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Vaclav Smil's Perspective on Fossil Fuels and Renewable Energy: A Review

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Abstract

Increasing pace of development coupled with higher standards of living and exponential population growth in recent years have increased the energy demand substantially worldwide. A considerable portion of these energy demands are met by fossil fuels. However, energy derived from fossil fuels release large amounts of greenhouse gases that possess many detrimental effects such as changes in weather patterns and extreme meteorological conditions. A transition to cleaner energy sources is, therefore, highly desired. There has been numerous advancements in achieving this objective but the pace of transitioning towards cleaner alternatives has been quite sluggish. However, grandiose predictions have been made towards the integration and pervasive usage of these alternative sources. In this paper, we examine these type of predictions and present the reality of the situation through the perspective of Vaclav Smil.

Keywords: *Vaclav Smil; Fossil fuels; Renewable energy; Energy transition.*

1. Introduction

Sustainable energy generation and greener alternatives have been the center of academic interest with substantial leaps to its integration in modern society being predicted. The world population currently stands at around 7.7 billion which is a significant increase compared to the meagre value of 2.5 billion in 1950 and at this rate, the population is bound to surpass the 10 billion mark by 2050. This explosive growth in population comes with increased energy demand and estimates show that there will be a 35% rise in energy consumption by 2035 [1]. Bulk of this energy demand will be supplied by fossil fuels and a 25% increase in its consumption by 2035 is predicted [1]. The rise in fossil fuels usage will be followed by an increase in greenhouse gas emissions, particularly carbon dioxide, and this has been agreed by the majority of the scientific community to bring forth drastic climate change all over the world. The International Energy Agency's 450 scenario aims to limit the concentration of CO_2 to 450 ppm in an attempt to limit the global average temperature increase to 2^0C. The current concentration of CO_2 in the atmosphere is estimated to be above 400 ppm and it would require a tremendous reduction in CO_2 emissions to achieve this scenario [1].

As mentioned earlier, there will be a rise of 35% in energy consumption by the year 2035. For the 450 scenario to take effect, there should be a drop of CO_2 emissions by 35% in the same time frame. This paradox is called the Energy Equation and solving it will be the prime factor that will determine the way energy will be used in the future [2]. However, fossil fuels still measured up to 86% of the world's primary energy in 2015 and the progress made is quite sluggish when compared to its share 25 years prior, which stood at 90% [3].

2. Vaclav Smil's perspective of the future

There exists a wide array of alternatives that have been proposed in lieu of fossil fuels. Scientist and interdisciplinary researcher, Vaclav Smil believes that *"We are a fossil fueled civilization, and we will continue to be one for decades to come as the pace of grand energy* *transition to new forms of energy is inherently slow"* [16]. He counters the common energy expectations and dispels myths on the subjects by giving specific evidence and sound reasoning.

The sub-sections below details his perspective on these alternatives and his supported opinion of the next energy transition.

2.1. Electric vehicles

Most of the countries import oil from OPEC nations and are, therefore, directly affected by the oil price fluctuations caused by the decisions of this international cartel. This provides the prime incentive to ensure the use of an electric car in addition to the fossil fuel emission. Since the commercial introduction in 1897 of the electric cars, the technology used has changed, however, their mass usage seems to have been postponed to date with each coming decade being touted as the generation of electric vehicles [4]. The commercial failures of electric cars or hybrids such as the Chevrolet Volt and Tesla's Model S and project flops such as the Renault-Nissan alliance which aimed to command 10% of the world car market share by 2020, indicates that the common use of electric cars is still an unfeasible reality [4].

The primary factor hindering the commercial use of an electric vehicle is the price of the car which makes it inaccessible to the majority of the public. For instance, the highly anticipated Tesla Roadster has a base selling price of $200,000 in the US (as on 2019). The next challenge is the base infrastructure involved to run these vehicles smoothly. High density charging stations need to be set up prior to the retail distribution of electric vehicles. The final point of contention, as per Smil, is that the energy source for the electric energy required to run these cars will come from non-renewable sources which would not result in primary energy savings and reduction of carbon emissions which defeats the purpose of the introduction of electric vehicles. The viability in terms of energy source can be achieved if the base sources are renewable and Smil states that it is only practical after a period of 50 years [4].

Smil argues that another impediment to the prevalence of electric vehicles is the battery used in electric vehicles. Efficient and higher capacity batteries are the only solutions to bring electric vehicles into the mainstream market. The current candidate is Lithium-ion battery but it comes with its own set of challenges. Idle discharge followed by battery degradation are the main concern. A Li-ion battery is expected to have a life of 2 to 3 years which pales in comparison to the 10 year mark of other car components. Furthermore, the degradation is dependent on temperature where "at the freezing point and at 100 percent charge, degradation is about 6 percent after one year; at 25°C it is 20 percent; and at 40°C it is 35 percent." Therefore, electric vehicle would not be realistic choice in the warmer regions where the population densities are comparatively higher. Smil claims that the above mentioned factors and potential for improvements in the efficiency of internal combustion (IC) engines would make a transition towards electric vehicles a gradual process unlike popular predictions [4].

2.2. Solar and wind

Solar energy seems to be the most optimistic solution to combat the use of fossil fuels. However, Smil states that the reality is far from it. Solar energy harnessed via photovoltaic cells seems to have garnered the most attention with positive trends in the production of these cell being forecasted by Moore's law [5]. Although it is true that the cost of producing photovoltaic cells have reduced considerably, the capital investment required (including batteries, inverters, and frames) as well as the labor costs to set up a system to convert solar energy to electrical energy is tremendous and would thus dissuade consumers from employing it. Moreover, the intermittency of solar energy and low energy densities would further delay its extensive use (1000 to 2000 W/m^2 for coal while only 6 to 10 W/m^2 for concentrated solar power) [6]. In addition to this, the materials used to manufacture photovoltaic cells require rare earth metals like neodymium, dysprosium, terbium and europium whose mining results in severe environmental repercussions such as land and water pollution with China, the biggest exporter of rare earth metals, cutting back on its exports due to these concerns [7]. The dumping of hazardous chemicals used in manufacture of solar panels in developing countries have also resulted in public outcry and therefore strips off the "clean" energy tag of solar panels.

Smil points out that the primary factors limiting wind power are same as that of solar: energy density, intermittency and capacity integration. Another significant hurdle is the land area required for the installation of wind turbines as each turbine requires a space of 5 to 10 rotor diameters from the adjacent turbine in order to mitigate excessive wake interference [4]. The maximum attainable power per unit area at the moment from wind farms stands at around 10 W/m^2 on land and 15 W/m^2 offshore. Secondary factors that limit the building of wind farms include aesthetics, noise and disruptions to bird and bat life [4]. Moreover, wind turbines are manufactured using steel and iron extraction from ore is highly dependent on fossil fuels as coke is required thereby making the technology dependent on fossil fuels.

2.3. Biofuels

Biofuels have been around for a while and it has been used in hybrid vehicles and aircrafts as means of transportation fuel. Lower carbon emissions, renewability and relative inexpensiveness is what prompted interest in biofuels and paved the way for further research into it. However, Smil counters that there are numerous limitations to biofuel that makes its broader use quite difficult. The major problem is the land area required to cultivate the plants needed to be turned into biofuels. The biofuel with the highest productivity (Brazilian ethanol from sugarcane) has a meagre power density of just 0.45 W/m^2 and the land required for producing this transportation ethanol would sum up to 600 million hectares which is equivalent to about 40% of the world's cultivated area [4]. Moreover, it has been found that in 2015 the global productions of biofuel amounted to a meagre 75Mtoe which just amounts 1.8% of the energy extracted from crude oil per year [3]. This is highly impractical. Moreover, the net energy return of biofuels is quite bleak. Mass production of biofuel plants like corn and cane will result in negative environmental effects like soil erosion and have economic implications such as food shortages due to arable land being used for cane and corn cultivation. Moreover, due to necessary use of fertilizers in growing corn, biofuel from corn is definitely not carbon neutral [8]. Smil does consider the possibility of third-generation biofuels like algae to mitigate the constraints of land area for cultivation but does not collate it with his arguments presently.

Another option that has been suggested is to use the stalk, stem and leaves of the corn to produce cellulosic ethanol. However, the process has its own set of limitations. The enzymatic hydrolysis to convert cellulose to glucose is very difficult as the number of organisms that can perform the hydrolysis is small and is limited to certain bacteria and fungi not easily found on the earth's crust. In addition, cellulase, the enzyme required for hydrolysis has no dedicated production plants and even if the six demonstration plants funded by the U.S. Department of Energy were to enter operation, the combined capacity would only equate to 0.1% of transportation fuel in the U.S. [4]. Therefore, Smil argues that this option is also not applicable in a larger scale.

2.4. Nuclear power

Nuclear power is a contentious energy source with its fair share of detractors primarily due to political rather than scientific reasons. The "zero carbon energy" promise of nuclear power and large energy densities are the hook that draws attention to it as an alternative power source. From a financial perspective, the cost of commissioning a nuclear power plant is massive albeit the energy generation being relatively inexpensive. Moreover, public perception towards nuclear energy has always been negative with the recent nuclear disasters such as the Fukushima Daiichi nuclear disaster further undermining its popularity [9]. The generation of nuclear waste, exposure of personnel involved to radiation and its weaponizing potential are some of the major arguments against nuclear power. Experts argue that a focus on nuclear energy is a necessity as it is the only low-carbon footprint fuel source that has energy potential at the gigawatt-level scale. This is an example where government policy and public perception are the limiting factors for the proliferation of the energy source [4].

As per the energy equation discussed in the introduction, CO_2 concentrations should be kept at 450 ppm in order to limit the increase in atmospheric temperature by 2°C. However, industrial expansion shows no signs of slowing down which eliminates reducing the rate of emissions as a viable option. Therefore, the focus has shifted towards carbon sequestration methods. These include capturing CO_2 within basalt layers; extraction from air using a liquid sorbent; large scale industrial carbon capture by scrubbing.

Smil believes carbon capture to be a very ineffective solution. The price of electricity generation would rise as carbon capture require the use of equipment such as electrostatic precipitators which have high capital and running costs. As per reports by the Intergovernmental Panel on Climate Change (IPCC), the cost of operating a pulverized coal-fired power plant could raise by about 44 to 74% [4]. Furthermore, the energy requirement for operating carbon capture systems is very high and Smil believes that it would "erase half a century of efficiency gains in electricity generation" [4]. Another potent problem is the storage after carbon capture. CO_2 leaks could occur and this could lead to adverse effects such changes in the soil pH and release of toxic substances due to changes in acidity. Moreover, carbon capture and storage is at its fledgling stage and the ramifications of the process are not fully understood yet.

Large scale industrial carbon capture and sequestration was a proposed solution and considered as a better alternative to carbon dioxide extraction from the air. However, Smil points out that sequestering even a meagre 15% of CO_2 emissions would requiring the creation of an entirely new industry which does not provide any monetary returns and would need several decades to set up. The scale of the whole process is a tremendous undertaking. For instance, more than 4.8 billion tons (about 15% of 2008 emissions) of CO_2 need to be stored every year and this would require infrastructure encompassing compression, storage and transport where the annual volume throughput would be about 1.3 to 2.2 times the annual volume throughput of the crude oil industry worldwide [4]. Smil puts forth this argument as the major drawback of industrial carbon sequestration and concludes that this option will not become economically realistic in the near future.

3. Pace of energy transition

Smil defines an energy transition as "the time that elapses between the introduction of a new primary energy source and its rise to claiming a substantial share of the overall market" [6]. From Smil's justifications, it is evident that a drastic energy transition in the direction of renewable energy is not realistic. Even if an innovative spurt brings forth a working technology, the widespread use of it in order to spur an energy transition would take longer due to existing infrastructure. An example of this is China's $300 billion investment (from 2001 to 2008) on coal based electricity generation which would require at least 35 years to break even [6]. Convincing the abandonment of such large scale investments in favor of transitioning towards renewables would be highly unlikely and would subsequently hinder the pace of integration of renewables. Add to this the increased extraction of coal in India and rise in exports from Indonesia indicates that the bulk of the electricity generation will be from coal. In the case of the United States, 50% of the US electricity comes from coal-fired power plants and 20% from nuclear stations while energy derived from renewable sources stand at less than 2.5% [4]. Thus, a transition from coal is highly unlikely. As per the studies done on the timelines of established technological products, a period of 30 to 40 years is required for complete commercialization of a new technology if it were to come into existence [10]. Claims made by the adherents of Moore's law such as former American Vice President Al Gore that the demand for renewable energy would reduce its cost while a solar revolution is imminent are also unsubstantiated [11]. All in all, the actual pace of the energy transition will be very slow. The predictions usually made with respect to this usually stems from wishful thinking and sociopolitical factors (Gore's claims) rather than substantiated evidence [12-13]. Furthermore, predictions pertaining to global energy shifts show that renewable energy might surpass each individual fossil fuel use but the cumulative sum of all fossil fuels will exceed that of renewable sources (refer graph below) [14].

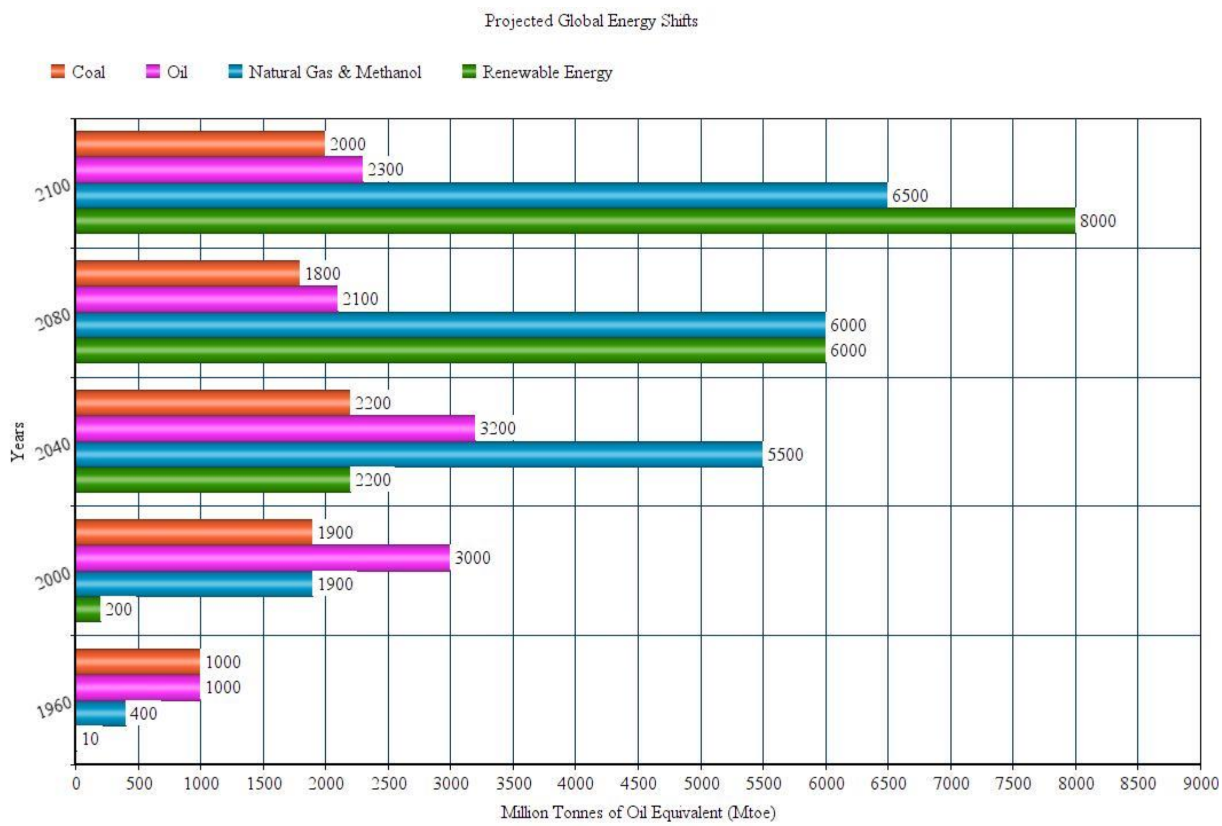

Figure 1 The Graph depicts the past usage of energy sources in Mtoe and the projected use of each energy source in the future. The global energy shifts indicate the rise in usage of renewable energy, however, the sum of all fossil fuel sources always exceeds that of renewable sources [14]

As per the historical trend, coal and oil took 60 years to achieve 50% and 40% of the global energy supply respectively [15]. Smil believes that the next energy transition will be dominated by natural gas which took 60 years to reach 25% of world energy supply with renewables contributing to less than 5% of world supply. As per the table below, natural gas is apt as its carbon content is minimal which results in lower CO_2 emissions as opposed to traditional fossil fuels like coal and gasoline (56 $kgCO_2/GJ$ for natural gas and 95 and 70 $kgCO_2/GJ$ for coal and gasoline respectively) [16]. There is renewed global interest in natural gas and techniques like fracking are gaining popularity, especially in America.

Table 1. Amount of CO_2 released by each fossil fuel [16]

Fuel type	Amount of CO_2 released in $kgCO_2/GJ$	Fuel type	Amount of CO_2 released in $kgCO_2/GJ$
Natural Gas	56	Diesel	75
Coal	95	Heavy Fuel Oil	77
Gasoline	70	Solid Biofuels	110

4. Natural gas – The future

As mentioned in the previous section, natural gas releases the least amount of carbon dioxide with respect to its fossil fuel counterparts therefore making it a better alternative to traditional fossil fuels like coal, diesel and gasoline. Moreover, there exists numerous years of hydrocarbon extraction expertise and state of the art computerized and automated technology which makes the extraction of natural gas a very systematic process with minimum risk. The refining of natural gas is simpler as operations such as denitrification and desulphurization is not required to be carried out due to its compositions which results in cost reduction when compared to traditional fuels like crude. Moreover, natural gas processing is mostly concerned with separation of undesirable material as opposed to its liquid counterpart which requires complex processing techniques involving high temperatures and pressures as well as expensive catalysts [16]. There has also been significant increase in the extraction of nonconventional gas such as shale, gas from tight sands and coal bed methane especially in the United States. It is worth mentioning that 73% of natural gas production the US was derived from non-conventional sources in 2012 and this is a large jump from the 18% production in 1990 [16]. From an economic point of view, improvements in the LNG transportation infrastructure would ensure higher rates of market penetration for natural gas. For instance, in the United States alone there are 3 million miles of mainline transporting natural gas [17]. This strengthens Smil's reasoning that natural gas could be the potential player in the upcoming energy transition.

5. Alternative perspectives

To lend perspective to Smil's conclusions, alternative projections of Industrialist Vincent Petit and Academic Sir David J. C. MacKay are included below. Vincent Petit's opinion is one of optimism, particularly in terms of solving the energy equation, while Mackay maintains one that is in support of Smil's perspective albeit being slightly more generous with the renewable energy transition.

5.1. Vincent Petit

According to Vincent Petit, the energy equation can be cracked by utilizing certain acute strategies. He states that increasing the end use efficiency of sectors such as industries, buildings and transportation would result in savings of about 25% of the total final energy consumption in the coming 20 years [2].

One-third of the energy consumption worldwide is attributed to the industry sector and equals about 2400 Mtoe of energy per year [2]. The bulk of this is utilized by electro-intensive industries such as petrochemical and iron and steel. Large portion of the energy requirement is for heat generation and this results in significant amounts of wastage to the environment. Petit says that reducing the heat loss and optimizing its use would be an effective strategy which would result in minimizing the fossil fuel requirement [2]. Better insulation and automated controls would optimize the heating process and using superior catalysts would reduce the heat input requirement for chemical processes to occur. In non- electro intensive industries, high efficiency motors would help cut down energy requirement. The above solutions coupled with carbon capture systems is Petit's solution to reduce CO_2 emissions in industry [2].

As per the International Energy Agency, 20% of the energy used in buildings could be saved with almost 2800 Mtoe of energy being consumed in 2010 [1]. Improving thermal insulation, optimizing equipment efficiency and appliances' consumption and by adjusting the energy requirement in particular zones depending on time and occupancy could save up to 60% of energy in buildings [2]. The transportation sector provides numerous possibilities for energy savings. In 2010, about 2400 Mtoe of energy was consumed by the transportation sector [2]. Innovations in motorizing technologies, aerodynamic designs and using lightweight materials could lead to higher energy efficiencies. Additionally, increased usage of public transportation, providing incentives for carpooling and utilizing work-at-home modes of employment would contribute to improving energy efficiency in the transportation sector [2].

Another sector where energy is wasted is during electricity generation where the conversion to usable form is significantly low. The ratio of primary energy requirement to trans- portable electricity is 3:1 which indicates that the electricity generation process is highly inefficient [2]. Therefore, to increase the efficiency, the process variables such as temperature and pressure should be optimized in addition to the system elements like ventilation systems, pumps, etc. Optimizing as mentioned above will improve the efficiency but not by a substantial amount. The alternative is to use other sources such as nuclear energy and renewable energy which are further discussed below.

The market growth of nuclear energy is stated to be within the range of 1.3 to 3.8% which is among the highest growth rates in comparison to other energy sources [2]. At present, most of the nuclear reactors use Uranium 235 and Plutonium 239 which drives the fission reaction.

There is ongoing research on nuclear breeder reactors which is estimated to produce 60 times more energy than a traditional reactor. The goal of these reactors is to reduce the waste produced while generating 300 times more electricity than current technologies [2]. This could have significant implications on the energy equation.

The other viable alternative, as per Petit, is renewable energy. It is abundantly available and clean. When compared with oil reserves, two-thirds of wind energy and 4% of solar energy are the equivalent [2].

Amongst the renewable energy sources, solar energy seems to be the most promising. Estimates show that about 26,000TW of solar power could be captured to produce electricity [1]. Also, the scale of production of photovoltaic modules, the key component of the cell that converts radiation into electricity and which forms the bulk of the initial investment cost, have increased while the production costs have come down primarily due to production practices by China which has resulted in increased competitiveness of solar cells. This could well be the solution to tackle the detrimental effects spurred on by the usage of fossil fuels such as the increase in carbon dioxide emissions (about 70% in the last 70 years). As of now, production capacity from solar energy stands at around 132 GW with a rise to 1720 GW by 2030 and above 4670 GW by 2050 as per the predictions by International Energy Agency [7]. The goal by then is that 16% of the global energy production will be from solar power.

Utilizing the above strategies of increasing end use efficiency and the integration of renewable energy seems to be the key to cracking the energy equation. The theoretical primary energy saving potential is about 8900 Mtoe [2]. The primary challenge for achieving this is to minimize the end use consumption. With increasing the rate of implementation of the above methodologies, Petit posits that the energy equation can be solved.

Petit's predictions are based more on undue optimism rather than technical progress and innovation as shown by Smil's justifications in the earlier sections.

5.2. Sir David J. C. MacKay

Sir David J. C. Mackay was a British academic whose book "*Sustainable energy - without the hot air*" provides a qualifying perspective to Smil while presenting a more realistic perspective than Vincent Petit. He has based his predictions on a case study of the UK. Mackay surmised that the average consumption is 125kWh/d per person in the UK [18]. As indicated in the graph below, he compares his estimates to that of other agencies and further modifies his results after public consultation to come to the subdued conclusion that current renewable energy resources in the UK can only generate 18 kWh/day per person [18]. This is significantly lower than the demand and depicts a live limitation of renewables.

Another significant hurdle towards a renewable transition is the cost. The UK's current consumption stands at 300 GW. To replace this equivalent with renewables, an input of £300 billion would be required. This is an enormous amount and a better perspective can be obtained by comparing it with the current market value of energy consumption in UK which totals to an approximate £130 billion per year [18]. Therefore, a renewable transition would be an economic disaster.

Another obstacle is the tackling of lulls and slew. Lulls are extended periods of time with smaller renewable energy production and slews are supply or demand changes in the short run. Given the intermittency of renewable sources, this is a very relevant issue. Proposed solutions include pumped storage and energy imports, however, these are plagued with high investment costs, lack of infrastructure and land shortages. This coupled with larger population densities makes the transition towards renewables all the more difficult [18].

The arguments of David MacKay and Vaclav Smil strike hard because they analyze renewable energy in terms of their power densities (see table below). Based on their analysis they conclude that investments in renewable energy to replace fossil fuel sources will need to be country-sized.

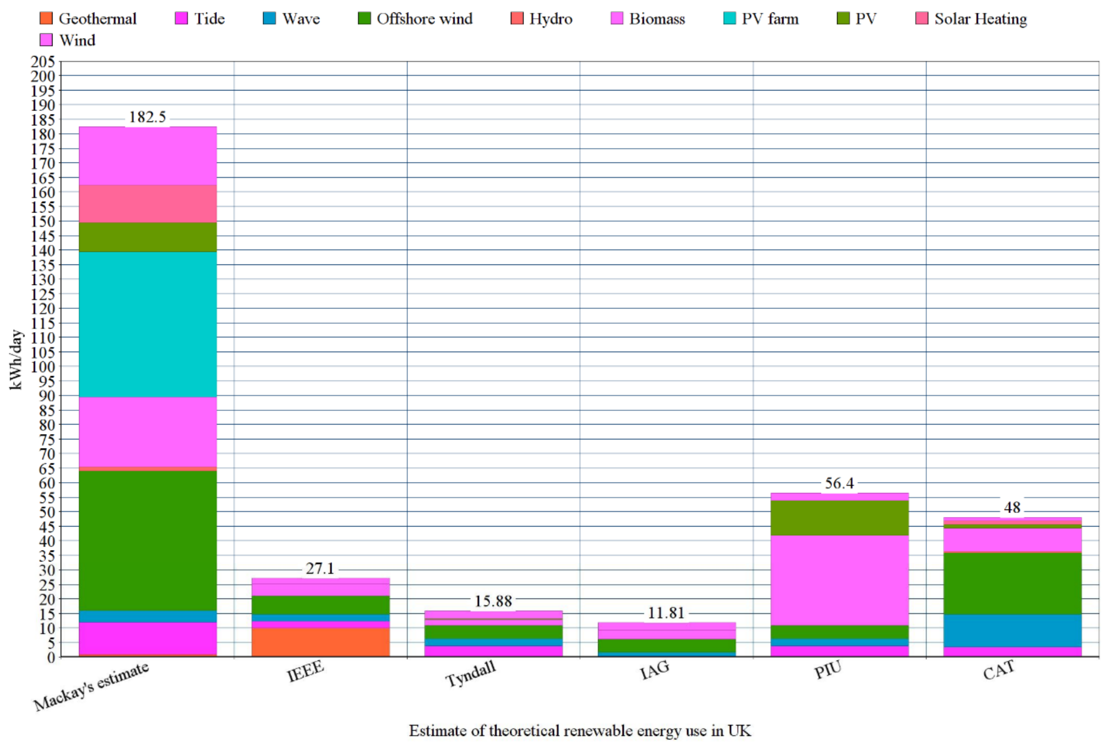

Figure 2. Estimates of theoretical or practical renewable resources in the UK, by the Institute of Electrical Engineers (IEEE), the Tyndall Centre, the Interdepartmental Analysts Group (IAG), the Performance and Innovation Unit (PIU); and the proposals from the Centre for Alternative Technology's (CAT) "Island Britain" plan for 2027 against that of Mackay [18]

6. Conclusion

In this paper, we review Vaclav Smil's perspective on fossil fuels and renewable energy. We started off with the Energy Equation (Energy Conundrum as we prefer to call it) which states that while the IEA proposes a drop of CO_2 emissions by 35% by the year 2035, actually there will be a rise of 35% in energy consumption in the same time frame. We have looked at several 'solutions' to tame the energy equation such as electric vehicles, solar and wind, biofuels, carbon sequestration and storage, etc. While Smil is not against renewable solutions and actually predicts the eventual dominance of renewable energy, he points out why the solutions are unrealistic and unfeasible in the present time.

Vaclav Smil's views on renewable energy offer a pessimistic outlook on its prospects albeit being backed by sound reasoning. Smil's arguments often find themselves in the crosshairs of individuals like Vincent Petit who back the renewable energy revolution as a potent solution for the problems caused by fossil fuels. However, Petit's models rely on optimistic projections whose assumptions have been countered by Smil. Moreover, the efficiency adjustments that have been suggested by Petit as a way of improving the existing energy sources are yet to be proved effective. David MacKay, on the other hand, provides the pragmatic perspective to view Smil's work. He supports Smil's arguments and provides data to lend credibility although he does believe that renewable energy can be integrated to a greater level into the current infrastructure. MacKay's careful optimism and Petit's outright optimism showcases the depth of the contentious topic of renewable energy and thus defines the perspective that Smil states.

We have also discussed the pace of energy transitions. The pace would not accelerate exponentially as adherents of Moore's law maintain. The pace would be gradual as Smil posits and it may take more than 50 years to wean ourselves away in considerable measure from fossil fuels.

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