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Energy Planning for Distributed Generation Energy System: The Optimization Work

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1. Introduction

Behind the public eye a quiet revolution is taking place, one that will permanently alter our relationship with energy. Most people today have heard about deregulation of the electric utility industry. Recently, privatization of most important energy sectors (electricity) in Iran has turned former monopolies into free market competitors. This has been specially the case with the unbundling of vertically integrated energy companies in the electricity sector where generation, transmission, and distribution activities have been split. Community consciousness of fossil fuel resource depletion and environmental impact caused by large scale power plants is growing. Because of large land area, losses in Iran power transmission network are significant. These reasons caused greater interest in distributed generation (DG) - small scale, demand site - technologies based on renewable energy sources.

Energy planning has to be carried out by modeling all sectors of energy system from primary energy sources (fossil fuels, renewable) to end use technologies for determination of optimal configuration of energy systems. Energy planning is a powerful tool for showing the effects of certain energy policies, which helps decision makers choose the most appropriate strategies in order to expand DG technologies and taking into account environmental impacts and costs to the community. Energy planning is carried out in Iran's energy system. Therefore, we have defined a reference energy system for Iran.

The aim of this paper is to evaluate the contribution of DG technologies when energy planning is carried out. For this purpose, the energy system optimization model MESSAGE has been utilized to take into account the presence of DG technologies. To provide a detailed description of DG production, a power grid scheme is considered. Planning procedure follows an optimization process based on the cost function minimization in the presence of technical and energy-policy and environmental constraints.

In Section 2, a brief explanation of model MEESAGE is given. In this section you will know main parts and aim of the model. In section 3, a brief review of the spread of DG technologies is reported. In Section 4, the reference energy system of Iran relating to the proposed optimization procedure and structure of model MESSAGE is illustrated. In section 5, Model validation is studied. The test results of several scenarios applied to Iran's energy system are reported in Section 6.

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2. Overview of model MESSAGE

MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) is a system engineering optimization model used for medium-term to long-term energy system planning (i.e. energy supplies and utilization), energy policy analysis, and scenario development. The model was originally developed at International Institute for Applied Systems Analysis (IIASA). The underlying principle of MESSAGE model is optimization of an objective function under a set of constraints that define the feasible region containing all possible solutions of the problem. In general categorization, MESSAGE belongs to the class of mixed integer programming models as it has the option to define some variables as integer. The model provides a framework for representing an energy system with the most important interdependencies from resource extraction, imports and exports, conversion, transport, and distribution, to the provision of energy end-use services such as agriculture sector, residential and commercial space conditioning, industrial production processes, and transportation. A set of standard solvers (e.g., GLPK, OSLV2, OSLV3, CPLEX, and MOSEK) can be used to solve the MESSAGE model. The degree of technological detail in the representation of an energy system is flexible and depends on the geographical and temporal scope of the problem being analyzed. A typical model application is constructed by specifying performance characteristics of a set of technologies and defining a reference energy system (RES) that includes all the possible energy chains that the model can make use of. In the course of a model run MESSAGE will then determine how much of the available technologies and resources are actually used to satisfy a particular end-use demand, subject to various constraints, while minimizing total discounted energy system costs which include investment costs, operation cost and any additional penalty costs defined for the limits, bounds and constraints on relations. For all costs occurring at later points in time, the present value is calculated by discounting them to the base year of the case study. MESSAGE is designed to formulate and evaluate alternative energy supply strategies consonant with the user-defined constraints such as limits on new investment, fuel availability and trade, environmental regulations and market penetration rates for new technologies. Environmental aspects can be analyzed by accounting, and if necessary limiting, the amounts of pollutants emitted by various technologies at various steps in energy supplies. This helps to evaluate the impact of environmental regulations on energy system development. For more details on the model and the mathematical representation of the reference energy system see [4],[5].

3. Overview of distributed generation technologies

The term distributed generation is defined in this paper as power generation technologies below 10 MW electrical outputs that can be sited at or near the load they serve or designed to deliver production to low voltage or medium voltage electricity networks. So, small hydro power plant, wind-powered generator, photovoltaic cells (PV), geothermal and solar-thermal power plants have been considered as DG technologies. In recent years, there has been a considerable expansion of DG technologies in Iran, thanks to progress in reliability and government policies. Despite the remarkable progress attained over the past decades, nowadays there are a few DG facilities in Iran (less than 0.5% of all electricity generation is supplied by DG facilities [1]). But DG facilities are expanding at high rate. It's predicted that 20% of demand for electricity will be supplied by DG facilities at 2030. The presence of DG facilities brings benefits both to the electric power system and the total energy system. With DGs energy can be generated directly where it is consumed. As a result, transmission and distribution networks are less charged; safety operation margins increase, and transmission costs and power losses are reduced [6], [7]. Since with most DG options renewable based technologies are used, there is a lower environmental impact. At the very least, the spread of DG technologies enhances supply safety in the energy field by reducing dependence on fossil fuels. Therefore, Renewable energy technologies are emerging as potentially strong rivals for more widespread use. Some DG technologies have already achieved a significant market share in comparison with other DGs in Iran. For example, Small hydropower systems are well established. Wind generators, which have been going through intense technology and market development, have achieved considerable market share, even though further technological improvements need to be made. Solar thermal power plants are also developed. But the solar photovoltaic and geothermal market is comparatively small. DG technologies are commonly connected to power distribution network.

4. The reference energy system

Fig. 1 illustrates the MESSAGE RES of Iran. As you can see, large conventional power plants production and DGs are assumed to be at the secondary and final level respectively. The ability of technology substitution is maximized by considering many end-use technologies. A few technologies have not been shown in fig. 1 because lack of space. The balance of primary energy sources is reported in table 1 [1].

	Electric energy (mboe)	Crude oil and Oil products (mboe)	Natural Gas (mboe)	Coal (mboe)	Biomass (mboe)	Hydro (mboe)	Renewables (mboe)
Production	-	1595.4	688.7	7.5	25.4	10.7	0.07
Imports	1.5	121.9	39.5	2.3	-	-	-
Exports	-1.6	-1115.7	-36.1	-0.3	-	-	-
International Marine Bunkers	-	-0.2	-	-	-	-	-
TPES	**-0.1**	**619.4**	**692**	**8.5**	**25.4**	**10.7**	**0.07**
TFC	**86.4**	**485.1**	**401.9**	**3.2**	**25.4**	**-**	**-**
Residential and commercial	44.5	90.5	263.6	0.07	25.4	-	-
Industry	28.7	60.7	107.1	1	-	-	-
Transport	0.08	267	3.3	-	-	-	-
Agriculture	10.4	26.1	0.3	-	-	-	-
Non-specified	2.7	-	-	-	-	-	-
Non-energy use	-	40.8	37.6	2.1	-	-	-

Table 1. Primary and End-use consumption energy source balance at the reference year in Iran

4.1 General information

We assumed that base year to be 2006 and time horizon to be 20 years. Model years were assumed to be 2010, 2014, 2018, 2022 and 2026. So, we have 4 periods for optimization. Discount rate is assumed to be 11% in Iran. The units for energy and power are MWyr and MW. All monetary values are given in dollars of 2006. (1$=8200 IRR - Iranian Rail -)

4.2 Load region

For those energy forms that cannot be stored such as electricity and heat, it is vital to model variation in demand within a year rather than considering only annual demand. The MESSAGE model allows modeling of variations in energy demand within a year with seasons, types of days or time of a day. This requires additional parameters to form the pattern of the energy demand. Parts of a year are referred to as load regions while energy demand pattern as per time-division, is termed as load curve. We assumed 4 seasons in this model, which every season contains 2 types of the day: holiday and workday. Load curves for some demands like space heat or space chill that their values depend on season are considered. For example it is assumed that demand of energy for space heating at winter is 50% of total annual demand of energy for space heating.

4.3 Energy forms and levels

We assumed 6 levels in this model. Each level contains some energy forms which are shown in fig. 1.
Effect of CO_2, SO_2 and NO_x emissions from large conventional power plants has been considered by adding a dummy energy form at the final level which is named environmental impacts. First the monetary damage costs for SO_2, NO_x and CO_2 per kWh electricity generated are derived. Emissions of CO_2, SO_2 and NO_x due to electricity production and Social costs of CO_2, SO_2 and NO_x emissions to air are reported in tables 2-3 [1]. We have defined some relations for electric output of power plants and emissions to the air according to the values in table 2. Costs of emissions are added to objective function. Therefore, minimization of objective function means to minimize emissions.
We have defined a dummy demand at the useful level to consider the exports in model According to table 1. We derived share of export of each energy carrier in total primary energy supply. For example, about 60% of oil production has been exported at the reference year. So we assumed that 60% of oil production can be exported in model years. The monetary values for export have been entered with negative sign.

	CO_2		NO_x		SO_2	
	Ton	$\frac{gr}{kWh}$	Ton	$\frac{gr}{kWh}$	Ton	$\frac{gr}{kWh}$
Steam power plant	58110093	628.346	90005	0.973	120211	1.300
Gas power plant	32249656	782.089	51609	1.252	52567	1.275
Combined-cycle power plant	19677900	487.766	30379	0.753	18934	0.469
Diesel	172120	743.178	338	1.459	1021	4.408
Hydro power plant	120464	6.595	0	0	0	0
Renewable	0	0	0	0	0	0
Total	110330233	-	172332	-	192733	-
Average	-	572.603	-	0.894	-	1.000

Table 2. Emissions to air at the reference year due to electricity production in Iran

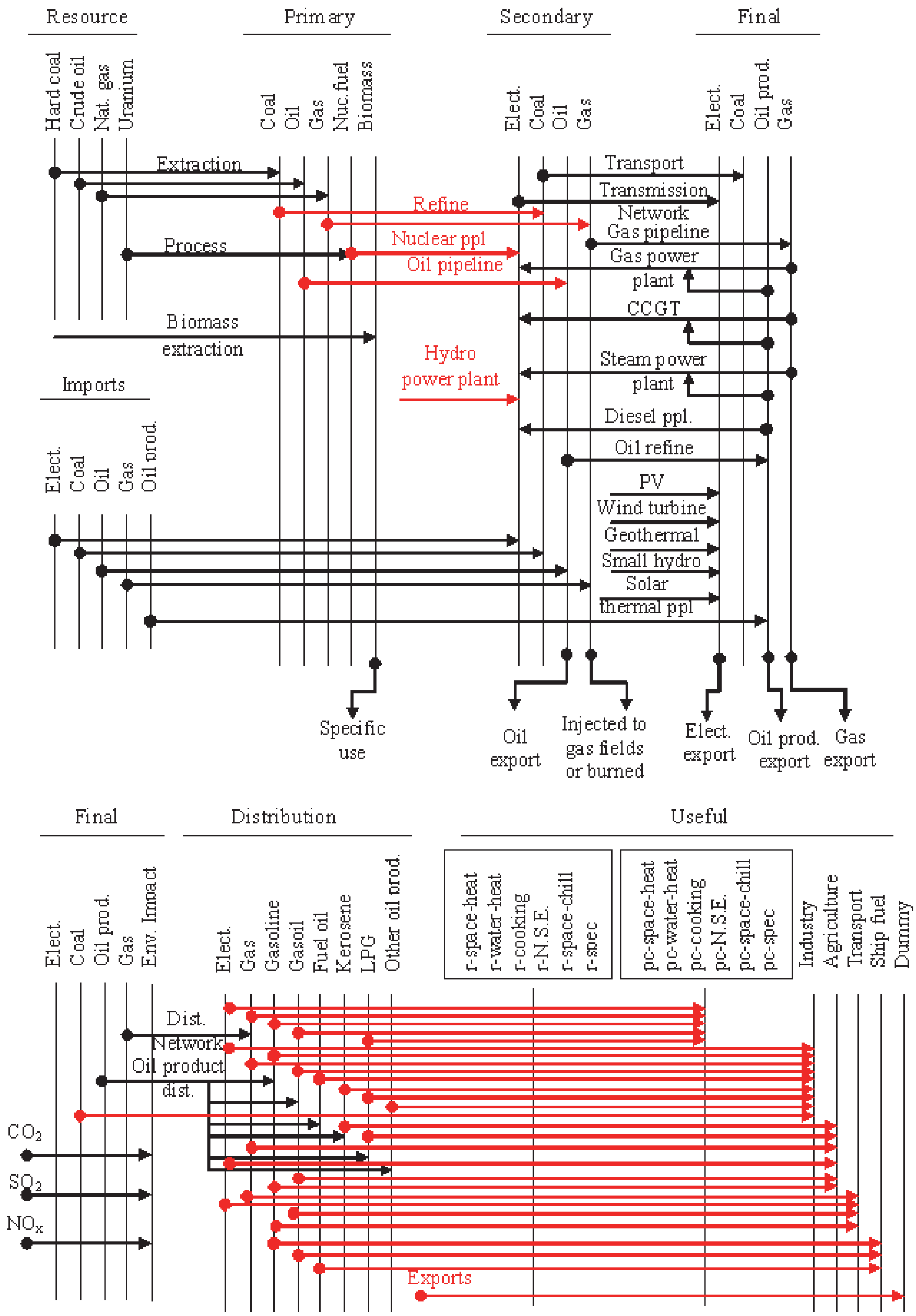


Fig. 1. Reference energy system of Iran

	CO_2	NO_x	SO_2
$\frac{Cent}{kWh}$	1.297	0.65	0.1

Table 3. Social costs of CO_2, SO_2 and NO_x emissions to air at the reference year (Cent per kWh electricity generated)

4.4 Demands

We assumed three types of demand: energy demands, non-energy demands and energy sector demands. Direct energy demands contains residential and commercial, industry, agriculture, transport sectors demands. In each sector share of different oil products is denoted and reported in table 4. End-use consumption at the reference year is reported in table 1. Energy carrier prices for end use technologies are reported in table 5. Annual growth rates of electricity demand and industry sector demand and other sectors demand are set at 8%, 10% and 2.6% respectively.

	gasoline	kerosene	gasoil	Fuel oil	LPG
Residential	0	6705494	848894	0	4456489
Public and commercial	107698	389908	1859630	1723850	26789
Agriculture	12572	38804	4150757	0	0
Transport	26669302	0	16407472	0	193085
Ship fuel	39477	0	475239	490687	0
Industry	37922	60546	2979076	5853445	0

Table 4.Oil products demand at the reference year in Iran (m^3)

Energy Carrier	Sector	Unit	Price
Natural Gas	residential	$\frac{Cent}{m^3}$	0.976
	Commercial		2.439
	Public		2.439
	Industry		1.689
	Power plants		0.357
	Transport		0.732
electricity	residential	$\frac{Cent}{kWh}$	1.255
	Public		2.216
	Industry		2.444
	Agriculture		0.259
	Other sectors		6.599
Oil products	Gasoline	$\frac{Cent}{Lit}$	9.756
	Kerosene		2.012
	Fuel oil		1.152
	Gasoil		2.012
	LPG		0.386
Crude oil	-	$\frac{\$}{Lit}$	60

Table 5. Energy carrier prices at the reference year in Iran

4.5 Resources

Hard coal, natural gas and crude oil resources as reported in [1] are 1.2×10^9 tons, 28.13 trillions m^3 and 138.2×10^9 barrels respectively.

4.6 Technologies

We have defined more than 110 technologies in our model. These technologies cover all part of Iran's energy system from extraction to end use. We can divide all technologies into 9 parts: extraction, refinery, transport, distribution, export, import, power grid, power plants and end use technologies. Most important technologies are shown in fig. 1. Most of technical and monetary information for technologies belong to Iran. Most of information in this subsection is extracted from [1]. For those that we don't have enough information, MENA or world data are used. Technical and monetary information about electric energy sector which contains power plants, transmission and distribution network and etc. are reported in tables 6-8. Data are extracted from [1], [2], [3], [8].

	Installed capacity (MW)	Activity (GWh)
Steam power plant	15553.4	92481
Gas power plant	14860.9	41235.3
Combined-cycle power plant	7675.5	40342.9
Diesel	417.9	231.6
Hydro power plant	6572.2	18265.6
Renewable (wind and solar)	58.9	125.4
Total generation capacity	45138.8	-

Table 6.Installed electric generation capacities and activity at the reference year in Iran

	unit	value
Gross production	GWh	192681.8
Transmission and subtransmission network losses	%	4.9
Distribution network losses	%	17.5
Own use (power plants)	%	4.2
Net electric energy import	GWh	2540
Net electric energy export	GWh	2775
End-use Consumption	GWh	148685

Table 7. Electric energy grid balance at the reference year in Iran

	Capacity factor (yrs)	Construction time (yrs)	Life time (yrs)	Investment Cost $\frac{\$}{kW}$	Investment Cost $\frac{Euro}{kW}$	Fixed annual cost $\frac{\$}{kWyr}$	Variable cost $\frac{Euro}{kWh}$	Efficiency %
Steam power plant	0.85	5	30	146.39	387	6.26	0.0125	36
Gas power plant	0.85	2	15	274.04	166	1.71	0.0325	28
Combined-cycle power plant	0.85	3	30	249.88	297	2.9	0.0163	44
Hydro power plant	-	-	-	3000	-	-	0.011	-
Nuclear power plant	0.9	-	35	2500	-	65	0.064$\frac{\$}{kWh}$	-
PV (MENA)	0.4	-	25	2000	-	-	0.08$\frac{\$}{kWh}$	-
Wind turbine (world)	0.3	-	20	1200	-	-	0.07$\frac{\$}{kWh}$	-
Geothermal power plant (world)	0.9	-	20	2000	-	-	0.045$\frac{\$}{kWh}$	-
Small hydro (world)	0.7	-	30	1700	-	-	0.097$\frac{\$}{kWh}$	-
Solar thermal power plant (MENA)	0.4	-	20	1750	-	-	0.2$\frac{\$}{kWh}$	-

Table 8. Main Cost and technology parameters of power plants in Iran (base year values)

	CO_2	NO_x	SO_2
	kton	kton	kton
Total	110800	170.3	187.6

Table 9. Emissions to air due to electricity production (Model Validation case study)

5. Model validation

In order to examine model validation, we assumed that all demands to be constant in all years. We have defined fixed bounds on activities of technologies. Demands and activities at all years are equal to base year. So, no optimization is done. In this case, Results of model should be same as real energy system. Emissions to air, in this case, are reported in table 9. If we compare results in table 9 (Model results) and data in table 2 (real data), we will see that they are very close together and it's what we expected. Maximum relative error is less than 3%.
In other case we have eliminated all constraints. It's obvious that in this case cost function should be decreased. The results show that cost function reduces about 67%. When no constraint is considered, with the aim of minimizing the cost function, model uses specific technologies and many technologies remain unused.

6. Results and discussion

In order to show the effectiveness of proposed reference energy system and procedure several scenarios have been analyzed for a time horizon of 20 years. Electric energy is estimated at 2427.1 $\frac{kcal}{kWh}$ for primary uses [1].
In DG-low scenario, DG technologies are not taken into account. No minimum level of expansion is imposed on DG technologies and share of DGs in total electricity production is assumed to be 0.5% and constant.
In DG-med scenario, the percentage of electricity production relating to DG technologies must reach 10% of total production by end of planning horizon.
In DG-max scenario, the percentage of electricity production relating to DG technologies must reach 20% of total production by end of planning horizon.
In all scenarios we assumed that DG technologies market penetrations on activities to be 100% which mean a growth rate of 2.
Results for each scenario are reported in tables 10-16. We see that in DG-max scenario transmission losses decrease 15% in comparison with DG-min scenario (from 4641 MWyr to 3930 MWyr). Also emissions to air decrease about 19.7% (from 305900 kton to 245600 kton). Emissions to air and transmission network losses are shown in fig. 2 and fig. 3 for different scenarios. In fig. 4 total installed capacity of DG technologies in different scenarios is reported. In DG-min scenario total installed capacity of DG technologies with a growth equal to 164% reaches 500 MW at the end of time horizon. In DG-max scenario total installed capacity of DG technologies reaches 27.1 GW at the end of time horizon. In DG-med scenario we see a constant growth rate in capacities in opposition to DG-max scenario. In fig. 5 total installed capacity of conventional power plants in different scenarios is reported. We can see that total installed capacity of conventional power plants growth equally in all scenarios until 2018. It means that in current situation which less than 0.5% of total electricity production belong to DG facilities, it lasts 8 years to DG technologies affect growth rate of conventional power plants and coordinate with consumption growth. In DG-min scenario total installed capacity of conventional power plant reaches 97.7 GW at the end of time horizon. In DG-min and DG-med scenarios total installed capacity of conventional power plant increase in all year, but in DG-max scenario a reduction in capacities occur from 2024 to 2026 which means that we don't need new capacities to be installed and we can discard old power plants which their life is finished.

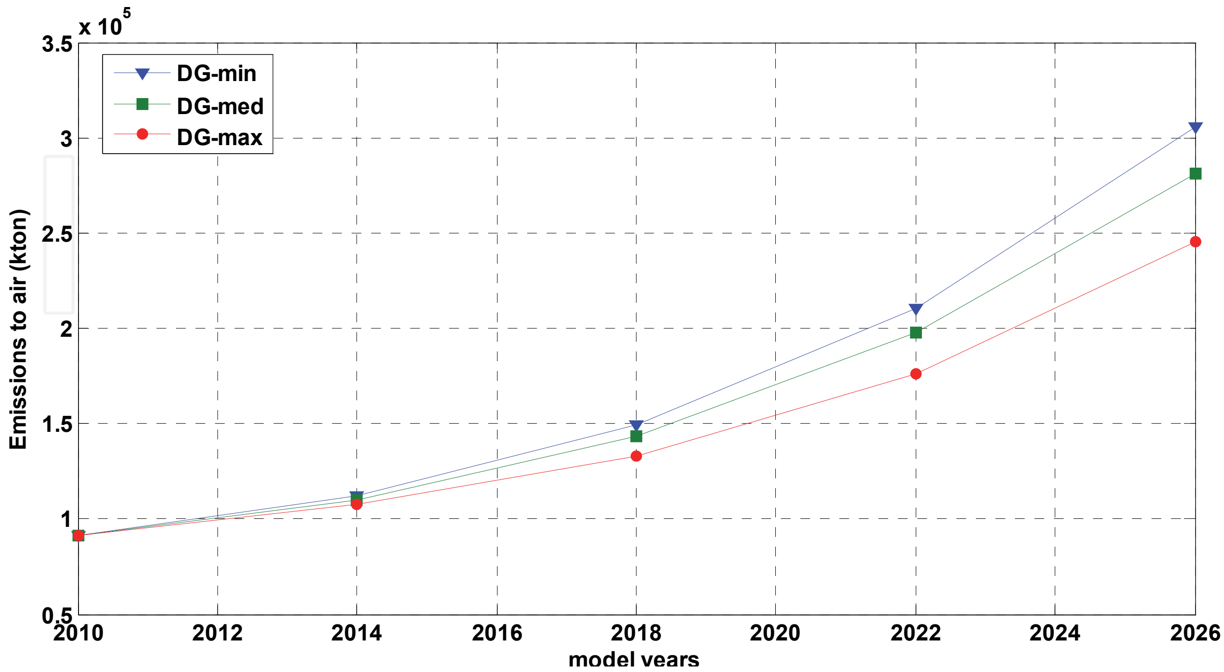


Fig. 2. Greenhouse gas Emissions

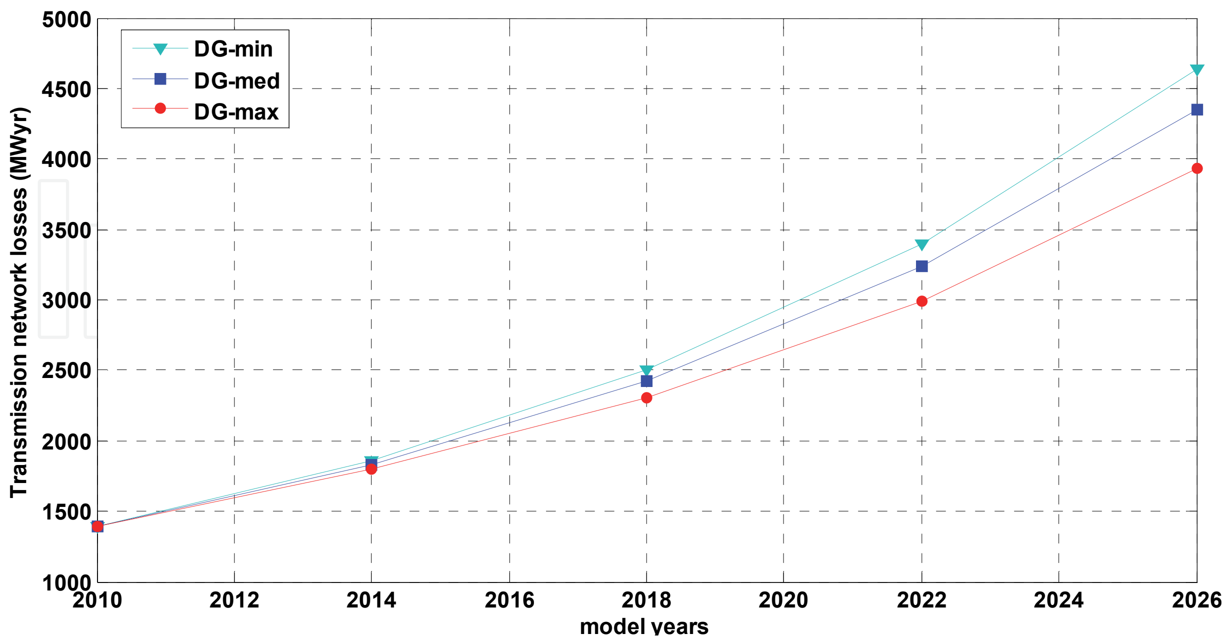


Fig. 3. Transmission network losses

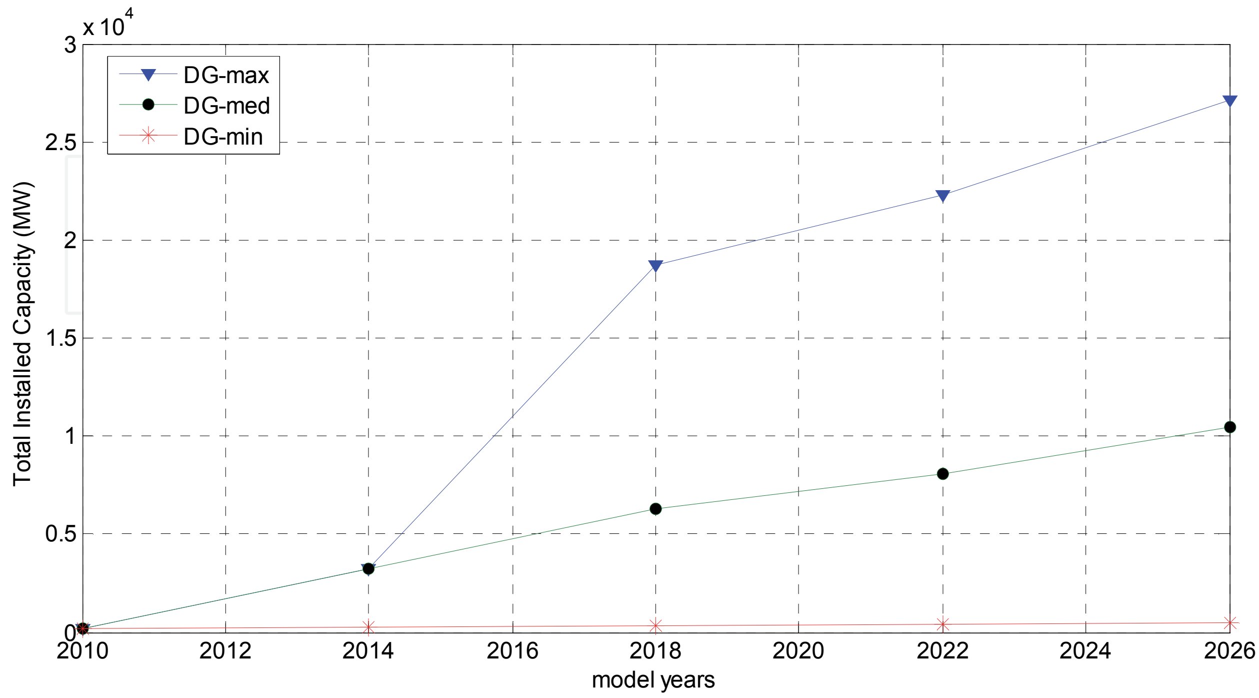


Fig. 4. Total installed capacity of DGs

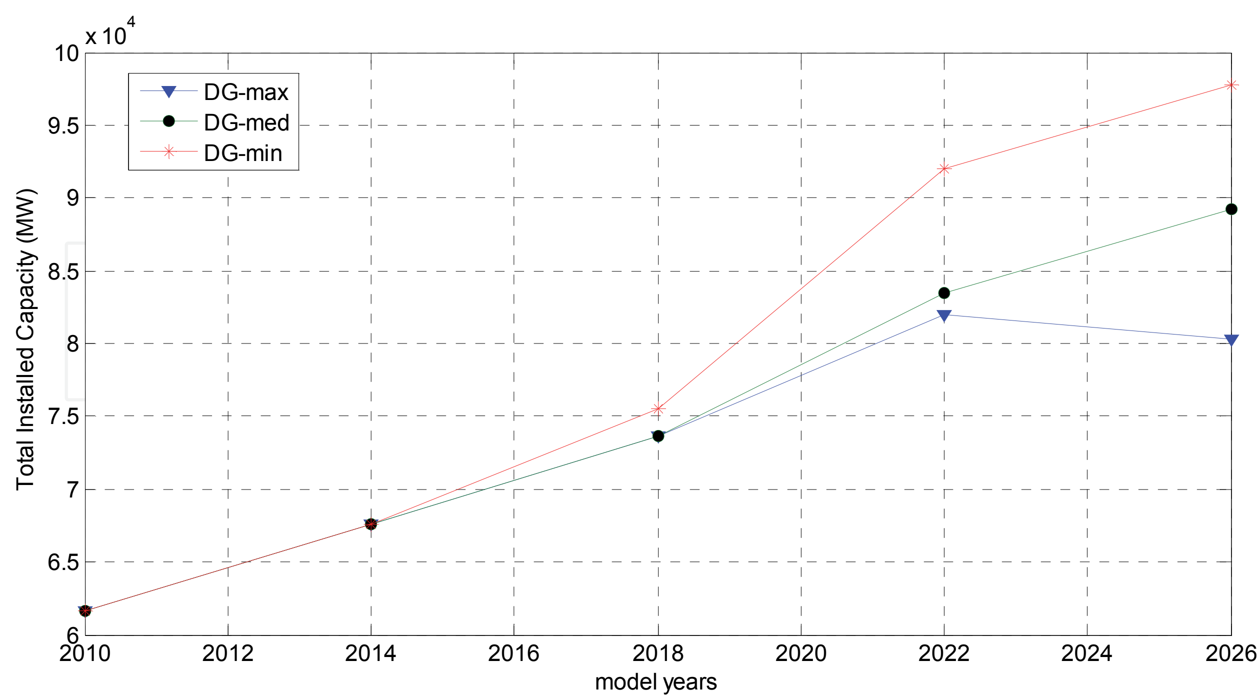


Fig. 5. Total installed capacity of conventional power plants

	DG-min	DG-med	DG-max
2010	91303.1	91303.1	91303.1
2014	112248	110294.8	107644.6
2018	149450.8	143303.4	132765.8
2022	210770.8	197652.1	176185
2026	305892.6	281445.5	245590.7

Table 10. Emissions to air (kton)

	Gas power plant	Nuclear power plant	electricity imports	Combined -cycle power plant	Steam power plant	Hydro power plant	Diesel	Total
2010	3274.8	250	263.9	7455.6	6549.5	9925.2	26.4	27745.4
2014	4382.5	0	352.7	7632.2	8765	15925.2	27.5	37085.1
2018	5909.9	0	475.6	9850.9	11819.7	21925.2	28.6	50009.9
2022	8026.3	0	645.9	15239.6	16052.6	27925.2	29.8	67919.4
2026	10968.2	0	882.7	25070.9	21936.5	33925.2	31	92814.5

Table 11. Activity of large conventional power plants and electricity imports (MWyr) – DG-min

	PV	Wind turbine	Geotherma l	Small hydro	Solar thermal power plant	Total
2010	0.2	44.6	0	32	0	76
2014	0	44.6	0	101.4	0	146.08
2018	0	44.6	0	152.4	0	197
2022	0	44.6	0	222.9	0	267.54
2026	0	20.3	0	345.4	0	365.61

Table 12. Activity of DG technologies (MWyr) – DG-min

	Gas power plant	Nuclear power plant	electricity imports	Combined-cycle power plant	Steam power plant	Hydro power plant	Diesel	Total
2010	3274.8	250.00	263.9	7455.6	6549.5	9925.2	26.44	27745.4
2014	4382.5	0.00	348.3	7175.8	8765	15925.2	27.51	36624.2
2018	5905.9	0.00	461.8	8414.7	11819.7	21925.2	28.63	48559.9
2022	8026.3	0.00	616.5	12174.4	16052.6	27925.2	29.79	64824.8
2026	10968.2	0.00	827.8	19359.2	21936.5	33925.2	31.00	87047.9

Table 13. Activity of large conventional power plants and electricity imports (MWyr) – DG-med

	PV	Wind turbine	Geothermal	Small hydro	Solar thermal power plant	Total
2010	0.2	44.64	0	32	0	76.8
2014	0.4	271.9	150	162	0	584.33
2018	0	271.9	483.9	820	0	1575.96
2022	0	271.9	483.9	2454.7	0	3210.5
2026	0	247.6	483.9	5118.3	0	5849.7

Table 14. Activity of DG technologies (MWyr) – DG-med

	Gas power plant	Nuclear power plant	electricity imports	Combined-cycle power plant	Steam power plant	Hydro power plant	Diesel	Total
2010	3274.8	250.00	263.9	7455.6	6549.5	9925.2	26.44	27745.4
2014	4382.5	0.00	342.4	6556.6	8765	15925.2	27.51	35999.1
2018	5909.9	0.00	438.2	5952.6	11819.7	21925.2	28.63	46074.2
2022	8026.3	0.00	568.3	7158.7	16052.6	27925.2	29.79	59761
2026	10968.2	0.00	747.4	10981.8	21936.5	33925.2	31.00	78590.1

Table 15. Activity of large conventional power plants and electricity imports (MWyr) – DG-max

	PV	Wind turbine	Geotherma l	Small hydro	Solar thermal power plant	Total
2010	0.2	44.64	0	32	0	76.8
2014	2.6	714.2	150	162	150	1178.8
2018	0	714.2	2255.5	820.1	150	3939.9
2022	0	714.2	3010.1	4151.9	150	8026.3
2026	0	689.9	3010.1	10043.1	150	13893.1

Table 16. Activity of DG technologies (MWyr) – DG-max

7. Conclusion

A reference energy system for Iran has been adopted to investigate DG diffusion in energy planning studies. The proposed approach is based on model MESSAGE that details the exploitation of primary energy sources, defined technologies, end-use sectors and emissions. Particular care has been given to the description of DG technologies and their energy injections in the electric grid. To this purpose, a representation of the electric grid with transmission and distribution network has been considered. The contribution of DG facilities in electricity generation under different policies has been shown by carrying out simulations on a realistic energy system of Iran. Test results have proved that energy policies aimed at reducing environmental impact of electricity production can be supported by DG technologies (mainly small-hydro and wind turbine). By promoting exploitation of DG technologies, reduction in conventional power plants production has occurred with a decrease in transmission losses and emissions.

8. References

[1] Iran Ministry of Energy, Deputy of Electricity and Energy Affairs. Energy Balance at 2006 (ترازنامه انرژي سال 1385), ISBN 978-964-91272-4-8 (http://pep.moe.org.ir/), 2008 (in Persian)

[2] World Energy Outlook 2005, Middle East and North Africa in sight. International Energy Agency. (www.iea.org)

[3] World Energy Outlook 2006. International Energy Agency. (www.iea.org)

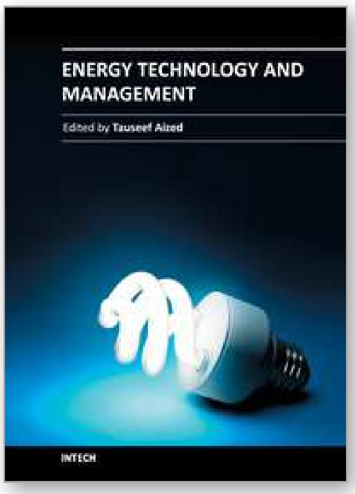
[4] Messner S, Strubegger M. User's Guide for MESSAGE III. WP-95-69, International Institute for Applied Systems Analysis (IIASA), Laxenburg, 1995.

[5] MESSAGE V User manual. International Atomic Energy Agency. October 2003.

[6] El-Khattam W, Salama M. M. A. Distributed generation technologies, definitions and benefits. Electric Power Systems Research 71 (2004) 119–128

[7] Pepermans G, Driesen J, Haeseldonckx D, Belmans R, D'haeseleer W. Distributed generation : definitions , benefits and issues. Energy Policy 33 (2005) 787–798

[8] 2007 Survey of Energy Resources. World Energy Council 2007. ISBN: 0 946121 26 5. (www.worldenergy.org)



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