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Integration of Renewable Energy-Based Systems for Transport Sector in 2050; a Case Study in Iran

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Abstract

The recent studies have shown that the integration of power generation, seawater desalination, and industrial gas production can significantly reduce costs and generate clean energy on a large scale. On the other hand, by the growth of population, transportation has been known as a major consumer of fuel and energy leading to a higher energy demand, increased total costs, and more pollutant components. In this work, the effect of merging the transportation sector to the integration system on energy production and total costs by 2050 in 5-year time steps is investigated based on an the optimization method and a linear model simulation. The modeling is under three scenarios: a) integrated scenario, b) current policy scenario, and c) combined integrated scenario. Renewable systems are considered to be the energy suppliers of power generation, seawater desalination, industrial gas, and transportation sectors. The results show that the addition of the transportation sector has a significant effect on reducing the final cost from 41 €/MWh to 36 €/MWh, which is attributed to the increased generated energy and the severe price drop of power generation technologies as a result of this merging. Also the share of various renewable technologies in energy generation show that in the combined-integrated scenario, the share of revenues, especially solar PV, is increased 2% from the integrated scenario. The results reveal that the installation capacity has a 32% growth compared to the integrated scenario, and 90% compared to the CPS scenario.

Keywords: *Renewable energy; Storage technologies; Transport system; Levelized cost of energy*.

1. Introduction

Moving towards a fully energy-based renewable energy system is not only possible but it is also essential to respond quickly to the rising energy demand and resolving the current climate crisis [1-3]. To that end, many studies have examined and demonstrated the feasibility of using a global path to 100% renewable power supply.

In 2014, 127 GW of renewable energy, accounting for 49% of the world's total power plants, was exploited [1, 4-6]. This rate increased to 70% in 2017.

According to statistics, there is a growing need for alternative revenue that can reduce energy costs while meeting the energy demand of the society.

As a developing country, Iran is experiencing population growth leading to the rising demand [7]. Today, Iran is heavily dependent on the oil and gas reserves, and much of its economy relies on the revenues from these resources, which are neither sustainable nor a viable solution to meet the needs of the future generations in Iran. On the other hand, international sanctions have had a significant impact on Iran's energy sector, and have suspended many oil and gas projects. The share of natural reserves in primary energy consumption in 2013 was different.

According to the Energy Information Administration, Iran has the fourth place in the world in terms of oil reserves, after Venezuela, Saudi Arabia, and Canada. The forecasts show that with increase in the population growth, electricity consumption will increase more than 2.5 times by 2050, and will reach 555.45 TWh [8].

Recently, the Iranian government has focused on the use of renewable energy in various economic sectors, and Iran's energy policy has shifted from an oil-dominated country to a diversified energy source with more sustainable resources. The 20-year goal, which was set by the government to support the private sector to exploit renewable power plants, is to develop the technologies that have been gained in more than 10 years, and increase the share of renewable energy in various industries [9-13]. According to the United Nations Climate Change Conference (COP21) in Paris, no pure CO_2 emissions will be allowed until the early 21st century [4, 14, 15].

In the last decade alone in Iran, the power plant installations have nearly doubled, from 37 GW in 2005 to 65 GW as electricity demand increased. During this period, electricity production increased by an average of 5% annually. An increase of 2.7% per year by 2040 would be needed to meet electricity demand [4, 15, 16]. Considering the high potential of wind energy and solar photovoltaic systems in Iran, the application of renewable sources for electricity generation is far more economical than consuming conventional revenues such as fossil fuels, which have heavy effects on the environment and health and imposes additional costs.

Several journals have examined a complete energy system based on renewable energy for several countries and regions around the world, noting that a renewable energy system is not only a practical theory but also comparable to the current systems [3, 4, 17-21]. Hoffmann in a study stated that the only rapid transfer of current fossil fuels to renewable power plants is a practical solution for the future energy system and to limit the global average temperature to below 2 degrees Celsius [15, 22]. Breyer *et al*. have shown a leap toward 100% renewable energy supply by 2050 [23]. This study indicated that a 100% renewable power system based on renewable resources is both practical and more economical than the existing systems. The Equilibrium Cost of Electricity (LCOE) for such a proposed power system in 2050 is estimated at 52 €/MWh, which seems to be much more efficient and cost-effective than the systems available in 2015 at the equivalent electricity cost of 70 €/MWh [24].

Demand modeling for different types of energy in Iran to reduce consumption costs using a techno-economic approach under two scenarios, Current policy Scenario (CPS) (not to change the consumption pattern) and efficiency scenario, from 2005 to 2030 was investigated in a study by Moshiri *et al*. [25]. The results showed that Iran had a great potential for energy storage and in particular, under the efficiency scenario, Iran would be able to reduce its energy consumption by 40% by 2030.

In another study, Ghorbani *et al*. have used this scenario to examine the total capacity required from 2015 to 2050 at 5-year intervals to meet Iran's electricity demand [2, 26]. The results of this study showed that merging the electricity sector with other sectors would further reduce the cost of electricity at a total cost of 41€/MWh.

Besides the power and desalination sector, by the growth of population, transportation has been known as a major consumer of fuel and energy leading to higher energy demand, increased total costs, and more pollutant components. The transportation sector accounts for about 26% of Iran's total energy consumption, 53% of total oil consumption, 2.5% of natural gas consumption, and 0.7% of electricity consumption [25, 27]. According to the estimates, the demand for cars will grow by an average of 4.4% per year, and will increase to 26 million units by 2030 [25, 27, 28]. According to a study conducted in [25], renewable resources can be the best alternative in reducing energy costs and emitting greenhouse gases.

Based on the previous studies on the use of renewable resources as a highly efficient option, as well as the integration of demand for power, desalination, and industrial gas production, in this study, we examined the effect of merging the transportation sector to the integrated sector. For this purpose, by using the levelised cost of energy of each section and then optimizing and modeling the amount of energy consumption and the amount of energy generated by each of the technologies until 2050, the effect of this section on the final levelised cost was examined.

2. Implemented scenarios

Three scenarios are implemented for this research work. These are: a) integrated scenario, b) current policy scenario, and c) combined integrated scenario.

a) Integrated scenario

This scenario describes a power system based on the renewable resources. In this scenario, the seawater desalination and the industrial gas sectors have been merged with the power sector [26]. Therefore, the electricity system can supply the required electricity for all three sectors of power, desalination, and industrial gas.

b) Current policy scenario (CPS)

In this scenario, the country's current policies have been used to model the Iran's electricity system. It is assumed that all policies and programs related to the electricity industry will be accomplished. These policies are mentioned below:

- 5 GW (Gigawatt) of wind and solar power plants will be added by 2021 according to the sixth development plan [29].

- In conformity with the 20-year approach program, 10 GW of total power capacity has been obtained since 2025 by the wind and solar energy [30].
- Installation of two nuclear power units, 1 GB (Gigabite) by 2024 and another 1 GB by 2026.
- Conversion of gas turbine power plants to combined cycle turbine power plants [31].

Since no official plan has been reported for post-2026, it is assumed that the installation of wind and PV (photovoltaic) production lines would continue according to the current policy. Therefore, 5 GW of solar systems and wind power plants in every 5 years will be installed in Iran until 2050.

c) Combined-integrated scenario

This scenario is the same as the integrated scenario except that in this scenario, the transportation sector was also merged into the power generation sector.

2.1. Demand for different sectors

The hourly electricity consumption of Iran in 2015 was extracted from the source [15, 31], which is calculated for the next year according to the growth rate of electricity demand estimated by the IEA (International energy agency). For the seawater desalination section, only the reverse osmosis technology has been used due to its high efficiency and cost-effectiveness. Non-energetic industrial gas consumption in 2015 was extracted from [32]. The average annual growth rate for gas demand is assumed 2.1% in accordance with the IEA [33] plan for natural gas demand in the Middle East. The energy-to-gas conversion technology is based on methanation, direct CO_2 capture, and water electrolysis [34]. The demand for each one of the different sections is reported in table 1. It should be mentioned that the non-energetic industrial gas demand was evaluated based on the estimation of IEA for the natural gas demand [35].

The full loading hours (FLH) for the wind energy, centralized solar thermal power (CSP), and fixed tilted PV in Iran are calculated according to [36], and for the single-axis, PV is calculated according to [15, 37]. The climate data is derived from the NASA Data for 2005 [38, 39], and the spatial and temporal resolution of the dataset is $0.45^{\circ} \times 0.45^{\circ}$ hours, respectively. Also the average full loading hours for CSP, PV, and wind power plants in Iran are presented in table 2.

Table 1. Demand for different sections.

Year	2015	2020	2025	2030	2035	2040	2045	2050
Annual power sector demand (TWh)	273	307	346	388	437	490	553	625
Electricity consumption (kWh)	3445	3683	3995	4386	4852	5377	6007	6782
Annual desalination demand [million m^3]	108	405	2981	23308	77494	90625	95990	101328
Annual electricity demand for desalination [TWh_{el}]	0.6	2.6	17.6	131/2	418/5	476.4	500.1	524.4
Annual industrial gas demand [TWh_{th}]	120.4	133.6	148.2	164.4	182.4	202.4	224.6	249.1
Annual electricity demand for industrial gas [TWh_{el}]	0	0	0	0	27.9	102.2	310.7	391
Annual energy demand for the transportation sector [TWh_{el}]	570.21	581.62	593.25	605.11	617.22	629.56	624.15	655

Table 2. Average full load hours for PV single-axis and fixed-tilted, CSP, and wind power plants.

Electricity ·neration system	PV single-axis tracking	PV fixed -tilted	CSP	wind
Full load hours	2064	1723	2253	2449

3. Optimization and modeling

To have a more accurate cost calculation, linear modeling had been used. Optimization was chosen based on the linear method because it performed the calculations in less time, and had a more favorable and tangible result. Optimization aims to find the least expensive energy system by considering a set of limitations including electricity demand, installed capacity limitations, and technical and economic constraints. Therefore, the proposed energy system has a minimum annual cost, which includes installation costs, energy production, and energy ramp costs [2]. The MATLAB software was used to model and optimize.

Initially, the levelised costs of each section were calculated using equation (1) [13]:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

It should be noted that the rate of decline is calculated by the weighted average cost method (WACC). The following flowchart demonstrates the modeling:

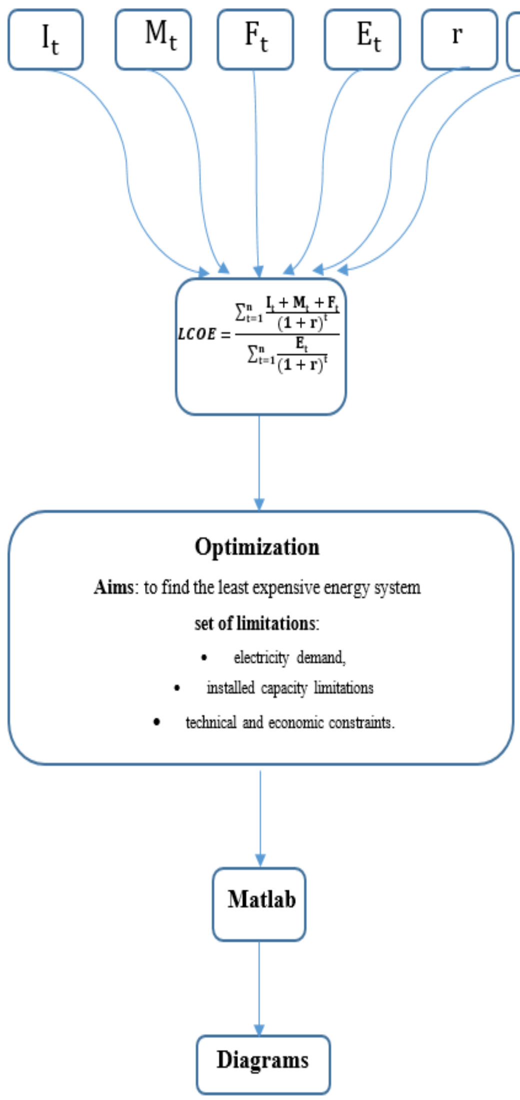


Figure 1. Flowchart of modeling and optimization process.

3.1. Validation

For optimization and modeling, the MATLAB software was employed. In order to investigate the verification of this modeling, the error percentage evaluation of the current study and Ghorbani *et al*. [13], as the reference source, for installed capacity and LCOE parameters was also evaluated and reported in Tables 3(a) and 3(b).

Table.3. Validation of the error bar of the current study and the reference study for (a) Installed capacity and (b) LCOE parameters

Installed capacity (GW) for 2050			
	Current study	Ghorbani et al. [13]	Error%
Hydro dam	910	910	0
Hydro ROR	920	915	0.0054
Wind	905	905	0
PV single	774	770	0.0052
PV fixed	495	490	0.0101
PV PRO	880	820	0.0681
OCGT	75	65	0.1333
CCGT	70	60	0.1428

LCOE in 2050			
	Current study	Ghorbani et al. [13]	Error%
Hydro dam	23	23	0
Hydro ROR	22	22	0
Wind	21	21	0
PV single	16	15	0.062
PV fixed	9	9	0
PV PRO	17	16	0.059
OCGT	25	24	0.04
CCGT	24	23	0.041

3. Generated electricity calculation method

Equation (2) is used to calculate the generated electricity per year [13]:

$$Et = P \times FLH \quad (2)$$

Figure 2 reveals the block diagram of the energy model. The main components of the model are classified into four categories:

Power generation technologies: fixed tilted PV, installed PV on the rooftops, PV single-axis tracking, hydropower plant (both kinds of river and dam), wind power plant, CSP, geothermal and, power plants based on biomass and waste recycling. Fossil power generation technologies and nuclear power plants are also conceived in the energy system. In the early stages of transmission, gas turbines use natural gas as their conventional way. By the progress of the transmission process, these turbines are fed by biomethane and synthetic natural gases obtained from renewable resources.

- Energy storage technologies: pumped hydraulic energy storage (PHES), batteries, adiabatic compressed air energy storage [40], thermal energy storage (TES), and conversion of power to gas storage (PtG). Energy-to-gas conversion technology comprises methanation, water electrolysis and, direct CO_2 trapping.
- The technology of power transmission: HVAC (heating, ventilation, and air conditioning). The length of transmission lines is evaluated based on the existing high voltage networks (400 and 230 kV) in Iran.
- Energy sector bridging communication technologies: power-to-gas conversion system (PtG), power-to-heat energy conversion system (PtH), and seawater reverse osmosis

desalination (SWRO). These technologies increase efficiency and flexibility, and reduce total costs by converting excess energy into valuable outputs.

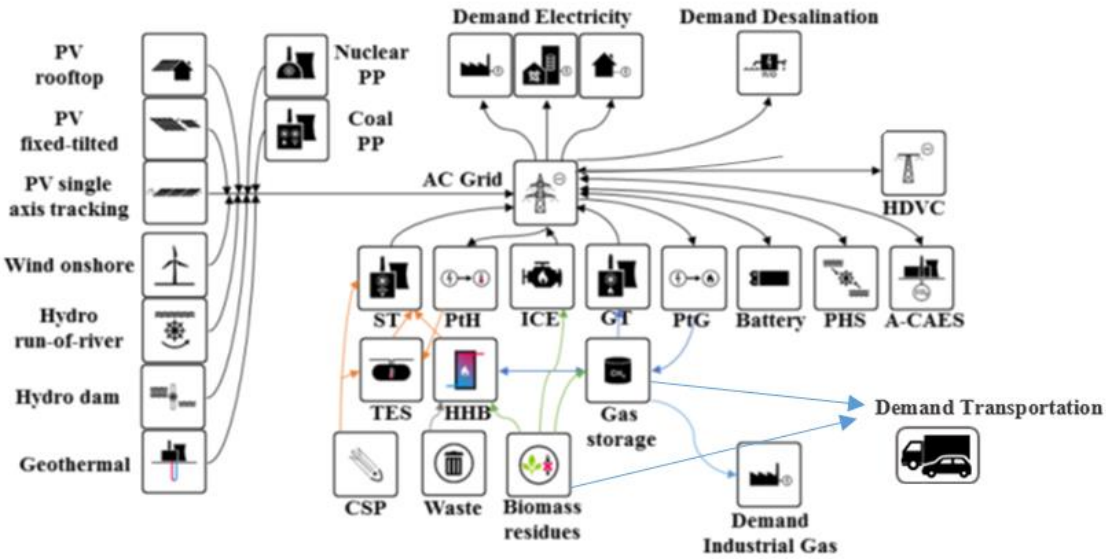


Figure 2. Diagram block of energy model components [41].

4. Results and discussion

4.1. Electricity generation

Figure 3 indicates the amount of electricity generated by energy-producing technologies from 2015 to 2050 according to the CSP scenario. Natural gas-based gas turbine power plants are the main technologies meeting the country's needs in 2015. After 2015, the only installed plants in the system will be combined cycle gas turbine power plants (CCGT) due to higher efficiency. Although the generated electricity by PV and wind systems increased, they play a very small role in generating electricity. Also the nuclear sector despite expensive costs has a noticeable share of electricity generation in the country's policy. However, the total electricity generation according to the integrated and combined-integrated scenarios is 1664 and 2362 TWh, respectively, by 2050. The share of electricity generation technologies is provided in Figure 4.

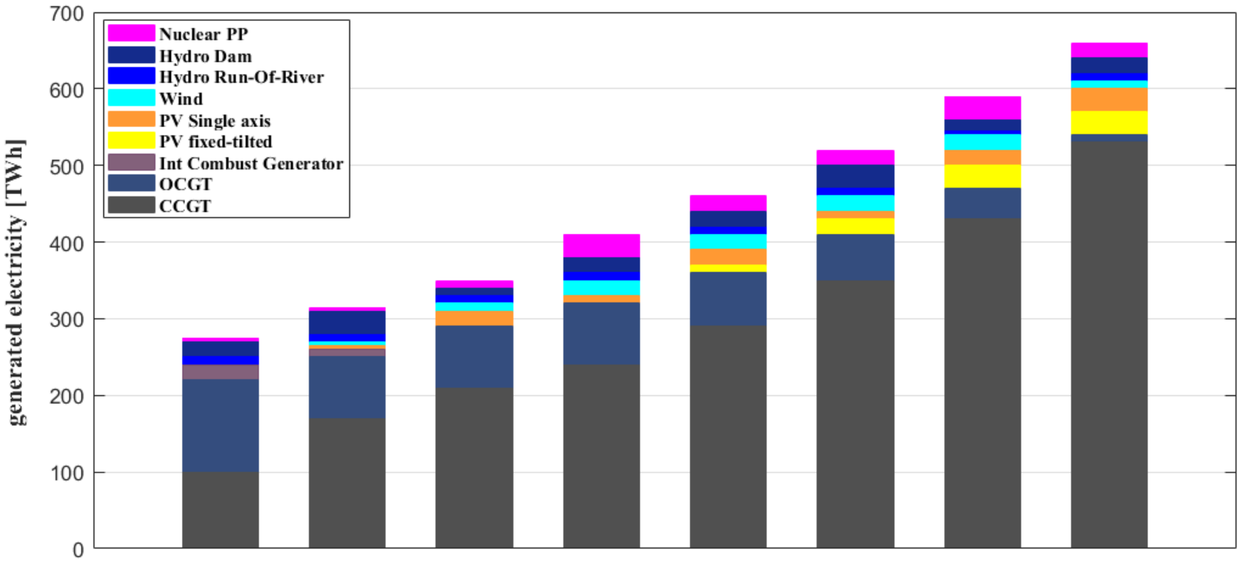


Figure 3. Share of different sectors of electricity generation from 2015 to 2050 according to the CSP scenario [2, 26].

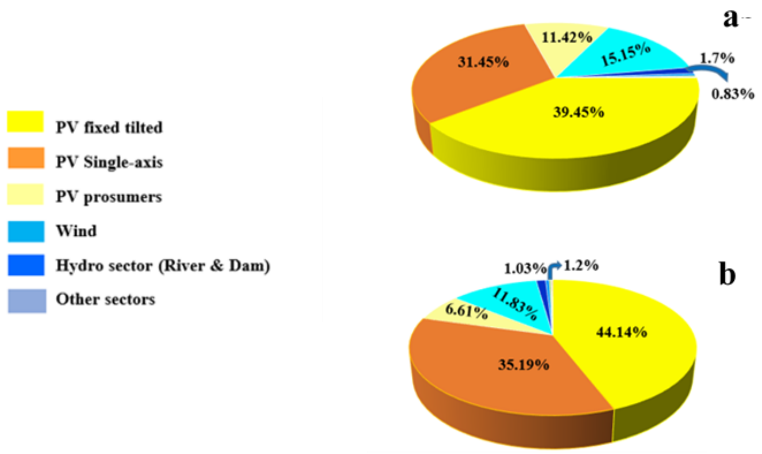


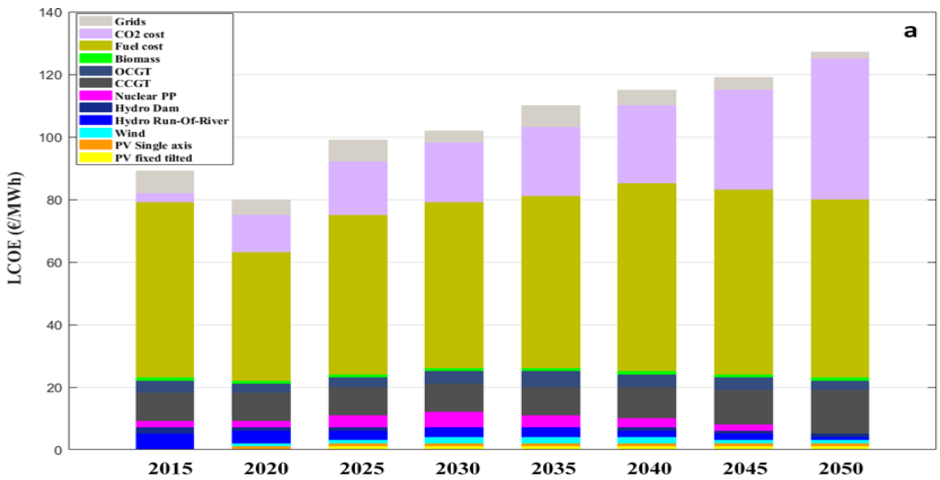
Figure 4. Share of different sectors of electricity generation from 2015 to 2050 according to the (a) integrated and (b) combined-integrated scenarios.

4.2. Installed capacity

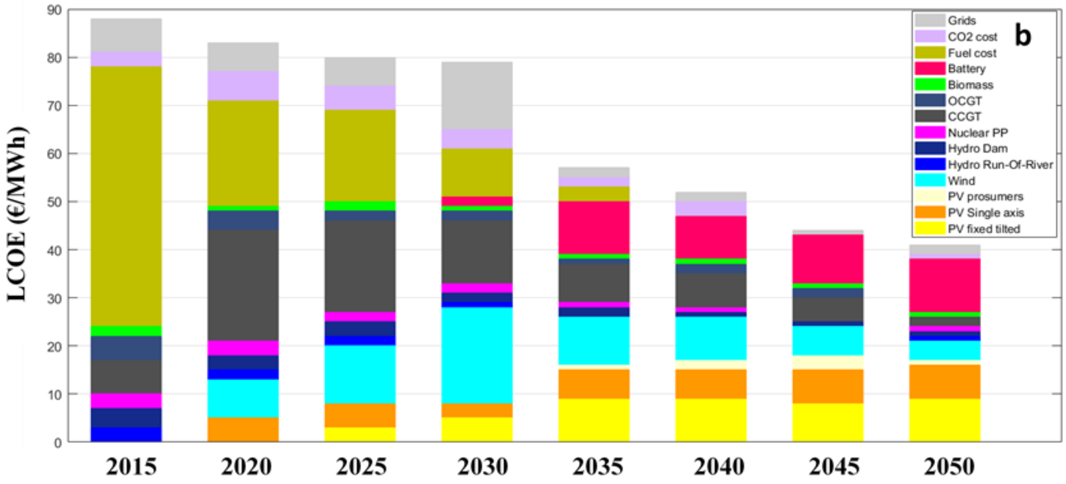
The installed capacity of different power plants from 2015 to 2050 for all scenarios has been illustrated in figure 5. The highest total installed capacity belongs to the combined-integrated scenario for all years compared to CPS and for 2050 compared to the integrated scenario. According to this figure, the CCGT technology has the highest installation rate in all years due to its higher efficiency than other production technologies for the CPS scenario. The OCGT installation capacity has declined over the years, while the capacity of photovoltaic and solar systems, as well as wind, has increased since 2025.

For the integrated scenario, in 2015, 83% of the installed capacity included fossil power plants. By employing more renewable energy, the installed capacity of solar PV has surpassed other capacities to reduce FLH fossil power plants, and replace the fossil plants that are phased out and meet the growing demand for electricity. By 2050, solar PV with a 70% share of the total installed capacity will be the prevailing electricity generation technology for being cost-effective than other technologies. There is a significant difference in capacities installed in the CSP and integrated scenario due to higher electricity demand in desalination and industrial gas sectors in the integrated scenario, which leads to increased energy storage.

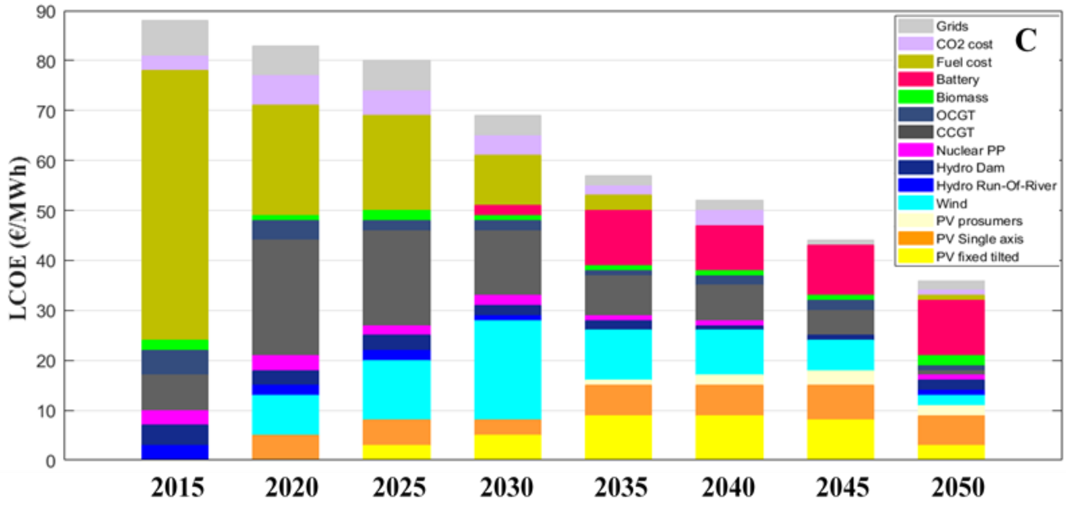
The amount of installed capacity for the combined-integrated scenario is also illustrated in Figure 5 (c). According to this chart, the amount of installed capacity in the combined-iIntegrated scenario has a similar pattern to the integration scenario, with the difference that the installed capacity in this scenario has increased by about 24%. This is due to the increased demand in the transportation sector. Most of this capacity is provided by the solar PV technologies, regarding its high performance and cost-competitive compared to other employed technologies. The more contribution of these systems results in much higher battery capacity. The wind plant installation capacity takes the second place after the solar PV technologies, which can produce a large amount of energy.



(a)



(b)



(c)

(a) Share of the energy system components for LCOE from 2015 to 2050 for CPS scenario. (b) Share of the energy system components for LCOE from 2015 to 2050 for integrated scenario. (c) Share of energy system components for LCOE from 2015 to 2050 for combined-integrated scenario.

The overall cost has declined from 41 €/MWh_{el} in the integration scenario in 2050 to 36 €/MWh_{el} in the combined scenario. The gradual reduction of the final cost in both of these scenarios is due to the rapid reduction in the price of these renewable resources, which has a significant impact on the final cost. In both charts, the fuel and CO_2 emission costs are reduced by increasing the capacity of renewable sources from 2015 to 2050. In line with the increase in the capacity of renewable sources, the use of batteries and their reserves will increase. However, the final cost is reduced due to the declining trend in the cost of using renewable resources between 2015 and 2050. The coupling of the transport sector into the integrated system will also reduce the final cost by up to 36 €/MWh_{el}, as it will increase the installation capacity of these resources.

Table 4 demonstrates share of the employed resources in energy production (MWhel) according to the two scenario, integrated and combined-integrated. According to this table, the PV fixed title has the most effect in energy production due to its high potential and capacity.

Table 4. Share of the employed resources in energy production (MWh_{el}).

scenarios	PV Fixed tiltec	PV Single-axi:	PV prosumer	Wind	Hydro Dam	Hydro Run-Of-River
Integrated	735	586	110	197	21	8
Combined-Integrated	784	625	227	301	43.9	11.6

5. Conclusion and policy implication

In the recent years, with the population growth in Iran, the demand for utilities such as electricity, water, and fuel has been rapidly increased, causing a rapid increase in pollution in the Iran's major cities. Transportation is an in-demand and costly sector as the fuel cost is constantly increasing. Therefore, employing renewable revenues would be the best alternative to the fuels, which could both decline the fuel costs and also the CO_2 release.

Several methods have been adopted to reduce pollution and the total costs such as renewable resources, which have attracted a lot of attention due to its efficiency. Among different proposed strategies, the integration scenario in which the most demanded sectors such as desalination and non-energetic industrial gas sectors are integrated into the power sector has attracted a lot of attention due to its high efficiency and cost-effectiveness comparing to other scenarios.

The goal of this work was to investigate the influence of merging the transportation sector into the integrated scenario. For this purpose, a model was employed, and the critical parameters were evaluated through optimization method for the CPS, integrated and combined-integrated scenarios by 2050. The ultimate results are listed as follow:

- The total electricity generation according to the integrated and combined- integrated scenarios is 1664 and 2362 TWh, respectively, by 2050.
- The total installed capacity of renewable revenues to fulfill the total energy demand had a 32% growth for the combined-integrated scenario from the integrated scenario. The higher installation capacity also increased the battery capacity and storage output as it generated more energy for the employed sectors. Merging the transportation sector into the integrated section also increased the total generated electricity from 1664 from the integrated scenario to 2414 TWh. It was also revealed that the share of energy generation technologies, specially the solar PV such as PV fixed tilted and PV Single-axis, was significantly increased from 39.45, 31.45 to 44.14, 35.19%, respectively. Also the total share of solar PV was increased from 82% to 85% in the combined-integrated scenario.
- According to the results obtained, the lowest LCOE of 36 €/MWh was obtained through the combined-integrated scenario, in which the transportation sector was merged into the integrated system. This happened for two reasons. First of all, as the transportation sector was merged into this sector, the total generated electricity was increased as this sector is a huge consumer of energy. Secondly, in addition to the environmental friendliness of these technologies that reduce pollution and fuel costs as their installed capacity is increased significantly by 2050 due to the higher energy demand, the severe price drop of power generation technologies also makes them affordable and a proper alternative.

6. Nomenclature

CPS	Current policy scenario
E_t	Annually electricity generated (TWh)
F_t	Cost of fuel (€/MWh) in the year (t)
I_t	Investment cost (€/kWh) in the year (t)
KWh	Kilowatt per hour
LCOE	Equalized cost of energy (€/kWh)
M_t	Cost of operation, supply, and maintenance (€/kWh) in the year (t)
n	Economic life of power plant according (year)
P	Maximum capacity of plant Megawatt (MW).
r	Discount rate (%)
t	Years
TWh	Terawatt per hour
TWh_{el}	Terawatt per hour of electricity
TWh_{th}	Terawatt per hour of thermal

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