The Potential and Barriers for Renewable Energy

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Abstract

Currently, only around 13 percent of global energy demand is met by renewable energy sources. While a significant increase in renewable energy production is expected in the future, a similar increase is expected in global energy demand. This means renewable energy will maintain only a small part of the total share of energy production towards 2030.

The most relevant sources of renewable energy are wind, solar, biomass, hydro, wave, tidal and geothermic heat. Common denominators for all these sources are the realizable potential being far below the theoretical potential. An assessment of the potential of energy production using renewable energy sources must be based on a barrier analysis, as well as an analysis of the environmental impact from each of the different technologies.

An increased implementation of renewable energy productions is slowed down by economic, technical, land use, social and environmental barriers. Especially the technical, environmental and social barriers related to renewable energy sources indicate the continued domination of fossil energy sources also in 2030. According to the International Energy Agency, IEA, only 16 percent of global energy demand in 2030, can be covered by renewable sources. A widespread effort could result in a share of renewable energy beyond the estimates by the IEA, this would require new financial incentives as well as other measures to reduce particularly the economic barriers related to renewable energy production.

1. Introduction

The Intergovernmental Panel on Climate Change has estimated that the increased level of emissions from greenhouse gases will lead to a increase in the average global temperature of 1,1 to 6,4 ^{o}C in the 21st century [1]. An increase above 2 ^{o}C will cause serious consequences, thus the IPCC recommends measures are taken to reduce CO_2 emissions by 50 to 80 percent by 2050 [2].

An apparent emission-reduction strategy is to replace fossil energy production with renewable energy production. Renewable energy sources only cover about 13 percent of current global energy demand. The remaining energy demand is met by fossil sources (81 percent) and nuclear energy (6 percent) [3]. A substantial increase in renewable energy production is expected towards 2030; however, a similar increase in global energy demand is also expected, and according to the International Energy Agency (IEA), the share of energy demand covered by renewable sources in 2030 will be around the same as it is today. The share could however slightly increase, according to the IEA, if global enhanced energy efficiency are achieved with a consequent slower growth in energy demand.

The theoretical potential of renewable energy is significant, however there are large barriers related to an increased production of renewable energy. An important aspect is the fact that energy production based on fossil

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sources is cheaper for the project developers, than renewable energy, based on the existing technology and framework. Other barriers include land use conflicts and regional impacts on eco-systems and biological diversity. Large scale development of renewable energy production within a short time frame can therefore have unintentional environmental consequences.

The objective of this paper is to analyze the potential and barriers for increased renewable energy production. Methods for estimating environmental consequences related to renewable energy are described in Section 2. In Section 3, the potential and barriers for new renewable energy production is described, while different scenarios for renewable energy production are presented in Section 4. Conclusions are given in Section 5.

2. Methodology

The realization of new energy production from renewable sources is delayed by economical, technical, social and environmental barriers as well as area conflicts.

An assessment of the potential of renewable energies must be based on an analysis of how much energy can actually be realized from the different sources, and the associated environmental consequences. Central elements of such an analysis are to establish methods for calculating future energy production as well as methods for calculating and weighing environmental consequences.

2.1. Nomenclature

It is important to distinguish between the theoretical and the realistic potential of renewable energy production. According to Howes [4], the theoretical potential is limited by what is economically feasible at any point in time, environmental and land-use considerations, and possible conflicts of interests with other industries. de Noord et al. [5] separate between; theoretical; technical; realistic; and realizable potential, as illustrated in Figure 1.

- **Theoretical potential:** The total physical amount of energy for a given source.
- **Technical potential:** The amount of energy that can be utilized with today's technologies.
- **Realistic potential:** The amount of energy that can realistically be utilized after marked barriers and barriers such as; social acceptance; environmental factors; and area conflicts are considered.
- **Realizable potential:** The energy which can be realized within a given timeframe. This energy potential depends on economic conditions as well as global market production capacity.

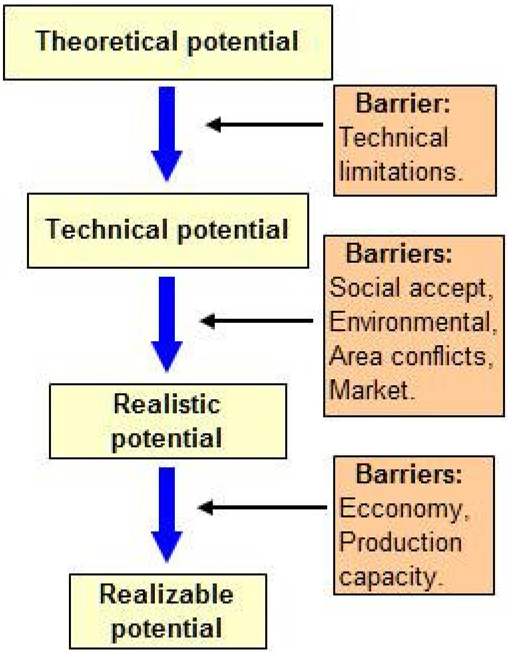

Figure 1 – Schematic presentation of energy potential.

The common denominator of all renewable energy sources is a realizable potential far below the theoretical potential. Despite the fact that solar energy has a theoretic potential of approximately 15 000 times global energy demand [6] , solar energy will most likely meet less than 1 percent of global energy need in 2030 [6].

The technical potential for wind power is around 500 000 TWh every year [7], *i.e.* almost four times more than the total global energy demand. However, this would require 23 percent of all available land to be used for wind power, which would neither be publicly accepted nor technologically and economically feasible.

The above mentioned examples illustrate the importance of bearing in mind the differences between theoretical and realizable potential. Estimates of realizable new renewable energy production provided in available literature vary widely, thus, it is important to be aware of the preconditions for these estimates.

2.2. Evaluation of Environmental Consequences

A life cycle analysis (LCA) describes the environmental aspects and potential environmental effects of a product through its value chain or lifetime. According to the ISO 14040 standard [8], an LCA accounts for how raw materials are obtained; the production process; and use and disposal of materials.

Several different types of LCA have been used for energy production. The purpose of these studies has been to compare the different environmental burdens caused by a range of energy production methods, in addition to decide which processes cause the most severe environmental strains.

It is common to introduce several sub-categories for different environmental consequences. Which category is used in a LCA depends on what is examined; which methods are used; and the aim of the analysis. A frequently used method for evaluating environmental consequences is the Eco-Indicator 99, developed by PRé Consultants in collaboration with Dutch and Swiss authorities. This method combines different environmental consequences in a value chain, based on three different categories; health, resources and ecosystem quality [9]. The results from the different categories are combined into a single parameter, describing the overall environmental consequences caused by a product or a value chain.

When comparing the environmental consequences caused by different alternatives of energy production, methods that provide a common standard of comparison must be used. An example is Holdren's "Impact Chain" [10]. This method is based on impact chains for different categories of environmental stress, where a standard relationship between cause and effect is present. The method is illustrated in Figure 2.

An important aspect of LCA is how the different environmental impacts are weighed against each other [11]. This will depend on which environmental parameters are considered to be more important or not so important, something that inherently will vary over time, and from person to person. It is also common to separate between local, regional and global environmental strains. Examples are deterioration of local habitats (local); acidification of large lakes (regional); and global warming (global).

When deciding which energy solutions to aim for in the future, having the knowledge of which environmental effects that could arise from the different alternatives becomes vital. However, it can be difficult to use different lifecycle analyses as a base of comparison, as choice of system boundaries, the methods for assessing environmental consequences as well as local settings could involve one source being favoured [12]. An example is a hydropower installation put up in a waterway which could be considered to be less environmentally burdensome in areas where only a small part of water resources are utilized, than in areas where untouched nature is rare.

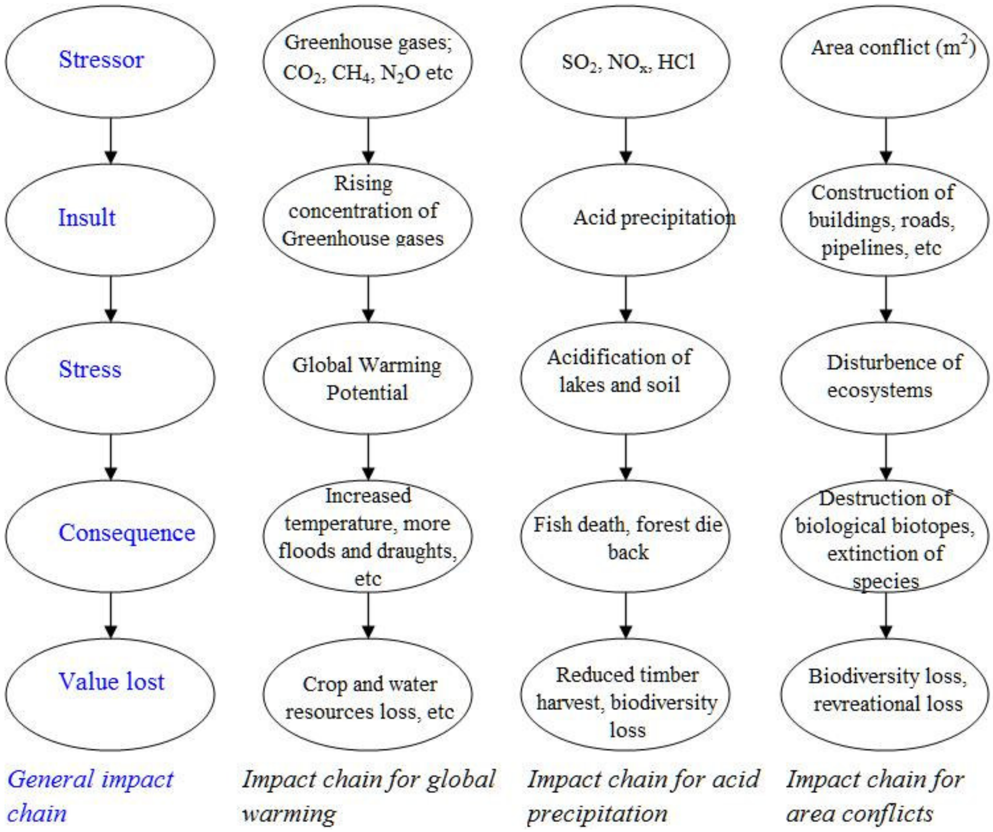

Figure 2 – Impact chains for different categories of environmental stress [10].

2.3. Quantification of Environmental Consequences

2.3.1. The Biotope Method

Vattenfall, a Swedish energy company, has developed a method for quantifying environmental effects with emphasis on loss of biological diversity through production of energy. This so-called *Biotope Method* estimates the area where different biotopes are affected as a consequence of the energy production. The method uses the following categorization of biotopes:

- *Critical biotopes:* Biotopes that provide or has the potential to provide shelter for endangered species, i.e. species that could soon be extinct.
- *Special biotopes*: Biotopes diverging from nearby areas due to their high degree of biodiversity, presence of key-species and/or uncommon species.
- *No biotopes*: Areas without suitable conditions for biological production (i.e. already urbanized or developed areas)
- *Other biotopes*: Those that do not fall under any of the above categories.

A prerequisite for the *Biotope Method* is the evaluation of the area before and after energy production. In addition, area per produced energy-unit (m^2/kWh) must be established. The objective is to be able to quantify the environmental strain caused by use of the land [13].

2.3.2. The CV method

The Norwegian company Statkraft has chosen an approach based on environmental costs, in order to document the environmental consequences from renewable energy projects. The so-called *CV Method* (Contingent Valuation) aims to estimate the environmental effects, using the willingness-to-pay principle, specifically for environmental benefits. The CV Method can be divided into four parts [14]:

1) Description of amount and quality of affected environmental benefits, with and without the project.
2) Description of the environmental effects caused by the project.
3) Description of a realistic method of payment, e.g. an add-on to the electricity bill.
4) Identification of the willingness to pay to avoid described environmental consequences. This can be measured against the amount of energy produced and quantified with the unit US$/MWh.

The *CV Method* does not account for the fact that willingness to pay may change over time. Neither does the method consider how willingness to pay should be weighed between people who are directly influenced, and those who stay at a distance but would benefit from the energy produced. In addition, some poor or deprived people may have no ability to pay at all; consequently, their environmental load cannot be quantified using the *CV method*.

3. The Potential and Barriers for Renewable Energy

Based on the methodologies presented in Section 2, the future energy production can be analysed based on energy sources, environmental issues and economic consequences. Such an analysis builds the foundation for decisions on which energy sources can contribute to cover future energy demand.

A transfer towards the sole use of renewable energy sources is dependant on a technological development to increase the ratio of energy production per area (*i.e.* energy production given as kWh/m^2). Another important element to be considered is profitability, meaning what is profitable to implement at any point in time, based on existing economic incentives and frameworks. The increased renewable energy production must also be considered in regards to available manpower and necessary infrastructural investments.

Renewable energy production will have environmental consequences, which will increase following further expansion. Consequently, increased production must be carried out to ensure minimal environmental strains.

3.1. Wind Power

All production of energy requires use of land. In an environmental context, land is a resource and use of land must be counterbalanced with alternative use of resources and also potential environmental damage. How a land is used will have implications for wildlife, vegetation and outdoor activities. It is therefore of great interest, from an overall perspective, to calculate how much area is used per kWh produced energy, and how much land that needs to be used to produce enough power to replace fossil energy sources and nuclear power plants.

A study by de Noord et al [5] estimates that, in the EU-15* and Norway combined, the total area suitable for wind power production is up to 14 700 km^2. The potential for power production per area unit can be analysed using estimates from existing projects. The wind power plant at Smøla in Norway has a total area requirement of 36.2 km^2, and a total installed effect of 300 MW, which makes an effect density of 8.3 MW/km^2 [15]. A second wind power park, Bessakerfjellet, has an area requirement of 3.5 km^2, and a installed effect of 50 MW, giving an effect density of 14.3 MW/km^2 [16]. Based on these two examples, it is reasonable to assume an average installed effect of approximately 10 MW/km^2. This suggests a potential of 147 GW installed onshore wind power in the EU. In comparison; the total power demand in the EU in 2030 is estimated to be 1000 GW, according to the IEA**. Hence, onshore wind power has only the potential

* EU-15: The 15 member countries of the EU before the extension in Mai 2004.
** All references to IEA in Section 3 are related to the IEA Alternative Policy Scenario [3].

to cover a small part of energy demand in the EU.

de Noord et al[5]. have produced estimates for offshore power production, concluding that the potential in terms of available area is high, assuming only minor conflicts of interest with the fishing industry. The realistic potential is calculated to be 485 TWh/year within the EU-15 and Norway. This would be equivalent to about 13 percent of EU's total energy demand in 2030 [3]. The limitation implied here is not related to land-use, but rather in what is economically viable, in particular regarding geographical distance to the mainland and grid-connection costs.

3.2. Solar Energy

Solar panels and thermal energy production from solar energy are often put forth as the solution to future global energy need. A widespread energy production from solar cellc will require a large scale production of high purity silicon. However, the production capacity of pure silicon is limited. Other barriers to increased solar energy production are lack of available land for photovoltaic installations and lack of economic incentives.

Power production using on solar panels has grown tremendously the last few years, and the growth is expected to continue. On a global scale, power production from solar energy is increasing by 17 percent every year, while the growth in the EU is more than 20 percent every year [3]. Due to the limited production capacity, a slower growth rate is expected towards 2030. According to the IEA, global power production from solar energy will be 60 times larger in 2030 than in 2004 [3].

This means solar energy will have a share of only 0.8 percent of total power production in 2030. Thus, in spite of the rapid growth in power production based on solar energy, the production compared to demand will remain small. Following the development of a better framework with the right economic incentives, a far higher growth than projected by the IEA could be expected.

Electricity- and heat-production using roofs and facades on buildings could easily be arranged for. The IEA [17] has documented that, for some select countries, the potential building area which can be utilized for power production is 9 300 km^2, see Table 1. It is estimated that this area can produce enough power to cover up to 43 percent of the total building's energy demand. This means that lack of suitable land areas doesn't necessarily have to be a limiting factor. It is rather the technological development to increase efficiency in photovoltaic installations, as well as the financial viability in the years to come, that will decide the development for solar power.

3.3. Hydro power

Hydro power already covers about 16 percent of global energy demand [3]. In some parts of the world, a large amount of hydro power plants have already been built, however environmental barriers limit a further spread. While there are a number of places with large potential for new water power, this potential is not sufficient to keep up with the current growth in global demand. In fact, according to the IEA, hydro power's share of global demand will be reduced towards 2030 [3].

The construction of hydro power projects often entails significant encroachment on nature and wildlife. An example is the worlds largest hydropower plant; The Three Gorges in China. The plant was opened in 2007 and annually produces 85 TWh. Due to the damming up of the Yangtze River, and the construction of the water reservoir, 1.2 million people were displaced and whole villages were submerged in water. A large proportion of those displaced were farmers, which were forced to find new labour. Thus, the social consequences of this project were tremendous.

Table 1. Technical potential for solar power production from buildings [17].

Country	Area available for power production on roofs and facades (km^2)	Realistic potential for solar power production (TWh/year)	Power demand in the buildings (TWh/year)	Potential for solar energy supply (%)
Australia	580	84	182	46
Austria	191	19	54	35
Canada	1325	152	495	31
Denmark	121	11	34	32
Finland	160	15	77	19
Germany	1782	160	531	30
Italy	1050	127	282	45
Japan	1328	147	1013	15
The Netherlands	356	32	99	32
Spain	617	86	180	48
Sweden	300	27	137	20
Switzerland	190	18	53	34
UK	1257	105	344	31
US	1258	2081	3603	58
Total	**9384**	**3064**	**7084**	**43**

3.4. Bio energy

Biomass is carbon neutral, and through replacing fossil fuel with biomass, a solid effort towards limiting the detrimental effects of global warming can be made. Bio energy and waste incineration cover 10 percent of current global energy demand [3], and the potential for an increased production of bio energy is significant, both for heating and power production. According to the IEA [3], global energy production from biomass could increase with as much as 45 percent from 2004 to 2030. However, due to the large increase in global energy demand, the share of bio energy will remain more or less unchanged towards 2030.

In the transport sector, gasoline and diesel is mainly used as fuel, with the subsequent release of greenhouse gases. In the OECD-countries in Europe, 20 percent of the energy end-usage is for fuel in the transportation sector [3]. A long term environmental aim is therefore to replace gasoline and diesel with CO_2 neutral fuels, *e.g.* biofuels and hydrogen. The European Commission has set a quantified target of a 14 percent marked share for biofuels by 2020 [21].

An increase in the production of bio energy must be based on a sustainable use of biomass. This necessitates the increased use of biomass for energy purposes to be realized without any negative impact on food production or bio diversity. This has already been exemplified in Mexico, where agricultural land was converted to biofuel production intended for the US market. As a consequence, the price of wheat increased to a high level, causing serious problems for the poor who could no longer afford wheat.

3.5. Wave, Tidal and Geothermal Energy

The global power production based on wave and tidal energy is expected to increase from the current level of 1 TWh per year, to 12 TWh per year in 2030 [3]. Despite this increase, the share of total global energy production adds up to as little as 0.1 percent. A larger share is limited in particular by significant technical challenges, but also by economic challenges related to the construction of large-scale wave and tidal energy plants.

Geothermic energy has great potential in areas where such energy is easily available. A good example is Iceland, where geothermic heat is widely used for heating. Geothermic energy also has a significant potential for production of power and heat. Geothermic power could have about 0.6 percent share of total global energy demand in 2030, according to the IEA [3].

3.6. Renewable Energy Combined with Hydrogen Production

In the long term perspective, hydrogen can become a very important energy carrier. The EU Technology Platform for Hydrogen and Fuel Cells has concluded that hydrogen can have a market share in the transport sector of up to 50 percent of total fuel use in the EU in 2050 [18].

Hydrogen production is energy intensive and the necessary energy can come from multiple sources. Based on a report from General Motors [19], Bellona has estimated that if half of the vehicles in Europe's OECD-countries use hydrogen in 2030, this will require 2 500 TWh per annum for production of hydrogen. This is more than 50 percent higher than the IEA estimate of renewable energy production in 2030 [3]. Even if all the renewable energy is used for hydrogen production; this would still not be sufficient to meet the demand for hydrogen in the transportation sector in OECD.

The main environmental consequence of hydrogen production based on fossil fuels is the release of greenhouse gases. A study done by Strømman and Hertwich [20] shows that introducing CO_2 capture and storage to hydrogen produced from steam reforming of natural gas will reduce greenhouse gas emissions by 77 percent. The emissions can be further reduced by 15 percent if the produced hydrogen gas is used as an energy source in the production process, see Figure 3. This illustrates how production of hydrogen from steam reforming combined with CCS is a realistic and environmental method of producing hydrogen.

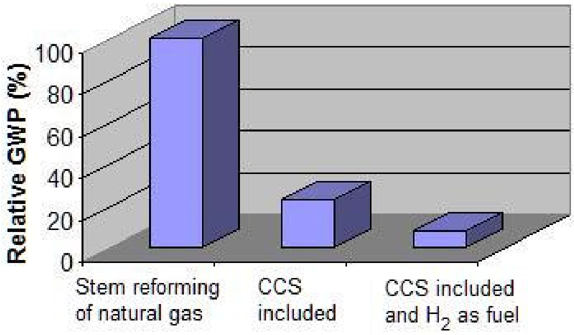

Figure 3 – Relative Global Warming Potential (GWP) for hydrogen production.

3.7. Economic Barriers

A problem with the current energy markets is that environmental costs are not adequately internalised. While the production of fossil energy causes huge greenhouse gas emissions and consequently global warming; costs of these external factors are poorly reflected in the market price for energy. This implies a hidden subsidise of fossil energy.

The EU's cap and trade system, the European Trading Scheme, does put a cost on CO_2 emissions, however external environmental costs are only to a small extent reflected in this system. Thus, there is a need for fiscal instruments and frameworks reflecting the full external environmental costs.

The IEA has estimated possible cost-reductions for future renewable energy production [22], and the results are summarised in Figure 4 and 5. From these estimates, it is evident that a reduced costs towards 2030 for all renewable energy sources is highly expected, especially for solar cell technologies. A consequent increase in the competitiveness of these sources is also expected. The current production-costs for fossil energy is approximately 40-50 Euro per MWh [21], which is lower than production costs for the cheapest renewable energy, *i.e.* wind energy. Following internalisation of external climate costs, wind power will become fully competitive with power produced using fossil sources.

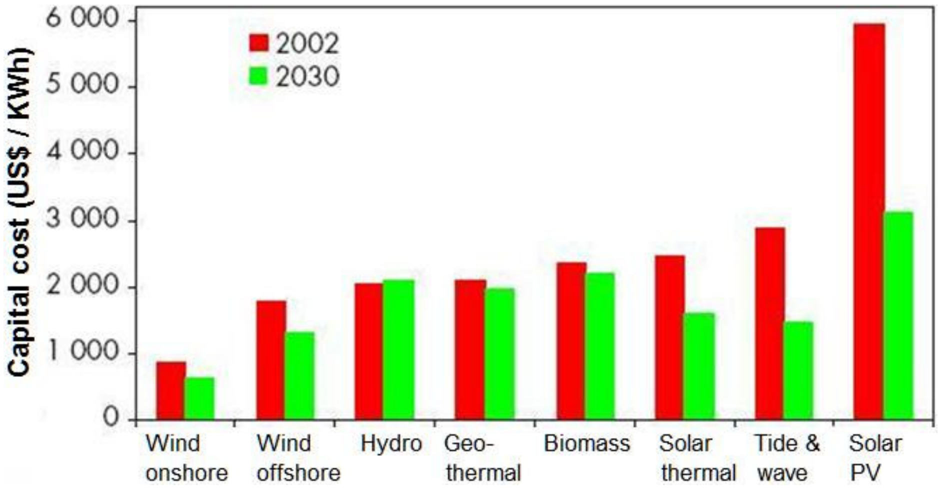

Figure 4 – Capital cost of renewable energy technologies in 2002 and 2030 [22].

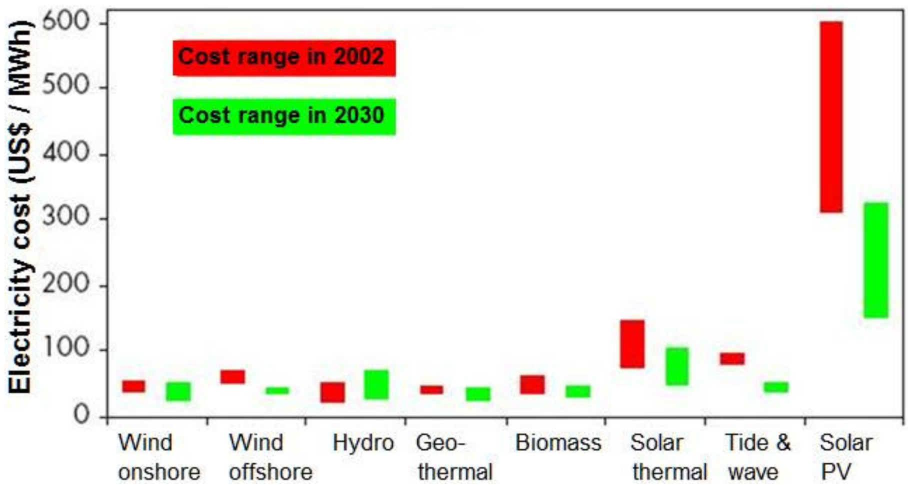

Figure 5 – Electricity cost of renewable energy technologies in 2002 and 2030 [22].

Economic barriers linked to renewable energy production can be overcome. This will require a widespread effort to promote technological development and capacity building, to reduce the price of renewable energy beyond the above mentioned estimates made by the IEA. In addition, governments must to contribute to the establishment of necessary infrastructure for renewable energy in the same way that they have contributed to infrastructural development for grids and transportation of oil and gas. Ambitious legal and economic framework conditions must be implemented to internalise external environmental costs and to promote renewable energy production.

4. Scenario for Renewable Energy Production

Renewable energy sources with the greatest realistic potential include biomass, hydro power, wind power, solar energy, tidal and wave power, and geothermic energy. Renewable sources only meet 13 percent of the worlds current energy demand. The remaining part is covered by fossil fuels and nuclear energy [3].

4.1. Realistic Potential

The IEA has analysed the realistic potential for renewable energy production in 2030 [3], see Figure 6. The total realistic potential for renewable electricity production on a global basis, is approximately 30 200 TWh per annum. This is equivalent to about 90 percent of expected global electricity demand in 2030. The IEA also estimates that approximately a forth of the realistic potential will be realized in 2030.

The potential for realizable renewable energy in Figure 6 is based on the Alternative Policy Scenario presented by the IEA. This scenario presupposes the implementation of measures that are currently being consideration for future implementation. Hence, the scenario is not particularly ambitious in its consideration of completely new measures, which would provide far more effective economic incentives that those currently considered by politicians.

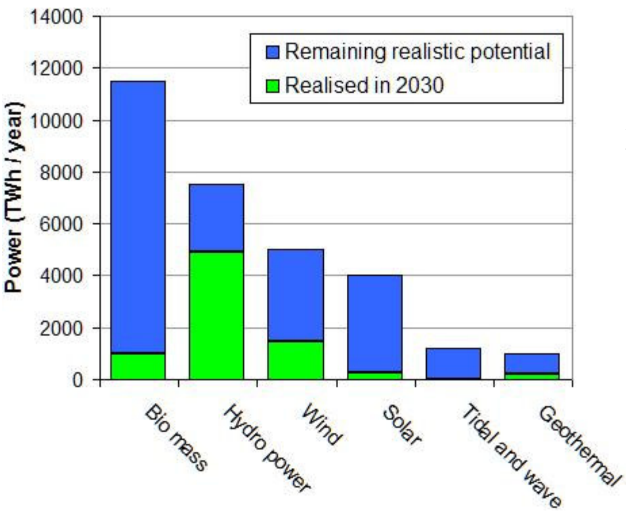

Figure 6 – Realistic and realizable potential for global power production. Source for realizable potential in 2030: IEA Alternative Policy Scenario [3]. Source for realistic potential: IEA WEO2004 [22].

A realization of renewable energy implementation beyond the estimates by the IEA is absolutely possible. However, a large scale effort towards introducing new instruments and economic incentives ensuring profitability for new renewable power production is necessary. In addition, measures should be established to replace high-grade electricity with renewable energy sources for heating purposes.

A large scale effort to implement renewable energy could result in additional renewable energy beyond what the IEA has projected. However, the barriers discussed in Section 3 suggest that the realizable potential in any case is far lower than the realistic potential illustrated in Figure 6.

4.2. Scenario for Renewable Energy production in 2030

A significant boost in renewable energy production is expected in the years to come, however a similar increase in global energy demand is also expected. According to the IEA [3], the world's energy demand will increase with 1.6 percent annually towards year 2030. As much as 83 percent of the growth is expected to be met by increased use of fossil energy sources [3].

The IEA has presented a reference scenario and an alternative scenario for global energy demand. The reference scenario is a business-as-usual scenario, while the Alternative Policy Scenario presupposes an increased effort towards energy efficiency and renewable energy. These scenarios indicate that renewable energy sources will only cover about 14 to 16 percent of global energy demand in 2030 [3]. A detailed analysis of the different scenarios is discussed in the Bellona paper *Scenarios for global CO_2 emissions* [23].

Global energy demand in 2030 divided on different energy sources is illustrated in Figure 7. This figure is based on the IEA Alternative Policy Scenario, and this scenario indicates that energy from renewable sources will met 16 percent of total global energy demand in 2030. The remaining share is fossil energy (77 percent) and nuclear power (7 percent).

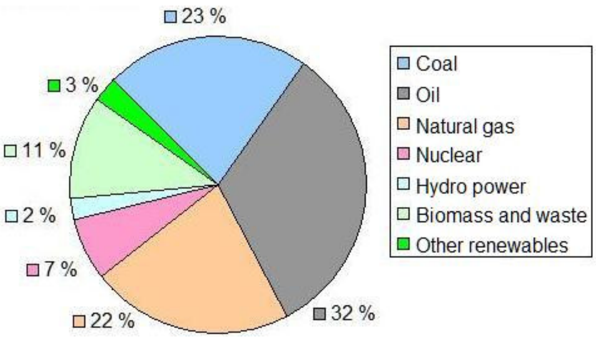

Figure 7 – Primary global energy demand in 2030 divided on energy sources according to the IEA Alternative Policy Scenario [3].

5. Conclusion

The most relevant renewable energy sources are; wind, solar, bio, hydro, wave, tidal and geothermic heat. A common denominator of these renewable energy sources is the realisable potential being far below the theoretical potential.

An assessment of the potential for energy production from renewable energy sources must be based on an analysis of barriers and environmental consequences related to the different energy sources. The realisation of increased renewable energy production is, however, limited by area conflicts and economic, technical, social and environmental barriers.

Renewable energy sources cover 13 percent of current global energy demand. A significant increase in renewable energy production is expected over the years ahead, however a similar increase is expected in global energy demand. This means the market share of renewable energies versus total energy demand will only have a small increase. The Alternative Policy Scenario presented by the IEA portrays only 16 percent market share for renewable energy sources in 2030.

A large scale effort to realize further renewable energy production can result in an more renewable energy production than indicated by the IEA scenario. However, this will require new measures and incentives to reduce economic barriers and thereby ensuring profitability for new renewable energy production.

Technical, social and environmental barriers indicate the continued domination of fossil energy also in 2030.

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