermal	0.3–2
Hydro	3–4
Biomass	2–6
Wind	2570
World's total demand	16

2. Methodology

In this paper, we assess indirect benefits from emission and water saving and job creation for power generation from solar and wind sources in comparing to most common fossil fuel (i.e. coal) in the whole life cycle. The assessment of indirect benefits for these two renewable sources on whole life cycle relate with multiple aspects such as technology, economics and environmental issues, and there appear no unique methodological framework to determine their indirect benefits together. In this paper, therefore, we used exploratory research approach to accumulate indirect benefits through analytical methods and literature sources for emission and water saving and job creation for power generation from solar and wind sources.

2.1 Life cycle approach

To allow a fair comparison, impacts (i.e. costs, emissions etc.) of electricity generation from fuel sources for the whole life-cycle stages are indispensable. Life cycle values encompass all processes and environmental releases beginning with extraction of raw materials and the production of energy through the final disposition of the products. The life cycle impacts comprise activities under three major stages namely upstream, spot, and downstream. Upstream impacts include emission and water consumption for raw materials extraction, materials manufacturing, component manufacturing and transportation, and onsite constriction. Spot impacts include emissions from activities such as combustions, and operation and maintenance of the plants. Downstream impacts are from those activities such as transmission, consumption, disposal and recycling (Dolan and Heath 2012). A block diagram representing upstream, spot (direct) and downstream activities for electricity generation from coal is shown in Figure 1.

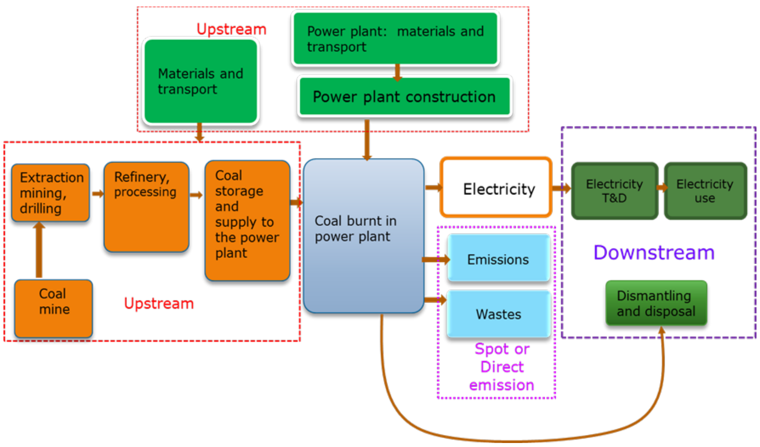

Figure 1. Upstream, spot (direct), and downstream activities for electricity generation from coal

3. Results and discussions

3.1 Emission Saving Benefit

Emissions for fossil fuels and renewable electricity occur during the whole life cycle stages of the products. Some sources emit more emissions in their conversion stage (spot emission) and some sources emit most of their emissions in the other stages. Life cycle emission is particularly well suited for comparing different power generation sources. The following Tables 3 presents emissions of different renewable and non-renewable based electricity generation on life cycle basis (Table 3) (Gagnon et al. 2002; Sovacool 2008). Table 3 shows that renewable sources emit lower emissions in comparing to non-renewable energy sources in their whole life cycle.

Table 3. GHG emissions for different renewable and non-renewable energy technologies

Energy sources	Life cycle GHG emissions (gCO_2e/kWh)			
	Literature sources			
	(Sovacool 2008)	(Amponsah et al. 2014)	(WNA 2011)	(NEI 2014)
Coal	960	888	888	979
Oil	778	733	735	-
Natural gas	443	499	500	462
Nuclear	66	24.2	28	13
Wind	9–10	8–124	26	12
Solar PV	32	9–300	85	53

3.2 Water Saving Benefit

3.2.1 Water scarcity

The electricity generation is a major consumer of fresh water for cooling, fuel extraction, and air emission control. Therefore, water consumption is a crucial factor that needs to include for evaluating performance of different power generation options. Several countries in the world, e.g. India, South Africa, Algeria, are already in water scarcity; further increased use of water will make them severity in water scarcity. Therefore, water consumption is a very serious issue for electrical power production from several fossil and non-renewable resources and technologies. Figure 2 shows water withdrawal level of different countries against their availability (FAO AQUASTAT 2014). The dotted line in Figure 2 represents the water stress indicator, which is the limit for maximum withdrawal of available water without causing any water stress. The countries that are placed above or close to the dotted line are already in water scarcity or nearly heading towards water scarcity.

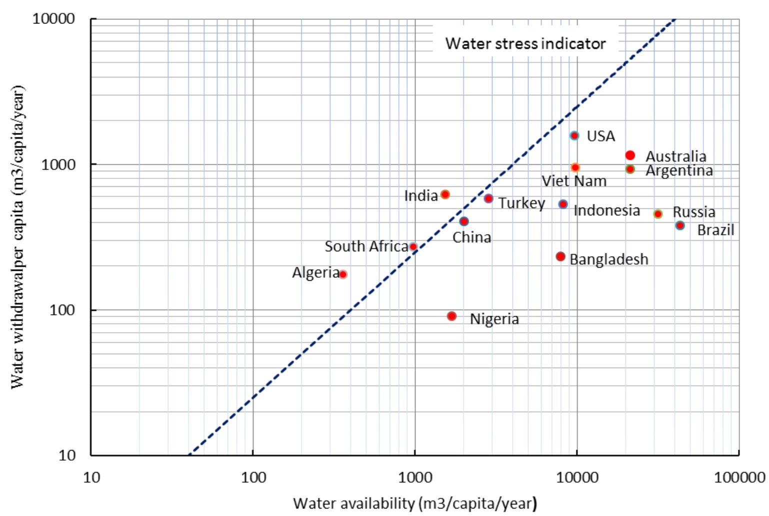

Figure 2. Water stress in major water consuming countries

Conventional power plants need a huge amount of water for the condensing segment of thermodynamic cycle. The following tables show water consumption of different renewable and non-renewable based energy on life cycle basis (Table 4). The table shows that water consumptions for solar and wind electricity are much lower than that of fossil based electricity. In country level, water consumption for conventional power plants in Malaysia, for example, is 1.48 L/kWh.

Table 4. Water consumption for Electricity generation for various energy sources

Fuel sources	Water consumption rate (L/kWh)				
	Literature sources				
	(Saidur et al. 2011)	(Rajaei and Tinjum 2014)	(Li et al. 2012)	(Dominguez-Faus et al. 2009)	(Spang et al. 2014)
Coal	1.90	3.12	2.6	0.90	2.60
Oil	1.60	1.96	-	0.17–0.68	2.76
Gas	0.95	0.44	0.70	0.23–30	0.79
Nuclear	2.30	2.55	2.70	0.90	2.72
Wind	0.004	0.00	0	-	0.00
Solar PV	0.110	3.11	0	-	0.02

3.2.2 Blue water footprint for power generation

Blue water footprint is another indicator to compare water consumption for power generation from different fuel sources. The blue water footprints refer to consumption of the blue water resources such as fresh surface and ground water. Blue water consumption footprint consist of 4 stages: water that evaporate, water that incorporate into the product, water that does not return to the same catchment area where it came from, and water that does not return in the same period. Blue water footprint for wind, solar and fossil fuels sources are presented in Table 5. Table 5 shows the amount of water saving for solar and wind electricity in comparing with fossil based electricity.

Table 5**.** Blue water footprint of different energy carriers

Energy carriers	Average blue water footprint (L/kWh)
Coal	0.72
Oil	0.21-0.50
Natural gas	0.36
Nuclear	0.36
Wind energy	0.00
Solar	0.02
Literature source: (Dallemand and Gerbens 2013)	

3.3 Job Creation Benefit

Job creation is another measure in comparing economic competitiveness of different fuels sources. Jobs created for energy generation is measured with numerous ways such as Jobs per annual MW installed, jobs per cumulative MW installed, manufacturing jobs per MW, person-year per MW, one-year jobs etc. According to the review (Lambert and Silva 2012), usually two forms are used for measuring the extent of job creation that are: jobs per MW manufactured and person-years per MW installed. These two forms are used to measure job creation for two different phases. Jobs per MW installed is used to indicate the number of permanent jobs created in the operation and maintenance phase, whereas person-years per MW manufactured is used for temporary jobs in the manufacturing and installation phase. For instance, 1000 jobs created for installing 500 MW wind turbine power plant means 20 person-year/MW (i.e. 20 temporary jobs for one year) jobs are created for manufacturing related activities. Similarly, 10 jobs created for 500 MW operation and maintenance of the power plants means 0.20 Jobs/MW permanent jobs (permanent means 30 years, for instance) are created (Lambert and Silva 2012). The different natures of job creation in manufacturing industry verses operation and maintenance industry can be represented by separate approaches with separate units (i.e. job-years/MW verses jobs/MW). This differentiation of approaches for job creation measurement make difficult to compare and interpret job numbers across various phases of technology deployment. To overcome this problem, jobs numbers across diverse technologies and phases can be normalized and aggregate to a common unit (Amponsah et al. 2014). For example, if wind power manufacturing and installation creates 6 person-years/MW and the designated lifetime is 30 years, the job creation for this technology in terms of operation and maintenance phase is 0.2 jobs/MW. The job creation in terms of operation and maintenance phase imply the number of full length jobs (i.e. permanent job for a period of 30 years) (Wei et al. 2010). Table 6 summarizes the job creation for various energy sources. The data of this table reveals some inconsistency. This is because there is lack of clarity whether these data refers to cumulative or non-cumulative capacity installation and whether they include indirect jobs.

Table 6**.** Employments for different energy generation technologies

Fuel sources	Number of jobs created (person-years/GWh)[a]			
	Literature sources			
	(Lambert and Silva 2012)	(Atherton and Rutovitz 2009)	(Dalton and Lewis 2011)	(Cameron and van der Zwaan 2015)
Coal	0.12	0.09	0.10	0.10[b]
Natural gas	0.11	0.07	0.13	0.08[b]
Wind	0.32	0.18	1.05	0.10
PV	1.21	0.31	0.34	0.29

[a]Original sources provide information for number in jobs in person-years/MW. We have adjusted them into person-years/GWh by using capacity factors 0.9, 0.9. 0.6 and 0.5 for coal, natural gas, wind and solar PV respectively.
[b] Estimated by the authors.

3.4 Valuing of Emission and Water Saving

3.4.1 GHG Emission Costs (avoidance costs)

Renewable energy options generally incur higher costs and emit lower emissions in compare to fossil based energy. The higher costs for renewable energy are usually resulted in for higher initial capital costs. The higher costs, sometimes referred to as emission reduction costs or avoidance costs, can be offset by applying a form of emission tax. The emission taxes are the taxes applied to the fossil fuels at which the unit energy costs are same for renewable and fossil fuels. Carbon tax is usually expressed as a value per tonne of CO2 equivalent (e.g. 20 USD/tCO2e).
The formulae for determining emission costs or avoidance costs is proposed by (Simbeck and Beecy 2011) as below.

$$C_{ER} = \frac{(C_r - C_f)}{(E_f - E_r)} \cdot x \qquad (1)$$

Where C_{ER} (USD/tCO2e) is the emission costs or avoidance costs, C_r (USD/MWh) is the cost of electricity from renewable sources, C_f (USD/MWh) is the cost of electricity from fossil sources, E_f (tCO_2e/MWh) is the emission for fossil sources, E_r (tCO2e/MWh) is the emission for renewable sources, x is the fraction of cost to be realized.

Several countries in the world already introduced carbon taxes, however, they have been meant for realizing only partial emission costs. The full emission reduction costs for wind and solar in compare to coal can be calculated by the given equation (Equation 1) and per unit electricity generation costs (Table 7) (ESMAP 2007). The full GHG emission cost for wind electricity is 19 and 322 US\$/tCO_2e for an electricity generation cost of 5.79 US¢/kWh and 34.57 US¢/kWh respectively. Similarly, for solar electricity, GHG emission costs stand on 400 and 620 US\$/tCO2e for their highest and lowest generating costs respectively (i.e. 41.57 and 61.59 US¢/kWh).
This way valuing and introducing of emission taxes could fully offset higher initial costs for renewables.

Table 7. Electric energy costs for different fuels sources

Fuel sources	Electricity costs (US¢/kWh)
Coal	3.97–5.39
Wind	5.79–34.57
Solar PV	41.57–61.59

3.4.2 Carbon Taxes in Different Countries

Different countries have so far introduced carbon taxes to offset a portion of the emission reduction costs for renewable energy options. The emission taxes for different countries are presented in Table 8 (World Bank 2013). A power source emits lower CO_2e means that the power source saves money in terms of escaping CO2e taxes. For example, in Finland, saving of emissions 920 gCO_2e/kWh for renewable sources can offset 3.68 US¢/kWh for a carbon price rate (or tax rate) of 40 US\$/tCO_2e.

Table 8. Emission taxes for different countries

Country	Year of adaptation	Tax rate or carbon price
Chile	2014	USD 5 per tCO2e (2018)
Denmark	1992	USD 31 per tCO2e (2014)
Finland	1990	Euro 35 per tCO2e (2013)
France	2014	Euro 7 per tCO2e (2014)
Iceland	2010	USD 10 per tCO2e (2014)

Ireland	2010	Euro 20 per tCO2e(2013)
Japan	2012	USD 2 per tCO2e (2014)
Norway	1991	USD 4-69 per tCO2e (2014)
Sweden	1991	USD 168 per tCO2e (2014)
Switzerland	2008	USD 68 per tCO2e (2014)
UK	2013	USD 15.75 per tCO2e (2014)

3.4.3 Valuing of Water Saving

Water is an invaluable natural resource and cannot be easily valued by money. The higher costs renewables also can be offset by applying a form of water value. Each litre water saving offset higher costs for the renewable sources.
The formulae for determining water saving costs to fully offset higher renewable energy costs can be calculated as below.

$$C_{ws} = \frac{(C_r - C_f)}{(w_f - w_r)} \cdot x \qquad (2)$$

Where C_{ws} (USD/L) is the water saving costs, C_r (USD/MWh) is the cost of electricity from renewable sources, C_f (USD/MWh) is the cost of electricity from fossil sources, w_f (L/MWh) is the water consumption for fossil sources and w_r (L/MWh) is the water consumption for renewable sources, x is the fraction of cost to be realized. For example, 1.8 L/kWh water saving for solar and wind would worth saving 3.6 USD/kWh if we apply a water price of 2.0 USD/L (Freashwater Org 2015). Thus water saving could offset a huge part of energy cost for solar and wind based electricity.
Valuing of creation of jobs would also bring worth to offset higher costs of solar and wind electricity. In Europe, one Job-year represents a worth equivalent to 40000 euros (Lund and Hvelplund 2012). If the number of job creation benefit is 0.10 person-years/GWh for solar electricity, it would bring worth of 4000 Euros for each GWh of electricity.

4. Conclusions

Fossil-based electricity generation are the major contributors to greenhouse gas emissions. Fossil fuel reserves are also depleting rapidly. Huge water consumption for fossil based electricity is another challenge and need to have alternative which consumes less water. The emissions, water consumption, and depletion of reserve of fossil fuels have led to look for alternative fuels for electricity generation. As an alternate source, renewables has a huge potential for power generation and are appeared to be candidate to combating emission, water consumption and depletion challenges.
This work has found that average life cycle emissions for solar and wind electricity are in the range of 8 –124 gCO_2e/kWh and 32 –300 gCO2e/kWh respectively. Whereas, the life cycle emissions for coal was found to be 888 – 979 gCO2e/kWh. The water consumption for solar and wind were found to be 0.02-3.11 L/kWh and 0-0.004 L/kWh respectively. The water consumption for coal is 0.9-3.12 L/kWh. Despite a wide variations, the job creation for solar and wind electricity are also found significantly higher, i.e. 0.29–1.21 and 0.10–1.05 person-years/GWh respectively against 0.09–0.12 person-years/GWh for coal based power.
Valuing of emission saving (i.e. avoidance cost) can easily offset the higher investment cost for solar and wind energy. For example, an emission saving of 925 gCO2e/kWh can offset 0.036 USD/kWh for an emission price of 40 USD/tCO2e. In addition to emissions saving, water saving and job creation also offset higher costs for the solar and wind. This work has shown that valuing of emission, water saving and job creation could offset higher cost of renewable based electricity to make them competitive with the fossil based electricity.

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Biography

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