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Investigating carbon emission abatement long-term plan with the aim of energy system modeling; case study of Iran

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ABSTRACT

Increasing electric vehicles usage, as a promising solution for environmental issues, might have unexpected implications, since it entails some changes in different sectors and scales in energy system. In this respect, this research aims at investigating the long-term impacts of electric vehicles deployment on Iran's energy system. Accordingly, Iran's energy system was analyzed by LEAP model in demand, supply, and transmission sides for all fuels and two different scenarios. Existing policies with limited optimistic assumptions was investigated as "reference" scenario. Alternatively, the other scenario, "electric cars" scenario, is gradually for substitution of electric vehicles for 15% gasoline cars until 2030 and renewable energy sources have more contribution in electricity production. Finally, carbon dioxide emission was predicted and compared in both scenarios for 25 years later. Results indicate that with "electric cars" scenario at 2030, Iran would have by 9.2 % and 1.9% less Carbon Dioxide emissions in comparison to the "reference" scenario in the transportation sector and total system, respectively.

Keywords: Carbon Emission, Sustainability, Battery Electric Vehicles, and Energy System Modeling.

1. Introduction

Climate changes and the necessity to take some serious reactions has been widely acknowledged. Reducing the global CO_2 emission appears necessary to limit the long-term global average temperature rise [1]. Many fiferent plans have been presented and implimented in regional, natioanl, and internatioanl scales to decrease GHG emissions. Based on Kyoto process commitment, Iran has to cut down by 4% of its Green House Gases (GHG) emissions by 2030 [2]. Consequently, decision makers in Iran should hold some new policies to achieve a sustainable energy system. Albeit, policymakers should not overlook the implications of new energy policies on different economic sectors because energy efficiency enhancement and GHGs mitigation policies might affect economic growth rate adversely [3]. Energy modeling can enable researchers to investigate energy system and consequently the environmental impacts of the energy system and present different policies and find the probable implications [4].

Furthermore, air pollution and its effects on people's health is another big problem in metropolitans and industrialized cities such as Tehran, Tabriz, Isfahan, Arak, Mashhad, and Karaj. [5]. In other words, merely by 70% of deaths from respiratory and cardiovascular diseases in Tehran occurs due to critical air pollution. [6] Another research showed that air

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pollution in Tehran leads to decrease 5 years of Tehran habitants lifelong and the other one unfoldes economical cost of air pollution [7][8]. Fig. 1 depicts a continuous increase in CO_2 emission in Iran and it reveals the importance of new policies to decrease GHG emissions. Mousavi et al. [9] investigated drivers of CO_2 emission in Iran and accordingly presented some recommendations for policymakers to a low carbon and sustainable future. However, there must be further studies to investigate the impact of these promising recommendations.

Transportation sector is one of the most effective sectors for CO_2 emission and policy assessment has been conducted in transportation sector by different researchers in recent years. Studies in diferent countries were mainly conducted in regional and national scales using WTW model for a life cycle assessment [11-17]. For instance, Li et al.[16] found the BEVs as a promising way to decrease air pollution specially in urban areas after investigating potential impacts of electric vehicles on air quality in Taiwan with the aim of WTW model.

Also, this research aims to investigate the implications of BEV usage in Iran's energy sytem. Accordingly, Iran's energy system was modeled by LEAP and some changes were cosidered in diferent sectors in a scenario named "Electric Cars Scenario". Then the athenticity of model was investigated by comparing the real data and outputs of model. Finaly, the CO_2 emission were compared in two scenarios.

Nomenclature

MAPE	Mean Absolute Percentage Error
GHG	Green House Gas
CO2	Carbon Dioxide
BEV	Battery Electric Vehicle
TED	Technology and Environmental Database
IPCC	Intergovernmental Panel on Climate Change
LEAP	Long-range Energy Alternative Planning
NG	Natural Gas
GDP	Gross Domestic Product
RES	Renewable Energy Sources
WTW	Well to Wheel
MBOE	Million Barrels of Oil Equivalent

2. Literature review

According to Fig. 2, the transportation sector has a share of approximately one-fourth in CO_2 emission in Iran [10]. This sector is also responsible for nearly 20% of total CO_2 emissions on the global scale and it is still increasing its GHGs emissions [18]. Before the emergence of electric vehicles, most common strategies to decrease CO_2 emission had been replacement of alternative fuels and alternative automotive technologies as well as implementation of new standards [19-20]. In this regard, Shabbir and Ahmad [21] investigated urban transportation in two cities of Pakistan with the aim of LEAP model which implys that developing countries have also been pondering over the reformation in transportation sector. Some countries have passed different supportive rules for Electric vehicles owners to spread their usage among their societies [22]. In many cities such as Vien, Berlin, Amsterdam, Hamburg, and Stockholm, policy makers support electric cars users by regulatory gifts [23]. Many countries have previously defined some targets for the number of electric vehicles in their transportation sector: China 5 million, France 2 million, Germany 1 million by 2020 and 6 million, India 6 million by 2020 [24].

Nevertheless, there are scanty researches about the implications of electric cars usage in Iran. Deficiencies in infrastructures are the most important barriers of using electricity as an alternative energy in transportation sector in near future [25]. Hashemian et al. [26] investigated environmental implications of using cars burning CNG and gasoline which has been called dual-fuel and results showed that joining dual-fuel vehicles to Tehran's transportation fleet affected the air pollution status adversely.

Sadri et al. [27] also presented a framework for developing countries long-term energy-environmental planning in transportation sector with the aim of LEAP and EnergyPLAN models and examined Iran as a case of developing country. Sehatpour et al. [28] have recently investigated alternative fuels for light duty cars. However, they have not considered BEV as a viable solution.

On the other hand, researches imply that BEV seems as a promising alternative for reducing GHGs emissions when NG is used to provide energy for transportation [29]. The

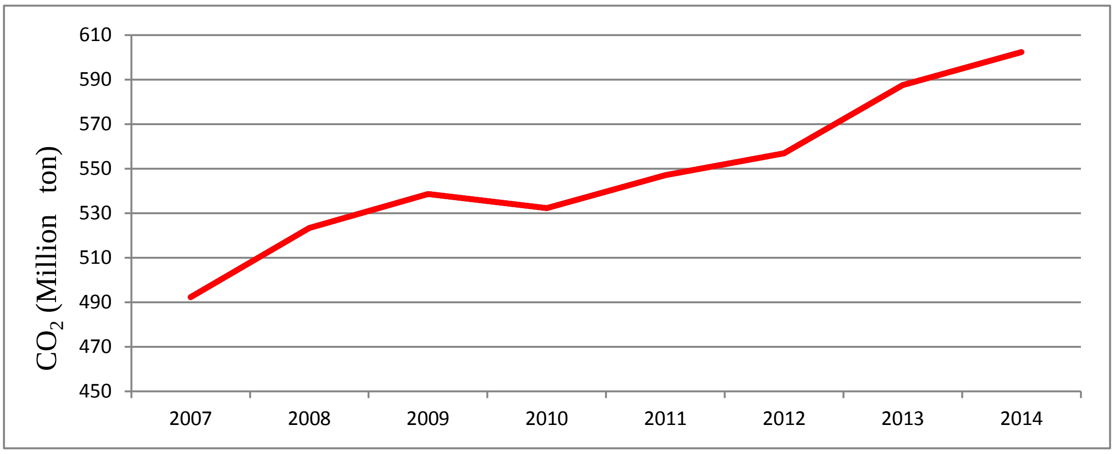

Fig.1. History of total CO_2 emission (Million Ton) [10]

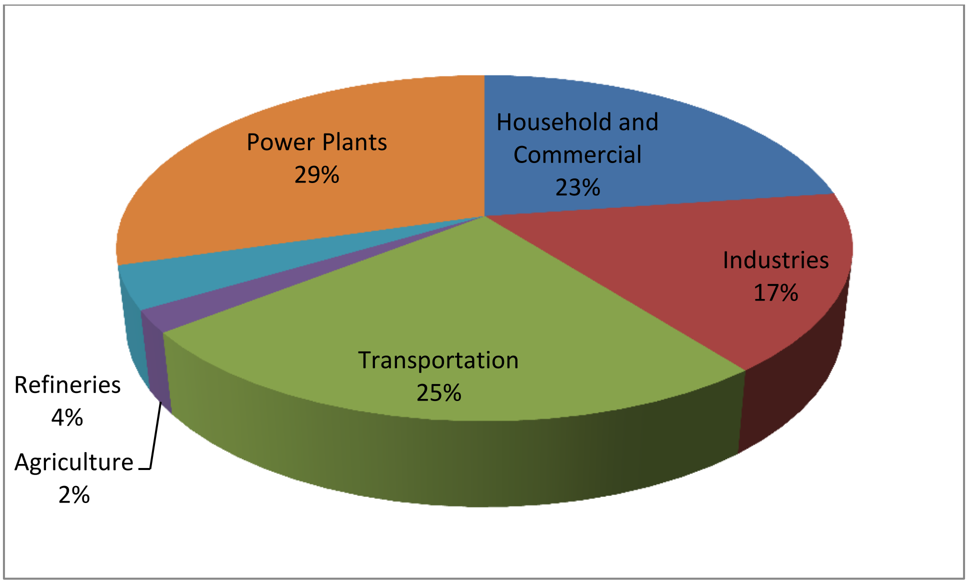

Fig. 2. Contribution of different energy subsectors in CO2 emission [10]

needed extra electricity for BEVs might increase GHGs emission when Coal is being burned for electricity production [30]. Iran has the opportunity to have cleaner and cheaper electricity, as Iran is endowed with great resources of natural gas. Additionally, a considerable number of BEVs, which are interacting with smart grids, can introduce significant energy-storage capacity to electric grids and help to overcome the load leveling problem [31].

3. Materials and methods

3.1.Methodology

BEVs have air pollution when they consume electricity which is produced by fossil fuels. Normally, there are different approaches for investigating the environmental impacts of electricity production: However, there is not yet any broadly accepted approach for assessing the CO_2 emissions in this case [32]. For instance, Gomez et al. [23] used the definition of well-to-wheel to assess the implications of BEVs usage. They, also, estimated the CO_2 emissions difference from hypothetical annual average of mileage. Wu and Zhang [33] also used Well to Wheel (WTW) method and concluded that pollutant emission which has been produced by a certain BEVs is much higher than that in developed countries. As developing countries use larger proportions of thermal power or present high line loss rates. Zhang et al. [34] developed some scenarios for a low-carbon city and

investigated them with LEAP model. They calculated energy consumptions and carbon emissions in all three scenarios and compared them. With this, they could assess the effectiveness of their new policies which has been recommended in distinctive scenarios.
Energy system modeling empowers researchers to design different scenarios and anticipates the status of the system in the future under different circumstances. CO_2 emission is one of the characteristics of Iran's energy system and should be predicted for future to examine the result of current policies. In this research, Iran's energy system was modeled by LEAP software in demand and supply sectors. Two scenarios were considered as "reference" scenario and "electric cars" scenario. Sociological impacts of new policies, which can be multiple impacts, were not considered. For instance, the total number of vehicle kilometers driven can be reduced by increasing fuel taxes, and it can be increased by fuel efficiency improvements due to the rebound effect [16]. Finally, the CO_2 emission was calculated and reported from the energy consumption in the total system and in transportation sector in two scenarios.

3.2.LEAP Model

Energy system modeling has been an appropriate method for decision makers to investigate the implications of their policies. Various modeling approaches and models have been applied to address a variety of energy policy related issues [35]. Modeling enables researchers to enforce new policies and strategies as scenarios investigate the implications of new policies in system and consider the interaction between different elements of the system [36]. Except modeling a hypothesis in energy system could be investigated with no other method. [37].

LEAP is an integrated scenario-based energy-environment modeling tool which can be used for energy consumption, conversion and production modeling with different assumptions which are based on researchers attitudes. LEAP can be used in regional, national, or even international scale energy system [38]. LEAP has the ability to model end users and it entails preparing wide range of data. Despite the extensive data requirements, model has a very simple structure and is suitable for predicting the effects of energy efficiency [10]. In addition, LEAP has been applied in many projects in different countries and regions and has approved its ability to adapt with different energy systems [39]. Bose and Srinivasachary [40] investigated scenarios, with the aim of LEAP, to decrease energy use and environmental impacts in Delhi city and Kale et al. [41] modeled electricity sector of this city. Dagher and Ruble [42] assessed the possibility of using renewable energies in Lebanon to reduce greenhouse gas emissions which have been caused by electricity generation and consumption and Abbaspour et al. [43] also applied LEAP for modeling Iran's household energy demand. In developing countries researchers chiefly prefer to use LEAP model simply because extensively accepted energy models are not presented in these countries specifically. After all, LEAP was picked up for modeling the energy system of Iran.

3.3.Carbon emission calculation

Carbon emission is calculated from energy consumption in LEAP software. In this model energy consumption for every activity is calculated as below:

$$ECn = \sum\sum AL_{n,j,i} \times EI_{n,j,i} \tag{1}$$

where EC_n is energy consumption of the sector for fuel n, AL is the activity level, EI is the energy intensity, i is the sector, and j is the device. Carbon emission of every fuel was defined in LEAP model, based on TED, and carbon emission was calculated by below equation after energy consumption calculation:

$$CEC = \sum\sum\sum AL_{n,j,i} \times EI_{n,j,i} \times EF_{n,j,i} \tag{2}$$

where CEC is the carbon emission and $EF_{n,j,i}$ is the carbon emission factor for fuel type n, equipment type j, and sector i. The other parameters are the same as Eq.(1).

LEAP has a built-in platform of the TED, which provides extensive information about the technical characteristics, costs, and most importantly, environmental impacts of a range of technologies (McPherson and Bryan 2014). With more than one thousand technologies in TED, researchers can examine the result of every fuel based on IPCC, the US Department of Energy and the International Energy Agency reports.

However, in the WTW method, a mean value of CO_2 emission for electricity production is reported and used for estimating total CO_2 emission of BEVs. In this research, CO_2 emission is alternatively reported based on Eqs. (1) and (2).

3.4.Transportation System modeling

LEAP observes details in transportation system modeling. It can divides the transportation system into many different branches. Researchers can develop their specific tree of branches and sub-branches based on the accessible data. However, this model needs a wide range of data but it can increase the accuracy of outputs. Some key needed data for calculation are listed below:

1. Number of vehicles by types that are added in a particular year and for previous years,
2. Survival lifecycle profile (in this case 30 years), fuel use per unit of vehicle,
3. Annual distance traveled per vehicle,
   The emissions rate for different pollutants according to the fuel.

Additionally, contribution of different sectors in transportation is needed for developing the branches. Structure of model should be developed based on official governmental reports. Internal transportation sector in Iran is considered as road, railway, and airway. Amazingly, almost 94% of transportation is by roads in Iran. Data for previous years were extracted from annual reports and data for next years were forecasted where necessary.

Nevertheless, energy consumption of BEVs was considered as a constant measure for electricity demand calculation in transportation sector. Different methods have been implemented for electricity consumption estimation for BEVs and mean value based on different reports was used in this research [44] [45]. Different amounts have been reported for electricity consumption and some of them are mentioned in Fig. 3. The mean value of energy consumptions for different cars was assumed as 14.5 kWh/100km as fuel energy intensity for input of LEAP software in transportation sector during all of the model years.

3.5.Electricity production modeling

Iran's different power plants were modeled with their specific characteristics. Additionally, ongoing plans of electricity production which are published annually by Iran's office of electricity and energy planning were considered. Figure 4 depicts the difference between CO_2 emissions by different sources in Iran in the year of 2014. [10] Conclusively, it is crucial to model different power plants with different efficiencies, sources, merit orders, dispatch rules, energy consumptions, air pollutions, etc.

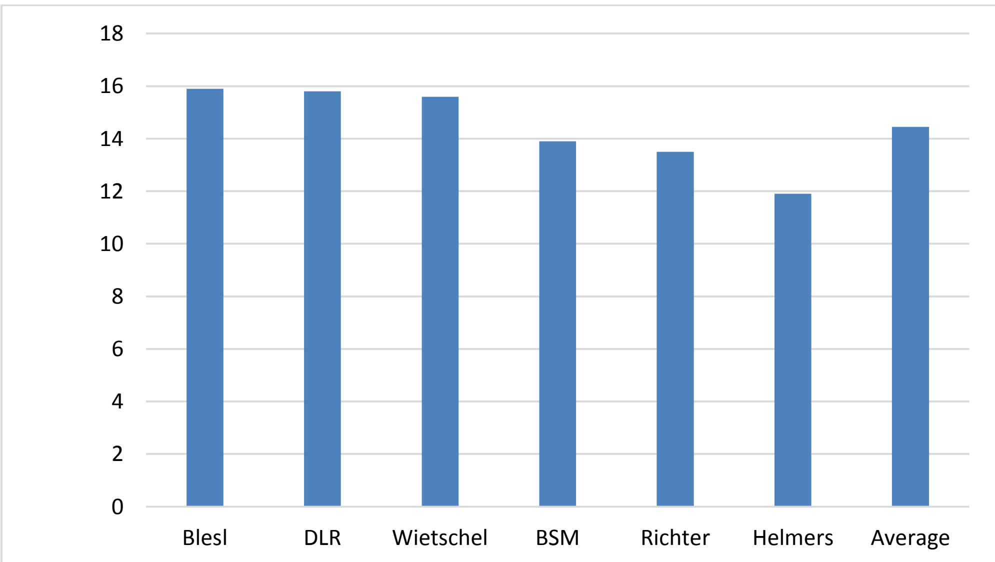

Fig. 3. Combined energy consumption of BEVs (KWh/100km) [45]

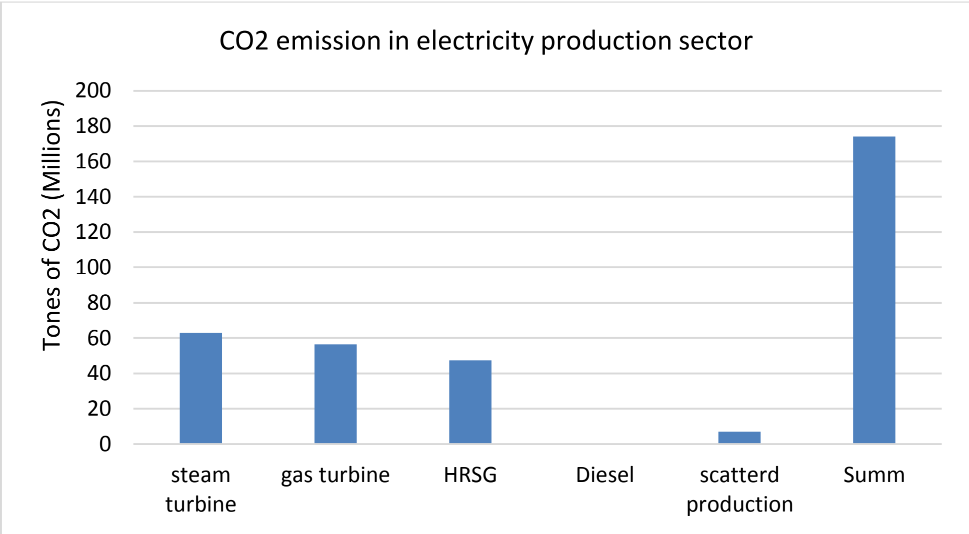

Fig. 4. CO2 emission in different power plants based on type of power plant [10]

Figure 5 shows the share of technologies in Iran's electricity production. Iran has not invested on RES in electricity production, since there have been adequate and affordable resources of fossil fuel inside the country. Currently, less that 1 percent of electricity production in Iran is by RES. Iran has planned to increase photo-voltaic power plants ambitiously [46]. Such plans must be considered in modeling meticulously. Additionally, planning for increasing energy efficiency, Iran had 14.3% energy loss in its electricity transition grid in 2011 and currently has 13 % energy loss. It was assumed that Iran will decrease energy loss in electricity distribution grid to 10% by 2035.

4. Scenarios

4.1.Reference scenario

In the "reference" scenario, to be able to compare the model and real data 2011 was considered as base year and 2037 was considered as model end year. In section 5.2 the output of model for between 2011 and 2014 are compared with the real statistics. Data such as population growth rate and number of cars were forecasted for future years and based on historical data [27][47]. In the key assumption module, data such as total population, percentage of urban and rural population, households, and similar data has been extracted from official annual reports by Iran's governmental organizations. Existing and future plans for electricity production sector in Iran and type of technologies are being used in power plants are extracted from Iran’s ministry of power annual report [10]. Iran's annual economic growth rates were extracted from annual statistics for first 4 years of model. [48] For the ensuing years it was optimistically considered 6 % until the end of year of model. This assumption was considered to guaranty that Iran's probable CO_2 reduction in this scenario is not because of economic activities reduction. With this assumption Iran’s GDP which are related to industrial, agricultural and commercial productions will not be jeopardized by carbon emission abatement plan. GDPs were calculated based on economic growth rates and quantities of vehicles were roughly estimated. Some of data which are the same in two scenarios are reported in Table 1.

4.2.Electric Cars Scenario

“Electric cars" scenario inherits all characteristics of "Reference" scenario. "Electric cars" scenario starts from 2012, a year after base year of model, and it continues until 25 years later. It has three differences with "Reference" scenario:

1) increasing the share of NG in electricity production

Iran has conducted some reforms in its energy system such as reorientation in industrial, technological, agricultural and cultural policies in different energy sectors. However, they have not yet ended in GHGs emissions reduction. In this research, NG is considered as the best

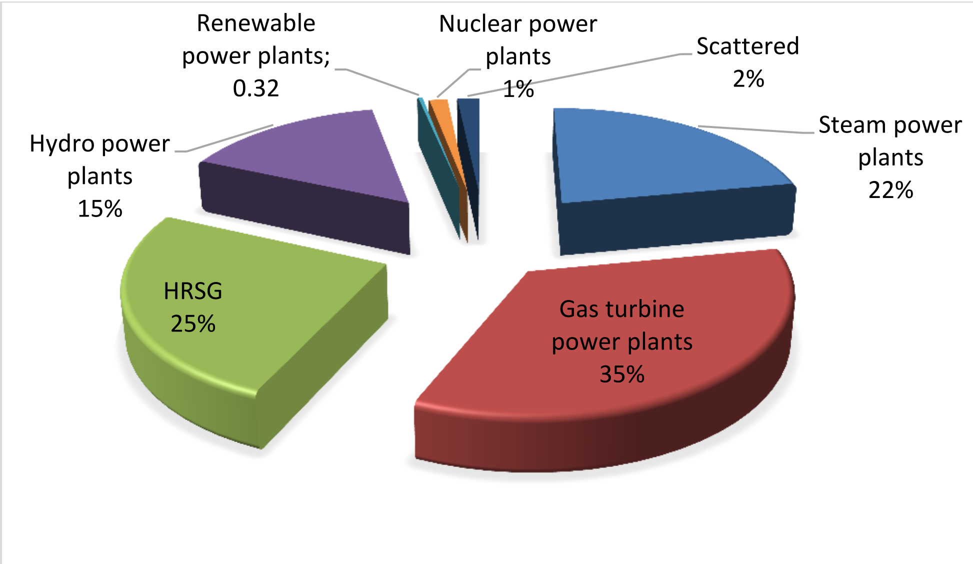

Fig.5. A contribution of different technologies in electricity production [10]

Table 1. Real and predicted measures for population, number of cars, and GDP

year	Population (million)	Car No.(million)	GDP (milliard) US$
2000	64.22	3.18	457.40
2005	69.39	6.03	615.10
2010	77.48	10.47	878.70
2015	82.39	15.75	1,047.03
2020	87.62	18.39	1,401.16
2025	93.18	22.23	1,875.07
2030	97.36	26.07	2,509.26
2035	100.36	29.91	3,357.96

resource to change the energy policies faintly to avoid from disturbing fluctuations in Iran energy system. In this respect, NG has been taken into account as the cleanest fossil fuel resource for electricity production in thermal power plants. By that, Iran can use its NG as an alternative fuel for light duty vehicles. Additionally, it empowers Iran's electricity grid by different advantages such as ability to export extra electricity, planning for smart grids in household sector, peak shaving, etc.

2) Increasing the share of RES in electricity production

Additionally, the share of renewable energy in electricity production will increase to 7% by 2025 and 10% by 2030. Iran had nearly 68 Giga Watt annual electricity generation potential in 2011 and currently has 77 Giga Watt annual electricity generation potential which, according to the plan of this research means, Iran has to establish 680 Mega Watt renewable-based electricity production potential in first year. This amount increases annually in proportion to the total amount growth in annual electricity generation potential to hold expected percentage of RES in total electricity production potential.

3) Increasing the share of BEVs in transportation sector

Furthermore, in "electric cars" scenario, Iran has to increase the share of electric cars to 15% of all sedan cars until 2030. This process will start in 2011 that is from a year after the model base year. Iran had 11.5 million sedan cars until 2011 and this amount has been continually increasing annually [49]. Based on this scenario, Iran will have 3 million BEVs by 2030. Power production in this scenario for extra electric power which has been needed for BEVs is with the aim of Natural Gas and RES.

5. Results and Discussion

5.1.Model Outputs

LEAP software outputs include a broad range of data and it helps users to analyze the results comprehensively. Energy consumption is one of the most prevalent indicators for energy systems which is monitoring in national, regional, and global scales. Figure 6 shows energy consumption of Iran in transportation sector. Energy efficiency improvement policies were not considered in this research due to receive a better comprehension of RES enhancement and BEVs deployment policies. However, differences in energy consumption were expectable through the energy resources exchange in transportation sector, electricity consumption increase, and gasoline consumption decrease. Figure 6 implies that Iran would need massive amount of gasoline for its transportation sector thirst for energy in the ensuing years.

Contribution of different sources in electricity production between 2011 and 2037 is clear in Fig. 7. Increase in RES share and decrease in residual fuel oil are noticeable. Additionally, Iran has already dedicated a great role to NG for electricity production and this plan will be continued. Iran will produce 30 MBOE electricity with solar power plant by 2037 under "electric cars" scenario.

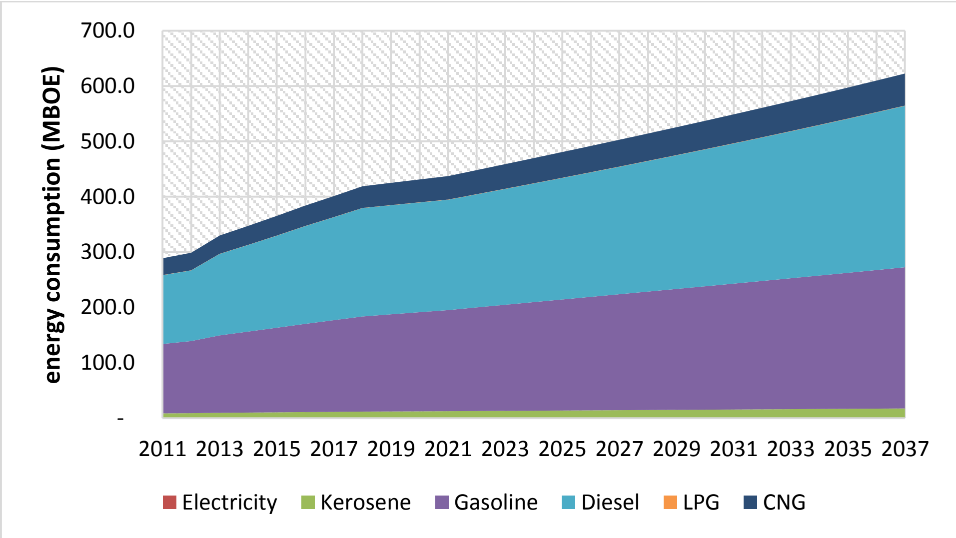

Fig.6. Iran's energy consumption in transportation sector, "reference" scenario (MBOE)

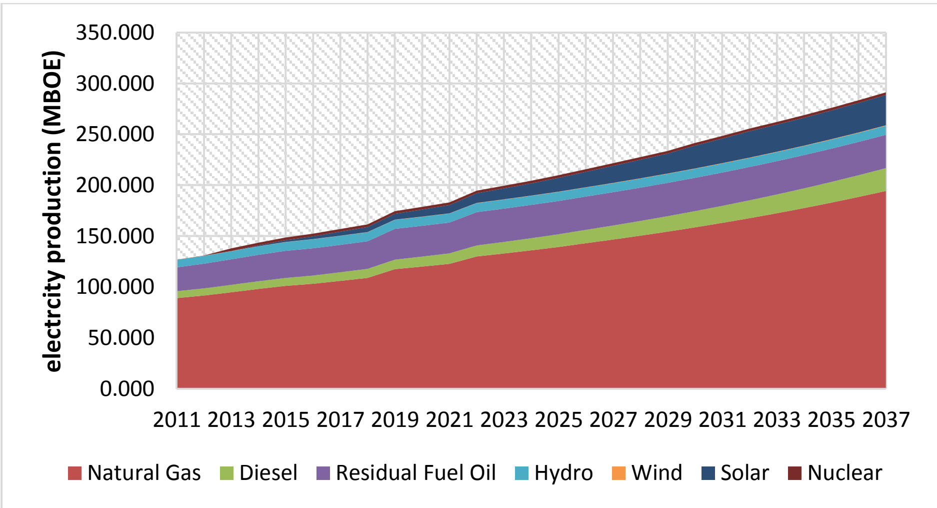

Fig.7. Total electricity production in "electric cars" scenario (MBOE)

Figures 8 and 9 illustrate the differences between CO_2 emissions in two scenarios. From Fig.9, CO_2 emission will be less in "electric cars" scenario in comparison to "Reference" scenario. Nevertheless, in both scenarios, the trend of CO_2 emission continues increasingly. It shows that this scenario cannot meet Iran's targets for CO_2 emission reduction. In "Reference" scenario, Iran will see the level of 777 million tons of CO_2 emission per year up to 2037, and in "Electric cars" scenario, Iran will annually emit 745 million tons of CO_2.

As it is obvious from Fig. 9 and based on calculations in this research, the CO_2 emission will rise up to 228 million tons by 2030 in "reference" scenario in transportation sector. It will also see the point of 207 million tons at that year under the "electric cars" scenario. It shows a 9.2% reduction in CO_2 emission in transportation sector.

5.2.Investigating Outputs Authenticity

The results of model should be investigated after providing the demand and supply model. The MAPE is one of the most popular measures of the forecast accuracy [50]. MAPE is scale-independent and easy to interpret [51]. However, MAPE could not be used when the actual values are zero or close to zero. MAPE will show large amount of errors when actual measures are less than one [52]. In this research, this index is acceptable, since the measures are big enough. In table 3, the results

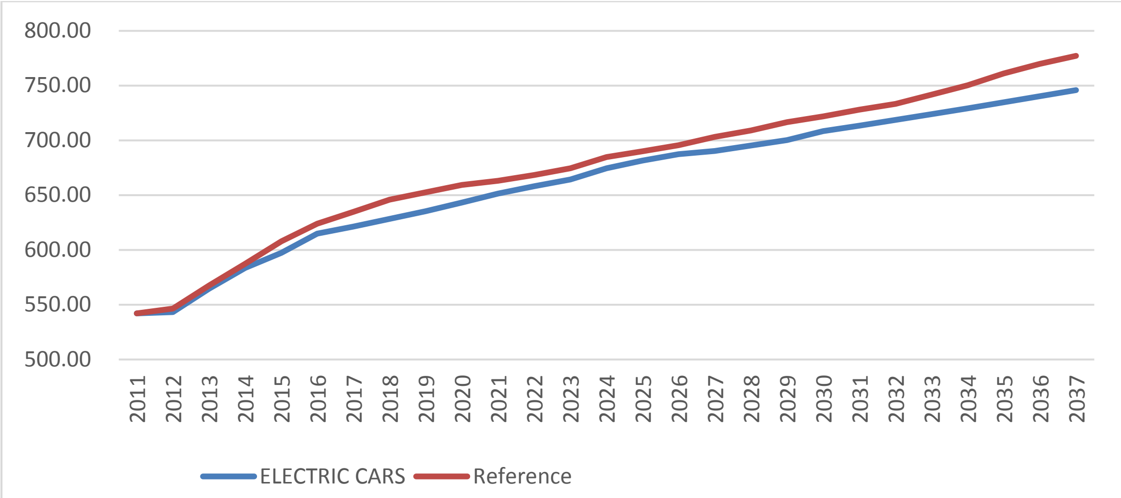

Fig. 8. Total CO2 emission prediction in two scenarios (million ton)

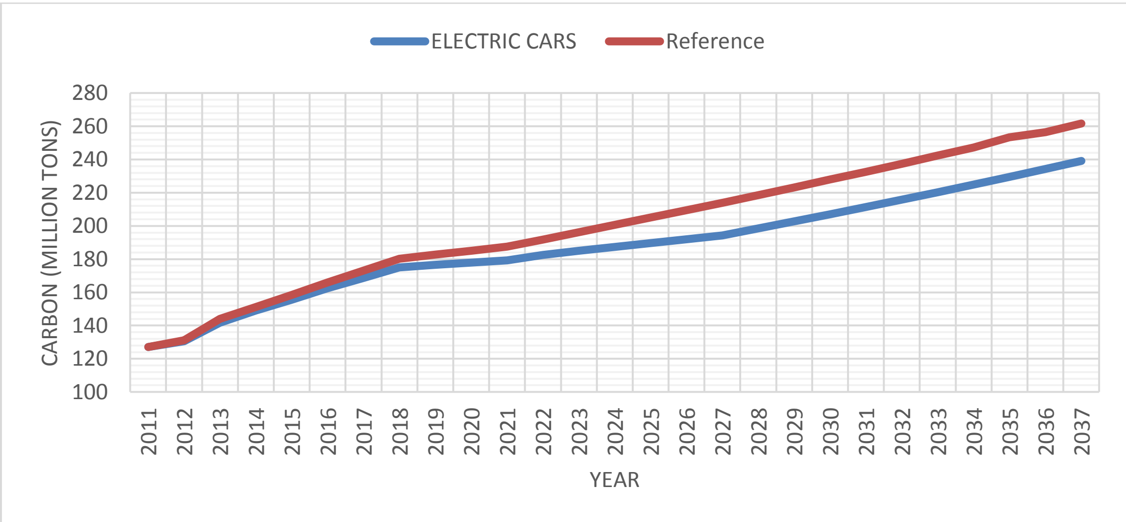

Fig. 9. Transportation sector CO2 emission predication in two scenarios (million ton)

of model were checked by validity. The results were calculated by equation below:

$$MAPE = \frac{\sum_{i=1}^{n} \left(\text{ABS}\left(\left(\frac{Yr - Ye}{Yr}\right) \times 100\right) \right)}{n} \quad (3)$$

where Yr is real data and Ye is data extracted from model.

Accuracy of predicted data by model can be perceived from Table 2. Afterwards, data extraction, depending upon the data needed for analysis and conclusion, would be extracted from model. All extracted data, which has been used in this research, was checked by accuracy and validated.

3. Conclusion

The possible benefits of BEVs in Iran are great: decreasing GHG emissions, reducing the dependence on gasoline, increasing the electricity production which can be exported, and expanding the electricity grid.

This research showed that deployment of BEVs in Iran deserves to invest on renewable energies and furnish the infrastructures, since it can categorically make a more sustainable energy system with reducing CO_2 emission. Iran has over 300 sunny days and has a good potential for using solar energy. This research substantiated that Iran can decrease its CO_2 without diminishing economic activities.

Furthermore, this research revealed that using BEVs can decrease the pace of CO_2 emission growth in transportation sector satisfactorily up to 4.8 and 9.2 percent by 2023 and 2030, respectively. Conclusively, this policy can help the government to solve air pollution problem in big cities. In addition, it can decrease pace of CO_2 emission amplification in total system up to 0.15 and 1.9 percent by 2023 and 2030, respectively. Conclusively, this policy can help the government to solve air pollution in cities.

Considering monetary and non-monetary persuasions for BEVs users, policymakers should convince people to gravitate toward new technologies in transportation sector. Incentives can be tax exemption, special rights for BEVs traffic as award, and cheap electricity in restricted times. This research showed that Iran can meet CO_2 emission abatement targets without decreasing economic activities.

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Table. 2. MAPE calculation for predicted data

Item/ year	2011	2012	2013	2014
Forecasted Transportation sector CO2 emission (Million Tons)	127.90	132.47	139.69	149.08
Real Transportation sector CO2 emission (Million Tons)	127.14	131.08	143.96	151.06
Forecasted Transportation sector CO2 emission (Million Tons)	542.20	546.37	567.51	587.36
Real Total CO2 emission (Million Tone)	548.29	550.46	578.80	597.63
MAPE (CO2 emission in transportation)	1.4837			
MAPE(Total CO2 emission)	1.3806			

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