Investigation of energy consumption and renewable energy resources in top ten countries with most energy consumption

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Abstract. Top ten countries with the most energy consumption (China, United States of America, India, Russia, Japan, Canada, Germany, Brazil, South Korea and Iran) - which consume 65\% of total world energy- is selected to analyze their energy resources and consumption. Data were collected from different world’s banks as well as RETScreen software and then data are analyzed using statistical Methods. The results of the study demonstrated that India has the least ratio of energy consumption per population (0.534 Million tones oil equivalent per Million numbers of people). In the other hand, U.S. (7.095) as well as Canada (9.202) has the highest ratio of energy consumption per population among studied countries because of their high rates of Gross Domestic Product (GDP). Moreover, Germany and Iran have the least (0.095 Million tones oil equivalent per billions of US dollars) and the highest (0.628) ratio of energy consumption per GDP, respectively which represent Germany has the best energy efficiency in production unlike Iran. This is due to the lack of suitable energy audit and management, and modern technologies. Analyzing the RETScreen data locations indicated that Brazil (5.057 kWh/m\textsuperscript{2}/d) and Iran (5.010) have the highest and Germany (2.866) has the least daily solar radiation horizontal averages. However, Germany uses the most (5.939 \%) and in contrast Brazil (0.003 \%) and Iran (0.037 \%) use the minimum percentage of solar energy for their electricity generation. Also, results illustrated Canada (4.391 m/s), Iran (4.233) and U.S. (3.948) have the highest Wind speed average at level of 10 m, but Germany use the most (13.595 \%) and Russia (0.001 \%) and Iran (0.087 \%) use the least of wind energy in their electricity generation. All in all, this study would suggest that Brazil increase solar energy usage and Iran to utilize more solar as well as wind energy resources instead of fossil fuels.

1. Introduction
By growth of energy consumption in recent years (see Figure 1), fossil fuels termination and global energy crises occur soon. Also, by growing carbon dioxide emission and global warming issue, each country should highly reconsider new energy policy and implement new resources of energy such as renewable ones.

Depletion of fossil fuels resources and onset of energy crisis is looming closer due to the growth of energy consumption [1]. Moreover, with the growth rate of carbon dioxide (CO\textsubscript{2}) production and greenhouse gas (GHG) emission leading to the global warming, all countries have given special attention to their energy policies and utilization of new energy resources especially renewable resources.
Figure 1. World energy consumption in recent 10 years [2]

Nematollahi [3] studied the potential use of renewable energy in the Middle East. In this study, increment of energy consumption was discussed in these developing regions. Then, the potential use of wind and solar energy was investigated by GIS maps.

Nejat [4] reviewed the energy consumption situation, carbon dioxide (CO$_2$) production, and energy policies in the global residential sector in top ten countries with the highest carbon dioxide (CO$_2$) production.

Acharya [5] investigated the effect of renewable energy utilization on global warming, and reducing rate of carbon dioxide production resulting from it.

Bahadori [6] briefly analyzed electricity generation from solar energy as well as utilization of solar energy in Australia in his research.

Salehin [7] evaluated the renewable energy systems through combination of technical-economic optimization and energy scenario analysis. Moreover, he modeled two systems of solar and wind renewable energy using Homer and RETScreen software in Kutubdia Island, Bangladesh.

The present literature shows that expansion of renewable energy and its resources is a critical necessity which requires further study. Meanwhile, the countries which are top energy consumers and main CO$_2$ and GHG producers would need to consider and pay more special attention to their renewable energies and energy policies. Hence, investigation of energy consumption and the potential use of renewable energies in the top ten countries with highest energy-consuming are considered in this study. To do so, the data was extracted from reliable websites and sources, then, the corresponding diagrams were drawn and each result was discussed separately. The results of this study can benefit these ten countries as well as other ones intending to revise their energy policies.

2. Energy Crisis and increase in CO$_2$ Emission

Various predictions show that the exhaustion of fossil fuel resources on earth in the not too distant future [8]. Although the estimates for exact time of this depletion vary, there is no argument that the fossil fuel resources (the current primary source of energy) will be exhaustible, and thus alternative sources are needed (Figure 2).
On the other hand, due to the increment of carbon dioxide and greenhouse gas emission as well as global warming in recent years, there is a strong need to replace fossil fuel resources with clean and renewable resources to resolve the said problems [9]. As shown in Figure 3, there was a considerable reduction in CO₂ emission in 2009 due to financial crisis and growing the use of renewable energy resources [10]. This proves the effective role of renewable energies to overcome air pollution and global warming.

3. Top Ten Countries with Maximum Energy Consumption in the World
Based on the latest statistics in 2015, the top ten energy consumers are China, U.S., India, Russia, Japan, Canada, Germany, Brazil, South Korea, and Iran [2]. Together, these countries use 65% of total global energy (Figure 4).
The rate of energy consumption for different types of fuel per total consumption in each of these countries is shown in Figure 5. As it is observed, the largest share of energy supply in the world is currently provided through fossil fuels. Moreover, Brazil and Canada are the main users of hydroelectric power, while Germany is the major user of renewable energies such as wind and solar.

Figure 6 depicts the energy consumption rate per GDP in these ten countries. Hence, among these countries Germany has secured the highest score while Iran holds the last place. The reason might be the high productivity of energy in German industry versus low productivity of energy in Iranian industry, having its roots in lack of proper energy management and auditing in Iran, and the low price of energy carriers.

Figure 7 shows the energy consumption rate per population in these ten countries. Thus, industrial countries with the high GDP consume energy more than the global average (per country population). Countries such as China and India, the most populated countries in the world, show more desirable results compared to other studied countries regarding energy consumption rate in this index.

As shown in Figure 8, China and India, which have the highest rate of coal consumption according to Figure 5, have a higher ratio of CO₂ emission per consumed energy (equivalent to oil) than the global average compared to other studied countries. Therefore, countries like China, India and other countries, whose main source of energy is coal, are recommended to adopt clean energies and renewable sources instead of coal in order to prevent the increase of GHG emissions and global warming.
Figure 5. Percentage of energy consumption by fuel type [2].

Figure 6. The diagram of energy consumption by million liters of oil equivalent (LOE) per GDP, in billion USD [12].
4. Renewable Energy

According to growth of energy consumption and the onset of a global energy crisis as well as global warming caused by GHG emissions, the importance of replacing fossil fuel with renewable resources and also using more renewable energy is increasingly obvious. However, according to Figure 9, currently only 10% of consumed energy and 23% of produced electricity in the world are obtained by
renewable energy sources. Hence, the expansion of renewable energy use is necessary for all countries around the world. Meanwhile, countries with the most consumption and dependence on energy need to pay special attention to their energy policies and investments related to this issue.

**Figure 9.** World energy consumption by fuel type [2].

**Table 1.** Number of studied points in each country [14].

| Country                | Location number |
|------------------------|-----------------|
| China                  | 528             |
| US                     | 2045            |
| India                  | 303             |
| Russian Federation     | 1149            |
| Japan                  | 199             |
| Canada                 | 614             |
| Germany                | 161             |
| Brazil                 | 454             |
| South Korea            | 52              |
| Iran                   | 104             |
| **Total**              | **5609**        |

Below, the wind and solar energy are discussed in detail as two important sources of renewable energy. Moreover, a detailed description is provided regarding the potential of geographical location
and extent of reliance of studied countries on these resources. Using the weather information available in RETScreen, the annual average horizontal daily solar radiation and the wind speed at a 10m height in different points for each country were obtained, and the average value was calculated for each of these countries to study the potential of use of these resources. The location of reported points and the number of points examined in each country are provided in Figure 10 and Table 1, respectively.

![Figure 10. Location of weather information reported for different points using RETScreen [14].](image)

4.1. Solar Energy
The annual average of daily horizontal sun radiation for each of studied countries is presented in Figure 11. It can be seen that Brazil and Iran respectively have the most annual radiation and therefore the most potential for utilization of solar energy, whereas Germany has the least annual radiation.

The percentage of used solar energy for electricity generation in each intended country is provided in Figure 12. Iran and Brazil, which according to Figure 11 have the most potential for solar power, are taking little advantage of it, whereas Germany, which had the least potential, is taking the most advantage of solar power.

This goes to prove the fact that Germany has fully understood the importance of solar energy. It can be certainly pointed that according the use of solar power in countries such as Germany and Japan, its application in high-potential countries like Iran and Brazil (As shown in Figure 11) will be effective and economical. Thus, Iran and Brazil are strongly recommended to develop and expand their use of solar energy.
4.2. Wind Power

The annual average of wind speed at a 10m height for these ten countries is presented in figure 13. It can be seen that Canada, Iran and the U.S. respectively enjoy the highest annual average wind speed and the most potential for wind power.

Figure 14 presents the percentage of wind energy used for electricity generation in each intended country. As can be seen, Iran, has a high potential for wind power according to Figure 13, takes the little benefit of it. Contrariwise, Germany, takes the most benefit of wind power which goes to show that Germany fully comprehends the significance of utilizing renewable energies.
5. Conclusion
This study examined the energy consumption in the top ten energy-consuming countries. Then, the potential of each country for utilization of renewable energies including wind and solar was studied. Also, the share of renewable energies used for electricity generation in each country was provided. Moreover, by considering the energy consumption rate per GDP and population as well as CO₂ emission per energy consumption rate for each country, those countries which take the minimum advantage of their consumed energy while produce the most CO₂ and doing the most damage to the environment were identified and the underlying reasons were investigated. Finally, these countries were provided with recommendations to improve the productivity of their energy resources and expand their use of renewable energies.
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