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The Impact of Capital Subsidy Incentive on Renewable Energy Deployment in Long-Term Power Generation Expansion Planning

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Abstract

Capital investment cost is the major obstacle to the increasing share of electricity from renewable energy sources (RES-E). Therefore, RES-E incentive mechanisms are incorporated into markets to compensate cost-related barriers and to increase RES-E deployment rate. In this study, the impact of direct capital investment subsidy on RES-E in generation expansion planning (GEP) has been analyzed and deployment rates of renewable power plants have been defined. The effect of current subsidy mechanisms on the installed power capacity of various sources has also been analyzed and policy recommendations have been put forth in the light of the characteristics of Turkey's current subsidization mechanism and its outcomes.

Genetic algorithm was applied to solve the GEP problem. The share of non-hydro renewable power plants for future additions in overall installed power was determined as 9.45% without the proposed incentive, while it was estimated to rise to 13.65% when it was promoted by direct capital investment subsidy of 50%. The deployment rates of renewable power plants are expected to grow as the imported coal share in total installed power is expected to decline after applying the proposed subsidy.

Key Words: Renewable energy, Generation expansion planning, Incentives, Capital subsidy, Genetic algorithm.

1. Introduction

Introducing renewable power plants as candidate plants in power generation expansion planning (GEP) will help diminish supply deficiency, decrease foreign energy dependency and reduce greenhouse gas (GHG) emissions.

Turkey has been experiencing rapid energy demand growth over the last decade, consequently the country's dependency on energy imports has increased [1, 2]. Approximately 75% of Turkey's total primary energy supply (TPES) is imported and the country is heavily reliant on imported natural gas and oil.

The country's total net electricity generation increased from 23.275 TWh in 1980 to 250.436 TWh in 2014 [3, 4]. In 2017, Turkey's electricity generation was 295.500 TWh [5] while the gross domestic product (GDP) increased from 67.46 billions of dollars to 800.11 billions of dollars within the same time period [6]. When Turkey's total net electricity consumption between 1980-2014 is analyzed, it can be seen that there has been a steady increase in consumption, except the limited decrease in the aftermath of the economic crises [4, 7, 8]. The total net electricity consumption was 554 kWh per capita in 1980, which increased to 3,288 kWh per capita in 2014 [4, 8, 9, 10].

Hydroelectric power plants (HPP) account for the largest share of Turkey's total installed power and are dominant among renewable power plants. However, most of Turkey's electricity generation is based on fossil-fuel power plants and natural gas is the dominant one. The share of fossilfuels in electricity generation increased from 51% in 1980 to 79% in 2014 [3, 4]. In 2017, the share of fossilfuels in electricity generation was 71% [5].

Carbon dioxide (CO_2) emission has the largest share among the anthropogenic GHG emissions, which are the leading cause of global warming. Even though Turkey's CO_2 emission per capita is below the world average, there is a rather high surge in emissions [11,12,13,14]. Total GHG emissions in Turkey increased by 125% since 1990, and the amount reached 467.6 Mt CO_2-eqv. in 2014. Energy-related emissions are the largest source of GHG emissions in Turkey, accounting for 72.5% of the total [14].

Coal is still the backbone of Turkish energy sector [2] and 33% of GHG emissions is caused by the coal combustion. Despite this issue, Turkey aims to utilize all existing domestic lignite and hard coal potential for power generation to ensure energy supply security of the country [2, 15]. Subsidies that have been in effect so far have failed to facilitate Turkey's utilization of its RES potential for electricity generation [16].

In the literature, there are several studies which emphasize the harmful environmental impact of coal utilization and They suggest that coal is to be replaced with renewable energy sources (RES) as an efficient and effective solution to reduce the rapidly increasing GHG emissions of Turkey [17, 18].

Even though the RES investment has entered into a virtuous cycle of falling costs, there are still market barriers that do not exist for conventional power plants. Yet, the most important barrier is cost. Generally, initial capital investment costs of renewable power plants are higher than conventional power plants, and the major part of renewable power plants' cost is the initial investment cost. In order to avoid undesirable under-investment in renewable power plants and to make RES technologies technically and economically feasible, a wide variety of incentive mechanisms are being employed to promote electricity from RES (RES-E). Feed-in-Tariff (FiT), feed-in-premium (FiP), quota systems (green certificates or RPS–Renewable Portfolio Standard–), Investment subsidies, Auctions (Tendering), and Tax incentives/Fiscal measures have been used to promote RES-E investments [19]. Renewable energy subsidy mechanisms need to be used in combination and their efficiency and effectiveness should be evaluated at regular intervals. A combination of short-term (such as the direct investment subsidy recommended in this article) and long-term (such as the FiT mechanism, which Turkey currently relies on as its chief subsidy mechanism) subsidy mechanisms is an efficient mechanism that has made it possible to increase installed RES power [20,21,22,23,24].

Just like many other subsidy mechanisms, investment subsidy is also a widely used mechanism that brings returns in the short run. This mechanism is largely used in combination with other mechanisms in order to increase the installed capacity of RES [25,26].

Despite all the incentives and additional support, the desired installed power in RES-E has not been attained yet. The RES potential in Turkey is not yet adequately exploited except for hydropower. Turkey has been very slow in the process of attaining its 2023 energy policy targets. Therefore there is a need to implement new policies to foster the promotion of rich RES potential of Turkey. Turkey's energy policy agenda prioritizes energy supply security. As part of this agenda, tapping into RES is one of the three major objectives.

Turkey has abundant potential for RES [27, 28]. The country's realizable renewable energy potential is equal to 13% of EU-27's total potential and Turkey's total RES-E generation potential is 240,165 GWh/yr for 138,000 MW economic potential. It has several different types of RES: 144,000 GWh/yr hydro (for 36,000 MW), 14,665 GWh/yr geothermal (for 2,000 MW), 60,000GWh/yr wind (for 48,000MW), 14,000 GWh/yr biomass (for 2,000 MW) and 7,500 GWh/yr solar (for 50,000 MW) potential [29, 30].

An analysis of the licensed and unlicensed power plants as of the end of February 2018 reveals that exploitation levels for wind, solar, biomass, and geothermal potential remain very low. Exploitation rates for hydraulic, wind, solar, geothermal, and biomass are respectively as follows: 72.26%, 13.6%8, 7.87%, 53.18%, and 13.07% [16].

To this day, capital subsidy incentive has not been applied to promote RES-E. This paper proposes capital subsidy incentive mechanism as a complementary mechanism to the already existing FiT incentive in order to overcome the market barriers that impede the RES-E deployment in Turkey. Economical and technical impacts of the proposed incentive have been analysed. In this context, additional installed power values were found for the planning horizon and RES deployment rates in the additional power according to the source types were determined.

The rest of the paper is organized as follows: The second section presents a brief overview of the studies carried out in GEP and RES-E incentive mechanisms. The third section provides information on incentive mechanisms for renewable energy policies. The fourth section presents the details of existing incentive mechanisms and additional support available to RES-E in Turkey. The fifth section presents the mathematical model of the GEP. The sixth section gives a short explanation of a genetic algorithm (GA) and explains the data given as an input to the optimization model. The seventh section discusses the findings of the study. Based on the discussion of the findings, the last section offers concluding remarks and includes policy suggestions.

2. Studies on GEP and RES incentive mechanisms

Power GEP is an investment planning that deals with the expansion of the existing power system. A least cost GEP is to minimize the total cost to meet the forecasted demand within a prespecified reliability criterion over a planning horizon of typically 10–30 years [31,32,33]. Governments define their energy policies according to their priorities and objectives to meet growing energy demand. GEP is based on these energy policy constraints, together with other technical and economic constraints and supports energy policy of countries.

Power GEP defines the optimal size, type, location and commissioning date of additional power units within the planning horizon [31,32,34]. GEP problem can be solved by using mathematical and meta-heuristic methods. Dynamic programming, decision tree, iterative algorithm, mixed integer programming, linear programming are mathematical methods that have been used to solve GEP problems. Meta-heuristic optimization methods such as ant colony optimization evolutionary programming, tabu search, honey bee algorithm, artificial immune system, differential evolution (DE) algorithm, GA and particle swarm optimization (PSO) have been successfully used to solve GEP [31, 34,35].

Yildirim et al. [35], describe an improved GA to solve the GEP for a 20-year planning horizon. Aghaei et al. [32] have used a Corrected Normal Boundary Intersection (CNBI) method to solve a Multi-period Multi-objective Generation Expansion Planning (MMGEP). Hemmati et al. [36] have used PSO method to solve the security and reliability constrained GEP in the presence of wind farm uncertainty. Rajesh et al. [34] have used the DE algorithm to solve GEP, and the impact of the inclusion of solar power plants was analyzed for two different planning horizons.

Murugan et al. [37] have applied an improved non-dominated sorting GA version II (NSGAII) to solve a multi-objective GEP problem.

Maturity in technological developments of renewable energy technologies and decrease in the costs of RES-E make these sources more acceptable worldwide [30]. Since the cost of RES-E is generally higher than electricity generated from conventional energy sources, governments create incentives for the penetration of RES-E in the electricity generation mix [20, 38].

Financial incentives are important policy instruments available to encourage RES- E investors. Policy makers deploy different incentives to support RES-E. In order to be effective, these incentives have to contribute to ensure affordable, reliable, sustainable electricity [66].

By deploying these incentive mechanisms, governments indirectly aim to decrease CO_2 emissions and improve energy supply security [21]. Morever, policy makers aim to increase employment and to foster technological innovation in RES by deploying these incentives [40]. Incentive policies need to be adjusted according to different government objectives or RES development stages [22].

Different types of incentive mechanisms are available to promote RES-E around the world. For the purpose of assessing the effectiveness and efficiency of incentive mechanisms applied to generate RES-E, various studies have been undertaken: Butler et al. [41] and Haas et al.[42] have examined the performances of incentive mechanisms used in some European Union (EU) countries and FiT were found to be more effective and efficient than other mechanisms. Frondel et al. [40] argue that government intervention can serve to support renewable energy technologies through mechanisms such as European Trading Scheme and funding for R&D. Technological improvements in the renewable technologies production chain reduce costs and the subsidies will be eliminated as renewable power plants become competitive with conventional power plants [20].

3. Incentive mechanisms for renewable energy support policy

There are various incentive mechanisms utilised to make renewable power plants more competitive against conventional power plants. Table 1 shows characterization of incentive mechanisms for promoting RES-E [43,44,45].

As capital subsidy and FiT incentive mechanisms have been proven to be the most successful mechanisms in attracting private investment in RES-E and being the core subject of this paper, a brief discussion have been made for these mechanisms.

Capital subsidy is one of the most broadly used incentive mechanisms that governments provide for the commissioning of renewable power plants. In this mechanism, governments grant different capital subsidies by which a percentage of the total capital cost for the investment is subsidized [43, 44, 45]. Capital subsidy scheme has a low transaction cost relative to other schemes. However, this scheme usually depends directly on the public treasury and therefore alters with a changing political agenda. Policy makers should consider the factors that influence the mechanism’s effectiveness and efficiency to create a sustainable market before choosing to apply the mechanism. A phase out time has to be defined for capital subsidy to ensure efficiency improvements in RES technologies.

Table 1. RES-E incentive mechanisms**.**

		Direct		Indirect
		With price priority	With capacity priority	
Regulatory	Investment focused	Capital subsidy, Grants, Rebates, Loans	Tendering, Quota, Tradable renewable energy certificates	Environmental taxes, Other incentives (licensing priority,grid connection priority etc.)
	Generation based	Feed-in tariff, Net metering / Net billing		
Voluntary	Investment focused	Share holder programmes, Contribution programmes		Voluntary agreements
	Generation based	Green tariffs		
Fiscal	Investment focused			Tax incentives
	Generation based			

FiT offers purchasing electricity through guaranteed payment per kWh generation (currency/kWh) for a pre-determined period of time. Payment type differs according to countries. The FiT is a regulatory price-based mechanism which is widely used to promote the RES-E deployment. This incentive mechanism which has been designed according to the economic, technical and social conditions of the countries has played an important role in promoting the RES-E deployment rate [22, 38, 39, 46, 47]. Payment in this mechanism may be at a fixed price which is market- independent or at a premium price which is market-dependent.

Determining an appropriate FiT is a highly challenging task. An appropriate FiT makes RES projects more attractive to investors, improves resource efficiency and limits the cost to society. Technology specified incentive scheme encourages investments in more expensive RES technologies and has lower risk involved for investors. This mechanism eliminates purchase and price risks [38]. FiT mechanism aims to support the technological maturity of renewable power technologies with contracts ranging from 10 to 25 years. Renewable power generation penetration into the energy mix has the highest impact on FiT's sustainability [47].

An analysis of the energy policies of the countries that transition into RES [48,49,50,51], Germany in particular, reveals that the most efficient and effective RES-based electricity generation incentive mechanism is the source-dependent and long-term FiT mechanism. The success of this core RES-E incentive scheme relies on a combination of a predictable legislation and robust policy framework. The scheme is implemented along with a set of complementary policies such as R&D and innovation subsidies, capital investment subsidies, direct funding, tax exemptions, grid access support and emissions trading system [48,49,50,52].

FiT and direct capital investment subsidies have been the mostly prefered types of financial incentives to promote RES. These incentive mechanisms have led to the largest deployment quantities with the lowest costs [52,53, 54, 55]. Direct subsidy scheme has yielded good results in many EU countries to promote RES-E especially in PV sector [54]**.**

4. The existing incentive mechanism in Turkey

Technology specified FiT incentive mechanism is used as a core national renewable energy support policy instrument to promote RES-E in Turkey. The FiT rates and maximum possible FiT rates in case of domestic component bonuses are given in Table 2 [56].

Table 2. RES-E feed-in tariffs [56].

Technology		Capacity	FiT rate ($/kWh)	Maximum possible FiT rate in case of domestically manufactured components ($ / kWh)
Hydro		All sizes	0.073	0.096
Wind			0.073	0.110
Geothermal			0.105	0.132
Biomass (including landfill gas)			0.133	0.189
Solar	PV		0.133	0.200
	CSP		0.133	0.225

In order to support RES-E, further regulations have been pursued [57,58,59,60]: Table 3 provides existing incentives and support mechanisms of RES-E in Turkey.

Table 3. Existing incentives and other support mechanisms of RES-E in Turkey.

Incentives and other support mechanisms

Feed-in tariff	Capital subsidy / Grant/ Rebate/Loans	Quota obligation	TREC	Tendering	Net metering	Environmental taxes	Renewable energy targets	Tax incentives	Investment / Production tax credits	Grants/ Deductions/ Exemptions for R&D	Other incentives (licensing priority,grid connection priority etc.)
●				●	●		●	●		●	●

Although FiT and some other supports have been applied to promote RES-E, direct capital investment subsidy mechanism has not yet been applied for promoting RES-E in Turkey.

5. GEP model

In this study, GA was used by considering the features possessed by the GEP problem. For the solution of the GEP problem, determination of the objective function and inputs for the model have been defined and construction and programming of an algorithm were realized to find the lowest value of the objective function.

5.1. Objective function

The objective function is a linear / non-linear function of multiple variables that contains investment costs of energy generation units to be installed during the planning period, as well as operation and maintenance (O&M) costs and constraints. For this reason, firstly, the planning horizon is determined. In this study, the planning horizon is set as 16 years. The notation used in the study is as follows:

Z	total cost in planning horizon,
Z_c	total investment cost in the planning horizon,
Z_{om}	total O&M cost in the planning horizon,
C_{jt}	unit investment cost for *j* type unit to be put into operation in the year *t*,
C_{j0}	unit investment cost for *j* type unit for the first year of the planning horizon,
x_{jt}	total power capacity of *j* type units to be put into operation in the year *t*,
n_{jt}	number of *j* type units to be put into operation in the year *t*,
X_{jmax}	maximum power capacity of a single *j* type unit,
f_{jtk}	O&M cost of *j* type unit to be installed in the year *t* and will be operated until the end of planning horizon,
f_{j0}	O&M cost of *j* type unit that is in operation in the first year of the planning horizon,
y_{jt}	energy value to be met by *j* type units to be put into operation in the year *t*,

K	number of years that a unit will remain in operation until the end of the planning horizon,
k	number of years that a unit remained in operation since it was put into operation,
c_{jt}	capacity coefficient of j type unit in the year t,
P_t	peak power value of the year t,
m	reserve capacity coefficient ($1 \geq m \geq 0$),
E_t	energy demand in the year t,
h_{jt}	theoretical working time of j type unit per year,
e_{jc}	investment cost escalation rate for j type unit,
i	interest rate,
ξ_j	effecting rate of additional expenses to cost related to environmental problems to be created by j type unit,
r_{jt}	capital recovery factor of j type unit installed in the year t,
L_j	economic lifetime of j type unit,
e_{jf}	O&M cost escalation rate of j type unit,
R_{jmax}	maxium reserve capacity of unit type j.

The objective function in the GEP was found by using Eq.(1) and (2) as the total of Z_c and Z_{om} functions and penalty that will bring the investment and O&M costs to the lowest value together. Eq. (2) is a modified version of the objective function used in reference [61]. Penalty is the cost of violated reliability constraints.

x_{jt} values are calculated by using n_{jt} values referred to as the decision variable for the model. n_{jt} must be determined in a manner that will meet reliability constraints and simultaneously achieve the lowest value of the objective function.

$$Z = Z_c + Z_{om} + penalty \tag{1}$$

$$Z = \sum_{j=1}^{J}\sum_{t=1}^{T} C_{jt} x_{jt} + \sum_{j=1}^{J}\sum_{t=1}^{T}\sum_{k=1}^{K} f_{jtk} y_{jt} + penalty \tag{2}$$

Here;

$$x_{jt} = n_{jt} X_{j\max} \tag{3}$$

Unit costs are evaluated by considering the economic and technical factors that may change between the dates when the unit is planned and its construction is realized, and by considering the environmental factors. The unit investment costs of units installed in the year t were calculated with the Eq.(4) by using the first-year values. In the same manner, the O&M costs of units installed in the year t were calculated with the Eq.(5) by using the first-year values f_{j0}, where f_{jtk} is the O&M cost of j-type unit, which is installed in year t and will be operated k years until the end of planning term. Again, economic and technical factors of O&M cost may change between the years a unit is planned to be installed and it starts operation.

$$C_{jt} = C_{j0}\left[(1-e_{jc})(1+i)\right]^{-t} r_{jt}\xi_j \tag{4}$$

$$f_{jtk} = f_{j0}\left[(1-e_{jf})(1+i)\right]^{-t} \tag{5}$$

In the study, to meet the investment costs, the capital recovery factor, as given in Eq. (6), is used. The purpose of using this factor is to ensure recognition of an expense of investment cost with higher shares in the first years and with lower shares towards the end of economic lifetime of the units. The capital recovery factors are determined by considering the economic lifetime (L_j) of units.

$$r_{jt} = \frac{2}{L_j(L_j+1)}\sum_{t=1}^{T}(L_j - t + 1) \tag{6}$$

5.2. Constraints

Constraints that will ensure reliability while minimizing the cost are given below.

Contsraint-1: For each year, the higher limit value of total available capacity must meet P_t peak power in that year with a defined reliability. The constraint defining this condition is given by Eq. (7).

$$\sum_{j=1}^{J}\sum_{t=1}^{T} c_{jt}x_{jt} \geq P_t(1+m) \tag{7}$$

Constraint-2: For a defined year, total energy generations of units in operation must be sufficient to meet the energy demand of that year. The constraint ensuring this condition is given by Eq. (8) and Eq. (9).

$$\sum_{j=1}^{J}\sum_{t=1}^{T} y_{jt} \geq E_t \tag{8}$$

$$y_{jt} = c_{jt}x_{jt}h_{jt} \tag{9}$$

Constraint-3: The total power capacity of j type units to be put into operation in the year t must be smaller than or equal to the highest limit of reserve capacity R_{jmax} that may be installed related to j type unit. This condition is given in Eq. (10). While determining the highest capacity values that may be installed, domestic fuel generation amounts, reserves, importable fuel quantities and energy policy targets must also be considered.

$$\sum_{t=1}^{T} x_{jt} \leq R_{jmaz} \tag{10}$$

Constraint-4: To limit use of imported sources and to be able to consider a low-energy value to be generated in hydroelectric units in arid climate conditions, available capacity for all source types in any year may not exceed 35% of available capacity of all candidate unit types installed in that year. This is given by Eq. (11).

$$c_{jt} x_{jt} \leq \left(\sum_{j=1}^{J} c_{jt} x_{jt} 0.35 \right) \tag{11}$$

Maximum energy that may be generated by generation units decreases as units degrade. Based on the year the unit is installed, the energy value it may generate depending on the number of years it is in operation is calculated by using the capacity coefficient (c_{jt}) given by Eq. (12).

$$c_{jt} = c_{j0} (1 - 0.007)^{k} \tag{12}$$

6. Planning method and parameters

The goal of optimization technique is to efficiently explore the search space in order to find the optimal solution. Exploring all the feasible solutions is a difficult task if the search space is large and the evaluation process takes a very long time. For this reason, in problems having large search space, a method which tries to explore different areas in the search space in a smart way to find optimal solution in less cost and short computation time is required [62].

In order to cope with the limitations of the classical optimization techniques, many different meta-heuristic optimization techniques have been developed. These techniques are designed to handle non-convex problems, since they have mechanisms to escape the local optimum. The meta-heuristic optimization algorithms are simple in nature, have an easy implementation procedure and provide a better computation time performance as compared to conventional optimization techniques. These techniques have proved their ability to solve GEP problems[63, 64].

There has been a growing interest in applying metheuristic techniques to solve GEP problems and GA is one of the most commnly used technique among these techniques [63, 64, 65, 66]. Compared with other metheuristic techniques, GA’s are suitable for discovering large and complex search spaces and mutatiton operator prevents the GA from becoming trapped in a local minima. GA discover large search spaces relatively rapidly and could find the global optima in a short time. Calculations of the GEP problem could be speeded up due to its inherently parallel feature. This feature can significantly reduce the CPU time required [67,68]. GA is commonly used as a main algorithm in hybrid optimization methods [66]. Considering all the aforementioned advantages, we preferred to apply GA to solve GEP problem.

An integer coded GA was used for the optimization algorithm in this study. The chromosome structure of the GA used in the optimization is given in Fig. 1. The roulette-wheel selection method was the preferred selection method, and the rank-based assignment method was used for fitness value assignment. Population size, crossover rate and mutation rate were taken as 400, 1.0, and 0.005, respectively. Previous studies [61, 69, 70] that were conducted by the co-authors of this paper provide more detailed information on the application of GA to a GEP problem.

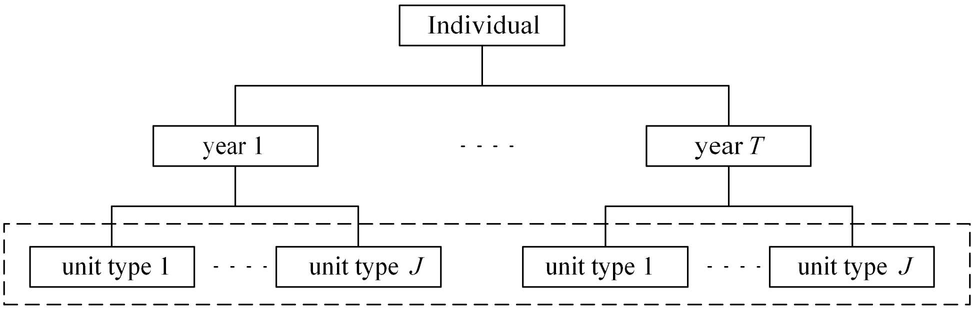

Fig. 1. Chromosome structure of GA.

In the study, a GEP having 11 candidate unit types, including renewable power units, is analyzed with a GA. The planning horizon is taken as 16 years and the problem was solved to find which types of additional units will be constructed, how many units will be added and when these units will be commissioned.

In the planning stage, one of the most important data given as an input to the model is the power demand that must be met during the planning horizon. Growth trends in historical loads form a basis for future load forecasts. The cumulative power demand (in column 2) and energy demand (in column 4) values given in Table 4 [71], which were stated in the generation capacity projection of Turkish Electricity Transmission Co. (TEİAŞ), were taken as forecasted demand. These demand values were determined by subtracting the already installed capacity value in that year from that year's demand value. The values in column 3 and 5 in Table 4 were determined by means of GEP that show they meet the demand values in column 2 and 4, respectively.

Table 4. Demand values and planning results for the planning horizon.

Year	Cumulative power demand in each year (MW)	Cumulative planned power capacity in each year (MW)	Cumulative energy demand in each year (GWh)	Cumulative planned energy generation capacity in each year (GWh)
1	2,200	7,424	15,280	50,260
2	4,565	8,505	32,535	58,218
3	7,080	12,137	50,875	83,797
4	9,878	12,478	70,465	86,585
5	13,025	16,168	91,325	112,440
6	16,465	18,267	113,550	127,240
7	20,105	20,152	137,180	140,298
8	23,975	25,480	162,295	176,956
9	28,093	28,105	189,030	194,309
10	32,579	32,618	218,152	225,824
11	37,380	37,505	249,313	258,620
12	42,516	42,662	282,655	292,471
13	48,012	48,103	318,330	328,750
14	53,893	53,903	356,504	366,865
15	60,186	60,286	397,349	410,736
16	66,919	66,919	441,053	454,678

The technical and economic parameters of candidate unit types for the first year of the planning horizon are given in Table 5.

Table 5. Technical and economic parameters for candidate unit types [69,70].

j	Unit type	X_{jmax}(MW)	C_{j0} (\$/kW)	f_{j0} (\$ /kW-year)	c_{j0} (%)	e_{jc},e_{jf}	kj	h_j(hour)	L_j(year)
1	Natural gas	700	500	273.50	85.00	0.03	0.007	7,000	30
2	Lignite	350	1,146	335.40	85.00	0.03	0.007	6,500	40
3	Hard coal	300	1,084	403.80	85.00	0.03	0.007	6,500	40
4	Imported coal	500	1,110	321.90	85.00	0.03	0.007	6,500	40
5	Fuel-oil	150	1,280	357.80	77.02	0.03	0.007	6,500	40
6	Nuclear	1,000	2,000	657.00	85.00	0.03	0.007	7,000	60
7	Hydro	500	1,350	4.40	50.00	0.03	0.007	7,000	80
8	Wind	45	1,912	61.77	30.00	0.03	0.007	3,000	25
9	Geothermal	50	3,000	145.68	75.00	0.03	0.007	8,000	40
10	Biomass	30	2,599	116.88	85.00	0.03	0.007	8,000	20
11	Solar	5	3,500	15.05	11.00	0.03	0.007	2,640	25

The unit investment costs vary according to the unit types. For the first year of planning, the unit investment cost C_{j0} for a *j* type unit is given in Table 5. The unit investment cost of a unit *j* to be installed in the year *t*, C_{jt}, is calculated with Eq. (4).

In calculating unit investment costs, capital recovery factors given in Eq. (6) must be taken into consideration. Depending on the developing technology, electricity generation units are designed to minimize the negative effects on the environment. By considering this situation in unit investment costs, ξ_j rate is accepted as “1”. For the first year of the planning horizon, the O&M cost f_{j0} of a *j* type unit is given in Table 5. The O&M cost f_{jtk} of a unit *j* to be installed in the year *t* is calculated with Eq. (5). The capacity factor c_{j0} values of unit types used in the planning study are given in Table 5. By considering the annual 0.7% decrement of capacity factors, the capacity coefficient of any j type unit related to the year *t* is calculated by using Eq. (12).

7. Analysis of results for capital subsidy in the GEP

After selecting the GA parameters, least-cost GEP was carried out to determine the type and number of candidate plants that meets forecasted demand within prespecified constraints over a planning horizon of 16 years.

Firstly, optimization was made without the subsidy (without-subsidy case) in order to set a benchmark. Further optimization results, with different levels of capital investment subsidies were compared with this benchmark. The results of the without-subsidy case, the type and number of candidate plants types are given in Table 6.

Table 6. Numbers of new units to be added during the planning horizon.

Year	CANDIDATE SOURCE TYPES

	Natural gas	Lignite	Hard coal	Imported coal	Fuel oil	Nuclear	Hydro	Wind	Geothermal	Biomass	Solar
1	4	6	0	6	0	0	1	0	0	18	0
2	0	0	0	0	0	0	3	0	0	15	0
3	0	0	0	0	0	0	13	4	0	15	1
4	0	0	0	0	0	0	0	0	1	15	1
5	4	0	0	1	1	0	2	1	1	12	0
6	1	1	0	0	0	0	4	1	0	12	0
7	0	3	0	0	0	0	3	1	0	14	0
8	4	0	0	3	3	0	4	4	0	16	1
9	0	0	0	2	8	0	2	10	1	14	0
10	3	0	0	2	1	0	6	1	1	16	0
11	1	1	0	6	0	0	6	1	3	1	4
12	1	0	0	9	0	0	3	9	0	5	0
13	3	5	0	3	1	0	3	11	0	7	0
14	1	4	0	8	1	0	1	11	2	14	1
15	7	2	1	2	3	0	1	2	1	9	1
16	2	7	0	7	2	0	2	0	0	3	0

According to the candidate unit capacities and unit numbers given in Table 5 and Table 6 respectively, a total 95,700 MW installed power was found for future additions in planning horizon as shown in Table 7.

Table 7. Development of available capacity (MW).

Year	**CANDIDATE SOURCE TYPES**												
	Natural Gas	**Lignite**	**Hard coal**	**Import coal**	**Fuel-Oil**	**Nuclear**	**Hydro**	**Wind**	**Geothermal**	**Biomass**	**Solar (PV)**	**Total**	**Total (Cumulative available capacity)**
1	2,800	2,100	0	3,000	0	0	500	0	0	540	0	8,940	7,424
2	0	0	0	0	0	0	1,500	0	0	450	0	1,950	8,505
3	0	0	0	0	0	0	6,500	180	0	450	50	7,180	12,137
4	0	0	0	0	0	0	0	0	50	450	50	550	12,478
5	2,800	0	0	500	150	0	1,000	45	50	360	0	4,905	16,168
6	700	350	0	0	0	0	2,000	45	0	360	0	3,455	18,267
7	0	1,050	0	0	0	0	1,500	45	0	420	0	3,015	20,152
8	2,800	0	0	1,500	450	0	2,000	180	0	480	50	7,460	25,480
9	0	0	0	1,000	1,200	0	1,000	450	50	420	0	4,120	28,105
10	2,100	0	0	1,000	150	0	3,000	45	50	480	0	6,825	32,618
11	700	350	0	3,000	0	0	3,000	45	150	30	200	7,475	37,505
12	700	0	0	4,500	0	0	1,500	405	0	150	0	7,255	42,662
13	2,100	1,750	0	1,500	150	0	1,500	495	0	210	0	7,705	48,103
14	700	1,400	0	4,000	150	0	500	495	100	420	50	7,815	53,903
15	4,900	700	300	1,000	450	0	500	90	50	270	50	8,310	60,286
16	1,400	2,450	0	3,500	300	0	1,000	0	0	90	0	8,740	66,919
Total	21,700	10,150	300	24,500	3,000	0	27,000	2,520	500	5,580	450	95,700	

When the capacities (Table 4, column 3) and energy values (Table 4, column 5) of units commissioned after the first year of planning are examined, it is seen that forecasted demands in Table 4 (column 2 and column 4) can be met for each of the planning horizon years within the prespecified constraints.

The total installed power of non-hydro RES was found as 9,050 MW as shown in Table 7. The installed power percentages of units for future additions in the planning horizon are given in Fig. 2. The ratio of non-hydro RES, which consists of wind, geothermal, biomass and solar energy, to overall installed power were found as 9.45%.

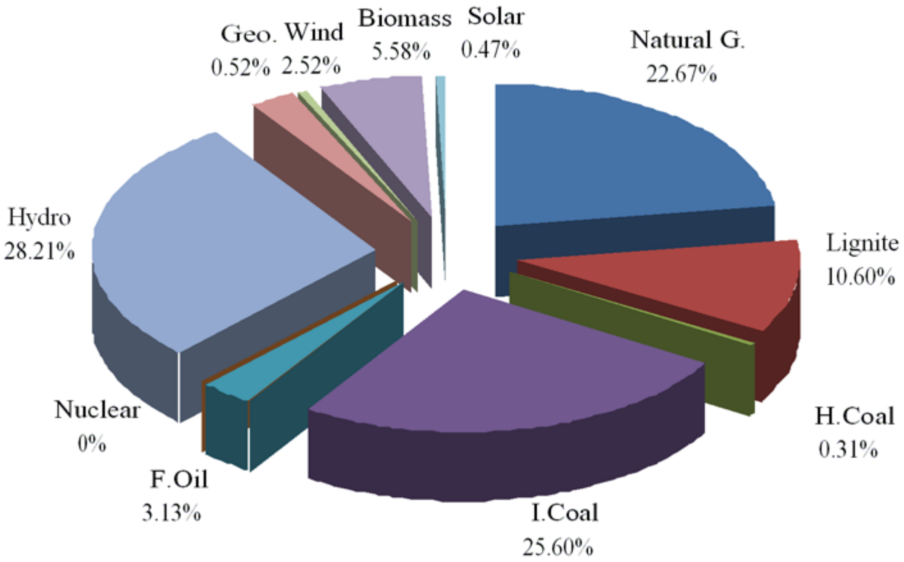

Fig. 2. Installed power rates without investment subsidy for non-hydro renewables.

Secondly, planning was carried out for three different direct capital investment subsidy rates (20%, 40%, 50%) to cover a percentage of non-hydro renewable units’ investment costs. Investment costs following the application of different investment subsidy rates for non-hydro renewables are shown in Table 8.

Table 8. Investment costs after different subsidy rates for non-hydro renewables.

Incentive rate		0%	20%	40%	50%
j	Unit type	C_{j0} (\$/kW)	C_{j0} (\$/kW)	C_{j0} (\$/kW)	C_{j0} (\$/kW)
1	Natural gas	500	500	500	500
2	Lignite	1,146	1,146	1,146	1,146
3	Hard coal	1,084	1,084	1,084	1,084
4	Imported coal	1,110	1,110	1,110	1,110
5	Fuel-oil	1,280	1,280	1,280	1,280
6	Nuclear	2,000	2,000	2,000	2,000
7	Hydro	1,350	1,350	1,350	1,350
8	Wind	1,912	1,530	1,147	956
9	Geothermal	3,000	2,400	1,800	1,500
10	Biomass	2,599	2,079	1,559	1,300
11	Solar	3,500	2,800	2,100	1,750

The total installed power of the non-hydro renewables was calculated as 9,540 MW when investment cost is reduced by 20% (Table 8). The installed power percentages of units for future additions in the planning horizon are given in Fig. 3. The ratio of the non-hydro renewables to overall installed power was estimated as 9.98%.

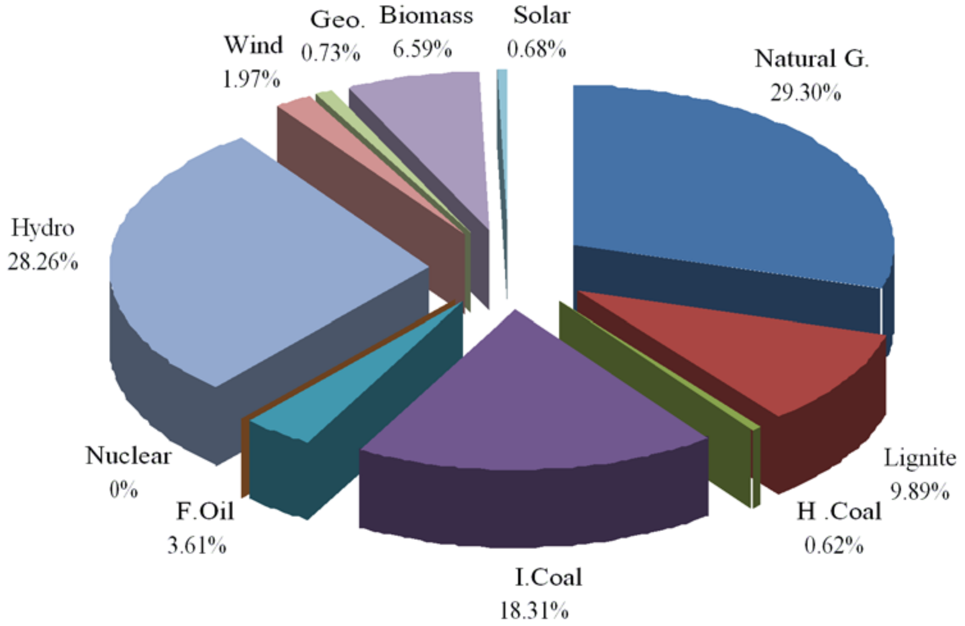

Fig. 3. Installed power rates under the condition of 20% investment subsidy for non-hydro renewables.

The total installed power of the non-hydro renewables was found as 11,740 MW when investment costs are reduced by 40% (Table 8). The installed power percentages of units for future additions in the planning horizon are given in Fig. 4. The ratio of the non-hydro renewables to overall installed power was estimated to be 12.0%.

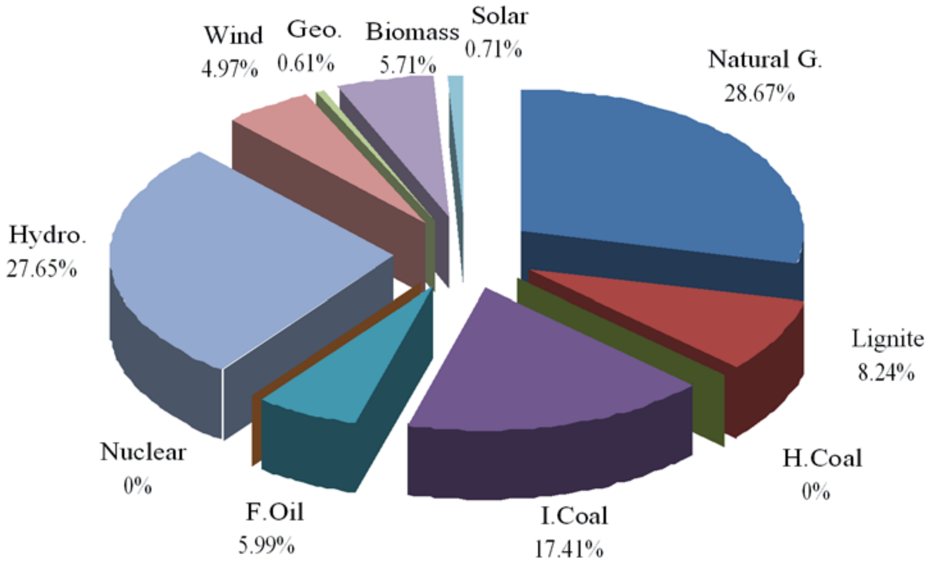

Fig. 4. Installed power rates under the condition of 40% investment subsidy for non-hydro renewables.

The total installed power of the non-hydro renewables was calculated as 13,405 MW when investment costs are reduced by 50% (Table 8). The installed power percentages of units for future additions in the planning horizon are given in Fig. 5.

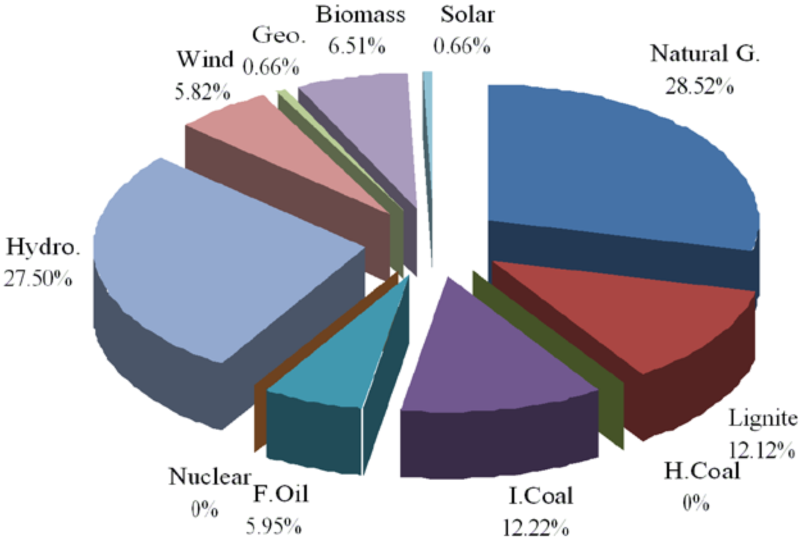

Fig. 5. Installed power rates under the condition of 50% investment subsidy for non-hydro renewables.

Finally, the ratio of the non-renewables to overall installed power was estimated as 13.65%.

8. Conclusion

Increase in the subsidy rates for non-hydro renewable power plants has not resulted in remarkable changes in lignite shares. NPP was not selected as a solution in any case since it has the most expensive cost. It has been observed that the share of imported coal decreases monotonically as the share of renewables increase. In parallel with developments in Turkish energy demand in the previous period, imported coal ratio in the total installed power had increased. This increase in total installed power caused the current account deficit of Turkey to widen and it increased the country’s dependence on imported fossil fuels. This study has shown that the proposed complementary incentive mechanism could help the country overcome its current account deficit problem caused by the high amount of coal imports.

Increases in the subsidy rates for non-hydro renewables contribute to the growth of renewable power plants. It was found that a total of 95,700 MW installed power addition is required until the 16th year without the subsidy. At that time, the ratio of RES will be about 37.30 % and the ratio of non-hydro RES to overall installed power is estimated as 9.45%. For the investment subsidy rates of 20%, 40% and 50%, it was observed that the ratios of non-hydro RES rose to 9.97%, 12.0% and 13.65 %, respectively.

It was found that an increase in the subsidy rates for non-hydro renewables does not affect the hydroelectric shares. The results show that hydroelectric capacity is almost stable while the renewable capacity increases. Turkey’s hydroelectric potential will be fully exploited within the next 15-20 years and a modest increase in the hydroelectric power share is anticipated in the next two decades. In view of this situation, effective and efficient utilization of RES-E is one of the most promising options for Turkey to decrease its foreign energy dependency and to mitigate GHG emissions. Turkey has amended its RESM, and inbalance cost has been inserted in FiT payments. Potential impact of the amendments on Turkey's RESM will be seen in the future. Considering the low utilization rates of the country's RES potential, policy makers should take market maturity and penetration level of RES in the power system into account for all future considerations of incentive policies. RES-E, especially electricity from wind, are often not balanced as it is really hard to forecast the wind speed. By considering this hurdle, implementation of this amendment may be postponed for a period of time, and different tolerance co-efficients can be defined for each renewable technology to diminish the financial risk that is to be faced due to the constant tolerance co-efficient. This study has shown that proposed incentive mechanism will increase the share of RES in total installed power. The actual percentage of capital subsidy and the cost of capital subsidy to the public treasury have to be calculated, and capital subsidy incentive can be complemented with FiT, which already exists in Turkey. The implementation of this incentive scheme could be started from unlicensed electricity generation from renewable power plants. One positive development has been the introduction of incentives for rooftop and facade PV systems of up to 10kW while another one is the exemption of excess generation from income tax through Renewable Energy Resources Support Mechanism (YEKDEM), which means that when the system generates more electricity than needed during the billing period, net metering customers get bill credits. These policies both lower the costs and enable smoother operation of the system by obviating the need for certain procedures. The existing 10-year subsidization period is shorter in comparison to many EU countries that tend to provide it for 15 years. Extending the “premium for use of domestic equipment” scheme, which is currently provided only to licensed plants, to the facilities of up to 10 kW for a period of five years would promote the use of renewable energy for self-consumption. It has been announced by the MENR that the RESM will no longer be in effect by the end of 2020. Incentives for RES should be continued. A crucial consideration that will come into play with the new incentive mechanisms is what type of energy sources they should cover and how they should be implemented based on the way resources are exploited. Incentive mechanisms adopted for rooftop solar energy systems should differ from those adopted for large-scale PV systems. Municipalities should cut down on taxes in order to promote RES. For instance, they can reduce municipal solid waste and environment tax for households or businesses that use RES. Lengthy licensing and authorization periods act as a major deterrent to RES investments. Such lengthy periods slow down project development phase and increase the Levelized Cost of Generating Electricity (LCOE) for RES in Turkey in comparison to many other countries. Hence, it is important that attempts be made to shorten these periods. Market-based emissions reduction mechanisms such as carbon tax and emissions trading should also be considered to promote RES-E deployment in Turkey.

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