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An Investigation of Engineering and Economic Aspects of Sustainable Energy

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Abstract— Overview of hydrocarbon and other energy sources and their impact on global warming is given. It is shown that the developed countries, which represent 15% of the world's population, should provide business plans and clean technologies for the developing countries which constitute 85% of the world's population. Thus, greenhouse gas (GHG) emissions and global warming can be globally reduced. Furthermore, cleaner transportation, such as electric and hybrid vehicles need much more adaptation in order to be universally applicable, this as well as other green technologies that are environment-friendly.

Keywords— Sustainability, electric vehicle, hybrid electric vehicle, gasoline cars, fossil fuels, emissions

I. INTRODUCTION

Energy is essential to the modern lifestyle and it can be considered as the primary drive for many of daily life activities. Energy extracted from fossil fuels such as oil, coal and natural gas is exhaustible. Hence, these fossil fuel resources have been crucial sources in the economic growth and world development. Fossil fuels have served the humanity for hundreds of years in terms of satisfying their electrical energy needs. However, typical ways of energy extracting from fossil fuels have negative impacts on the environment. Therefore, the world started moving toward cleaner and more reliable energy resources with efficient extraction technologies such as photovoltaic (PV) cells, wind mills and hydro turbines.

Renewable Energy is the energy generated from inexhaustible and environmentally friendly resources, such as solar radiation, wind speed, tidal waves and geothermal energy [1]. Exploitation of these types of energy resources helps reduce emissions on a global basis.

Therefore, the developed countries are moving toward using renewable resources, and working on solving the energy supply challenges in the developing countries by utilizing these resources to reduce emissions and save our planet.

II. ENERGY AND FOUNDATION OF ECONOMY

A. The World Energy Consumption

The world population is increasing rapidly and it is estimated to reach 9.1 billion people in 2050 [2]. Therefore, energy demand will be increasing while the energy conventional sources are shrinking. Moreover, the use of electrical power is needed in every aspect in our life which led to increase the electricity consumption. Statistics show that energy consumption in 2001 was 13.5 TWh. With the expected increase in energy demand, energy consumption will grow significantly in the near future compared to the same year [3]. Table I shows the high dependence on fossil fuels resources (oil, natural gas and coal) which represents 86% of the total energy consumed worldwide according to the statistics of 2016 [4].

TABLE I. GLOBAL ENERGY CONSUMPTION

Fuel type	Usage percentage
Oil	34%
Natural gas	24%
Hydro electric	7%
Coal	28%
Nuclear energy	4%
Renewables	3%

B. Global warming and climate change

Electrical energy plays a positive role in global change as energy, coming from fossil fuels, was the main driver of the industrial, social, economic revolution, and development progress. However, fossil fuels have undesirable impacts as being the main source of air pollution, carbon dioxide emissions and other greenhouse gases (GHG).

C. Uranium Supplies

Nuclear fuel is being used in the process of electricity generation contributing to almost around 7% of the global energy demand [2]. Thereby, nuclear power could be considered as an alternative solution to the fossil fuels. However, the nuclear energy resource, uranium, is depletable. In addition, the nuclear reactor technologies are non-publicly acceptable due to high risk associated with the nuclear radiation and nuclear wastes.

III. Fossil Fuel and Orientation Toward Renewables

A. The US Scenario

The USA is considered as the world largest producer of oil and natural gas. Moreover, the coal reserves in the USA constitute around one-third of the world reserves. The total undiscovered resources of oil and natural gas are 322 to 655 million barrel and 11 to 22 million cubic barrel, respectively [5]. Due to the rapid development in numerous technologies and innovations, there is a consequent of very high demand on the fossil fuel as in case of NG. For instance, the yearly production rate of the NG is around 7.9% starting from 1995 [6].

B. Fossil Fuel Global Consumption

In 2018, there were 1.4 billion people around the world who lack access to electricity, 85% of them came from developing countries [7]. These countries are seeking for economic growth. As a result, global energy demand grew by 2.3% in the same year. Fossil fuels usage was around 47% and 30% of primary energy consumption in Africa and South Asia, respectively [8]. Fig.1 shows the global fossil fuels consumption (measured in TWhs) in the period from 1800 to 2017.

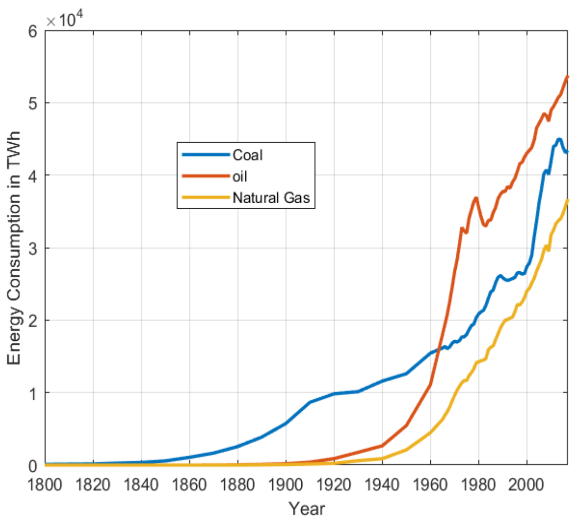

Fig. 1 Global fossil fuels consumption [9]

This increase in energy demand was driven by economic growth, engine combustion vehicles, cooking, heating and cooling and electricity generation. Over the coming years, the increase in reliance on fossil fuels by large populated countries, i.e. India and China makes these sources being unsustainable.

C. Fossil Fuel Shortage and Sustainable Energy

Fossil fuel resources are running out sooner or later. So, it is essential to move to alternative energy resources in order to meet the increasing energy demand and solve climate change problems. Fossil fuel shortage is not the main reason for the world's orientation toward renewables. The primary reason is to reduce GHG emissions and local forms of pollution.

D. Solving the Energy Problem by Developed Countries

As mentioned before, 15% of the world's population live in the developed countries, while the remaining of 85% live in the developing countries. As a result, developed countries are facing two challenges: Meeting the needs of billions of people who still lack access to new energy services and transitioning to a low-carbon energy system as well. Therefore, governments of developed countries should support policies that achieve maximum collaboration in the energy sector with developing countries. Hence, people of developing countries can have an access to energy generated from clean and renewable resources [10]. This will ultimately help save the World's ecological system.

IV. Global Warming and Climate Change

A. Review

In the past decades, the world is facing a serious problem related to high levels of Carbon Dioxide in the atmosphere. With the current trend in world's fossil fuel consumption, the risk of global climate change is increasing. GHG emissions, resulting from the usage of fossil fuels, are the main factor of the global temperature increase. Studies showed that in 2004 CO_2 emissions increased by 3.8% and the average atmospheric Carbon Dioxide concentration reached 377.4 parts per million [11].

B. Carbon dioxide emissions

Carbon emission is a main source of atmosphere pollution and global warming. There are many factors that increase CO_2 concentration, such as electrical power generation, transportation and direct use of fossil fuel in daily life activities. So, it is essential to find solution in order to reduce CO_2 emissions. One of these solutions is to develop renewable energy resources and employing new transportation technologies.

Fig. 2 shows the GHG emissions, assuming that the proposed Copenhagen treaty has been applied and abided by developed countries. In addition, this Figure is based on the assumption that developing world countries are satisfying high economic growth rate [12].

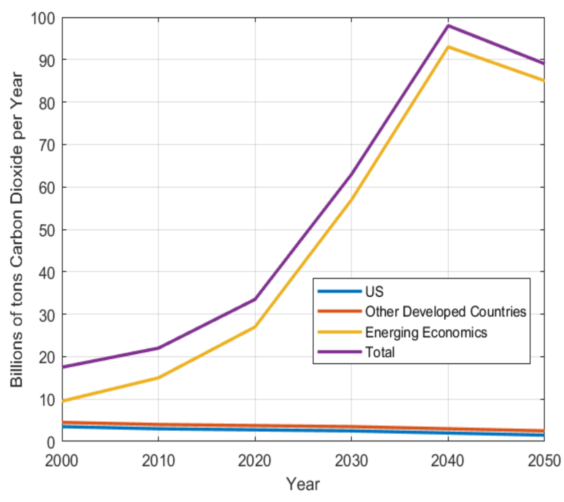

Fig. 2 GHG emissions (primary CO_2 and methane) [12]

C. *Selected Types and Example Technologies of Sustainable Energy*

a) Wind Energy: It can be converted into several useful forms. The utilization of wind energy can be done by using wind turbines to make electricity, windmills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships [1]. During 2012, approximately 44 countries increase their capacity of wind power to generate electricity. This capacity was around 45 GW and it increases the extracted global wind capacity by a factor of 19% to be almost 283 GW [1].

b) Geothermal Energy: Using geothermal energy for electrical power generation could be performed by direct use of heat. Also, heat and power can be combined in cogeneration applications in order to get efficient, cost-effective and reliable energy supply . By the end of 2012, the geothermal capacities reached around 11.4 GW, which is an increase by a factor of 2.6% from the previous year. By 2050, the estimated electric capacity that will be extracted from geothermal power plants will be between 140 GW and 160 GW [1].

c) Tidal Energy: It could have a significant potential in the coming years. Compared to wind speed and solar radiation, tides are reasonably predictable [13]. For example, the UK is of the highest potential of tidal energy and is able to provide approximately 20% of the national energy demand from tides. Furthermore, one of the attractive energy extraction proposals from the tides is in Swansea Bay in the UK with a 320 MW to power around 155,000 homes [14].

d) Solar Energy: Solar energy is the most abundant energy resource available in the earth. It can be harvested to generate electricity in two ways. First, the heat coming from the sun is received by concentrated solar power systems to drive a steam turbine. Further, solar photovoltaic energy can be captured using a solid-state device, a solar cell which absorbs photons, to provide a source of electric power [14]. For example, Saudi Arabia, an oil producing country, is of high potential of solar energy, where several research projects are being conducted to maximize national revenue due the solar plants, connected to the Saudi utility grid, displacing the fossil fuel plants. This will save oil for export at a higher national income than domestic power production. Also, 60% of Saudi electricity is used for water desalination, which is an opportunity for solar "value storage".

V. Overview on Vehicle

The environmental impacts of using fossil fuels in the Internal Combustion Engine vehicles are important topic investigated these days. Tremendous effort is being done to reduce this effect and find transportation alternatives to solve the problem of the GHG emissions out of the ICE vehicles. In 2001, the CO_2 emissions from the ICE vehicles were 308 million metric tons (MMT), which represents 16.28% of the total emissions produced in the USA [13]. Moreover, in 2007, the transportation was responsible for approximately 17% of global carbon emissions [15].

The emissions resulting from the use of ICE vehicles had a significant negative impact leading to the so-called global warming. So, efforts are being made to find solutions to this problem. One of these solutions is to develop more stringent standards for fuel consumption and emissions. However, as ICE vehicles have matured over the last 100 years, it will continue to improve with the aid of automated electronic technology. However, it will rely mainly on alternative development methods to significantly improve fuel economy and reduce emissions [16].

Another solution is the production of Electric Vehicles (EVs), which use Electric Motor and has zero-emission, instead of ICE vehicles. EVs were first introduced in the late 1800s after the invention of rechargeable Lead-acid batteries. Early of the 1900s was the golden era for EVs but that was not sustained for a long time. Then, EVs production drastically decreased and the whole market was dominated by the ICE vehicles by 1920. This is due to the limitations of heavyweight, short trip range, long charging time and poor durability of batteries at that time [17]. However, all of the aforementioned reasons have changed recently after the development of the batteries industry which has become more efficient.

Even more, the ICE was hybridized with EM to produce Hybrid Electric Vehicles (HEV). Automobiles manufacturers and governments should give considerable attention to hybridize automobiles to get the privileges of ICE and EM simultaneously [16]. This orientation is due to two main reasons: Environmental impact of fossil fuel and the fact that HEVs are more fuel-efficient which means low-cost systems.

Replacement of today's automobiles with more energy-efficient vehicles will reduce Carbon emissions that cause adverse climate change as well as dependence on imported oil [13].

On the other hand, reducing environmental impact cannot be achieved unless the use of fossil fuel, the main source of electricity, is reduced. In the same manner, EVs cannot reduce carbon emissions when charged with electricity generated from the combustion of fossil fuel. Sustainable energy resources of electricity must be used in transportation to reduce environmental impact to save our planet from global warming.

VI. Fundamental Vehicle Fuel Fact

The most affordable fuel for air and land transportation is liquid hydrocarbon fuels such as gasoline and diesel which consist of hydrogen and carbon elements in their atomic structure.

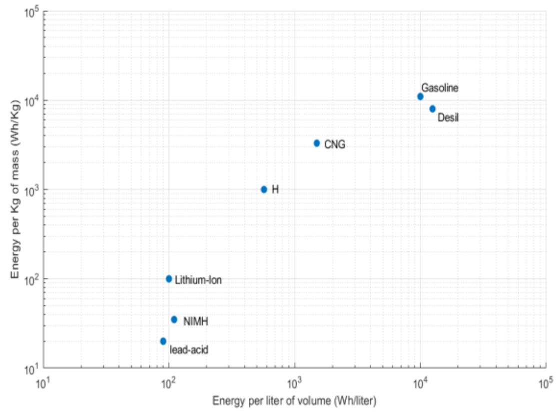

Fig. 3 Energy densities of vehicles energy sources [18]

Cars that work on liquid fuel have many features since they are more powerful, more flexible, easier to handle and their high energy density compared with vehicles having other energy sources as shown in Fig. 3.

A. *Hydrocarboon Fuel facts*

ICE vehicles have become an integral part of people's lives in the world, and there has been an increase in demand for this type of cars [19]. Moreover, gasoline cars are used due to their advantages which include Fill rate. When a fuel tank is filled from a gas station, the gasoline is delivered at a rate of 2 gallons per minute approximately. Given the energy density of gasoline, this is equivalent to 4 MW. However, the efficiency of ICE is typically 20% or less. Therefore, useful energy is delivered at a rate of 1 MW only which is a large amount of electricity sufficient to power 1,000 small homes. In the USA, gasoline price is around $3.50 per gallon. Thus the cost of transportation using ICE vehicles is around 10 cents/mile [12].

B. *Electric Vehicle*

Usage of EVs, which use electric motors only, such as Tesla, Roadster and Nissan Leaf is still limited in the USA. There are three main problems that must be solved so EVs become widely used in the United States: energy density, cost and charging time.

a) Energy density: Electric batteries have a small energy density compared to gasoline. Batteries can save around 1% of the energy per pound than gasoline. However, electrical engines can operate about 4 times more efficiently than the ICE which slightly compensates this shortcoming. Therefore, the useful energy density for batteries is around 4% of gasoline. That means a lot of batteries are needed unless range is very limited [12].

b) Price and recharges: Electrical energy cost, needed to charge EV batteries, can be considered negligible compared with the cost of EV batteries. Therefore, battery is the major component which has the highest cost in EV. Typically, Lithium-ion batteries are used in these cars. Lithium-ion batteries price range from $30 to $150 per pound. Some companies guarantee their batteries for 400 recharges and some for 1000 recharges. However, these batteries need to be replaced afterward [12].

VII. Electric Vehicle - Facts and Figures

From economic and environmental prospective, it is recommended to charge EVs battery using renewable energy resources in order to save money and reduce the GHG emissions. For example, charging 50,000 EVs using renewable energy resource can reduce GHG emissions by 409,793.865 tons per year [20].

EVs are considered as an excellent alternative to the ICE vehicles since they can provide an emission-free transportation service. Compared to ICE which has an efficiency of 20% or less, the efficiency of EVs is around 27% [12].

EVs are very efficient for short daily trips, having a range between 40-60 miles. Currently, EVs are optimal for typical daily trips and can significantly reduce the dependency on fossil fuel which reduces GHG emissions. For longer trips, batteries run out after driving beyond the specified range, this emphasizes the need for 200-mile range EVs. Thus, there may still be a need for ICE vehicles or HEVs which have long ranges and several available energy sources on the road.

Nowadays, the use of brown energy as the main source to produce electricity for EVs is still dominating in the world representing around two thirds of electrical energy production. For instance, France produce energy using nuclear-fission as a main source in transportation. On the other hand, most countries use coal to power vehicles such as India and china, where coal represents 63% of China's primary energy consumption [21]. But there are green energy countries such as Norway and Canada that use pure renewable energy to charge EVs [22].

Fig.4 shows comparison between the total vehicles sales and EVs sales in U.S.

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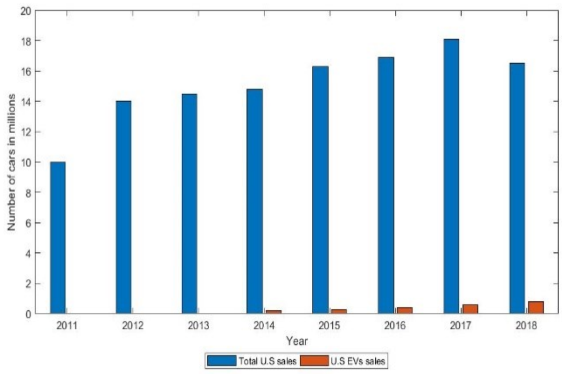

Fig. 4 Comparison of the total vehicles sales and EVs sales in U.S [23, 24]

VIII. Selection Criteria of HEV

A. *Design Philosophy of Full-Size-Engine HEV*

The philosophy behind the HEV is to exploit the features of EM and ICE through the hybridization of the two systems to work in an integrated manner. Thus, this helps achieve the full benefit of the advantages and flexibility of electrical, electronic and control technology. These days there is a lot of interest in manufacturing HEVs, since they are affordable and have better fuel economy than traditional ICE vehicles which improves energy efficiency. In addition, they are environment friendly compared with conventional transportation common services. On the other hand, there are some issues that needed to be taken into consideration in HEV such as battery sizing and management [16]. Further, the high initial cost compared with ICE vehicles is another challenge of the HEV [25].

B. *HEV Design*

Modern HEVs are classified into four types which are Parallel, Series, Parallel/Series and Complex HEVs. Parallel HEVs are composed of a combination of EM and full-size ICE connected in parallel to the torque coupler which is, in turn, connected to the drive wheels as shown in Fig. 5. The ICE has the capacity to propel the vehicle alone as efficient as the conventional vehicle and the EM helps achieve the fuel economy goal [25].

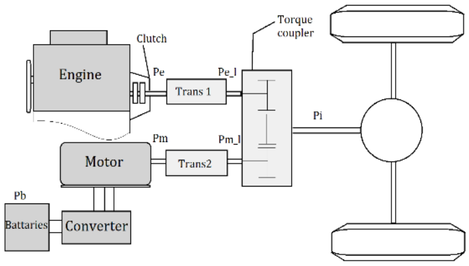

Fig. 5 Configuration of a full-size-engine parallel HEV [19]

Fig. 6 shows the effect of the number of mileages per gallon (MPG) with increasing the electrical drive power capacity (hybridization ratio) on a 100 kW ICE capacity. As shown the optimal hybridization of the electrical power range is between 10 to 25 kW. While for any hybridization increase beyond 25 kW, the negative impact of weight increase starts to dominate [19].

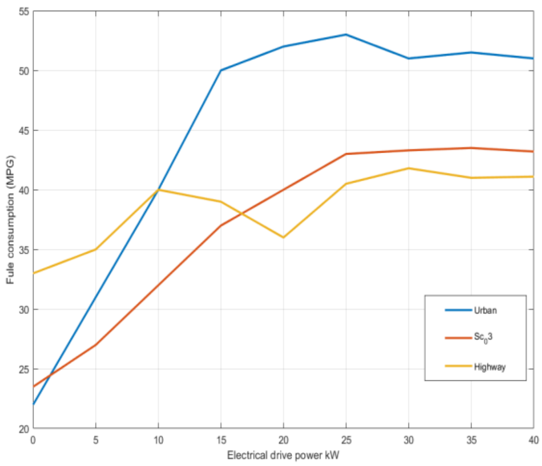

Fig. 6 The sensitivity curves based on weight of the car, a 100-kW IC [19]

As a matter of fact, the efficiency of conventional vehicles decreases in the low-speed range. This range is defined at a vehicle speed below 25 km per hour. This is illustrated in the fuel consumption map for a typical 80 kW ICE in various gear ratios to the drive wheel as shown in Fig. 7.

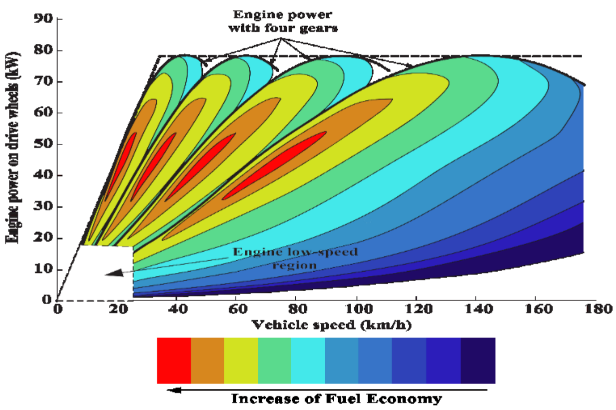

Fig. 7 Fuel consumption map for a typical 80 kW ICE in various gear ratio to the drive wheel [19]

This map specifies the demand power for low speeds and high speeds at different operating points. To obtain a fuel-efficient vehicle, a parallel electrical drive is used either by improving the fuel efficiency at low speeds or by the recovery of the regenerative braking energy [19].

Furthermore, Fig. 8 shows the vehicle speed against load power plan curve overlapping with load points in the urban drive for 1200 kg vehicle. From this figure, it can be noted that for regenerative mode a 10 kW electric motor has a significant capacity for the recovery operation. Nevertheless, a 10 kW is not the best ratio for hybridization, due to its incompetence of supplying traction power demand. However, low weight and cost of 10 kW vehicle can be considered as an advantage. On the other hand, a 25 kW is an adequate capacity to supply traction power demanded in 1200 kg vehicle. At this point, the 1200 kg car is compared with the case of a vehicle having a mass higher than 1200 kg. The higher the mass of a vehicle, the higher the traction power demand needed. However, a 25 kW motor still has the capability of supplying a significant amount of traction power demand [19].

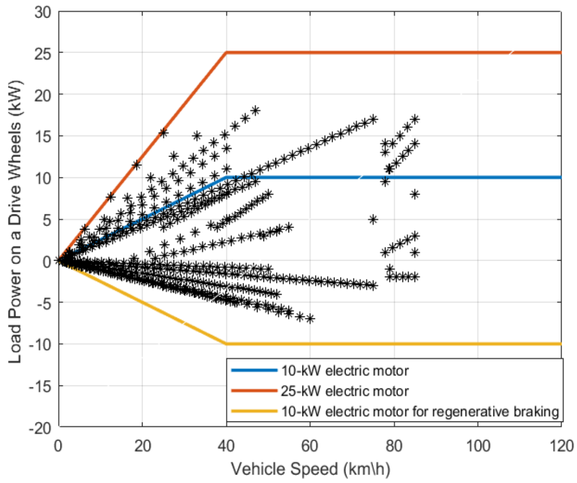

Fig. 8 Vehicle speed versus load power plane curve overlapping with load points in urban drive for 1200 kg vehicle [19]

The aforementioned discussion states that the optimal electrical drive power for most passenger cars is in the range of 10 to 25 kW. Therefore, most of the compact, medium and heavy cars manufacturers can use similar assembly line and materials in the fabrication of hybrid vehicles [19]. However, the most expensive input to the hybridization assembly line is the cost of batteries. Therefore, the key challenge to lower the capital cost of EV can be done by optimizing the performance of batteries. Moreover, energy density of Lead-acid batteries is half energy density of Lithium-ion batteries. Yet, Lead-acid batteries are commonly used in conventional vehicles because it is affordable. The price of Lead-acid batteries is around $4.4/kg compared to around $88.2/kg of Lithium-ion batteries [12].

IX. Present Hybrid Electric Vehicles – Toyota Prius Case Study

Toyota Prius is one of the HEV that are economical and environmentally friendly [19]. It uses series and parallel architecture with two electrical machines to generate electric power and drive a power train. Tables II and III compare between the Toyota Prius 2011 model and Toyota Prius 2011 with the replacement of the HEV full engine system. Table II is based on the worst-case scenario strategy in determining the cost for each type, this strategy is applied by these assumptions: The typical price of an induction motor is $ 110 /kW, price of ICE is $35/kW and price of Li-ion batteries packs is $1000/kW. Both of full engine show superiority in cost and acceleration time criteria. Whereas Table III shows the fuel economy in terms of MPG in different drive cycles for each vehicle [19].

TABLE II. COMPARISON ON POWER PLANE COST AND ACCELERATION PERFORMANCE FOR PRIUS-BASED HYBRIDIZATION [19].

	Cost ($)	**Acceleration Time (s) (0-60 mph)**
Prius hybrid	9955	9.7
HEV (10 kW)	4300	8.76
HEV (25 kW)	6450	7.79

TABLE III. FUEL CONSUMPTION IN MPG FOR PRIUS-BASED HUBRIDIZATION ON TYPICAL DRIVE CYCLE [19].

	Urban	**Highway**	**Combined**
Prius hybrid	43.59	41.03	42.47
HEV (10 kW)	42.89	39.81	40.55
HEV (25 kW)	55.7	42.92	49.90

X. KEY CONSIDERATIONS OF SUSTAINABILITY

Actually, in the developing countries, the demanded automobile range by consumers is up to around 160 km. Thereby, in this case simple EVs and lead-acid batteries can compete with ICE cars. However, people should be beware of feeling-good measures (like electric cars for the US) that will have tiny (1/40˚C) effects on global warming over the next 50 years. But, this can mislead people into thinking they're addressing the concern. As a matter of fact, recharging an EV, from a fossil fuel power plant, releases Carbon emissions in the atmosphere higher than the ICE car does. HEVs are destined and expected to be much more widespread transportation technology in the upcoming years. The light weight and the strong material of HEV effectively improve the car mileage [12].

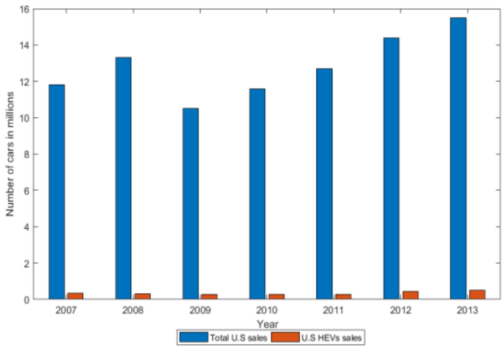

Fig.9 Comparison between the total vehicles sales and HEVs sales in U.S [26]

Fig .9 shows that the HEVs sales had increased over time, since the HEV is more fuel-efficient and fewer emissions, but it still has a poor market transportation share of 3.19% in 2013. As a projection in the future, the HEV market will be flourished. HEV sales are expected to grow from 3.19% in 2013 to 14% in 2020 and 20% in 2025 [27].

CONCLUSIONS

The global average temperature increase and the greenhouse gas emissions can be mitigated by looking to alternatives to the fossil fuels. This needs to be done in the developing countries which constitutes the majority of the world's population, i.e. 85%. So, the developed countries (15%) should provide assistance and sustainable technologies to the developing countries in order to have a global solution to the climate change issues.

Moreover, it can be seen that ICE conventional vehicles become a crucial means of transportation of people's daily life. This results in an increasing demand on fossil fuels leading to global warming. Therefore, the EVs and HEVs are the best alternatives to the conventional automobiles. This can be done be developing more stringent transportation standards for fuel consumption and emissions. HEVs, compared with the conventional vehicles, have lower emissions. However, it is preferable to use HEVs having a hybridization ratio of 10-25 kW in order to have more affordable power plant, acceleration performance and economic fuel consumption.

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