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Research Article

Cost and Environmental Pollution Reduction Based on Scheduling of Power Plants and Plug-in Hybrid Electric Vehicles

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ABSTRACT

There has been a global effort to reduce the amount of greenhouse gas emissions. In an electric resource scheduling, emission dispatch and load economic dispatch problems should be considered. Using renewable energy resources (RESs), especially wind and solar, can be effective in cutting back emissions associated with power system. Further, the application of electric vehicles (EV) capable of being connected to power grid reduces the pollution level in the transportation sector. This paper investigates a resource scheduling with uncertain behavior of RESs and EVs by considering the penalty factors of emission for each conventional power plant in Hormozgan province of Iran for a 10-year period from 2016 to 2026. In this study, combined-cycle and thermal units are also taken into account. The CPLEX Solver is utilized for resource scheduling problem in GAMS. For combined-cycle power plants, ramp rate constraints are also included. To investigate the impact of uncertainties, different scenarios are considered. The obtained results demonstrate that Hormozgan province has a decent potential of utilizing RESs and EVs to achieve pollution reduction and optimal cost.

1. INTRODUCTION

In recent years, global warming and pollution have become one of the main environmental issues worldwide [1]. The power industry produces 40 % gas emission of global greenhouse per year, whereas the transportation industry is recognized to be responsible for 24 % of universal emission [2]. From the environmental approach, thermal units are the most polluting power plants, especially when their fuel is coal [3].

According to the rising concern over global climate change, Green House Gas (GHG) emission problem, policymakers are promoting the integration of renewable energy sources [5]. Further to that, as the worldwide energy reserves are rapidly depleted, renewable energy resources should be substituted for oil and gas, even for the transportation sector where the use of electric vehicles and electric vehicles (EVs) must be raised [6].

The use of EVs with vehicle-to-grid (VG) capability is another solution to decrease GHG emissions in the transportation sector [5]. Therefore, these EVs can be used as loads, energy resources, and energy storage units. An investigation conducted in the national renewable energy laboratory shows that the application of EVs can significantly reduce CO_2 emissions [7]. Although renewable energy resources (RESs) are cheap, they often exhibit uncertain behavior [5]. Therefore, resource scheduling in the grid with RESs and EVs is an important problem. In this new paradigm, the main objective should be not only to meet the power demand by operating power generators with the minimum cost while satisfying the constraints, but also to minimize their GHG emissions [8].

In several resource scheduling studies, the Particle Swarm Optimization (PSO) algorithms are employed to calculate the unit's emission contribution [1], [2], [5]. In [1], a combined economic emission dispatch was employed to investigate the effectiveness of using EVs and renewable energy sources from different aspects. Ref. [5] proposed scheduling for the smart grid with RESs and compared the emissions in different states. For minimizing the expected cost and emissions of the unit commitment schedule for the set of scenarios, an optimization algorithm was used. In [2], the study was the same as [5], but the emission rate was noticed more, and scheduling for charging and discharging of the EVs was described in more detail. The optimal energy scheduling for residential smart grid applied with centralized RESs was discussed in [9]. In [11], the role of RESs in environmental protection and CO_2 justification through solar cookers, dryer, improved cookstoves, biofuel, and water heaters was debated. In [12], an economical and environmental comparison study of conventional, hybrid, and EV was carried out. In [13], historic developments of urbanization, thermal power generation, and GHG emissions were investigated. Zhu Chuanyong and et al. [14] and K. Alrafea and et al. [15] studied the emissions of coal-fired power plants. There has not been any investigation on resource scheduling with EVs, RESs and combined-cycle power plants by considering penalty factor for emissions. Other recent related investigations about scheduling and emission were presented in [16-18]; however, there is no comprehensive scientific report for the effectiveness coefficient of solar-wind-EVs penetration according to traditional power plant on emission improvement in dual peak load curve.

According to the National Weather Service (NWS) report, the average ambient temperature of Iran in 2014 was one degree higher than the average ambient temperature in 2013.

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Additionally, the pollution indicator was increased compared to the previous year [19]. Therefore, increasing pollution is one of the significant environmental issues in Iran, too.

The considered region for this research is Hormozgan province. Iran has significant reserves of natural gas and oil [20], [21]. Hence, naturally, almost total production of energy (99 %) comes from oil and gas [22]. On the other hand, Iran, particularly in its southern part, has a great potential for solar energy. Moreover, the south offshore has a suitable wind speed, which can be appropriate for applying energy convertor system wind turbines [23]. Wind energy harvesting is expected to rise in the future. The number of vehicles, which is used for this study, is logical according to Hormozgan's population. The solar farm size and the wind farm size are estimated. It is assumed that the wind farm and the solar farm are located on an energy convertor system and in Bandar-Abbas, respectively. The resource scheduling is presented under uncertainty to investigate the cycle of RESs and EVs.

In this paper, to take into account the uncertainty, a set of one thousand scenarios for load demand, solar radiation, wind speed, and EVs regime are considered and simulated in GAMS; finally, the probability of each scenario is estimated. One of the output parameters of the algorithm is the power of each unit on a random day. The charging and discharging modes of vehicles, which are placed in parking lots, are considered for different hours. The effect of increasing the penetration coefficient of EVs, solar and wind resources is discussed for a 10-year period from 2016 to 2026. Three penetration levels for solar, wind, and EVs including zero, low, and high are considered for Hormozgan province.

The main objective of this paper is to reduce cost and environmental pollution based on the scheduling of power plants and EVs. In this regard, three different cases are considered, and all results are analyzed for each case. This problem is solved in low penetration of EV and RES, high penetration of EV and RES, and absence of EV and RES.

In Section (2), the problem formulation is proposed, Section (3) describes the methodology of this research, Section (4) describes result and discussion, and the final section presents the concluding remarks.

2. PROBLEM FORMULATION

Due to the uncertain behavior of resources, EVs, and load demand, the normal probability distribution is estimated to present the nature of uncertainty. For proving the effect of conventional power plants on air pollution, RESs such as solar energy and wind sources with traditional power plants such as combined-cycle ones are proposed.

According to uncertain solar radiation, the output power of PV panels can be calculated as in (1) [24].

$$P_{PV} = F_{PV} P_{PV-r} \frac{G}{G_{STC}} [1 + \alpha_T (T - T_{STC})] \tag{1}$$

The output power of solar panels depends on the rated output power of PV (P_{PV-r}), de-rating factor considering wiring, shading, (F_{PV-r}), solar radiation in current time (G), and the solar radiation in the standard test condition (G_{STC}). To calculate the output power of solar radiation, α_{PV}, F_{PV}, and α_T are proposed to be 0.8, 0.8, and -0.48, respectively.

Wind turbines are more complex because of their mechanical nature. The wind power is related to the output power of wind turbine (P_{wt-r}), the cut-in and cut-out wind speeds (V_{ci}, V_{co}), the wind speed (V_w), and the rated wind speed (V_r) [23] and [26].

$$\begin{cases} P_{wind} = 0, & \text{if } v_w < v_{ci} \text{ or } v_w > v_{co} \\ P_{wind} = P_{wt-r} \dfrac{v_w - v_{ci}}{v_r - v_{ci}}, & \text{if } v_{ci} \le v_w \le v_r \\ P_{wind} = 0, & \text{if } v_r \le v_w \le v_{co} \end{cases} \tag{2}$$

The wind and solar energies exclusively may not meet all the load demand; therefore, the use of some conventional units is often required. The pollution rate of combined cycle power plants is lower than other types of traditional plants [11], [25].

In the transportation sector, current vehicles cause pollution. The amount of carbon dioxide released is proportional to the amount of carbon in the fuel. The quantity of the fuel burned is also pretty important [26]. As a practical point, the combined-cycle power plants must be included into the investigation as a critical source of pollution. However, some thermal power plants are discussed and formulated [1], [2], and [5].

A. Saber et al. [2], [5] and Yuan Wu et al. [9] did not consider the pollution factor, because resource scheduling according to cost reduction was more important than scheduling according to pollution level minimization for them. The emission penalty for each unit is indicated by ef_i and calculated as in (3) [23].

$$ef_i = \frac{a_i P_i^{max2} + b_i P_i^{max} + c_i}{\alpha_i P_i^{max2} + \beta_i P_i^{max} + \gamma_i} \tag{3}$$

Ramp rate constraints are not defined for thermal units; therefore, other papers did not investigate them. However, in this paper, for combined-cycle power plants, ramp rate up and down constraints are considered. These constraints are discussed in (8) and (9). All constraints and functions are defined as follows:

$$emission_i(P_i^s(t)) = \alpha_i + \beta_i(P_i^s(t)) + \gamma_i(P_i^s(t))^2 \tag{4}$$

$$emission_i(L_i, e_i) = L_i \times e_i \tag{5}$$

$$fc_i(P_i^s(t)) = a_i + b_i P_i^s(t) + c_i(P_i^s(t))^2 \tag{6}$$

$$\sum_{i=1}^{N} P_i^s(t) + P_{PV}^s(t) + P_{wind}^s(t) + \sum_{j=1}^{NV2G} P_{EV}^s(t) = D^s(t) \tag{7}$$

If EVs are in the charged mode,

$$\sum_{i=1}^{N} P_i^s(t) + P_{PV}^s(t) + P_{Wind}^s(t) = D^s(t) + \sum_{j=1}^{NV2G} P_{EV}^s(t) \tag{8}$$

EVs are in the discharged mode,

$$P_i^s(t) \le P_i^s(t-1) + RU_i \tag{9}$$

$$P_i^s(t) \ge P_i^S(t-1) - RD_i \tag{10}$$

$$P_i^{min} \le P_i^s(t) \le P_i^{max} \tag{11}$$

$$\Psi_{min} P_V \le P_V^s(t) \le \Psi_{max} P_V \tag{12}$$

$$n \times E_{min} \le E_t^s \le n \times E_{max} \tag{13}$$

$$E^s(t) = N \times E_0 + \left(R \times P^s_{ch}(t)\right) - \left(P^s_{dch}(t)/R\right), \quad \text{if} \quad t=t1 \tag{14}$$

$$E^s(t) = E^s(t-1) + \left(R \times P^s_{ch}(t)\right) - \left(P^s_{dch}(t)/R\right), \quad \text{if} \quad t>t1 \tag{15}$$

$$\psi_{min} \times E_{max} \times nv2g^s(t) \times i1_{ch}(t) \le P^s_{ch}(t) \le \psi_{max} \times E_{max} \times nv2g^s(t) \times i1_{ch}(t) \tag{16}$$

$$\psi_{min} \times E_{max} \times nv2g^s(t) \times i1_{dch}(t) \le P^s_{dch}(t) \le \psi_{max} \times E_{max} \times nv2g^s(t) \times i1_{dch}(t) \tag{17}$$

$$P^s_{dch}(t) - P^s_{ch}(t) = P^s_{EV}(t) \tag{18}$$

As mentioned before, the main purpose of such a resource scheduling problem is to minimize the GHG emission and generation costs simultaneously. This objective can be mathematically described by (19).

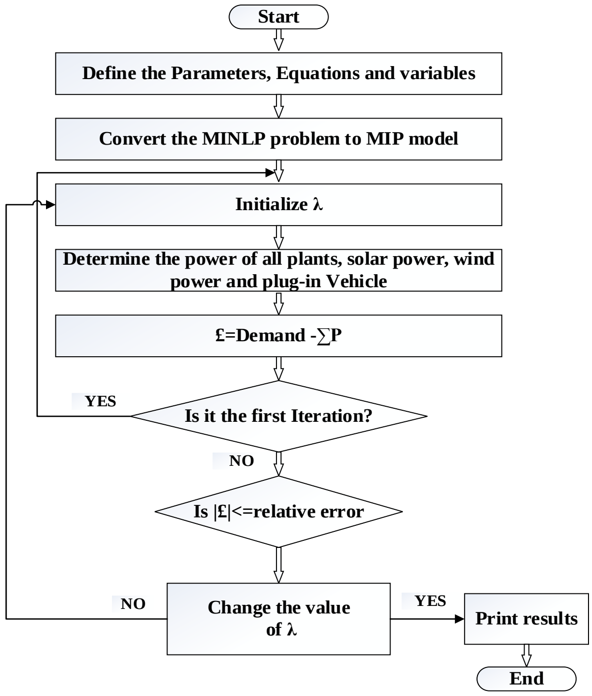
$$\text{Min}\left\{\sum_{s\in S}\sum_{i=1}^{N}\sum_{t=1}^{H}\left[w_c\left(fc_i(P_i^s(t))\right) + sc_i\left(1 - I_i(t-1)\right)\right] + \left[w_e\left(ef_i(emission_i(p_i^s(t)))\right)\right]\right\} \tag{19}$$

3. METHODOLOGY

The behavior of EVs, solar and wind resources, and the value of load demand are under uncertainty. For instance, both wind speed and solar radiation are uncontrollable. The load demand is also not constant during the day, and the number of EVs located in parking lots is not deterministic. This makes resource scheduling a complex problem. To investigate uncertainties, 1000 different scenarios for both solar-wind-EV resources and demand are observed. These scenarios are defined based on normal probability distribution of the estimated values for a random day. These scenarios are assumed with stated probabilities to analyze random behavior of demand, solar radiation, wind speed, and EVs. Normal distribution with suitable mean and standard deviation values based on estimated data and predictable data is used to investigate the uncertainties. By running the functions **(**For s: 1: 1000;) and (Psolar(s, :) = Psolar + randn × Psolar × 0.1**)** in MATLAB, different thousand scenarios for power of solar farm are established.

The proposed algorithm for scheduling is shown in Figure 1. To run the program by GAMS, the nonlinear functions should be broken into numerous linear functions. An iterative method is used for optimization. As is shown in Figure 1, in the first step, the equations, variables, and parameters should be defined in GAMS software. The nonlinear functions must be converted to linear ones to reduce the time of calculating the results. In the third step, λ value should be initialized. Next, according to the amount of λ, the power of all resources and EVs should be calculated. Then, the difference between load demand and sum of the produced power should be computed. If this value is smaller than the relation error and the iteration is more than one, the results are achieved. Otherwise, the value of λ should be changed or the iteration method must be done again.

In this analysis, the operation costs of resource scheduling, as well as a punishment factor for releasing GHG by conventional units, are considered. According to the multi-objective function, by considering penalty factor in emissions, the power of conventional power plants decreased to minimize the pollution and cost. The proposed case study is Hormozgan province with one and a half million inhabitants in an area of 70,697 km^2.



The GHG released by power plants and conventional vehicles includes several gases such as NO_X, SO_2, CH_4, and CO_2. The amount of released CO_2 is much more than the other gases; therefore, the amount of released dioxide carbon is illustrated as GHG emission. In Hormozgan, there are three power plants; two of them are combined cycle power plants, while another is thermal one. The size of plant and its capacity are given in Table 1. A summary of the generator emission coefficients is given in Table 2 [27]. In this investigation, the average solar radiation data and average wind speed on a random day, as shown in Figures 3 and 4, are used [28], [29]. Considering the uncertainties of wind and solar resources, 1000 scenarios are defined.

Table 1. Plant size and capacity of 3-Unit system.

	Termal unit	**Combined-cycle**	**Combined-cycle**
	Unit 1	Unit 2	Unit 3
P_{Max} (MW)	1200	990	660

Table 2. Generator emission coefficients.

	α_i **(Ton.h^{-1})**	β_i **(Ton.MWh^{-1})**	γ_i **(Ton.MW^{-2}h)**
Unit 1	30.039	-0.2444	0.00502
Unit 2	10.339	-0.40695	0.00312
Unit 3	20.039	-0.49695	0.00409

Since the total number of clients in the region is almost 485000, this is a logical assumption to consider the number of EVs which includes approximately 240000 units in 2026 [30]. Data of Figure 3, 4 are given based on real information. Each

EV includes a 15 kWh battery. The load demand curve on a random day is depicted in Figure 5. Data of Tables 1, 2 and Figure 5 are given based on real data of Hormozgan regional electric company, which were published through the 2015 annual report. It must be noted that Hormozgan load curve has two peaks. This is due to tropical weather of Hormozgan. Normally, people come back home at 12:00 am and rest for three or four hours while air condition is on. Then, the second working time starts at 4:00pm. In particular, nights continue up to 1:00am or 2:00am. This is the reason for the dual peak load curve.

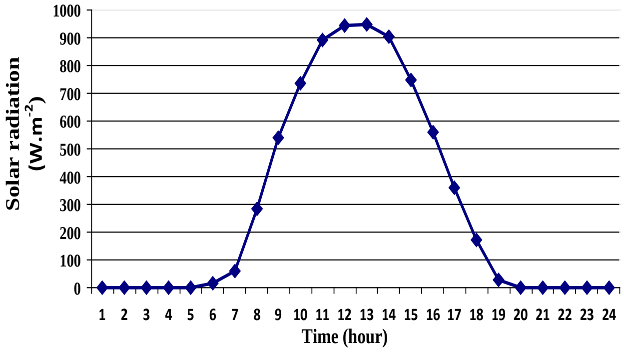


Figure 2. Average solar radiation for a random day of Hormozgan province.

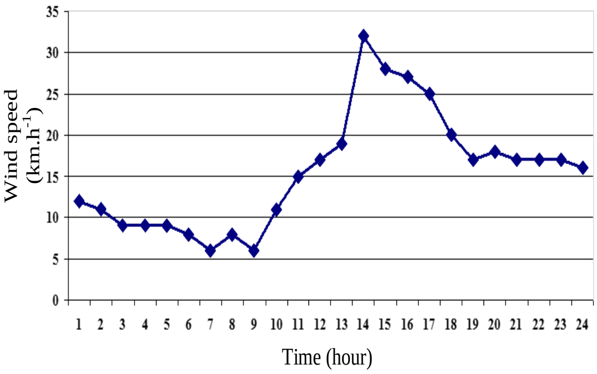


Figure 1. Average wind speed for a random day of Hormozgan province.

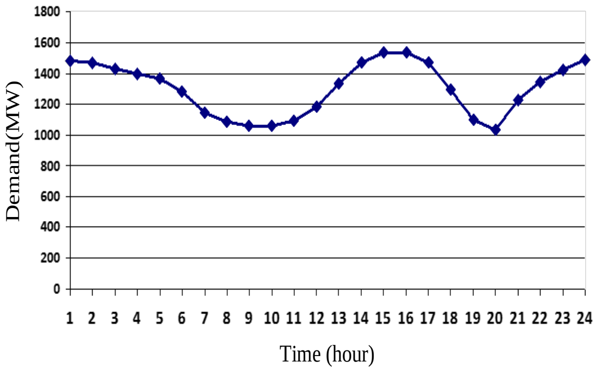


Figure 2. Load demand curve for a random day.

4. RESULTS AND DISCUSSION

Simulation of an independent system operator for the three-unit system with 240000 registered EVs is carried out in this investigation. They are conceptual scenarios; however, there are several logical reasons for the selection of the suggested scenarios:

1. These scenarios are designed based on actual specifications of Hormozgan province such as population, power plant capacity, customer power consumption, and so on.
2. There are some targets for Hormozgan province for the penetration of wind and solar energy. These targets are considered in suggested scenarios.
3. These scenarios introduce a logical approach to penetration of wind power, solar energy, and EVs.

Firstly, the simulation is performed without any EVs, solar and wind sources for 2016. Secondly, the solar farm, wind farm, and EVs are proposed. The solar farm and wind farm size are assumed to be 20 MW and 12 MW for 2020. In this case, just 120000 EVs, which can be connected to the grid as loads and sources, are analyzed. Finally, the penetration coefficient of renewable energy sources and EVs gets promoted. The solar farm size is increased to 40 MW. The wind farm size is estimated to be 25.5 MW for 2026. In this case, the EV's number is assumed to be 240,000. The results of each case are presented as follows:

Case 1: Scheduling without EVs and RESs

Resource scheduling problem is solved by only taking into account the three conventional units. In Hormozgan, there is no renewable source and EV. The obtained results for the best state are presented in Table 3.

The total emission and total running cost in the optimal state are 34,160.303 Tons and 62,668.760 $, respectively. In order to calculate the emission of the transportation system, the effect of conventional vehicles should be investigated. Based on an average distance of about 12000 miles driven by each vehicle in a year and an average emission from each vehicle being 1.2 l b/mile, the emissions from total 240,000 vehicles are 1,567,503 Tons.

Case 2: Resource scheduling with low penetration of RESs and EVs

In this case, 120,000 EVs are proposed for Hormozgan province for 2021. In addition, 240000-120000=120,000 mechanical vehicles are assumed. The charging regime of EVs is under uncertainty. These 120000 vehicles are not connected to the grid instantaneously. Some vehicles are in the charged or discharged mode, and the others may be in the ideal state. The number of vehicles, placed in parking lots for different hours, is estimated, and 1000 scenarios for the assumed numbers are defined. The solar farm size is proposed to be 20 MW. The wind farm size is considered to be 12 MW. The obtained results of optimal resource scheduling are presented in Table 4.

The total emission and cost are 41, 327.32 tons and 681, 250.6 $, respectively. The cost for a random day and the emission are 1, 792.9 $ and 1,015.5 tons, experiencing an reduction. This reduction was calculated without considering the emissions of mechanical vehicles. The emissions, which are released from 120,000 mechanical vehicles, are 783, 751.68 tons in a year. In comparison with the last case, by considering RESs and EVs, the decreased amount of emissions is 1, 154, 409.18 tons. In other words, the amount of cost and emissions in the optimal scenario decreased by 1.56 % and 9 %, respectively.

Case 3: Resource scheduling with high penetration of RESs and EVs

In this case, all the vehicles are considered as EVs and there is no conventional vehicle. The proposed wind farm size is 25.5 MW. It is assumed that the solar farm size increases to 40 MW. The obtained results of optimal resource scheduling are presented in Table 5. The total cost and emissions are 682465.06 $ and 40,297.7 per day, respectively. Both decreased more than the second case. Therefore, according to the results, it is obvious that if the penetration coefficients of renewable sources and EVs rise, it will be better for clients, suppliers, and even for the environment. In comparison with Case 2, the cost and emissions decreased by 2.30 % and 8.71 %; in addition, in comparison with Case 1, cost and emissions in the optimal scenario reduced by 3.79 % and 17 %, respectively.

According to the above table, the EVs at peak-load hours are in the discharged mode. They are charged at off-peak hours like 8, 9, 10, etc. They try to be beneficial for grid and reduce the cost and emissions. In this case, there are no mechanical vehicles and all vehicles are plug-in ones. Therefore, the emission rate is significantly lower than other cases. When comparing Cases 3 and 2, it is shown that if the solar farm size and wind farm size are less than the 20 MW rise and all of the vehicles are plug-in vehicles, the annual costs and emissions will be reduced to 359, 722.1 $ and 1, 157, 555.6 tons, respectively.

The emission value without considering the pollution of conventional vehicles for different cases is shown in Figure 5. At 1:00, which is the time for discharging, the emission amount is lower than other states. In comparison with the first case, a reduction in value is 883.9 tons. From 1:00 to 5:00, the difference between the second and third cases decreases and, at 6:00, the curves of these two cases converge to each other. In the second case, the 7:00 is the time for charging; therefore, the emission value grows and gets higher than the amount of the first case. Times 9:00, 10:00, and 11:00 are charging hours for the second and third cases. For the charge hours, the emission rates of the second and third cases are more than the emission values of the first case. For charging, more power should be generated by other resources; therefore, the emission seems to increase at charging hours. From 9:00 to 11:00, the emission curves of the second and third cases converge to each other. The solar and wind farm size in the second case is smaller than that in the third case; therefore, to supply the power, which corresponds to the demand, more hours for charging the batteries are needed. For instance, according to Figure 4, 1:00, 2:00, 4:00, 14:00, 15:00, 16:00, and 17:00 are the peak-load hours. From 13:00 to 17:00, all three curves diverge from each other.

According to Figures 6 and 7, at peak-load hours, EVs are in the discharged mode, which is the reason for a large difference among the cases. In the second case, 1:00, 14:00, 15:00, 16:00, 17:00, and 24:00 are the discharging hours. Therefore, before 16:00, the emission amount of the second case is smaller than others. However, from 17:00 to 18:00, the emission in the third case is the smallest one. 19:00 and 20:00 are the charging hours for charging more vehicles which require more power; thus, the plants supply more power and cause more emission. From 21:00 to 23:00, the curves of the second and third cases get close to each other; however, from 23:00 to 24:00, they differ from each other and the emission rate of the third case decreases significantly.

Table 3. Schedule and dispatch of 3-unit system without considering RESs and EVs in 2016.

Time (Hour)	Unit 1 (MW)	Unit 2 (MW)	Unit 3 (MW)	*P*solar (MW)	*P*wind (MW)	Demand (MW)	Summary of important points
H1	480	383.5	404	0	0	1,267.5	Expected cost=683,043.530 $
H2	480	373.24	404	0	0	1,257.24	
H3	480	340.24	404	0	0	1,224.468	
H4	480	318	397.89	0	0	1,195.899	
H5	480	318	369.12	0	0	1,167.125	
H6	480	318	299.310	0	0	1,097.32	
H7	377.724	318	286	0	0	981.724	Expected emission=42,342.87 Tons
H8	324.125	318	286	0	0	928.125	
H9	300.919	318	286	0	0	904.91	
H10	304.825	318	286	0	0	908.8	
H11	330.104	318	286	0	0	934.10	
H12	409.677	318	286	0	0	1,013.677	
H13	480	318	344.326	0	0	1,142.326	
H14	599.702	486	404	0	0	1,489.702	
H15	480	464.41	404	0	0	1,348.419	Emission for optimal scenario=34,160.303 Tons
H16	480	463.30	404	0	0	1,353.032	
H17	480	410.063	404	0	0	1,294.063	
H18	480	318	404	0	0	1,137.294	
H19	362.522	318	286	0	0	966.52	
H20	304.724	318	286	0	0	908.724	
H21	475.344	318	286	0	0	1,097.34	
H22	480	318	387.423	0	0	1,185.4	
H23	480	369.24	404	0	0	1,253.24	
H24	564.75	486	404	0	0	1,454.75	Number of scenarios=1000

Table 4. Schedule and dispatch of 3-unit system with RESs and EVs in 2026.

Time (Hour)	Unit1 (MW)	Unit 2 (MW)	Unit 3 (MW)	P_{solar} (MW)	P_{wind} (MW)	P_{EV} (MW)	Summary of important points
H1	300	424.7	404	0	9.31	129.4	
H2	359.02	486	404	0	8.22	0	Expected cost=681,250.6 $, expected
H3	328.4	486	404	0	6.02	0	
H4	300	458.8	404	0	6.02	0	
H5	300	457	404	0	6.02	0	
H6	300	388.13	404	0.24	4.93	0	
H7	300	360.3	404	0.961	2.73	-86.11	Emission=41,327.32 tons
H8	300	319.6	404	4.61	4.93	-105.03	
H9	300	318.8	404	8.82	2.73	-129.46	
H10	300	318	335.3	11.99	8.22	-64.7	
H11	300	318	354.7	14.54	11.508	-64.11	
H12	300	369.05	404	15.42	11.508	-86.7	
H13	300	411.3	404	15.47	11.508	0	
H14	429.5	486.0	404	14.77	11.508	143.8	Emission for optimal scenario=32,720.8 tons
H15	300	478.1	404	12.17	11.75	154.14	
H16	407.6	486.00	404	9.12	11.83	46.2	
H17	339.9	486	404	5.9	12	46.2	
H18	300	418.4	404	2.82	12	0	
H19	300	318	404	0.48	12	-67.967	
H20	300	318	404	0	12	-125.2	
H21	300	363.3	404	0	12	0	
H22	300	469.4	404	0	12	0	
H23	351.2	486	404	0	12	0	Cost for optimal scenario=61,715.06 $
H24	414.02	486	404	0	12	138.7	

Table 5. Schedule and dispatch with larger RESs and 240000 EVs in 2026.

Time (Hour)	Unit 1 (MW)	Unit 2 (MW)	Unit 3 (MW)	P_{solar} (MW)	P_{wind} (MW)	P_{EV} (MW)	Summary of important points
H1	300	318	365.2	0	23.80	260.4	
H2	346.2	486	404	0	21	0	Expected cost=680,265.06 $
H3	319.06	486	404	0	15.4	0	
H4	300	476.4	404	0	15.4	0	
H5	300	447.7	404	0	15.4	0	
H6	300	380.1	404	0.52	12.6	0	Expected emissions=40,297.7 Tons
H7	300	318	354.6	2.061	7.001	0	
H8	300	318	404	9.88	12.6	-116.3	
H9	300	318	404	18.9	7.001	-142.9	
H10	300	318	374.3	25.7	21.004	-130.2	
H11	300	318	389.6	31.17	25.5	-130.2	
H12	300	318	337.1	33.51	25.5	0	Total cost for the optimal scenario=60,292.2 $
H13	300	379.6	404	33.15	25.5	0	
H14	480	486	466.5	31.65	25.5	0	
H15	432.3	486	404	26.09	25.5	0	
H16	339.4	486	404	19.56	25.5	104.04	
H17	300	465.2	404	12.64	25.5	86.7	
H18	300	401.7	404	6.04	25.5	0	
H19	300	374.7	404	1.048	25.5	-138.7	
H20	300	376.1	404	0	25.5	-196.8	
H21	300	349.8	404	0	25.5	0	
H22	300	455.9	404	0	25.5	0	
H23	337.7	486	411.4	0	25.5	0	Total emission for optimal scenario=31,864.9 Tons
H24	300	404.4	404	0	25.5	320.8	

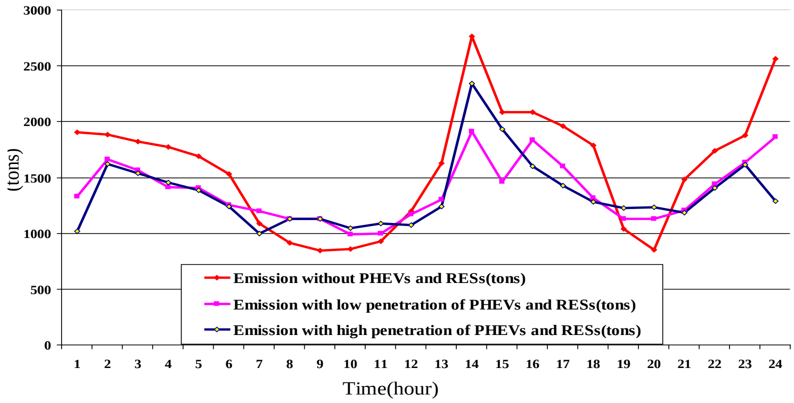


Figure 5. Emission rate in different cases for Hormozgan province.

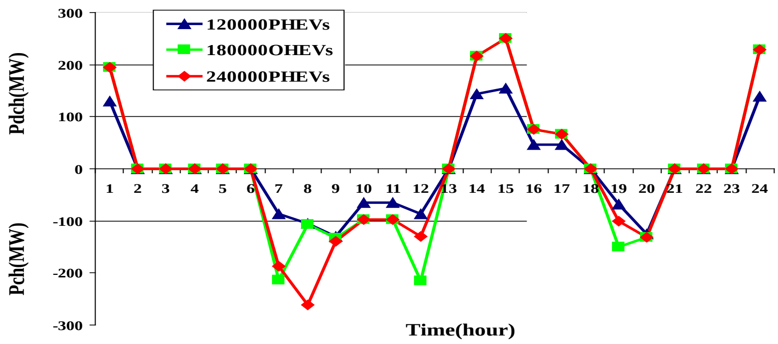


Figure 3. Values of charged and discharged power at different hours for different numbers of EVs.

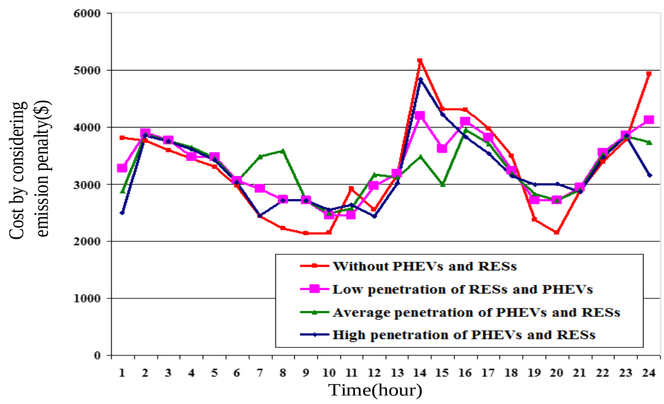


Figure 4. Cost by considering emission penalty for 4 different states.

In Figure 7, costs associated with the emission penalty factor are calculated. For three states including EVs, 120,000, 180,000, and 240,000 EVs are considered. The negative powers are for the discharged mode and the positive values are for the charged mode. The behaviors of all cases are similar to each other. To help suppliers and level the load demand curve, during peak-load hours, vehicles are discharged and, during off-peak load hours, EVs are charged. When the number of EVs grows, the values of discharged and charged power will increase.

In this paper, the objective is to minimize the cost and emissions simultaneously. Moreover, the penalty factor in polluting the weather is defined for each power plant. In Figure 8, costs are shown considering the pollution penalty factor. The worst case is the case without any PHEVs. Particularly at the peak load hours, the cost values are high. At charging hours such as 7:00 and 8:00, the value of the objective function rises. At discharging hours such as 1:00, 16:00, 17:00, and 24:00, the amounts of the objective are reduced. When the number of EVs grows, the expected amounts of emission and cost will decrease. However, the batteries of EVs should be charged at off-peak hours, and the cost considering the pollution penalty factors will rise and converge to the values of the first case. At the discharging hours like 1:00, 16:00, 17:00, and 24:00, the curves separate from each other. The third case which includes 240,000 EVs is the best and has the lowest cost.

5. CONCLUSIONS

In this research, increasing the penetration coefficients of using RESs and EVs to minimize the pollution level and costs in the southern part of Iran for a period of 10 years is studied. Resource scheduling for combined-cycle power plants, considering PV power and wind power, is performed. The uncertainties of load, solar energy, and wind speed are derived from prior statistics, heuristics, and experiences. The mode of EVs is presented for each hour. The uncertain behavior of EVs, solar radiation, and wind speed are investigated in 1000 scenarios. According to the proposed model, the charge times for EVs are at off-peak hours and are discharged at peak hours to help the supplier. Using the high penetration of RESs and EVs in 2026 for Hormozgan province, which has not any RESs and EVs in 2016, the cost and emission, considering the penalty factors, will decrease 3.79 % and 17 % per day, respectively. In the past research by PSO for the same sizes of wind farm, solar farm and 50000 EVs, the value of cost and emissions decreased by nearly 2.5 %. Therefore, it is proved that our results are logical and even better because of considering GHGs penalty factor.

6. ACKNOWLEDGEMENT

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NOMENCLATURE

Ψ_{min}/Ψ_{max}	Min/max state of charge
$I_i(t)$	Status of unit i at hour t
L_i	Length of travel in mile
RU_i, RD_i	Ramp rates of unit i
N_{EV}	Number of electric vehicles connected to the grid at time t
$\alpha_i, \beta_i, \gamma_i$	Emission coefficients
a_i, b_i, c_i	Fuel cost coefficients
H	Scheduling hours
S	Sets of scenario
N	Number of generators
R	Efficiency of the battery
$D^s(t)$	Load demand at time t considering scenarios
ef_i	Emission penalty factor of unit i
e_i	Per mile emission from vehicle
w_c, w_e	Weight factors for cost and emissions
$Sc_i()$	Start-up cost function of unit i
$Fc_i()$	Fuel cost function
emission $c_i()$	Emission function of unit i
$P_V(t)$	Capacity of the vehicle's battery at time t
$P^s_{solar}(t)$	Power from solar farm at time t considering scenario S
$P^s_{wind}(t)$	Power from wind farm at time t considering scenario S
$P^s_i(t)$	Power of unit i at time t considering scenario S
$P^s_{EV}(t)$	Power of the electric vehicle at time t considering scenario S
P^{max}_i/P^{min}_i	Max/Min output limit of unit i
$E^S(t)$	Total energy of all batteries at time t considering scenario s
E_F	Energy of battery at final hour of day
E_0	Primary energy of battery at starting time for scheduling
E_{min}, E_{max}	Maximum and minimum energy of battery
$P^s_{ch}(t)$	Charging power of all plug-in vehicles at time t considering scenario s
$P^s_{dch}(t)$	Discharging power of all plug-in vehicles at time t considering scenario s
P_{pv}	Output power of solar panel
P_{pv-r}	Rated output power of solar panel
G	Solar radiation in current time
G_{STC}	Solar radiation in standard test condition
v_w	Wind speed
v_r	Rated wind speed
v_{ci}	Cut-in wind speed
v_{co}	Cut-off wind speed
P_{wt-r}	Output power of wind turbine
Randn	A random number between 0 and 1 in normal probability distributed curve
N	Number of electric vehicles in each case
$n^s_{v2g}(t)$	Number of electric vehicles which are connected to the grid at time t considering scenario s
$i1_{ch}(t), i1_{dch}(t)$	Status of charging and discharging plug-in vehicles

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