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ENERGY SOURCES ANALYSIS FROM THE PERSPECTIVE OF SUSTAINABLE DEVELOPMENT

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Abstract

A judicious use of energy is a fundamental factor to achieve sustainable development. The limited character of energetic fossil resources and the pollution generated by burning fossil fuels for electricity production generate the need to replace them with other sources of energy. Despite the fact that fossil fuels would continue to play a prevailing role in the energy supply for decades to come, renewable energy resources have the potential of contributing to the increasing global energy demands, while simultaneously emerge the most efficient solutions for clean and sustainable energy development in the world. In this framework, the main scope of the present study is to provide an analysis of the current state of world natural resources used to produce energy and energy consumption degree across different regions of the world. At the same time, this paper aims to compare the environmental impacts in water, air, soil and ecosystem produced by a range of conventional and renewable energy sources, which is necessary to be reduced for building a genuine low-carbon society.

Key words: energy sources, natural resources, sustainable development, urbanization

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1. Introduction

Energy is a vital factor in economic growth and prosperity, improving the quality of life and satisfying human needs (Michalena and Angeon, 2009; Tantau et al., 2017). The availability of energy is a requirement for the functioning of modern societies, and the demand for energy resources has an effect on the politics of countries in all stages of development (Chalvatzis and Hooper, 2009; Sheau-Ting et al., 2016). The urbanization and economic development are strictly connected phenomena that have numerous implications on global environmental change. The intensive urbanization since the mid-half of the last century has been associated with urban sprawl and, with urban land area doubling in the OECD countries and growing by a factor of five in the rest of the world (OECD, 2010). The human impact on the environment manifests through many and various ways, but the most important factor, in terms of extending and consequences is represented by natural resources degradation and abatement (IEA, 2010a, b; Tosovic et al., 2016).

Frequently, specific literature mentioned that the most common natural resources classification divides into non-renewable resources (e.g. oil, natural gas, coal, uranium, minerals) and renewable resources, which may be power source for renewable

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energy (wind energy, solar energy, geothermal energy, hydroelectric energy) (Axinte et al., 2015; Boyle et al., 2003; Casper, 2010; Grübler and Fisk, 2012; Tong, 2010; Zaharia, 2004). There are many definitions of sustainable development, including the following common one: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Bruntland, 1987).

Due to the rapid development of the global economy, energy demand has grown quickly, particularly in emergent countries, which tend to have a greater part of their economies in manufacturing industries. Fossil fuels supply the majority of energy needs worldwide, with 86.7 percent of global energy consumption in 2013 (BP, 2014). A recent World Energy Council study found that without any change in our current practice, the world energy demand in 2050 would be 50 percent higher than 2013 level, at least 80 percent of this increase is anticipated to come from developing countries (WEC, 2013). Because the fossil fuel resources required for the generation of energy are expected to dominate the global consumption of energy resources in the coming years, as well as because these are becoming scarce, alternatives that would be viable and regenerative to attain sustainability have to be explored (Shamsuddin et al., 2014). In this regard, renewable energy resources represent one of the most efficient solutions to environmental problems that are faced today by humanity.

The renewable energy technologies are recording significant worldwide growth due to declining costs of generation, increasing electricity demand and the environmental concerns, especially those concerning climate change. According to Bloomberg New Energy Finance (BNEF, 2014), global investment in clean energy was $254 billion in 2013, almost five times the total of $54 billion in 2004. Natural resources exploitation represents a key factor of economic growth and development, but is important to consider the consequences of potential irreversible changes that may occur to the environment (Bond et al., 2003; Zaharia, 2004). Sustainable development and natural resources are indissoluble related with the social, economic, technological development, and environmental protection. The economic competitiveness and ecological sustainability are complementary aspects of current society’s common goal (ASCE, 2010). In this context, the main scope of this paper is to analyze and compare the current state of natural resources used worldwide to produce energy, in terms of their potential of contributing to climate change mitigation and sustainable development, as well as to review the environmental impact assessment for water, air, soil and ecosystem for a range of conventional and renewable energy sources.

This paper is based on data sources including peer-reviewed papers, state and agency reports, non-governmental organizations’ reports, and recent statistical data and reviews. A unitary manner of data synthesis clearly and meticulously gathered from the sources mentioned above is proposed by the authors, along with a pertinent analysis of results.

2. Urban-industrial systems

Urbanization and economic growth are inextricably linked. Globally, there is no country that has reached middle-income status without a substantial population shift into cities (Hughes and Cain, 2003). Studies have revealed that the simple correlation coefficient across countries based on the percentage of urban residents in a country and gross domestic product (GDP) per capita is of about 0.85 (Henderson, 2003), fact that leads to the conclusion that urbanization is an inevitable part of a modern society. Cities generate about 80 percent of world’s GDP (Grubler and Fisk, 2012). The world’s GDP is expected to rise by an average of 3.6 percent per year from 2010 to 2040, particularly in emerging, non-OECD regions, where it increases by 4.7 percent per year. This increase drives the sustained growth in future energy consumption, based mostly on fossil fuels, which in turn plays a key role in the upward trend in CO_2 emissions (EIA, 2013). However, relatively high levels of urbanization do not always assure high levels of economic welfare in developing countries. This is most evident in Latin America where the urbanization levels are above 80%, yet with real per capita incomes and GDP about a third that of developed nations (UNEP, 2012).

In the present era of rapidly growing development, urban sustainability is threatened by complex global uncertainty and change which have broad range, and threaten multiple sectors – such as water, energy, transport and waste – that are critical for urban sustainability (MGI, 2011). The urban population growth rate is superior to that of the total population. As can be noticed in Table 1 not all regions around the world have reached the same level of urbanization (United Nations, 2014).

Rosenthal and Strange (2004) show that doubling city size increases productivity across industries in the United States by roughly 5 percent. Similar work for Europe finds the impact of density to be comparable (4.5 percent).

Table 1. Percentage of urban areas around world’s major regions (United Nations, 2014)

Region	***1950***	***1970***	***2014***	***2050***
Africa	14.1	23.5	40	56
Asia	17.5	23.7	48	64
Europe	51.3	62.8	73	82
Latin America	41.4	57.1	80	86
North America	63.9	73.8	81	87
Oceania	62.4	71.2	71	74

Currently, urban areas generate 60-80 percent of all greenhouse gas emissions and consume 75 percent of natural resources (UNEP, 2012). Therefore, it can be asserted that urbanization has enormous environmental consequences, putting pressure on energy and water resources; thus it can be stated that sustainable cities are going to be vital for the future, as urbanization expands.

3. Fundamental natural resources

Natural resources are regarded as "fixed endowments", being used to fuel industrial economies. Environmental pollution became an important global concern because of the rapid growth of industrialization and urbanization. The intensive exploitation of fundamental natural resources (water, air, land, ecosystems) contributed in disturbing the ecological balance and the environmental quality (Fulekar, 2010). In this section the main energy sources are being discussed.

3.1. Energy production sources – generalities

Smalley (2004) stated that the growing energy demand of the world is going to need a new sustainable energy source. The risk of catastrophic climate disruption increases due to anthropogenic impact on the environment, especially the changes of the Earth atmosphere composition (the concentration of CO_2, N_2O, CH_4).

Several studies report that CO_2 is the primary greenhouse gas emitted due to human activities. Fossil fuels combustion in the electricity generation process is the largest source of CO_2 emissions in the world (IEA, 2011). Globally, the atmospheric CO_2 concentration for July 2014 was 399 ppm far above the maximum CO_2 concentration of about 280 ppm registered before the Industrial Revolution in the 19th century; today's rate of increase is more than hundred times faster than the increase that took place when the last ice age ended (Scripps Institution of Oceanography, 2014).

Nonetheless, globally, the energy systems are at different stages of development and also at different stages of achieving sustainability. According to the World Energy Council (WEC) the energy sustainability is based on three core dimensions: energy security, social equity and environmental impact mitigation (WEC, 2012). During the last century, the world energy consumption has increased significantly. Table 2 shows the world energy consumption during the last four decades in relation with the world's population. Also, presented are data regarding the world carbon dioxide emissions due to oil, gas and coal consumption and the main energy carriers. In order to highlight the importance of energy, a recent statistic (United Nations, 2014) regarding world energy consumption in 2011 per world's regions is presented in Table 3. It can be noticed that world's largest energy consumer is Asia Pacific region, accounting for 40.5 percent of the global energy consumption and over 70 percent of the global coal consumption. Asia Pacific was also an undisputed leader in oil and hydroelectric consumption. Europe and Eurasia is the leading region for nuclear power consumption, natural gas and renewable energy (BP, 2014). Table 3 shows a significant disparity between the highest per capita energy consumption region and the lowest, reflecting disparities of development between various regions in the world.

According to IEA (2011), in the last three decades the per capita energy consumption increased about 10 percent while world population increased 27 percent. Middle East recorded the most significant growth of energy consumption per capita, with 170 percent. By 2035 in industrialized regions, such as North America, the energy use per capita is estimated to decline at an annual average of 0.5 percent per year because the population rate growth is going to be higher than the energy use rate. In developing regions such as East and South-East Asia, by 2035, the energy use per capita is estimated to rise at an annual average of 3 percent per year (IEA, 2011).

According to Observ'ER (2013), the structure of electricity production from renewable sources in 2012, was as following: the main source was hydroelectricity with a 78% share; wind power reclaimed the second place summing 11.4% of the renewable total. It is essential to mention that in 2002 wind power generated was 52.5 TWh and in 2012 the same source generated 543.3 TWh, an increase of over ten times. These were followed by biomass power (6.9%), solar power (2.2%), geothermal power (1.5%) and marine energies (0.01%).

3.2. Energy production sources analysis

In 2012 (Observ'ER, 2013) world energy production summed 22613 TWh, from which the renewable electricity production weighted in with 4699.2 TWh, representing 20.8% of 2012 yearly total. Fossil fuels generated 15394.3 TWh, representing about 68% of global electricity production. The other conventional source, the nuclear fission generated about 11% of electricity production.

Table 2. Global energy consumption [tons oil equivalent] and CO_2 Emissions (BP, 2011)

Year	*Population [10^9 inh.]*	*Energy consumption*		*CO_2 Emissions [10^6 tons CO_2]*
		[10^6 tons oil equivalent]	*[tons oil eq./inh.*]*	
1970	3.7	4945.3	1.337	14992.5
1980	4.45	6624	1.489	19322.4
1990	5.28	8108.7	1.536	22613.2
2000	6.08	9382.4	1.543	25576.9
2010	6.9	12002.4	1.739	33158.4

* equivalent/inhabitant

Table 3. World energy consumption at the end of 2013 (BP, 2014; United Nations, 2014)

Region	***Source of energy***							***C [t oil equivalent/capita]***
	Oil	***Natural gas***	***Coal***	***Nuclear energy***	***Hydro-electricity***	***Renewable****	***Total***	
Europe and Eurasia	878.6	958.3	508.7	263	201.3	115.5	2925.3	3.33
North America	1024.2	838.6	488.4	213.7	156.3	65.4	2786.7	5.78
Africa	170.9	111	95.6	3.1	25.7	1.7	408.1	0.36
Latin America	311.6	151.8	29.2	4.7	158.1	18.3	673.5	1.34
Middle East	384.8	385.5	8.2	0.9	5.7	0.2	785.3	3.38
Asia Pacific	1415	575.2	2696.5	77.8	308.7	78.2	5151.5	1.28
Total	4185.1	3020.4	3826.7	563.2	855.8	279.3	12730.4	1.76
Consumption by fuel [%]	32.87	23.73	30.06	4.42	6.72	2.19	100	-

* *includes wind, geothermal, solar, tidal energy etc.*

Fig. 1 presents in points A, B, C and D, the global cumulative installed wind power, geothermal, solar and nuclear capacity.

3.2.1. Fossil fuel energy

Currently, fossil fuels represent the cornerstone of global electricity production with more than two-thirds of the total. Fossil fuels grew between 2002 and 2012 from a 64.99 percent share to a 68.08 percent share (Observ'ER, 2013). The main fossil fuel reserves are unevenly distributed on Earth due to the geologic history of the areas. This is presented in Table 4. The global oil demand was estimated to average 89.7 million barrels/day in 2013 (OPEC, 2013) and is expected to increase by close to 18 million barrels/day over the period 2014-2035, reaching almost 107.3 million barrels/day by 2035 (OPEC, 2012). Coal is currently the second largest source of primary energy worldwide. Likewise, coal is powering the largest growing economies because it is widely distributed across the globe, abundant, accessible and it is also the least subsidized of all fuel sources (WEC, 2013). Natural gas is expected to play an increasingly important role in meeting the energy demand in the world. At the moment there is an important potential for shale gas, but are considerable uncertainties about the size of the resources and the economics of developments (OPEC, 2012).

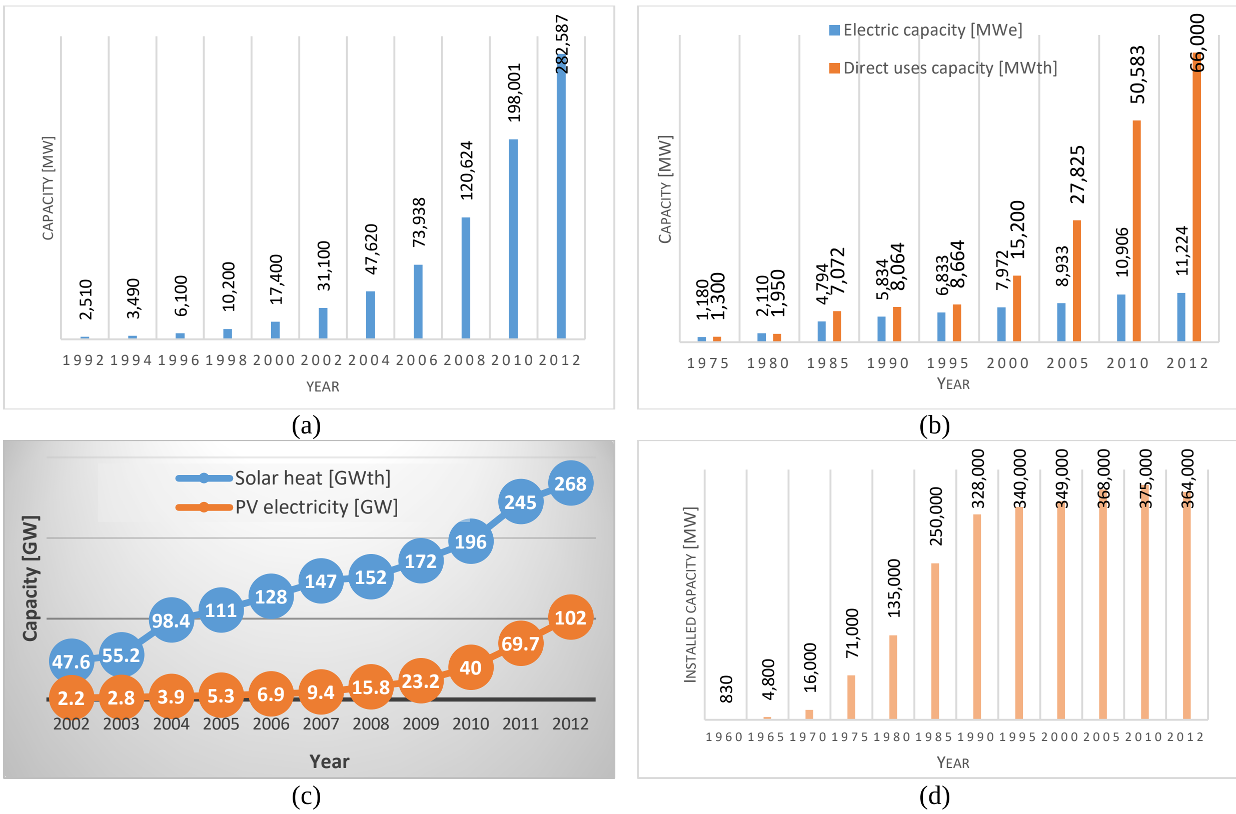

Fig. 1. Global cumulative installed wind power, geothermal, solar and nuclear capacity (modified after GWEC, 2014; GEA, 2013; IEA, 2011-2013; EPIA, 2014; IAEA, 1960-2012): (a) Global cumulative installed wind power capacity; (b) Global geothermal installed capacity; (c) Global solar installed capacity; (d) World nuclear installed capacity

Table 4. Distribution of fossil fuel reserves on Earth in 2013 (BP, 2014)

Region	*Oil*		*Natural gas*		*Coal*	
	[10⁹ t]	*[%]*	*[10¹² m³]*	*[%]*	*[10⁶ t]*	*[%]*
Europe and Eurasia	19.9	8.8	56.6	30.5	310538	34.8
North America	35	13.7	11.7	6.3	245088	27.5
Africa	17.3	7.7	14.2	7.6	31814	3.6
Latin America	51.1	19.5	7.7	4.1	14641	1.6
Middle East	109.4	47.9	80.3	43.2	1122	0.1
Asia Pacific	5.6	2.5	15.2	8.2	288328	32.3
Total	238.2	100	185.7	100	891531	100

The global natural gas demand is estimated to increase by 2.4% per year to reach 3962 billion cubic meters in 2018, at a barely slower rate than coal (2.6% per year) but faster than oil (0.7% per year) (IEA, 2013). Despite the shale gas revolution in the United States where over the past years took place a switch from coal to natural gas in power generation, the use of coal is expected to rise by over 50 percent by 2030, especially in developing countries that face major challenges in providing energy to their populations, and is expected to replace oil as the world's largest source of primary energy (WEC, 2013).

3.2.2. Hydroelectric energy

Hydropower is a renewable energy source based on the natural water cycle. To meet the increasing world electricity demands the electricity generation from hydropower produces about 16 percent of the world electricity. During 2012 an estimated 30 GW of new hydropower capacity came on line, about 51% of it was in China. In 2012 the world production of hydroelectricity reached 3748 TWh/year, three times more than that of 1970s. Table 5 presents the hydropower technical potential in terms of installed capacity, undeveloped potential for 2012 and estimated for 2035.

Hydropower is the largest current source of renewable energy in the electricity sector with a significant potential. It is noticed that the percentage of undeveloped potential range from 18.35% in Europe to 93.28% in Africa, indicating a lot of opportunities for hydropower development in the world.

3.2.3. Wind energy

Wind energy has been used by humankind for thousands of years, at the beginning it was used to provide mechanical energy and currently to provide electricity. It has been estimated that the available wind power that can be converted into other forms of energy is about $1.26x10^9$ MW. Due to the fact that this value represents 20 times the rate of the present global energy consumption, wind energy could meet the entire global needs (Tong, 2010). Fig. 1a shows the evolution of global cumulative installed capacity of wind power during the last two decades. A spectacular increase of the cumulative installed capacity worldwide can be noticed; in 2013 was 126 times larger than that of 1992. Europe was the global leader in wind energy technology use. Almost 39% of the world capacity was installed in Europe by the end of 2013; wind is meeting 8% of Europe's electricity demand (GWEC, 2014). In 2030 the global cumulative capacity for installed wind power is estimated to reach 917798 MW, Asia is expected to be the global leader with a 41% share (GWEC, 2012).

3.2.4. Geothermal energy

Geothermal resources consist of thermal energy from the Earth's interior stored in both rock and trapped steam or liquid water. Resource utilization technologies for geothermal energy can be grouped as types for electrical power generation, for direct use of the heat, or for mixed heat and power in cogeneration applications (Goldstein et al., 2011). In Fig. 1b is presented the global evolution of geothermal power and geothermal direct use during the last 37 years. A significant development is observed. In 2012 the installed electric capacity was almost ten times larger than that of 1975, and the installed capacity of direct-use geothermal energy in 2012 was 50 times more than that of 1975s.

Asia is the leading market for geothermal power having about 44 percent of the global geothermal installed capacity (11765 MW) in August 2013 (GEA, 2013). By 2050 geothermal deployment is estimated to generate 1180 TWh_e/yr for electricity, representing more than three percent of global electricity demand, and 2100 TWh_{th}/yr for heat applications, representing about five percent of global heat demand (Goldstein et al., 2011). Although the world's geothermal resources are immense and ubiquitous, it is difficult to accurately determine the global geothermal resource potentials, mostly because the technologies used are continuously evolving (INL, 2006).

3.2.5. Solar energy

Solar energy is the most abundant of all energy resource on Earth. Annually, the total amount of solar radiation falling on Earth is more than 7500 times the world's annual primary energy consumption of 500 EJ (WEC, 2010). The most widely used solar technologies are solar photovoltaic (PV) systems and solar thermal power plants. In Figure 1c it is shown, globally, the evolution of solar photovoltaic systems and solar thermal power plants during the last decade, being noticed a substantial development. At the end of 2012, Asia (especially China) was the undisputed global leader in solar thermal energy with a 67 percent share, followed by Europe with 16 percent share (IEA, 2014).

Table 5. Regional hydropower technical potential and hydroelectricity generation (Kumar et al., 2011; Rajgor, 2013).

World region	*Installed capacity at the end of 2012 [GW]*	*Technical potential, installed capacity [GW]*	*Undeveloped potential [%]*	*2012 Total generation [TWh]*	*2035 Total generation [TWh]*
Europe	276	338	18.35	745	1062
North America	189	388	51.28	664	771
Asia & Oceania	510	2104	75.76	1654	2320
Latin America	133	608	78.12	611	1054
Africa	19	283	93.28	74	274
Total	1127	3721	69.71	3748	5481

In terms of global cumulative installed PV capacity, at the end of 2013, Europe was leading the way with about 59 percent share, covering 3% of the electricity demand. Nevertheless, in 2013, for the first time in more than a decade, the European market for PV lost its leadership in terms of new installations due to ongoing rebalancing between Europe and the rest of the world, and furthermore reflecting the pattern in electricity consumption (EPIA, 2014).

3.2.6 Bioenergy

Bioenergy is one of the most widely used forms of renewable energy in the world, providing over 10 percent of world's energy supply (WEC, 2013). Biomass is presently the most important renewable energy carrier globally. It is used in the production of electricity, heat and transportation fuels. The main feedstock for electricity and heat biomass generation comes from agricultural crops and residues, forestry, wood-processing industries, and organic wastes. In 2012 the global biomass heating capacity was of about 293 GW_{th}, being noticed an important growth in the last decade, especially in Europe. At the end of 2012 the cumulative biomass power generation capacity worldwide was approximately 83 GW (IEA, 2013).

There are multiple ways to quantify the global biomass resource potential. Probably the most important one is the technical potential, which takes into account the requirements for maintaining the economic, ecological and social value of ecosystems (Chum et al., 2011). Table 6 presents the technical potential of biomass plantation worldwide determined by taking into account a specific set of assumptions with respect to nature protection requirements, the current agriculture practice and productivity, populations, diet, climate. Currently, it is noticed that the largest technical potential comes from Africa with over 40 percent share. Unlike industrialized countries where the biomass use is average only about 3 percent of the total primary energy, in developing countries, biomass contributes about 22 percent to the total primary energy mix, especially in Asia, Latin America and Africa where are registered the highest rates of urbanization in the world (WEC, 2013). Pappas et al. (2012) mentioned that the main barriers to the deployment of biomass are low conversion efficiency, low feedstock availability, lack of supply logistics, risks associated with intensive farming. The studies arrived at the conclusion that the sustainable upper bound of the global technical potential in 2050 can amount to approximately 500 EJ (Dornburg et al., 2010), which means there is an important potential to expand biomass use, especially by increasing plant productivity, land efficiency, water management and sustainable use of residues and wastes for bioenergy.

3.2.7. Nuclear energy

Nuclear energy is produced as the result of nuclear fusion, nuclear fission of a radioactive element. The amount of energy released by the nuclear fission of 1 kg of uranium is similar to that obtained by the combustion of 3000 tons of coal or 14000 barrels of oil (Joesten et al., 2007). In Fig. 1d it is shown that the global cumulative installed capacity for nuclear power during the last six decades. It is noticed a spectacular capacity increase in the 1970s and 1980s, as countries sought to reduce dependence on fossil fuels, especially after the oil crisis of the 1970s.

Table 6. Technical potential of biomass plantations worldwide (Chum et al., 2011; Fisher et al., 2009)

Region	*Total grass- and woodland area [Mha]*	*Unproductive or very low productive areas [Mha]*	*Bioenergy area [Mha]*	*Technical Potential [EJ/yr]*
Europe and Russia	902	618	122	17
North America	659	391	111	19
Africa	1086	386	275	69
Latin America	765	211	160	45
SE Asia	556	335	14	4
Pacific OECD	515	332	97	17
Middle East and N Africa	107	93	1	0.2
World	4605	2371	780	171

The growth stagnated in the 1990s due to increased concerns about safety following the Chernobyl accident, and even more in the 21st century due to the Fukushima accident (Hernández- Ceballos et al., 2012), but also due to a return to lower fossil fuels prices. By the year 2030, world nuclear capacity is expected to grow between about 540 GW net in low demand case and 746 GW net in the high demand case, especially in Asia (OECD, 2012). Currently, nuclear and hydropower are the only low-carbon sources, providing significant amounts of energy. Energy generated from nuclear plants avoids annual CO_2 emissions of about 2.9 billion tones compared to coal-fired generation (IEA, 2010a, c). Although a generally high security standard is required as accidents can happen with devastating consequences for human beings and for the ecosystem. Therefore deployment of nuclear energy should be preceded by complex comparative analyses of all available options (Vujic et al., 2012).

4. Energy production and environmental impact assessment

A major objective of sustainable development is to guarantee environmental quality. However, an ideal energy production technology that is at the same time environment-friendly, risk-free and cost-effective does not exist. Every technology deployment implies some trade-offs to be made, in order to ensure optimal use of energy resources, while restricting environmental and health impacts (Vujic et al., 2012).

The goal of this section is to review the environmental impact assessment for water, air, land and ecosystem for different types of electricity generation sources.

4.1. Environmental impact assessment for water in case of energy production

Currently, worldwide, industry accounts for 20 percent of all water consumption, compared to 70 percent for agriculture and 10 percent for domestic use (UNESCO, 2012).

The global average water footprint related to consumption was 1385 m^3/y per capita over the period 1996–2005 (Hoekstra and Mekonnen, 2012); the water footprint is one of the most used indexes when analyzing the relationship between the total amount of fresh water that is used to produce the goods and services consumed by the inhabitants of a nation. However, freshwater withdrawals have tripled over the last 50 years. Globally, the annual population increase of 80 million per year implies an increased demand for freshwater of approximately 64 billion cubic meters a year. Considering that there would be an additional 1850 cubic kilometers of water consumption by 2030, 30 percent higher than today's level, more sustainable water use programs have to be implemented, especially in the regions with rapid population growth and with growing water stress (MGI, 2011). Energy and water are intricately connected. Electricity generating technologies use water for different production processes throughout the entire lifecycle. For assessing the impact regarding freshwater use two aspects are analyzed: "withdrawal" (the water removed from the ground or diverted from a water source for use) and "consumption" (the water evaporated, transpired, incorporated into products or crops, or otherwise removed from the immediate water environment) (Kenny et al., 2009).

The electrical energy necessary for economic growth requires massive withdrawals of water. Table 7 presents the median lifecycle uses of water for conventional and renewable electricity generation technologies.

Table 7. The average water footprint for different electricity generation technologies (adapted upon Fthenakis and Kim, 2010; Macknick et al., 2011; Wilson et al., 2012)

Electric fuel	*Water footprint [l/MWh]*
Coal	63382
Hydroelectric	1699649
Natural gas	26986
Nuclear	68191
Geothermal	5823
Solar PV	882
Wind	234
Biomass	46984

Wind and PV technologies are by far the most "water-friendly" energy options (their lifecycle median water usage ranging from 234 to 882 l per MWh produced) while hydropower, coal and nuclear have the largest water use (ranging from 63382 to almost 1.7 million l per MWh).

Considering that most of the energy is generated by conventional technologies that require large volume of water flows, energetic efficiency and water conservation programs are essential for protecting the freshwater resources from the impact of electricity production. Instead of altering the site's hydrology and ecosystems, technologies like solar PV and wind, which are highly sustainable with respect to water consumption, should be implemented at larger scale (Wilson et al., 2012).

4.2. Environmental impact assessment of air in case of energy production

This section reviewed available estimates for major air pollutants that are emitted by renewable and non-renewable electricity generation sources. These include CO_2 emissions, nitrous oxides (NO_x), sulphur dioxide (SO_2) and particulate matter (PM) emission. All these cause negative impacts on human health and the ecosystems' quality.

Lifecycle greenhouse gas emissions intensity in electricity generation depends on the source used. It is necessary to be evaluated not only the emissions exhausted during the generation of electricity, but also emissions from upstream processes (fuel exploration, mining, fuel transport, plant construction), as well as downstream processes (decommissioning, waste management and disposal), in order to assess the impact of the power generation sources (Weisser, 2007). Fig. 2 illustrates a comparison of greenhouse gas emissions, normalized in tones of CO_2 equivalent per GWh, for different electricity generation sources.

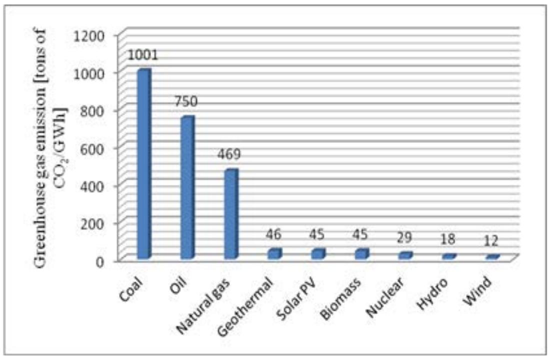

Fig. 2. Lifecycle greenhouse gas emissions from different electricity generation sources (adapted upon Chum et al., 2011; Goldstein et al., 2011; Hsu et al., 2012; Stacey and Garvin, 2012; Weisser, 2007; WNA, 2011)

It is noticed that fossil fuel sources generate the highest greenhouse gas emissions on a lifecycle basis, ranging from 469 tones CO_2/GWh (natural gas) to 1001 tones CO_2/GWh (coal). Most of lifecycle greenhouse gas emissions for fossil fuels sources are registered during the operation of the power plant. The emissions throughout downstream activities are insignificant but during upstream activities may be released considerable emissions depending on processes involved in extraction, fuel transportation and fuel preparation (Weisser, 2007). Fossil fuel based electricity production can be a major source of air pollution: NO_X (lifecycle emissions ranging from 0.4 g/kWh (natural gas) to 4 g/kWh (oil)), SO_2 (lifecycle emissions ranging from 5 g/kWh (natural gas) to 27 g/kWh (coal)), PM (lifecycle emissions ranging from 0.02 g/kWh (natural gas) to 2.3 g/kWh (coal)) (Bauer, 2008; Sathaye et al., 2011).

For geothermal plants, the greenhouse gas emissions are less than 50 tones CO_2/GWh for flash steam plants and less than 80 tones CO_2/GWh for projected EGS (Enhanced Geothermal System) plants (Goldstein et al., 2011). Lifecycle NO_X emissions are lower than 0.4 g/kWh. SO_2 and PM emissions are negligible (Sathaye et al., 2011).

PV systems generate negligible greenhouse gas emissions during the electricity generation. However, about 70 percent of emissions arise during upstream processes, especially in the system components manufacture (Hsu et al., 2012). Solar power equipment releases 50–1000 times less direct Hg emissions than traditional electricity generation (Turney and Fthenakis, 2011). In terms of NO_x, SO_2 and PM emissions are negligible (Sathaye et al., 2011).

Lifecycle greenhouse gas emissions from bioenergy systems range between about 16 and 74 tons of CO_2/GWh depending on the combustion efficiency, power rate, type of feed. The majority of emissions arise during the upstream processes (Chum et al., 2011). Lifecycle NO_X emissions are about 5 g/kWh, SO_2 emissions are approximately 2.5 g/kWh and PM emissions are about 0.5 g/kWh (Bauer, 2008; Sathaye et al., 2011). For nuclear energy, the majority of greenhouse gas emissions occur upstream of operation, depending on the enrichment process. NO_X, SO_2 and PM emissions are negligible (Sathaye et al., 2011). Lifecycle greenhouse gas emissions from hydropower projects range between 1-34 tones CO_2/GWh, depending on type of the plant (reservoir or run-off), its size and usage as well as the electricity mix used for its operations (Weisser, 2007). Lifecycle NO_X, SO_2 and PM emissions are negligible (Sathaye et al., 2011). Wind energy is currently the most environmental friendly technology with the median of greenhouse gas emissions at 12 tones CO_2/GWh, 83 times less than coal fired power plants (Stacey and Garvin, 2012). Lifecycle NO_X, SO_2 and PM emissions are negligible (Sathaye et al., 2011).

Hence, for reducing greenhouse gas emission from electric power generation is required a substantial increasing of the share of total electricity generated from renewable source and improving efficiency of existing power plants (Scripps Institution of Oceanography, 2014).

4.3. Environmental impact assessment for land use in case of energy production

In order to assess the land use impact of the power generation sources, this has to be evaluated not only the land on which the power plant is situated, but also the impact of the full land use life cycle. Land transformation and land occupation are the main metrics used in the literature to describe and compare land requirement for different energy production sources. The former indicates the area of land altered from an original state, while the latter involves the duration over which the area of the transformed land returns to its reference state, measured as a product of land area (m^2) and time (year) (Koellner and Scholtz, 2007). Table 8 summarizes the land transformation and land occupation for power production using different conventional and renewable sources (Fthenakis and Kim, 2009).

It is noticed that land use impacts vary widely between and within sources, also depending on regional conditions. From Table 8, it is noticed that, as concerns the non-renewable sources, coal-fuel cycle affects the land transformation pattern the most. The mining, beneficiation, and electricity-generation stages can involve destruction of existing landscape, soil erosion, land subsidence, water contamination, land acidification, removal of vegetative cover and topsoil (Fthenakis and Kim, 2009; Miranda et al., 2003; Spath et al., 1999).

As regards renewable sources, hydroelectric power plants affect the pattern of land transformation the most (Fthenakis and Kim, 2009). Nuclear power entails the lowest land transformed per unit of electricity. However, land transformed accidentally by disasters in the nuclear-fuel cycle can have dramatic consequences. In November 2011, the Japanese Science Ministry reported that the destruction of the Fukushima Daiichi nuclear power plant contaminated more than 30000 square kilometers of land with radioactive cesium (Ishizuka, 2011).

Table 8. Land transformation and land occupation for electricity production from different sources (Fthenakis and Kim, 2009)

Energy source	*Land transformation [m²/GWh]*	*Land occupation [m²/GWh]*
Coal	239-489	1290-25200
Natural gas	265	4200
Nuclear	109-124	300000
Solar PV	164-552	9900
Wind	1030-3230	2040
Hydro	2350-25000	100000
Biomass	12550	380000

For non-renewable fuel cycles, such as coal and nuclear energy, the land occupation is dominated by upstream and downstream processes. The full recovery of coal-mined lands is expected to be several hundred years (it would take 200–300 years before the composition of native forest to be reestablished (Burger, 2002).

As shown in Table 8, bioenergy requires the greatest land occupation (380000 m^2 year/GWh) because of the need to cultivate feedstock. It has to be noticed that inadequate land use change due to biofuel production can aggravate soil and vegetation degradation associated with overexploitation of forests, too intensive crop and forest residue removal (Koh and Ghazoul, 2008; Robertson et al., 2008). Wind power-plants entail the lowest land occupation per unit electricity. Moreover, wind farms can be located on low quality lands (e.g., brownfields or other contaminated site), and often be used for a variety of other productive purposes, including livestock grazing, agriculture, highways, and hiking trails (Mai et al., 2012; NREL, 2010). The assessment of environmental impacts of land transformation and occupation is complex. Although hydroelectric energy and bioenergy require large amounts of land, the other renewable technologies, such as wind energy and solar PV, involve similar or less disturbance of land than non-renewable sources (Fthenakis and Kim, 2009).

4.4. Environmental impact assessment for the ecosystem in case of energy production

In energy systems around the world changes, which will have implications for ecosystems and livelihoods take place (Boyle et al., 2003). All energy sources affect the ecosystem. Although renewable sources are significantly safer, they can have a negative impact on the ecosystem. The constructions of fossil fuel-fired power plants, as well as oil refineries, destroy habitats for animals and plants, affecting the biodiversity, due to the inability of many species to survive in such conditions (Wake, 2005).

Hydrocarbons-based energy sources impact maritime ecosystems through different ways. Seabird populations are vulnerable to the effects of oil and gas pollution, especially from the surface oil pollution. Fish and shellfish populations, benthic communities and plankton are vulnerable to impacts from hydrocarbon pollution, especially from hydrocarbon spills (BP, 2010; Karacik et al., 2009; Mosbech, 2000). Studies have shown that new road building, pipeline construction and expanding drilling operations disrupt migration, habitat, and wintering grounds for many wildlife species (EPA, 2008; Riley et al., 2012). Coal mining causes extensive degradation to natural ecosystems, reducing the number of tree species in the mined areas and impairing the plant diversity (Sarma et al., 2010). The environmental impacts of coal mining-derived runoff (e.g., acid drainage) are severe, large scale, and long lasting, especially on aquatic fauna and flora (Bernhardt and Palmer, 2011; Ochieng et al., 2010). Hazardous air pollutants emitted from fossil fuels-fired power plants deposit into rivers, lakes and oceans and are taken up by underwater fauna and flora. These pollutants lead to bioaccumulation of toxic metals, environmental acidification, contamination of aquatic life, can harm plants and the wildlife (EH&E, 2011).

Hydropower, usually, requires the reservoir formation which involves special biotope and habitat loss due to inundation, climate change and can cause the relocation of communities living nearby the lake (Salvarli, 2006). When the oxygen-poor water from the bottom of the lake is released through a dam into the river, downstream habitat condition change (e.g., it can kill fish that are accustomed to warmer, oxygen-rich water) (Hamilton, 2013). The construction of onshore wind farms alters ecosystems through the clearing of vegetation and can lead to habitat loss and fragmentation, especially on forested ecosystems (Katsaprakakis, 2012).

Wind energy developments cause fatalities of birds and bats through collision, being responsible for 0.003 percent of bird mortalities caused by human activities (EWEA, 2009). The construction of offshore wind farms may disturb benthic communities and marine mammals, changing the existing biodiversity in the area and creating a new local ecosystem (EWEA, 2009). The construction of a geothermal plant and roads alters ecosystems through the clearing of vegetation. During well testing, due to the noise, wildlife in the vicinity of the drill rig can be moderately affected (Noorollahi and Yousefi, 2003).

Solar PV may cause disturbance during the installation stage. Also the PV panels cast shadows and may change the microclimate, causing an unstudied effect on vegetation (Turney and Fthenakis, 2011). Studies revealed that central concentrator power systems could pose a danger to birds (OECD/IEA, 1998), and flying insects can also be burnt when flying in the vicinity of the reflector's area, but the loss of the insect population is negligible (Tsoutsosa et al., 2005).

Diversion of crops into bioenergy production can influence food commodity prices and food security (Headey and Fan, 2008). Growing demand for bioenergy put pressure on the degradation and loss of more remote habitats and landscapes (Firbank, 2008). The insertion of invasive or genetically modified species causes the decline of biodiversity, especially if forest, peat, grass and wetlands are used for feedstock production and if large monoculture plantations are created (CBD, 2008; Sathaye et al., 2011). Regarding nuclear energy, the loss of biodiversity is frequently associated with contamination due to uranium mining and milling processes. The setting up of a nuclear plant disrupts the ecological balance of the region (Bond et al., 2003; Teixeira et al., 2012).

5. Conclusions

This paper has provided an overview of the current state of world natural resources used to produce energy, and the energy consumption degree across different regions of the world, as well as the main conventional and renewable energy technologies as regards specific sustainable factors. Global natural resources have been diminishing over the years, mainly due to factors such as fast growing population and industrialization. Worlds' economy requests ever-increasing amounts of energy, contributing thus to an increasing use of natural resources.

Taking into account the identified fossil and uranium resources, at current rates of consumptions, these are sufficient for a few decades of supply for global power plants; most of the energy is generated by conventional sources that have significant environmental impact, and because of this, the energy transition from fossil fuels to renewable sources of energy should be urgently embarked upon.

Sustainable development requires adequate methods to measure and compare the environmental impacts for energy production technologies. An ideal energy production technology does not exist; each has its advantages and disadvantages. Renewable technologies, excepting hydropower, are by far the most "water-friendly" energy options; thereby their increasing utilization could reduce the stress in water resource availability in many regions of the globe. Fossil fuels generate the highest greenhouse gas emissions on a lifecycle basis, especially during the operation of the power plant, being responsible for global warming, one of the major environmental problems that the humanity is currently facing. Wind energy, on the other hand, has minimum impact on the environment in terms of greenhouse gas emissions.

A substantial decreasing of greenhouse gas emissions cannot be obtained if renewable energy resources are not enhanced in share of generation mix. As regards land transformation, hydroelectric plants mostly affect the pattern of land transformation. Despite having the minimum impact on the environment in terms of land transformation, nuclear technologies are not universally considered sustainable due to the environmental and health hazards they bring along, as shown from the recent accident in Fukushima Daiichi, which seems to have halted their expansion.

Unlike bioenergy which requires the greatest land occupation, wind power plants entail the lowest land occupation per unit electricity. Finally, in terms of impact on the ecosystem, studies have shown that the renewable technologies are considerably safer than the conventional ones.

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