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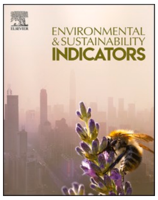

Monetization of policy costs and sustainability benefits associated with renewable energy in fossil fuel-rich countries (FFRCs)

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ABSTRACT

The electricity sector in Middle Eastern fossil fuel-rich countries (FFRCs) is characterised by the high electricity subsidies that result in a large price gap between Feed-in Tariffs (FiT) and consumer electricity prices, which inhibits electricity generation from renewable energy sources (RES-E). Meanwhile, RES-E development could reduce GHG emissions, allow fossil fuel to be sustainably commercialised or processed, and save water consumption in thermal power plants as an alternative solution in FFRCs. This study aimed at monetarizing those benefits and evaluating the performance of RES-E policy in a FFRCs framework by defining the benefit-cost ratio as a sustainability indicator, considering Iran as a case study scenario. Results showed that the FiT purchase price was seven times higher than the average consumer price of electricity, which implied a $US 345 million cost for renewable energy support during the 2009–2019 time window. Conversely, benefits from the use of renewable energy were estimated in $US 68 million. The resulting benefit-cost ratio of RES-E policy was found to be 0.2, which indicates that FiT policy was inefficient and only 20% of the expenditure could be recovered. To make RES-E policies more efficient and foster renewable energy deployment, limiting the electricity subsidy that widens the price gap between FiT and market price has been suggested. Furthermore, carbon price was identified to have high impact on the benefit-cost ratio indicator. A policy framework setting a 100 $US/t CO_2 would balance RES-E policy costs and benefits. This evidence could aid in decision-making for RES-E implementation in FFRCs.

1. Introduction

Conventional energy-intensive economy, paired with a fossil-based energy system, is the current paradigm for modern societies. This model reports a direct relationship between CO_2 emissions and economic expansion (Delgado and Herzog, 2012; Dogan et al., 2022; Hajko et al., 2018). Economic growth implies a proportional rise in energy demand that, when satisfied with the consumption of petroleum products, exacerbates environmental pollution. Despite this aspect is representative for any country, it is even more predominant for fossil-fuel-rich developing countries. Renewable energy sources (RES) have been recognized the only solution to match additional energy demand without penalizing the well-being of the environment (Radmehr et al., 2021). They can additionally contribute to increase fuel diversity, reduce energy price volatility, boost national economic security, lead to the electrification of rural areas, and create new jobs (Breitschopf et al., 2016; Dogan et al., 2021; Menegaki, 2008). In the last decades, RES deployment has been the center point on the strategy followed by developed countries to mitigate their environmental impact (Dogan et al., 2023). However, in a fossil-fuel rich developing countries (FFRCs) framework, such as Iran, a shift towards low carbon energy systems is much more challenging. Two principal barriers have been identified (Chua et al., 2011; SeetharamanMoorthy et al., 2019; Wei et al., 2010): (i) the access to vast and cheap fossil fuel resources and (ii) the existing subsidies for fossil fuels consumption that encourages the use of petroleum. These two factors, together with the inherent drawbacks of renewable energy –insufficient institutional capacity, high initial investment cost, and lack of measures for attracting investment–, makes these systems not competitive with fossil fuels (Choucri et al., 2010; Poudineh et al., 2018).

To overcome those barriers, renewable energy deployment requires favorable policy to close the wide price gap between Feed-in Tariff (FiT) and consumer electricity prices (Dyllick-Brenzinger and Finger, 2013).

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Nomenclature

B_{CO2}	Benefit of CO_2 reduction ($US)
B_{NG}	Benefit of avoided natural gas ($US)
B_W	Benefit of water saving ($US)
D	Demand curve
E	Final energy (kWh)
FFRCs	Fossil-fuel-rich countries
EU ETS	European Union Emission trading system (EU-ETS)
F	Primary energy (kcal)
FiT	Feed in Tariff ($US cent/kWh)
GWh	Gigawatt-hour
HR	Heat rate (kcal/kWh)
I_{CO2}	CO_2 intensity of power plants (kg/MWh)
I_W	Water intensity of power plants (m^3/MWh)
MC_{RE}	Marginal cost of renewable energy
MPC_A	Actual marginal private cost
MPC_S	Subsidized marginal private cost
MSC	Marginal social cost
NG	Natural gas
$P_{Consumer}$	Consumer price of electricity ($US cent/kWh)
P_{co2}	Social cost of carbon($/t$CO_2$)
P_{FiT}	Feed in tariff cost ($US cent/kWh)
P_{NG}	Price of natural gas ($US cent/$m^3$)
P_w	Price of industrial water ($US/$m^3$)
Q_{ff}	Fossil fuel electricity generation (kWh)
$Q_{RE,t}$	Renewable electricity generation (kWh)
$Rem_{RE,t}$	Renewable energy remuneration ($US)
RES	Renewable energy resources
RES-E	Electricity from renewable energy sources (kWh)
TB_{RE}	Total benefits of RES-S policy ($US)
TC_{RE}	Total cost of renewable energy policy ($US)
TE	Thermal efficiency (%)
V_{NG}	Volume of avoided natural gas (m^3)

The type of policy implemented, and the appropriateness of the selected indicators used to design the strategy, plays an important role in how efficient and robust those measures perform (Breitschopf et al., 2016; Dogan et al., 2021; Menegaki, 2008). Different policies, such as FiT policy and Renewable Portfolio Standards (RPS), could lead to a different renewable energy deployment (Carley, 2009; Choi et al., 2018b; Delmas and Montes-Sancho, 2011; Palmer and Burtraw, 2005). Those policy frameworks, that are based on an economical support for renewable energy, have a cost associated. The cost is expected to be elevated in FFRCs, since the price of fossil resources is generally very low.

Such a discouraging economic scenario for RES requires to consider all the sustainability benefits that these sources of energy encompass. Three key advantages can be identified.

1.1. Climate benefit: reduce the CO_2 emission national score

The benefits associated to CO_2 reduction from the use of renewable energy have been proven economically feasible in energy importer countries under a carbon emissions trading scheme, such as the European Union Emission Trading System (EU-ETS). The total net benefit ascribed to the avoided emissions from renewable energy use was estimated about 49 billion euro in Europe during 1998–2008 (Krozer, 2011). At a country level, in Spain it has been acknowledged that promoting renewable energy across different technologies could effectively reduce energy imports, thus resulting in RES-E implementation to offset deployment costs while maintaining the declining trend for national CO_2 emissions (Ortega-Izquierdo and Del Río, 2016; Ortega et al., 2013a). Conversely, most of the FFRCs in the Middle East are developing countries under the Kyoto Protocol (non-Annex I countries) and, therefore, do not have legally binding emissions reductions targets. However, this situation might shift in the future, and contribution for climate change mitigation via emissions reduction from FFRCs could be needed. This potential scenario makes attractive to measure the economic benefits of CO_2 emission reductions that could be achieved under a carbon price framework in FFRCs.

1.2. Increased natural gas availability for exports or utilization as feedstock in downstream industries

Natural gas (NG) is an alternative energy carrier that generates fewer carbon emission and air pollutants than coal or petroleum products while producing an equal amount of energy. For that reason, NG has been considered to take over the important role of crude oil in the economic growth process (Balsalobre-Lorente et al., 2019). This fact makes NG an important economic asset for those producer countries. Renewable energy implementation in FFRCs could liberate NG from energy generation and enable its use for other purposes, such as entering the international market or being converted into value-added products by downstream industry (Fattouh et al., 2018). This would add significant value to national economy in FFRCs, and help diversifying national industry and revenues (Hvidt, 2013). However, the high availability and low price of NG makes electricity produced in NG thermal power plants much cheaper than renewable electricity.

1.3. Reduced water demand in water stressed countries

The water-energy nexus is a recent scientific subject of discussion (Delgado and Herzog, 2012; Dogan et al., 2022; Hajko et al., 2018). Water is also essential for food production and it has been identified as a main risk factor for a secure electricity generation (Kablouti, 2015; Rodriguez et al., 2013). Non-renewable electricity production requires high amounts of water. It is used to extract and generate energy, refine, and process fuels (Nihalani and Mishra, 2020). Conventional thermal power plants have high water demands to operate cooling systems. The reported consumption ranges between 8.7 and 3.7 m^3 water per MWh generated depending on the water source (Nihalani and Mishra, 2020) while water footprints of renewable energies are much lower, such as wind energy (negligible) and solar power (1.0 m^3/MWh) (Gerbens-Leenes et al., 2008). The water access risk is more prominent in water stressed areas with also high energy demand like FFRCs from Middle East (Delgado and Herzog, 2012; Dogan et al., 2022; Hajko et al., 2018).

The described benefits are generally overlooked from an economic perspective. To make a fair comparison on the economic performance of renewable energy and fossil resources, not only the cost, but also the appointed advantages, should be accounted. Several authors have attempted to quantify the cost and benefits associated with renewable electricity promotion policies (Abanda, 2012; Banerjee et al., 2011; Buonocore et al., 2016, 2019; Inger et al., 2009; Ortega-Izquierdo and Del Río, 2016; Ortega et al., 2013b; Soeiro and Dias, 2020; Tan et al., 2014; Tourkolias and Mirasgedis, 2011; Zahnd and Kimber, 2009). There is, however, few studies evaluating the application of this concept for Middle Eastern FFRCs. This work pretends to fill that gap in knowledge considering Iran as a case study. A deep assessment of the situation of renewable energy in Iran was carried out in the next section.

This work ambition was to convert those non-economic benefits to monetary profit, so that they can be used as sustainability indicators to assist sustainability performance-based decision making in energy policy (Welfle and Röder, 2022). The aim of this paper is twofold: (a) present a methodology to convert the three advantages derived from the use of RES-E into economic benefits framework in a FFRCs of the Middle East; and (b) evaluate the costs-benefit performance of RES-E policy implementation in Iran in the period 2009–2019. A benefit-cost ratio criterion was implemented to compare renewable RES-E costs and potential sustainability benefits. The objective was to test if the benefits can offset the policy costs associated to foster renewable energy systems. It is worth mentioning that the total benefits obtained from this research may be underestimated. Further benefits beyond the scope of this work are job creation, health improvement, rural areas requalification, or enhancing gross domestic product (GDP) (Burgos-Payán et al., 2013).

The outline of this paper is presented as follows: the status of renewable energy development in Iran is presented in section 2, the theoretical concept of this research is described in section 3, materials and methods are presented in section 4, section 5 comprises the results of this research, section 6 presents the discussion of the results, and conclusions are covered in section 7.

2. Renewable energy development in Iran

Iran was selected as one exemplar of FFRC. Iran holds 10% and 17% of the world's crude oil and natural gas reserves (BP, 2021; Ifaei et al., 2018). The oil extraction cost is below 10 $/bbl, i.e. less than half of the regional average, which exceeds 20 $/bbl (Graphics, 2016; Pashakolaie et al., 2015). The energy intensity of primary energy in Iran is elevated, reporting a value 1.5 times higher than the world's average (World Bank, 2015). Iran is listed as a non-Annex I countries in the Kyoto Protocol, and thus there has not been any motivation on establishing reduced carbon emission targets. This scenario has led Iran to become one of the most CO_2 emitting countries during the last 60 decades (Hosseini et al., 2019). In 2019, Iran was the 9th top emitter producing 900 Mt CO_2e, i.e. 2% of annual global emissions (World Resources Institute, 2020). That contribution is similar to the emissions allocated to the whole international aviation sector (ICAO, 2019).

RES deployment in Iran is greatly limited like any FFRC in the Middle East. When focusing on electricity production, fossil fuel-based technologies dominate the grid, and thus, the sector has high GHG emissions associated. Natural gas and oil products report in FFRCs an average share of 63% and 31% of the total electricity generation respectively (BP, 2021). RES-E generation data for the FFRC cluster, excluding hydropower, is shown in Table .1.

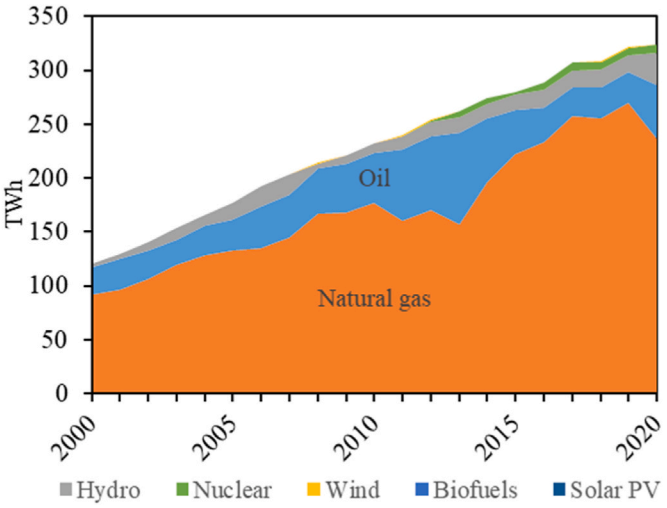

Fig. 1. Electricity generation mix in Iran -(IEA, 2021).

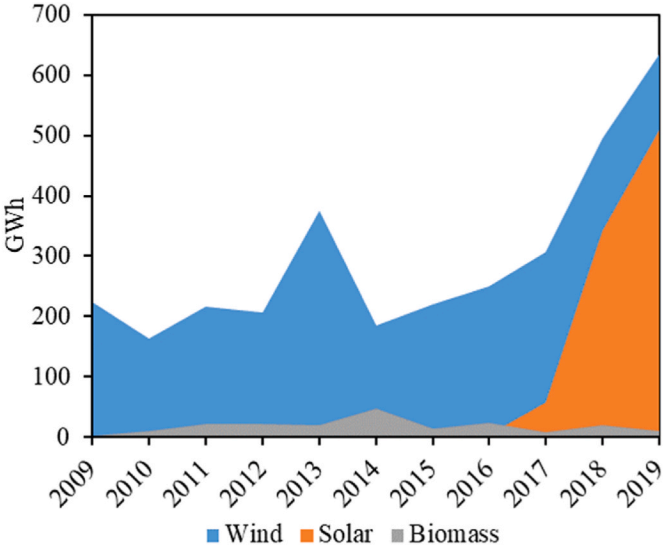

Fig. 2. Renewable energy development (RES-E) in Iran-(IEA, 2021).

Iran electricity generation reports a similar trend (see Fig. 1.), which showed a RES-E proportion below 1% in 2019 (Agency, 2020; BP, 2021). Green electricity generation in Iran during 2019 (see Table 1.) comprised 0.3% RES-E, which includes wind power, solar power, and biomass-to-power technologies. Fig. 2 shows the annual RES-E production in Iran during the 2009–2019 decade. Wind power has been traditionally the major renewable energy source in Iran. Solar power generation was firstly deployed in 2016 and currently accounts as the second major source of renewable energy. On the other hand, biomass-based electricity ratio remained small. The aggregated production of RES-E was 3278 GWh for wind, 915 for solar and 203 GWh for biomass-based power in that period (Niroo, 2016). However, despite the implementation of those non-hydro renewable energy sources during the last decade, the share of renewable energy in Iran still remains negligible (Ghorbani Pashakolaie et al., 2022).

Other non-fossil contributions to electricity generation were 9.2% hydroelectricity and 2.1% nuclear power (IEA, 2021). Hydroelectric generation has been traditionally used to match peak power demand in Iran. There are several constrains to promote wider use of hydroelectricity, which include weather dependency and very high water footprint (81.7 m^3/MWh (Gerbens-Leenes et al., 2008)) in a country with limited water availability. Nuclear power generation in Iran has not

Table 1
RES-E generation in the FFRCs of the Middle East- (GWh)-2019-(IEA, 2021).

Countries	Wind	Solar	Biofuels	Total Renewables	Total electricity generation	Renewable as % of total generation
Bahrain	–	–	–	–	33,441	–
Iraq	–	57	–	57	95,816	0.00
Iran	555	435	22	1012	322,756	0.3
Kuwait	36	20	0	56	75,000	0.00
Oman	–	4	–	4	38,337	0.00
Qatar	–	–	–	–	49,873	–
Saudi Arabia	–	433	–	433	385,537	0.1
UAE	–	3780	–	3780	138,455	2.7

growth either in the last decades, remaining a small percentage in the electricity mix. Hence, the only available source of primary energy for electricity generation in Iran is natural gas (Balsalobre-Lorente et al., 2019).

Natural gas is overall the main energy resource consumed in Iran. In 2019, it accounted for 68% of the whole primary energy consumption, while 73% of electricity was generated in NG thermal power plants (IEA, 2020). Iranian annual NG production exceeds national demand. In 2020, 250 billion cubic meters were produced, with 233 billion m^3 being domestically consumed and the rest being exported (BP, 2021). Electricity generation (30%) and residential heating (25%) were the main consumer sectors (MOE, 2020). However, the NG surplus is narrow. There is great risk for natural gas shortage to occur whether power grid and/or residential heating systems experience peak demand individually or simultaneously. This situation is likely to happen twice per year. First, stress on electricity network capacity has been identify during the hottest days in summer due to an increased power demand from cooling systems. Second, rise in natural gas supply for residential heating systems is observed during the coldest winter days. Both scenarios lead to an insufficient NG availability to supply thermal power plants and a reduced exchange capacity. Increasing the RES-E share in electricity generation could represent a stress-relief solution for the NG network, while also liberating national NG to trade or to be used as raw material for other industrial sectors. Converting natural gas to high value chemical products (e.g. hydrogen production) is one of the main energy-related policies in Iran (Parliament, 2016).

The Iranian government has also implemented several supportive policies looking to enhance renewable energy production and seek for positive welfare gains and domestic carbon emissions reduction (Blazquez et al., 2020). The most extended policy measure was the FiT (IRENA, 2018), which was implemented in 2009 and became more relevant in 2015. FiT consist of renewable electricity producers being economically supported to set an artificial selling price for the generated electricity, high enough to cover production cost and allowing a margin of profit that makes the business economically feasible. The funding for the FiT measure is sustained by the government and also by the consumer contributing a percentage on the electricity bill (IRENA, 2018). Iran Ministry of Energy charges 30 Rails per kilowatt-hour in electricity bills, on top of the electricity selling price, as electricity duties to support renewable energy development (Niroo, 2016).

The revenue generated must be dedicated for the deployment of electricity grids in rural areas and for renewable and clean electricity generation. As Fig. 3 shows, average FiT purchase price during 2009–2019 was 11.5 $US cents/kWh, almost 7 times higher than the average consumer price of electricity (1.7 $US cents/kWh). The average price gap between FiT purchase price and consumer price of electricity therefore resulted in 9.8 $US cents/kWh.

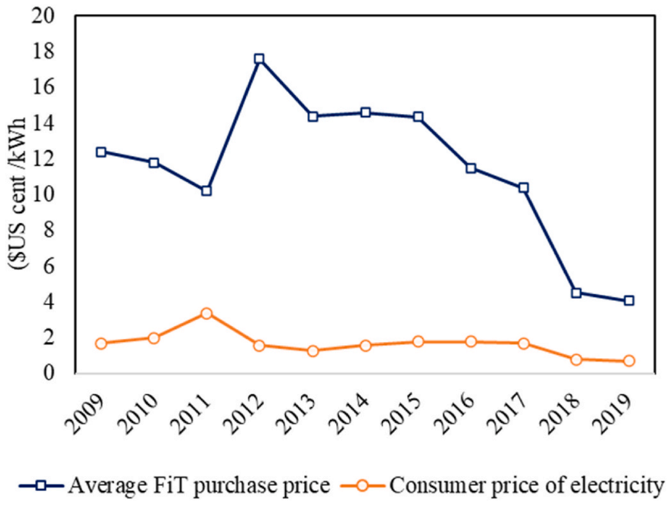

Fig. 3. Average FiT purchase price and consumer price of electricity in Iran (Tavanir, 2021).

3. Theoretical concept

Energy markets are always influenced by externalities. The price of the energy never reflects the real cost of production (Gies, 2017). Moreover, externalities are one of the most common causes of market failure, even impeding perfectly competitive markets to reach the best possible outcomes. On top of that, energy markets in FFRCs are massively subsidized. Unlike FiT, that supports renewable electricity generation by making the expensive technologies cost-competitive with the cheaper fossil-based electricity generation, subsidies to oil and gas can disrupt that competitiveness (Alizamir et al., 2016). In an energy market that excludes externalities and eliminates the distortion created by subsidies, the picture of competitiveness between renewable energy and fossil fuel would change.

Fig. 4 compares the marginal cost (MC) of fossil fuel electricity generation (left) and renewable electricity generation (right). Subsidized marginal private cost (MPC_S) refers to the subsidized production cost associated with fossil fuel electricity generation. Actual marginal private cost (MPC_A) represents the real production cost excluding subsidy and involves the market price of the main production inputs including natural gas and water. The marginal social cost (MSC) reflects all social costs related to fossil fuel electricity generation including.

1 climate change costs such as carbon dioxide (CO2), and methane (CH4) emission.
2 environmental and health related social costs such as damaging soil quality, emission of particulate matters ($PM_{2.5}$,PM_{10}), carbon monoxide (CO), nitrogen oxides (NO_x), and sulphur dioxide (SO_2) which cause adverse health effects, cardiorespiratory diseases, and acute respiratory infections (Lvovsky et al., 2000).

MSC is determined by the sum of actual and social marginal costs. Whenever social cost and production subsidies exist, the MSC will be higher than MPC_A and $MPC_{S.}$

Equilibrium E_1 in Fig. 4 would represent an ideal solution that leads to higher market prices for fossil fuel electricity. Equilibrium E_2 is the current situation involving subsidized price for consumer and superior fossil fuel electricity generation. Government must spend the FiT cost (P_{FiT}) to make renewable electricity an economically feasible option. This supporting scheme implies a cost to the government that equals the difference between P_{FiT} and $P_{Consumer}$.

Furthermore, competitiveness between fossil fuel and renewable energy depends on the uncertainty on where the actual MC_{RE} and MSC curves are located. High market prices for subsidized items, such as natural gas and water resources in fossil electricity generation, shift the MPC_A curve to higher positions associated with superior consumer prices and smaller demand for fossil electricity. Higher social cost of climate and environmental related emissions including CO_2, CH_4 CO, NO_x, SO_2 and so on also causes an upward shift in the MSC curve.

Externalities and subsidies can therefore affect the energy market, and market failure can represent an obstacle to renewable energy development. Thus, assessing the actual cost of fossil fuel electricity generation and the potential sustainability benefits of renewable electricity would allow to evaluate the real value of the investment in electricity generation.

4. Material and methods

The benefit-cost ratio of RES-E policy is defined as the proportion of benefits (or cost saving) to the expenses. The benefit-cost ratio in this research is set as indicator that incorporates the social and environmental costs and benefits of energy policy to evaluate the economic

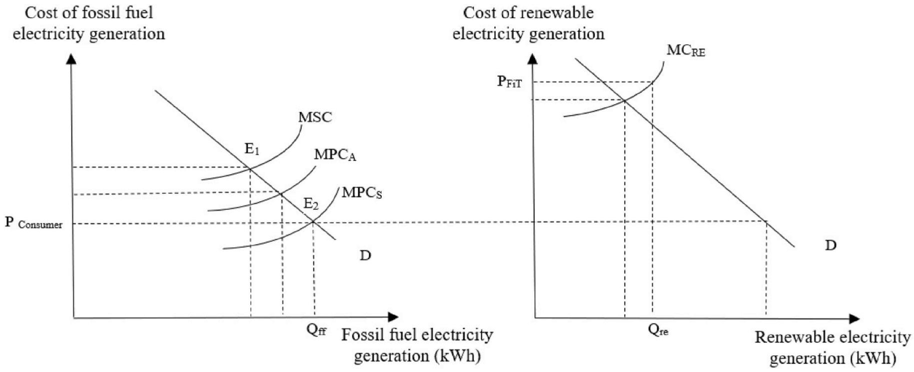

Fig. 4. Electricity generation from fossil fuel (left) and renewable energy (right) and market equilibria.

performance of RES-E and aid in policymaking. This indicator is defined from a government perspective, i.e. the benefit-cost ratio in RES-E policy measures the total (revealed and hidden) benefits of renewables which can offset the renewable policy cost.

Costs and potential sustainability benefits of renewable energy development in Middle Eastern FFRCs have been identified and evaluated under the Iranian energy policy framework. Fig. 5 presents the methodological approach used in this study to assess costs and benefits. Potential sustainability benefits have been classified into four items: avoided fossil fuel, avoided CO_2 emission, avoided water consumption, and other additional benefits.

4.1. Renewable energy policy costs

At first step, supporting cost of replacing thermal electricity generation with each source of renewable energy was estimated by incorporating their FiT purchase price and production capacity following Eq. (1). The supporting cost of renewable energy policy is calculated as the difference between feed-in tariffs paid to renewable electricity producers and the consumer prices for electricity at a respective time, considering the amount of renewable electricity generated (Breitschopf et al., 2016):

$$TC_{RE} = \sum_{t} \left(Q_{RE,t} * \left(Rem_{RE,t} - P_{consumer,t} \right) \right) + \text{Other additional costs} \qquad \text{Eq.1}$$

Where, TC_{RE} is the total cost of renewable energy policy, $Rem_{RE,t}$ is the compensation for renewable energy generation. Since the dominant renewable policy measure in Iran is FIT, while other renewable policies such as tax and soft loans do not significantly contribute to supporting policy cost in Iran, $Rem_{RET,t}$ was assumed to match the cost of FiT. $P_{Consumer,t}$ is the consumer price of electricity in time t, $Q_{RE,t}$ is renewable energy generated in time t, t is time (yearly), and Other additional costs includes R&D development of renewable energy, financial support cost of renewable energy, etc.

4.2. Renewable energy policy sustainability benefits

As aforementioned, despite multiple positive impacts of renewable energies in society, national economy, job market or power market exist (Breitschopf et al., 2016; Lacal Arántegui et al., 2013), the scope of this study focuses on the three main benefits – savings on CO_2 emissions, avoiding natural gas consumption and water use in thermal power plant (Menegaki, 2008). The evaluated RES-E deployment profits were determined as below:

$$TB_{RE} = B_{CO2} + B_W + B_{NG} + \text{Other additional benefits} \qquad \text{Eq.2}$$

Where, TB_{RE} is the total potential sustainability benefits of RES-S policy, B_{CO2} is the benefit of CO_2 emissions reduction, B_W is the benefit of water savings, B_{NG} is the benefit of avoided natural gas. Other additional benefits variable, which includes environmental social costs reduction, social, and socio-economic benefits such as job creation, energy access, energy security and reliability of electricity network, has not been assessed in this research. CO_2 reduction and water saving benefits were estimated as below (Choi et al., 2018a):

$$B_{CO2} = I_{CO2} * Q_t * P_{CO2} \qquad \text{Eq.3}$$

$$B_W = I_W * Q_t * P_w \qquad \text{Eq.4}$$

I_{CO2} is CO_2 intensity of power plants (Kg/MWh), I_W is water intensity of power plants (m^3/MWh), P_{co2} is social cost of carbon (US/tCO_2$) and P_w is the price of industrial water ($US/$m^3$).

To evaluate the benefit from NG liberation, it is assumed that renewable electricity displaces electricity generated in a combined cycle gas power plant. Potential benefit of avoided natural gas (B_{NG}) was estimated as:

$$B_{NG} = V_{NG} * P_{NG} \qquad \text{Eq.5}$$

Where, V_{NG} is the volume of avoided natural gas (m^3) and P_{NG} is price of natural gas ($US cents/$m^3$).

To compute the monetary value of RE benefits, energy output of a plant has to be converted to primary energy input. The power plant

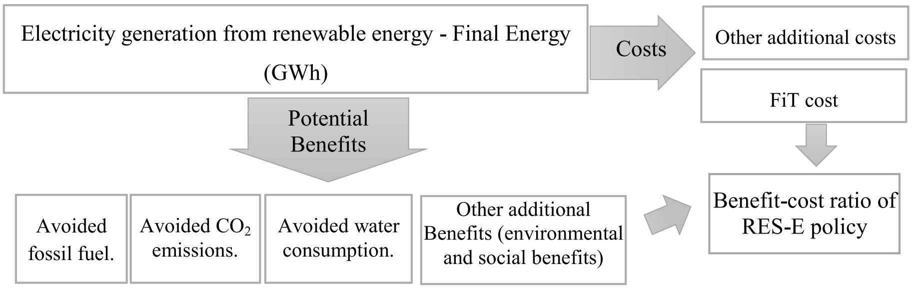

Fig. 5. Schematic of the methodology to assess cost and potential sustainability benefits of RES-E fostering policy.

efficiency was considered in V_{NG} estimation. This factor can be expressed either as heat rate or as thermal efficiency. Heat rate is one indicator to represent the efficiency of electrical generators/power plants converting fuel into heat and electricity. It is defined as the energy input required to generate 1 kW-hour (kWh) of electricity (EIA, 2019). Heat rate can be estimated as follows (Campbell, 2015):

$$HR = F/E \qquad \text{Eq.6}$$

Where, HR is heat rate (kcal/kWh), F is the energy content of the fuel supplied to the power plant (BTU) and E the total energy output from the power plant (kWh) in a defined time basis.

Thermal efficiency is defined as the percentage ratio of the electrical energy produced divided by the total energy content of the fuel consumed (Suppes and Storvick, 2007). Since the equivalent BTU of a single kWh of electricity is 860 kcal (3412 BTU), once F is converted to kcal, HR and TE can be related as:

$$HR = (100) * \left({}^{860}/_{TE} \right) \qquad \text{Eq.7}$$

Where, TE is thermal efficiency (%). Table .2 comprises the thermal efficiency of Iranian power plants, sorted by technology, during the 2009–2016 period. The eight-year thermal efficiency average reported was 29.9% for gas, 36.6% for heat and 44.9% for combined cycle power plants.

Eq. (8) was used to convert the electricity generated into natural gas input. Total volume of natural gas (V_{NG}) was calculated from the total heat energy input (F) and the higher heating value of natural gas (HV_{NG}), which is approximately 8600 kcal m^{-3}.

$$V_{NG} = \frac{F}{HV_{NG}} = \frac{860 * \ E/TE}{HV_{NG}} \qquad \text{Eq.8}$$

5. Results

5.1. Cost of renewable energy policy in Iran

According to Eq. (1) and considering the FiT cost and RES-E generation capacity (GWh) for each year, the total cost of renewable development was estimated to be $US 345 million (see Table .3.) Since Iranian Rial–$US exchange rate increased 23% by average in this period, this value can be a proxy of price index to adjust the nominal FiT cost in Rial currency and calculate the real cost of FiT in $US.

5.2. Potential sustainability benefits of renewable energy policy in Iran

The estimations computed for reduced CO_2 emission generation, avoided NG consumption and lower water consumption benefits, in an Iranian scenario, are presented here.

5.2.1. Benefit of avoided CO_2 emissions

The CO_2 emissions reduction from substituting fossil electricity with renewable electricity depends on the life cycle emission scores of both power generation technologies. The reported average carbon intensity of electricity production in Iran is 640 kg CO_2/MWh (I_{CO2}) (Niroo, 2016). Conversely, the renewable electricity generated in Iran during 2009–2019 saved 2.1, 0.58 and 0.13 Mt CO_2e for wind, solar and biomass, respectively. Total CO_2 emission savings account 2.8 million tonnes in ten years (see Tabe3).

To estimate the monetary value of the avoided emission, the social cost of CO_2 emissions, i.e. carbon price, was considered. The reported social cost of CO_2 in Iran ranges between 2.16 and 9.54 US/tCO_2$ (Nordhaus, 2017; Ricke et al., 2018). The emission cost varies depending on the location (e.g. different cities report dissimilar scores) and scenario evaluated (Lvovsky et al., 2000). Other studies evaluating the EU-ETS framework identified an average minimum carbon price of 2 US/tCO_2$ and showed variability across different regions (Goyal et al., 2018; Institute for Climate Economics, 2019). A social cost 2 US/tCO_2$ was considered for Iran in this research. Based on Eq. (3), the emission reduction volume leads to $US 6.1 million environmental benefit

Table 3

Total amount of support ($US thousand) received by the renewable energy in Iran in 2009–2019.

Year	Technology	Total support	Year	Technology	Total support
2009	Wind	24,038	2015	Wind	27,898
	Solar	7		Solar	153
	Biomass	193		Biomass	1058
	Total	24,238		Total	29,109
2010	Wind	1595	2016	Wind	24,312
	Solar	9		Solar	514
	Biomass	991		Biomass	1838
	Total	1695		Total	26,664
2011	Wind	14,834	2017	Wind	26,623
	Solar	3		Solar	6026
	Biomass	1497		Biomass	648
	Total	16,334		Total	33,297
2012	Wind	33,218	2018	Wind	18,478
	Solar	10		Solar	15,346
	Biomass	3634		Biomass	632
	Total	36,862		Total	34,456
2013	Wind	49,330	2019	Wind	2,2389
	Solar	9		Solar	21,591
	Biomass	2732		Biomass	261
	Total	52,071		Total	44,241
2014	Wind	24,200	Total: 2009–2019	Wind	28,127
	Solar	10		Solar	4368
	Biomass	6125		Biomass	1961
	Total	30,335		Total	344,557

Table 4

Avoided CO_2 emission benefit in 2009–2019.

Year	CO_2 emissions avoided (thousand tonnes)				Benefit of CO_2 avoided ($US thousand)
	Wind	Solar	Biomass	Total	
2009	144	0.04	1.2	145.2	313.6
2010	104.3	0.06	6.5	110.8	239.3
2011	139.1	0.03	14	153.2	330.9
2012	132.5	0.04	14.5	147	317.5
2013	240.8	0.04	13.3	254.2	549.1
2014	119.1	0.05	30.1	149.3	322.4
2015	141.7	0.55	9.2	151.5	327.2
2016	160.5	2.8	15.1	178.5	385.6
2017	196.3	37.1	6	239.3	517
2018	317.1	219	13.6	549.6	1187.2
2019	406.6	326.6	6.9	740.3	1599
Total	2101.9	586.5	130.4	2818.9	6088.8

Table 2

Thermal efficiency in Iranian power plants - 2009-2016-(%) - (Niroo, 2016).

Year	2009	2010	2011	2012	2013	2014	2015	2016	Average
Heat	36.5	36.6	37	36.8	37.1	36	36.1	37.1	36.6
Gas	29	29.4	29.5	29.7	29.4	28.5	30.4	31.1	29.6
Combined cycle	43.2	44.7	44	45.5	45.6	45.1	45.8	45.5	44.9
Average	36.0	36.6	36.9	37.2	37.0	36.3	37.4	37.8	36.9

(breakdown is shown in Table 4.)

5.2.2. Benefit of avoided natural gas

RES-E deployment implies lower feedstock requirements for the fossil based-electric system and creates a potential benefit from the liberated natural gas capacity. Eq. (8) was used to estimate the volume of avoided natural gas feedstock (V_{NG}) saved from displacing conventional fossil-based electricity with renewable power. The renewable energy generated in Iran during 2009–2019, i.e. 4397 GWh, implied that 999.2 million m^3 natural gas were liberated from feeding combined cycle thermal power plants, and could be converted in profit by sustainable downstream processing.

It is assumed in this study that the profit of exporting natural gas equals the climate friendly and sustainable commercialization of natural gas to calculate the monetary value of the avoided natural gas. To assess the value of natural gas in the market, the Henry Hub gas price was the criterion selected to set the international price of NG (EIA, 2020). The net benefit of natural gas was computed subtracting 5 $US cents/$m^3$ to the gas price, i.e. the expenses associated to piping, high pressure station operation and NG transportation. This net natural gas price is almost equivalent to the purchase price for domestic downstream industry. According to Eq. (5), potential benefit (B_{NG}) of liberated natural gas is about $US 61.5 million (Table .5.).

5.2.3. Benefit of avoided water

Renewable energy sources such as solar and wind, have a lower water footprint compared to conventional thermal power generation. A variety of water sources are used in thermal power plants including industrial water, wells water, and see water (Ferroukhi et al., 2016). Water consumption in Iran for electricity production in a combine cycle power plant was found to be 0.4 m^3/MWh (I_W) (Isapour and Abedi, 2014). Thus, water savings from the generation of renewable energy (wind and solar) can be estimated in 1759 thousand m^3. Considering 14 $US cents/$m^3$ for industrial water price (P_w) in Iran, the amount of water saving is equivalent to $US 244.3 thousand profit (Eq. (4)) (see Table .6).

5.3. Benefit-cost ratio of RES-E policy

A summary of the total costs and potential sustainability benefits of renewable support policy in Iran is presented in Table 7. The avoided natural gas feedstock of thermal power plants has the greatest potential to create high benefits for renewable policy. The benefit-cost ratio resulting from this study is 0.2, which infers that the total potential sustainability benefits of renewable energy can offset the renewable energy policy cost (FiT cost) by 20%.

A sensitivity analysis was performed on the social cost of carbon and water price. Social cost of carbon is likely to increase when strict decarbonisation policies are decided to be implemented. The benefit-cost ratio is highly sensitive to the price assumption. Results indicated that the benefit-cost ratio can be enhanced to −1 equilibrium between benefits and policy cost for renewable energy– by increasing the social cost of carbon to 100 $/t$CO_2$ (Fig. 6). On the other hand, this indicator is affected by water price in a lesser way. To achieve a small variation in the benefit-cost ratio (0.01%) an order of magnitude raises in water price (from 0.14 to 3 $US cents/$m^3$) has to be experienced.

Table 5
Avoided natural gas benefit in 2009–2019.

Year	Amount of avoided natural gas (million m^3)				Benefit of avoided natural gas ($US thousand)
	Wind	Solar	Biomass	Total	
2009	51	0.02	0.4	51.5	4624
2010	37	0.02	2.3	39.3	4128
2011	49.3	0.01	5	54.3	4995
2012	47	0.01	5.1	52.1	2481
2013	85.4	0.02	4.7	90.1	7424
2014	42.2	0.02	10.7	52.9	5561
2015	50.2	0.02	3.3	53.7	2309
2016	56.9	1	5.4	63.3	2496
2017	69.6	13.1	2.1	84.8	4762
2018	112.4	77.6	4.8	194.8	12,041
2019	144.1	115.9	2.4	262.4	10,723
Total	745.1	207.9	46.2	999.2	61,543

Table 6
Avoided water benefit in 2009–2019.

Year	Water avoided (Thousand m^3)				Benefit of avided water ($US thousand)
	Wind	Solar	Biomass	Total	
2009	89.8	0.03	0.7	90.6	12.6
2010	65	0.04	4	69.1	9.6
2011	86.8	0.02	8.8	95.6	13.3
2012	82.6	0.02	9	91.7	12.7
2013	150.2	0.03	8.3	158.6	22.0
2014	74.3	0.03	18.8	93.1	12.9
2015	88.4	0.34	5.8	94.5	13.1
2016	100.2	1.8	9.4	111.4	15.5
2017	122.5	23.1	3.7	149.3	20.7
2018	197.8	136.6	8.5	342.9	47.6
2019	253.6	203.9	4.3	461.8	64.1
Total	1311.3	365.9	81.4	1758.6	244.3

Additionally, sensitivity analysis on the benefit-cost ratio with respect to FiT and consumer price gap indicated that the indicator can be enhanced to 0.38 and 0.47 when the price gap is respectively reduced to 4.9 $US cents/kWh (−50% change) and 3.9 $US cents/kWh (−40% change).

6. Discussion

This research has evaluated the cost and sustainability benefits of RES-E development in Iran as a case study of Middle Eastern FFRCs scenario. Results showed that the costs of renewable energy deployment are higher than the sustainability benefits under current circumstances and assumptions.

The existing massive subsidy in electricity prices makes RES-E supporting policy in Iran too expensive. When evaluating the 2009–2019 time window, the cost of FiT policy was estimated in $US 344.5 million, while the potential sustainability benefits from the implementation of renewable energy accounted $US 67.8 million (see Fig. 7). The potential benefit from natural gas liberation was the highest contributor to RES-E monetary profit. Sustainable commercialization of avoided fuels should be the main part of government's energy strategy. The second significant benefit of RES-E is the avoided GHG emission, which accounted for $US 6.1 million for the same evaluation period when converted to monetary profit. The social cost of carbon (SCC), which was found highly variable by region, has a major impact on the benefit (Lvovsky et al., 2000). Market-based climate frameworks, such as emissions trading systems and carbon taxes, are necessary to raise the potential economic benefits derived from preserving the environment via carbon emissions reduction. Finally, the payback generated from the reduction of water footprint was estimated as $US 244 thousand, returning the lowest figure.

The renewable energy FiT policy benefit-cost ratio scored 20% in Iran. The defined indicator helped to understand that for each $US 100 spent by the Iranian government on FiT policy, $US 20 were recovered when assuming the lowest social cost of carbon reported for this country. The weak coverage of renewable energy development policy is mainly caused by the highly subsidized oil sector in Iran, concurring with the conclusions of other authors (Breitschopf et al., 2016). That scenario results in very low cost for fossil-based electricity generation, which causes a wide price gap between RES-E FiT purchase price and consumer price and consequently rockets the cost of FiT policy. The consumer price of electricity was found 7 times lower than renewable energy FiT purchase price. Therefore, to favour the competitiveness of renewable

Table 7
Total cost and potential sustainability benefits of RES-E promotion policy in Iran – (2009–2019) -($US thousand).

Technology	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Wind												
TC_{RE}	24,038	15,950	14,834	33,218	49,330	24,200	27,898	24,312	26,623	18,478	22,389	281,271
B_{CO2}	311	225	301	286	520	257	306	347	424	685	878	4540
B_{NG}	4586	3884	4536	2235	7033	4436	2159	2245	3906	6946	5889	47,857
B_{W}	12.5	9	12.1	11.5	20.9	10.3	12.3	13.9	17.0	27.5	35.2	182.1
Total benefits	4910	4118	4849	2533	7574	4704	2478	2605	4347	7658	6803	52,579
Benefit-cost ratio	0.20	0.26	0.33	0.08	0.15	0.19	0.09	0.11	0.16	0.41	0.30	0.19
Solar												
TC_{RE}	7	9	3	10	9	10	153	514	6026	15,346	21,591	43,67.9
B_{CO2}	0.1	0.1	0.1	0.1	0.1	0.1	1.2	6.1	80	473	706	1266
B_{NG}	1.4	2.1	1	0.6	1.3	1.9	8.4	40	737	4797	4735	10,326
B_{W}	0	0.01	0	0	0	0	0.05	0.2	3.2	19	28.3	50.8
Total benefits	2	2	1	1	1	2	10	46	821	5289	5469	11,643
Benefit-cost ratio	0.21	0.26	0.33	0.08	0.15	0.19	0.06	0.09	0.14	0.34	0.25	0.27
Biomass												
TC_{RE}	193	991	1497	3634	2732	6125	1058	1838	648	632	261	19,608
B_{CO2}	2.5	14	30.3	31.3	28.8	65.1	19.9	32.7	12.9	29.4	14.8	281.7
B_{NG}	37	241	458	245	389	1123	141	212	119	298	99	3361
B_{W}	0.1	0.6	1.2	1.3	1.2	2.6	0.8	1.3	0.5	1.2	0.6	11.3
Total benefits	39	256	489	277	419	1190	161	246	132	328	115	3654
Benefit-cost ratio	0.2	0.26	0.33	0.08	0.15	0.19	0.15	0.13	0.2	0.52	0.44	0.19
Total												
TC_{RE}	24,238	16,950	16,334	36,862	52,071	30,335	29,109	26,664	33,297	34,456	44,241	344,557
B_{CO2}	314	239	331	318	549	322	327	386	517	1187	1599	6089
B_{NG}	4624	4128	4995	2481	7424	5561	2309	2496	4762	12,041	10,723	61,543
B_{W}	12.6	9.6	13.3	12.7	22	12.9	13.1	15.5	20.7	47.6	64.1	244.3
Total benefit	4951	4377	5339	2811	7995	5896	2649	2897	5300	13,276	12,386	67,876
Benefit-cost ratio	0.2	0.26	0.33	0.08	0.15	0.19	0.09	0.11	0.16	0.39	0.28	0.2

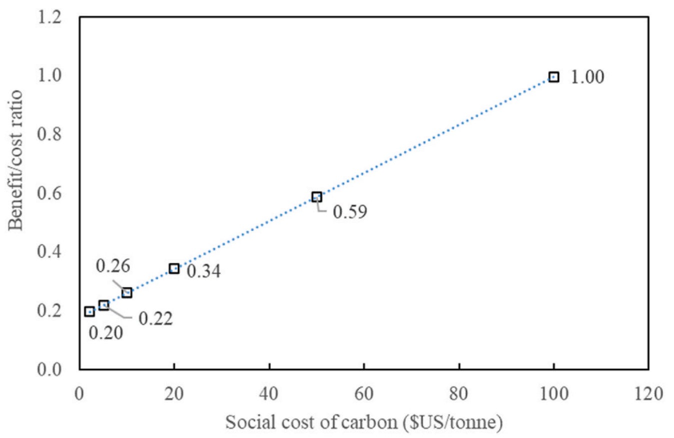

Fig. 6. Sensitivity analysis of the impacts of social cost of CO_2 on RES-E policy benefit-cost ratio.

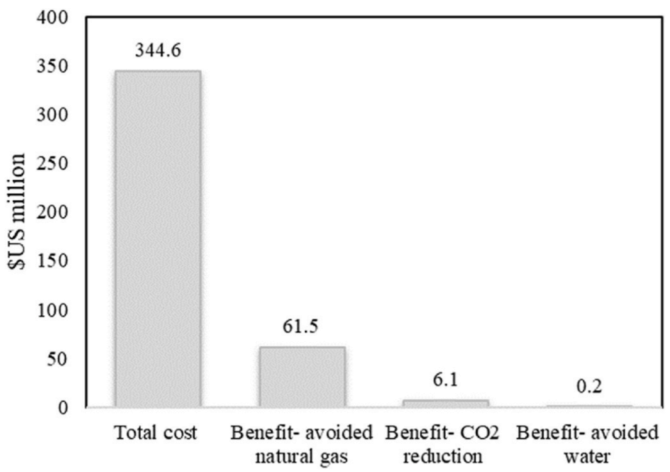

Fig. 7. Total costs and potential benefit associated with RES-E development in Iran.

energy and improve the benefit-cost ratio of RES-E policy, the current electricity pricing system must be changed.

Furthermore, carbon price was identified to provide control on the FiT policy benefit-cost ratio indicator. Policy frameworks increasing the cost of carbon emissions would result in higher payback from RES-E policy. A carbon price of 100 $/tCO_2$ resulted in balancing cost and benefits for RES-E policy in Iran, i.e. a unitary value in the benefit-cost ratio indicator. Previous studies have suggested imposing carbon prices that exceed 200 US/tCO_2 in order to achieve the net zero emissions scenario (Gies, 2017). That figure would represent a 100 times multiplier on the initial carbon price considered in this work. The value obtained to match RES-E policy costs with benefits, i.e. 100 $/tCO_2$, still remained below those projections on carbon price recommended to reach the net zero emissions global target.

7. Conclusions

This research has assessed and monetarized the cost and benefits associated with renewable energy development in Iran, a case study in a Middle Eastern FFRCs framework. A sustainability indicator, i.e. the RES-E policy benefit-cost ratio, was defined to evaluate the economic performance of the renewable energy-supportive policy implemented in Iran, and aid in future policymaking.

All the accounted potential benefits of RES-E generation could only offset 20% of the FiT policy expenditure. The higher contribution was associated to the liberation of fossil fuel (natural gas) from power generation, and its availability to be commercialised or converted to higher value-added products. Emissions avoidance was found to have varying monetary values related to the social cost of carbon. Elevated social cost of carbon could offset all expenses associated with RES-E policy, so promoting climate mitigation frameworks –e.g. stablish a carbon price under a carbon emission trading system– could be a game changer. The estimated revenue from water savings reported the lowest impact, but wind and solar power deployment could represent a water stress relief for those FFRCs suffering from underground water depletion. In addition, increasing the renewable energy share in the energy system would reduce the present dependency of the electricity network on the natural gas network and improve the system's reliability.

The limited access to validated data was the main constraint to conduct an accurate estimation of all the sustainability benefits of RES-E deployment. Future research should attempt to complement this work and convert the remaining sustainability contributions to monetary profit. Thus, quantifying and incorporating other environmental benefits from non-CO2 emissions –CH_4, SO_x, NO_x, CO, SPM, and N_2O– avoidance, job creation, improvement in energy access, rural areas requalification, or induced rise in GDP shall be considered.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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