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TECHNOLOGICAL REVOLUTION AND RETROFITTING FOR ENERGY EFFICIENCY

[1]Syed Muhammad Muddassir Abbas Naqvi
Independent Researcher, 669-F Johar Town Lahore, Pakistan
(Correspondence author)
Email: muddassireconomist1985@gmail.com
[2]Muhammad Khalid Naeem
Extra Assistant Director of Agriculture (E&M), Agriculture Department, Government of the Punjab, Lahore, Pakistan.
Email: mkhalidnaeem@gmail.com
[3]Zaheer uddin Farooqi
Assistant Chief, Planning and Evaluation cell, Agriculture Department, Government of the Punjab, Lahore, Pakistan.
Email: zaheerf85@gmail.com

Abstract
Energy is indispensable for survival of human being. It is used for lighting, heating, cooling and transportation. Energy efficiency is definitely an effective tool to cater the increasing demand of energy across globe. History revealed a tremendous technological improvement in energy usage. The first great energy technology was "fire". This paper reviews the technological advancement in energy use efficiency, specifically after 18th century. Since the invention of electricity in 1831, frequent inventions in energy efficient appliances were seen. After a series of energy transitions, man has successfully attained a modern and sustainable living in which compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) for lighting, hi-tech energy efficient appliances for heating and cooling, electric vehicles (EVs) for transportation are being used. These modern technologies provided safe, reliable and sustainable living as well as gave a solution of energy security and environmental challenges. But the adoption rate for these technologies is low. Different policy programs may be launched to enhance the saturation of energy efficient appliances, keeping in view the behavior of society.
Keywords: *Technology, Energy efficiency, Lighting, Heating, Cooling, Transportation, Consumption, Sustainable environment.*

Introduction

Energy is a fundamental requirement of livelihood. People required energy for lighting, heating, cooling and transportation. These purposes of energy are prerequisite to provide basic needs of food, shelter and clothing. Without the said purposes, basic necessities of people can never be fulfilled. Therefore, survival of man is tightly connected with energy. However, energy can be utilized in any form, it may be chemical, mechanical, kinetic, potential, magnetic, electric, nuclear, thermal etc. and these forms of energy are inter-convertible with technology, possessing quantitative equivalence i.e. famous thermodynamics law [1].

History revealed that one form of energy or the other was remained in use of people as per availability and need. Primitive people use their muscle power as a source of energy and almost do everything with hands. With the passage of time, they formulated tools for cutting (hand axe, mousterian scraper), hammering (wooden mallet, stone hammer), boring/drilling (flint borer, bronze chisel) and digging (antler pick, wooden hoe) in order to reduce their own muscle power

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CJSSR
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Vol.03 No.03 (2025)

[2]. The first great energy technology was "fire". Record revealed that "fire" for the first time was seen in Neolithic period which is about 10,000 years ago [3]. Over the centuries, efficiency of old tools was enhanced through necessary amendments as well as new tools were formulated. Invention of steam engine during 18th century was a great revolution in industry sector which enabled coal and oil energy to be transformed into mechanical energy. During 1831 Michael Faraday discovered the principles of electromagnetic induction [4]. This discovery allowed the conversion of mechanical energy into electrical energy through electric generators which led the foundation of new modern electricity.

Global energy demand has been increasing day by day. It has increased at a geometric average of 5.6 percent from 1973-2010 [5]. During 2010, energy demand was 5.5×10^{20} Joules which is predict to increase at 6.6×10^{20} Joules in 2020 and 8.6×10^{20} Joules in 2040 [6]. This increasing demand of energy calls for energy efficient technological improvements on supply as well as on demand side.

Generally, efficiency means "ability to achieve a desirable effect, result or output wasting minimum resources" [7]. It may be measured as technical efficiency [8], allocative efficiency [9], economic efficiency [10-12], x-efficiency [13]. While energy efficiency is the "the ratio between service output or result and energy input required to provide it" [7]. It provides safe, reliable and sustainable living as well as gives a solution of energy security and economic challenges.

Usually, at national level, energy efficiency is measured through energy intensity which means "the amount of energy needed to provide the unit of service or activity" [7]. Energy intensity is growing rapidly in developing and emerging economies. In 2015, primary energy intensity (total primary energy supply per unit of gross domestic product) improved by 2.6%. As energy intensity is the ratio of energy consumption to GDP. Therefore, it does not reflect the energy inefficiencies accurately because total energy consumption may be changed due to several socioeconomic and climate factors [14-16]. Parametric and non-parametric approaches can be used to measure the energy efficiencies. Parametric approach may include Data Envelopment Analysis (DEA) having no specific functional form while non-parametric may include Stochastic Frontier Analysis (SFA) having some specific functional form is required. Each approach has some advantages over the other [16]. Still there is a large potential of improvement in energy efficiency particularly in developing countries due to less efficient technology and large share of coal in electricity generation process as thermal power plant converts only about 1/3rd of energy inputs into electricity [17]. Energy management gap is another reason of less energy efficiency [18]. Energy management may include energy auditing, training and housekeeping [19]. There was 5-13% technological potential and 13-20% management potential found in Swedish manufacturing firms [20], called extended energy efficiency potential [18]. At appliance level, energy efficiency is measured through "energy efficiency ratio" which means capacity of appliance to the power input, mostly used for air conditioners. Devices that use less energy may be called energy efficient device. They conserve electricity and reduce energy cost and energy poverty.

By lowering the energy consumption, hence cost, people would have more money to spend on other goods. In this way, they may achieve the visualized concept called "Factor Four" [21] which means quadruple increase in resource efficiency through halving resource use and doubling wealth. Moreover, industrial sector is responsible for 37% of global green house gases emissions out of which 80% come from energy use. Since the era 1971-2004, energy related

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

emissions raised by 65% [22]. In this situation, energy efficiency is only way to mitigate the green house gases emissions. Energy efficiency is not only cost effective but also supports sustainable environment with minimum green house gases emissions. With the technological improvements over time, energy sector has gained substantial energy efficiency. This paper will review these technological improvements and retrofitting for energy efficiency over the time.

Change in Energy Resources Use Over Time

Before 1800, wood and coal remained major sources of energy, 90% and 10% respectively. During industrial revolution, there was a drastic shift in energy use by resources in which percentage share of wood decreased while that of coal increased, gradually. During era 1860-1880 oil, natural gas and hydro added up as new resources of energy. In 1915, the percentage share of coal, wood, oil, natural gas and hydro reached at 62%, 32%, 4.5%, 1% and 0.5%, respectively [23]. These all (except hydro) are non-renewable energy resources. After a century later in 2015, oil contributed 32.94% (6.32 times up), coal 29.20% (0.53 times down), gas 23.85% (22.85 times up), hydro 6.79% (12.85 times up), nuclear 4.44%, wind 1.44%, solar 0.45% and other renewable 0.89% as resources of primary energy consumption [24]. Now a day, among all sources of energy, electrical energy is the most vibrant form. Electricity is generated from primary energy resources at power stations and after series of processes it is distributed among households. During 2015, coal still remained the largest raw material for generating electricity globally and contributed 39.2%. Rest of raw materials used were natural gas (22.9%), hydro (16%), nuclear (10.6%), oil (4.1%), wind (4%), solar (1%) and bio-fuel (2.2%) [24, 25].

Resources like hydro, wind, biomass, solar, geothermal etc. can be used again and again are called renewable or alternative sources of energy [26]. Renewable energy resources fulfill 18% of total energy demand [27]. They contributed about 20% of the earth's total electricity consumption. Out of which hydroelectric power made up the largest share (96%), geothermal heat is ranked at second and wind power generator is at third rank. The last sources on this list include solar energy [28]. Now the world is switching towards renewable energy resources to control the pollution problems and to conserve limited resourced for the use of future generations.

Technological Revolutions in Energy Purposes

Since the start of human life on earth; lighting, heating, cooling and transportation remained the need of people across globe. Sun and moon are the natural sources of light in day and night time respectively. People need artificial source of light during night. The ideal artificial light should be close to sunlight spectrum of visible light having wavelength 0.38 to .78 μm [29]. Heating and cooling energy is used to maintain the human body temperature as man belongs to the specie of homoeothermic [30]. So that man needs heat during server winter season and cooling during hot summer season. Fuel and vehicles has also become necessary for human life. People have to travel to fulfill their daily necessities of life. Following are technological revolutions in the purposes of energy over time.

1. **Lighting**

Firewood remained a single source of lighting for many millennia. Evidence of *oil lamp* usage for lighting emerged in the period more than 4,500 years ago. With the passage of time, different types of oils replaced the others in order to get more luminous light. Since 2000 years ago, *candles* are added as a new source of light [3]. Fire spread through wood, oil lamp or candle was a continuous risk for life at that time. Great fires of Valencia in 1447 [31] and London in 1666 [32] are distress examples of fire destruction.

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

During 1805, luminous *flame of burning coal gas* revolutionized the lighting system. Pipe wiring was made from factories to households, offices and public places. [3]. From 1816 onward, gas lighting replaced candles in theatres of London to adjust illumination and get greater brightness and visibility [33]. These flame burners were widely used in 1890. Then flame burner adopted mantle burner which were 10 times more aluminous. Kerosene lamps were also used at that time in rural areas. Dietz burner became an international standard. After the invention of electricity, electric generators were widely used during 1844 and usage of *acr lights* powered by electric dynamo machines started. With some improvement, "Jablochkoff candle." was widely used in Europe. Modern lighting device engineering started at the end of eighteenth century [29]. During 1881, usage of *incandescent lamps* started in factories, large stores and rich houses. During 1880-1920, era of incandescent lamps, gained efficiency started from 1.7 lumens/ watt to 15 lumens/ watt. By 1890, usage of *fluorescent mercury lamps* started having efficiency 15 to 20 lumens/ watt but they were unsuitable for home use. The efficiency was enhanced up to 35 lumens/ watt during 1934. Although they considered high efficient and low cost which boosted the demand of fluorescent lamps and replaced incandescent lamps until Second World War [3] but it converts only 63% energy into ultraviolet radiations and then converts into visible light. Thus the overall efficiency cannot exceed 28% [29]. Later on, in 1960, *metal-halide lamps* were introduced having high efficiency and good light colour properties. During 1965, *sodium lamps* began using having more than 80 lumens/ watt [3]. Fluorescent technology provided about 4 times more luminous efficacy, 9 times extended life time, saved 53% input power, saved 85% capital cost, 81% operational cost and 82% ownership cost [29, 34]. Luminous efficacy has been enhanced from less than 1 to about more than 70 lumens/ watt through the technological revolution started from fire to fluorescent light [34].

Alternative lighting devices are semiconductor LEDs having revolutionary advantage of attaining 100% efficiency which converts complete power into light. The current inefficiencies in LEDs are due to device structure imperfection or material quality but not due to basic physics [29, 35]. This development is based on the pioneer working of J. I. Pankove and Maruska in the 1970s. The luminous efficiency of fluorescent tubes are 78 lumens/ watt [29]. By 2020, LED technology will have more luminous efficacy and provide 200 lumens/ watt [34].

2. Heating

Sun is the natural source of heating called thermal or geo energy [36]. Fire is inherently a great source of heat rather than light [29]. The history of fire is unexplored, however, usage of "bow-drill fire making" technique found in some 6000 years ago [37]. It burns fossil fuel, biomass and waste incineration which are other sources of heat energy [38-41]. Fossil fuels or biofuels could be in solid, liquid or gaseous forms [42]. Fossil fuel and biofuel burning have some advantages and disadvantages based on availability, cost effectiveness, efficiency and environment hazards [42, 43]. Firewood remained a major source of heat energy for a long time, until nineteenth century, it was being used for cooking and heating. It is also being used in modern age because of its greater efficiency i.e. efficiency of seasoned wood in usual stove is 80% to 85% [42]. Energy efficient stoves can further reduce the consumption of firewood significantly in developing countries, owing to consume most energy through firewood [44].

Tropical countries generally needed heat energy during winter season and for cooking during the whole year. Whereas in temperate regions of the world, temperature is extraordinarily low and for the survival of life, people needed a well established heating system to mitigate the effects of climate. Therefore, they have developed a systematic heating system since 14th century [45].

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

Based on the sources, heating system can be divided into four generations i.e. first 1880–1930, second 1930–1980, third 1980–2020, forth 2020–2050 [43, 46]. The energy resource in 1st, 2nd, 3rd and 4th generation are, coal, coal & oil, biomass waste & fossil fuels and renewable sources respectively [43]. USA was a pioneer in establishing heating system (in 1880) in which steam was used as heat carrier [43]. Later on, this technology was extended in Europe. High steam temperature caused great loss of heat and continuous threat for heat explosion. Grover Shoe Factory disaster was such an incident of boiler explosion [47]. Steam is still being used as a main heat carrier in old New York and Paris [46]. After 1930 and up till 1980, pressurize hot water having temperature above 100C^{o} were used as heat carrier and combined heat and power (CHP) boilers were used. Large scale solar panel were also started using [43, 46]. After 1980, still hot water remained heat carrier but at lower temperature than 100C^{o}. More renewable sources were added in the system [46]. Electricity and natural gas are also great sources of heat energy. Since 1880, heating energy efficiency has been enhanced significantly through different energy smart technological advancement. After 2020, future heating system is considered 4th generation heating system in which large scale CHPs will be used widely and heat recycling coupled with extensive use of renewable resources will be started [43, 46].

3. Cooling

Water is good cooling agent. Ancient people live along the banks of rivers as the weather is moderate therein. Technological revolution in cooling system can be explained through district cooling systems [46]. During the start of 19th century, pipeline refrigeration system started comprising of centralized condensers and decentralized evaporators with the refrigerant as the distribution fluid [48]. These systems were firstly appeared in North American and Europe. Since 1960, mechanical chillers were introduced having cold water as distributed fluid in Hartford and Hamburg. Afterwards, new technology in cooling system arises like absorption chillers, mechanical chillers with or without heat recovery. Natural cooling from lakes, excess cold streams, and cold storages started. The distribution fluid is still coldwater. A future fourth generation of district cooling systems can be defined as new smart district cooling systems more interactive with the electricity [46]. Energy can be saved remarkably by using thermal storage for cooling [49] in which ground source heat pumps may be good option for storage [50].

4. Transportation

Primitive people use animals for moving one place to the other for which limited luggage was possible to transport. The invention of “wheel” revolutionized the world in transportation sector during Neolithic period. Wheel adopted many shapes as per technical advancement and became more efficient. Bicycle invented in 1817 [51] that was considered the first personal vehicle. Much technical advancement was made in bicycles as per safety and convenience. In 1885 motorcycle was invented and gave a fast channel of transportation [52]. First automobile car was invented in 1888 by Carl Benz. Many features have been evolved in automobile industry since its invention [53]. Fuel and vehicle are part and parcel of transportation sector.

Conventional drive (CD) including vehicles consuming gasoline, diesel and CNG engines [54]. Many studies have been conducted regarding fuel efficiency. Transportation efficiency leads to cost saving and more importantly less green house gas emissions. Since 1960, various approaches have been utilizing on automobile industry to control pollution [55]. Fuel consumption has been reduced by 5% in US new cars during the period from 1975 to 1990. Based on ceteris paribus assumption, 1% increase in weight and 1% reduction in 0-97km/h acceleration may increase the consumption of fuel by 0.69% and 0.44% respectively in US [56].

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

Similar results were seen in European automobile industry during period 2006 to 2015 i.e. 1% increase in weight and 1% reduction in 0-100km/h acceleration may increase the consumption of fuel by 0.3 to .5% increments in fuel consumption per 100km and 0.3% respectively. After 2006, more work was undertaken on reduction in weight and on engine capacity in European automobiles, due to which 32% reduction in fuel consumption was observed during 2006 to 2015 [57].

Hybrid electronic vehicles (HEVs) or conventional hybrid vehicles were introduced in 1997 [58]. While, plug in hybrid electronic vehicles (PHEVs) and electric vehicles (EVs) were introduced in 2004 and 2011, respectively. Plug-in electric vehicle (PEV) term is used for cars which consume partial rechargeable battery power. Two types of PEVs i.e. plug-in hybrid vehicles (PHEVs) and battery electric vehicles (BEVs).

Energy Efficient Appliances and their Consumption Pattern

Soon after the discovery of electricity in 1831, scientists became able to invent an electric generator. During 1900, generators were being used in many western cities. Since then, new electric appliances have been developing to fulfill daily needs of lighting, heating, cooling and transportation.

For lighting, compact fluorescent lamps (CFLs) and light emitting diodes (LEDs) are the most energy efficient lighting household appliances now a day. When compared with incandescent lamps (ILs), CFLs consumes 80% less energy and 6 time longer life whereas LEDs consumes 85% less energy and 26 times longer life span [59]. LED bulb saves $80 electricity cost during its life time [60]. Other LED appliances are becoming popular, for example, LED tube lights, LED lamps, LED torch lights etc. A survey was conducted in New York, Chicago, San Francisco and Houston during 2012 and found the share of each lighting which showed incandescent (27%), fluorescent (25%), CFL (24%), and LED (24 %) [61]. In EU, household share of ILs was dropped from 85% to 54% during the year 1995 to 2007 respectively. Market share of ILs was also dropped i.e. from 61% in 2006 to 41% in 2010. Market share of CFLs jumped from 15% to 23% during 2006 to 2010, respectively. LEDs technology entered in residential lighting rapidly [59, 62-64]. Higher CFLs prices and lack of awareness in general masses are main causes limiting the adoption rate by 20% as compared with ILs [65]. Main factors in adoption of LEDs found were expected performance, effort expectancy, social influence, behaviour and facilitating conditions [66].

For heating and cooling, boilers are widely used in the developed world. “Energy Star ®” is US government backed symbol bearing trademark, “the simple choice for energy efficiency”. There are following heating, cooling and multipurpose appliances are available at Energy Star [60].

Energy Star Appliance	Benefit
Boiler	i. annual fuel utilization efficiency (AFUE) is 87% or more for oil boilers and 90% or more for gas boilers ii. Bears electric combustion technology having sealed combustion iii. Safer and efficient
Central air conditioner	i. Greater seasonal energy efficiency ratio (SEER) and energy efficiency ratio (EER) ii. Consumes less energy by 8% than conventional new models
Room air conditioner	i. Consumes 9% less energy ii. Turn off unit through phone or computer

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CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

	iii. Schedule changes specification to maintain temperature
Freezers	10% more energy efficient
Refrigerators	9% more energy efficient
Ventilation fans	i. High efficiency ii. More comfortable with less noise iii. Better performance and longer life
Ceiling fans with light combination unit	60% more efficient than conventional fan or light units
Heating pumps	i. Consumes less energy by 5% as compared to conventional models ii. Provide heat during winter season iii. Provide cooling during summer with 30% reduced cooling cost
Geothermal heat pumps	i. Used for heating and cooling both ii. 45% more energy efficient

Heating and cooling appliances contribute significant proportion of energy use at household level. Greater the number of these appliances, there will be more electricity consumption. In Germany, among the appliances, refrigerator consumes most electricity (23%). Subsequent energy consumption appliances are TV, cooker, dishwasher, freezer, tumble dryer, computer, washing machine and DVD player [67]. Similar findings are found from Japanese household in which refrigerator contributed 28% of household electricity consumption followed by air conditioner (23%), television (14%), rice cooker (3%), dishwasher (3%) as depicted in [68]. According to American Council for an Energy Efficient Economy (ACEEE), refrigerator energy consumption has been declined 84% since 1972 to 2014. With the advancement in hi-tech, the operating cost of appliances has also been decreased dramatically since 1972 to 2005 i.e. refrigerator (70%), freezer (68%), dishwasher (76%), cloth washer (80%) and room air conditioner (33%) [69].

For transportation, Toyota Prius was first hybrid vehicle introduced in 1997. Since then, over 150 HEVs have introduced in the market worldwide [70]. Chevrolet Volt and Toyota Prius (PHEVs) can fulfill the same driving range as compared to a typical gasoline vehicle. This may serve as a viable bridge to transform to electric mobility [71]. U.S. 2014-15 sales data also showed excess sales of BEVs as compared to PHEVs [72]. In US, it costs about half as much to drive an electric vehicle [60].

Many developed countries are providing support to electric transportation system to cater the problems of greenhouse emissions and high burden of foreign exchange due to their dependence on petroleum fuel [73, 74]. Market share of PEVs for US and Norway in 2015 were 0.138% and 22.5% respectively [75]. China has market share of PEV 0.1% in 2013 mostly purchased by government. Whereas sale of PEVs became tripled in China for the period from 2014 to 2015 [76]. Although PEVs are environment friendly and mitigate the problems oil insecurity as well but still it cannot gain the expected pace commercially due to recent reduction of oil and gasoline prices coupled with low fuel taxes in US [75]. Despite rigorous efforts through technology forcing approach and strict regulation and setting ambitious goal of “zero emission vehicle”, Californian government could not be able to put a significant number of EVs at road [77]. BEVs was preferred option for 423 potential new vehicle purchasers out of 961 in US cities, over PHEVs, conventional hybrid and gasoline vehicles [75] despite of high purchase price, inadequate public charging facilities, limited driving range [78-80], depreciation, resale value

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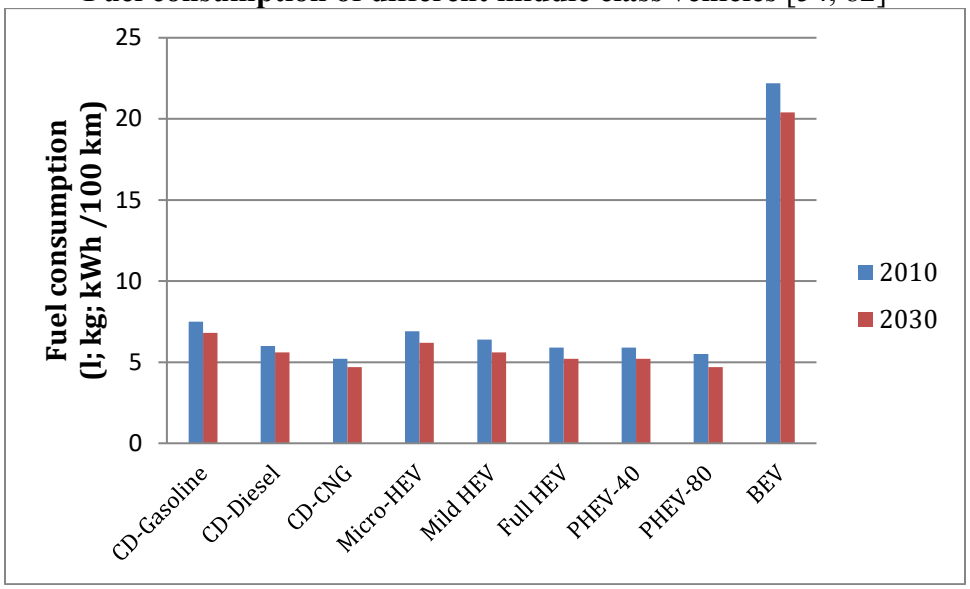
CJSSR
CONTEMPORARY JOURNAL OF SOCIAL SCIENCE REVIEW
Vol.03 No.03 (2025)

and battery life. These issues require technological improvement over time. Wire transport Sky Ways has been recently introduced in Russia as commercial transport. It is high speed, time saving, cost effective, environment friendly and safe transport as compared to the plane, sapsan, car, bus or train [81]. It is expected that future transportation system will be switched towards electric driven vehicles having safe, less polluted and sustainable environment.

Fuel consumption of different middle class vehicles [54, 82]



Fuel consumption has been decreased as technology developed. It is expected to further decrease fuel consumption by 2030 as depicted in the figure. The pace of adoption rate of new energy efficient technologies has been low till now, especially in developing countries [59, 66]. In the developed world, the adoption rate is comparatively higher.

Route to Sustainable environment

With every day passing, rapidly growing green house gas and carbon emissions caused by energy production and consumption processes, are adding pollution in the environment. To safeguard people from these environmental impacts, it is mandatory to eliminate the root cause of energy pollution. Energy efficiency is definitely be effective tool to mitigate harmful impacts on environment, hence on health of people [60]. In developing countries, energy efficiency and CO_2 emissions have a significantly negative relationship [83-85]. It is not only sustainable but also a cost effective measure. Energy efficient technologies, through energy saving, save money on utility bills [60].

There are substantial energy efficiency gain over time but their adoption is low which resulted in decrease of ongoing damage to the environment [66]. Some companies are really working on energy efficiency mandate, for example, Honda and Toyota are actively working on ZEV mandate vigorously [77]. Energy Star in US is also working rigorous efforts on energy efficiency appliances, building and transportation. The pace of adoption of energy efficient appliances may be enhanced through policy programmes keeping in view the behaviour of community, for example, technological innovation, stringent regulations, replacement programmes, subsidies and taxation may enhance the saturation of energy efficient appliances in a country [61, 77, 85].

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CJSSR
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CJSSR
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