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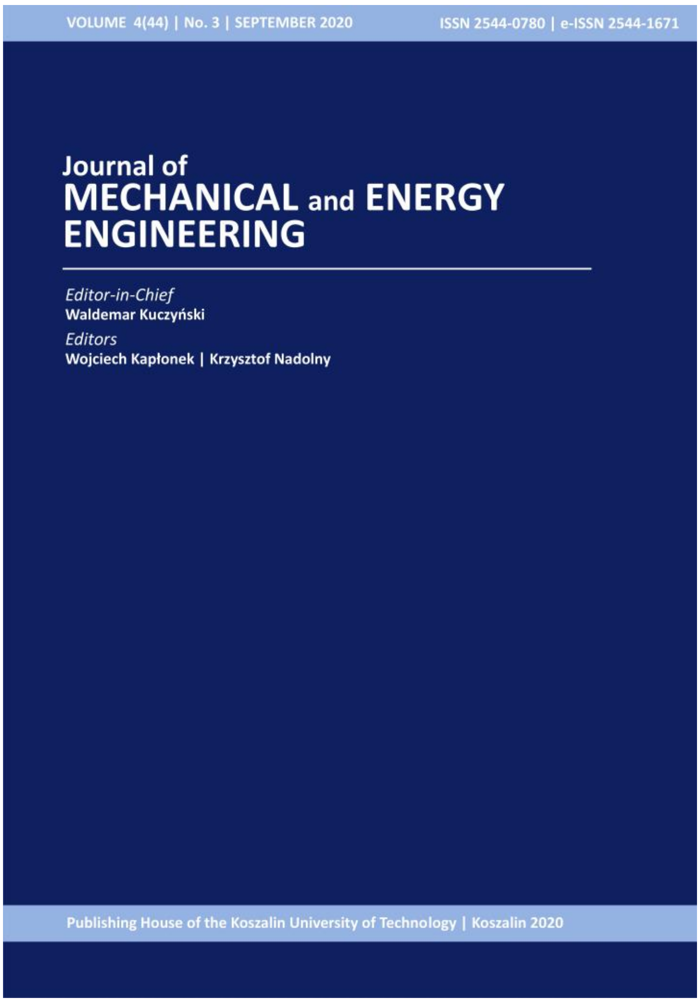

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RECENT UPDATES ON ENERGY PLANNING MODELS – A REVIEW

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Abstract: Energy is the most important part for community and financial growth of any country. Energy planning models play a vital role in strategy formulation and power sector progress. In this paper a systematic review and comparison of energy planning models developed and applied from 1977-2019 has been presented. The review indicates that most of the energy planning models has been presented and applied in developed nations. Only few numbers of energy planning models have been presented and applied in under developing countries. The review also shows the comparison of energy planning models applied in developed and under-developed countries. This review article will assistance the energy managers, scholars and strategy makers broadly.

Keywords: energy models, simulation, optimization, renewable energy

1. INTRODUCTION

It is very important to design energy as it is a crucial component for the progress of a nation. Appropriate planning is essential at the global and national level to manage energy requirement and consumption [1]. Energy security is a socio-economic and political aspect that promotes sustainable development (SD) in any country [2]. Recently, various contests have appeared in public such as variations in climate, security of energy consumption and requirement supply and financial decline. So, energy sector, particularly renewable energy is being managed to compete energy concerns. It is very important to build energy systems based on renewable energy. The renewable energy system can overcome pollution and improve the economy of a country [3]. Energy planning models support to forecast the effects and to evaluate the implications of energy strategy [4]. Various energy planning models have been established and used in various countries. Application of specific energy model depends on input and output data parameters, procedure and skills requirement. Some energy planning models are technically obvious and needed a large number of parameters, most of these are not freely accessible in developing nations. The skills and software requirements for some energy planning models are too difficult for establishing and running of models. Mostly, energy planning models have been established in developed states to evaluate a particular matter. A very few number of energy planning models have been used in developing countries [5]. Though many reviews have been done in previous studies, comprising [6-18], but a comparative, state of the art study is hardly found in research. The objectives to conduct this review are (i) to give a comprehensive, state of the art and systematic review of energy planning models applied in developed and under-developed countries from 1977-2019 (ii) comparison of energy planning models presented in developed and under-developed countries of the world.

2. REVIEW OF LITERATURE

There are many revisions on energy planning models have been done in literature. Studies conducted in many countries including [19-41] confirm the importance of applications of energy planning models for the formulation of energy policy selections at various stages. Huge number of researchers have done the research to develop the integrated energy planning models. A systematic and comprehensive review of energy planning models has been introduced in this review paper.

Landsberg [42] suggested a simple energy planning model for economic viability of solar energy transformation. Marchetti [43] established an artificial energy model for energy conversation. In 1977, Stern [44] developed a quasi-equilibrium power planning model to ensure the supply of exhaustible assets for crude oil utilization.

Smith [45] presented an optimization energy planning model for the requirement and consumption of energy in New Zealand. Riaz [46] suggested an approach for optimization of energy for industrial areas. Borg [47] presented an energy planning monopolist model for natural gas in USA for the period 1960–1966. Ambrosone et al. [48] established an energy planning model to manage the thermal power. Fawkes [49] developed an energy planning model for the management of energy by using soft system method. Hammarsten [50] presented review about various energy signature optimization models. Hsu et al. [51] established an energy optimization model by applying multi-objective programming techniques associated with input–output energy model. Rahman [52] planned an energy economic simulation model for energy economy policy. Natarajan [53] used an energy model for long-term forecasting of energy. Capros et al. [54] discussed the short/medium term of energy–economic by linking system of energy models. Baker and Finizza [55] reviewed the energy economic models and their applications for business strategy. Kaya [56] conducted a research on energy model credibility in Japan. Reister [57] presented numerous engineering approaches for the development of energy models for demand forecasting. Cai et al. [58] gave an energy planning model for community RES planning. Shi and Lu [59] presented a standard PILOT macro-economic energy model for china. Weyant [60] presented a review for energy policy modeling. Walter and Weyant [61] discussed the integrated energy modeling theory. Boyd et al. [62] illustrated a NAPAP Integrated Energy Model. Alam et al. [63] developed an energy planning model for integration of Bangladesh's rural energy systems. Werbos [64] compared the econometric models applied in energy planning modeling and engineering. Labys and Asano [65] discussed the process energy models for industrial applications. Poch and Jenkins [66] discussed the application of energy planning models by dynamic programming. Psarras et al. [67] introduced multi-objective programming techniques in large scale energy planning model. Labys et al. [68] studied numerous special energy planning models. Oliver [69] discussed the relationship between computer and mental energy planning models. Belyaev [70] applied pay-off matrix technique for the energy planning. Bowe et al. [71] presented the application of MARKOV energy planning model. Loagn [72] discussed the decision analysis techniques in energy economic modeling. Zeng et al. [73] applied multi-criteria evaluation procedure to explain the development of new energy planning system in Taiwan. Calderan et al. [74] suggested an energy planning model for food industry application. Joshi et al. [75] established linear energy optimization energy model for town application in India. Mohanty and Panda [76] introduced a computer based programming model to optimize energy system in industrial area. Mackay and Probert [77] argued the upcoming difficulties of oil related industry.

Nilsson and Soderstrom [78] proposed an energy planning model for optimization of electricity requirement in industry sector. Sinha [79] introduced a combined energy model for optimization of economic policy. Malik et al. [80] developed an energy planning model for India. Johnson [81] reviewed theories associated with energy management. Zaheer and Zheng [82] gave an energy planning model which is applied to simulate different energy economy and management functions. Kydes et al. [83] argued the current development in long term energy planning. Ramanathan and Ganesh [84] presented an AHP model to address the energy and environmental related systems. Huang et al. [85] directed a comparative review on decision making models in energy planning. Räsänen et al. [86] used Daily consumption pattern energy models to study the rate effects. Rodriguez and Vargas [87] developed a new model for the analysis of energy sector reforms. Spinney and Watkins [88] presented the application Monte-Carlo optimization procedures for integrated resource planning (IRP). Kumar et al. [89] studied the financial viability analysis of solar cookers by using cost functions. Thomas [90] conducted a review for the advantages and requirements for the transformation of renewable energy and technology development. Khemiri and Cenaffif [91] presented models for energy utilization and conservation. Sing et al. [92] established energy model by applying MOP procedure. Malik and Satsangi [93] conducted a study to review the energy related difficulties at various stages. Boonekamp [94] established a bottom–up simulation model to argue the application of energy in household. Neubauer et al. [95] gave an energy planning model for electric applications. Alam et al. [96] established a model for energy strategy to apply for electricity consumption. Martins et al. [97] proposed a method for energy management. Akisawa et al. [98] presented two energy models for optimization of power in Japan. Scott et al. [99] related a stochastic simulation model to integrated Mini CAM 1.0 model for energy development. Shrestha and Marpaung [100] developed an integrated model for long term energy planning. Sorensen and Meibom [101] developed a model for apply to different energy planning scenarios.

Tessmer et al. [102] developed TESOM model for the optimization of energy systems. Kavrakoğlu [103] presented an energy planning model at national scale. Samouilidis et al. [104] presented many approaches based on linear optimization models. Musgrove [105] applied MARKAL model for Australian energy planning system. Macal et al. [106] developed an integrated model for supply and demand for Illinois State. Hsu et al. [107] linked Leontief input output model with MOP model to develop a new model. Wene and Rydën [108] proposed a model for the management of community- based power systems. Harhammer and Infanger [109] established a DSS planning model for decision making in multiple scales of energy planning systems. Kahane [110] conducted a comprehensive review on optimization models for the management of different power Systems. Suganthi and Jagadeesan [111] developed MPEEE energy model. Tiris et al. [112] proposed linear optimization and multi-attribute models for long-term energy economy in Turkey. Arivalagan et al. [113] established a MILP energy model for the optimization of energy for industry. Schoenau et al. [114] developed an energy planning model for small scale power planning systems. Edmonds et al. [115] presented a Second Generation Model that is an energy planning model based on general equilibrium and used for energy economy. Lehtilä and Pirilä [116] developed an energy planning model for energy utilization and sustainable development. Martins et al. [117] proposed an energy model for electricity demand and supply management. Özelkan et al. [118] developed a model in order to optimize the hydroelectric electricity generation. Henning [119] developed an energy planning model called as MODEST model to reduce the initial and operational expenditures of energy requirement and supply. Heyen and Kalitventzeff [120] presented an energy optimization model to increase energy application efficiencies. Bojic and Stojanovic [121] developed MILP energy model for the optimization of heat and electricity generating policies in an industry. Farag et al. [122] developed various techniques for optimum energy strategies. Peippo et al. [123] adopted an optimization numerical multivariate model for the energy optimization. Gopalakrishnan et al. [124] developed an energy optimization model for the management of stand-alone power systems. Santos and Dourado [125] proposed an optimization method for the solution of power problems. Messener et al. [126] developed link between MESSAGE and MACRO energy planning models to evaluate the effect of energy supply expenses. Nagel [127] proposed a MILP energy model to define the economic policy. Bruhns et al. [128] argued a database technique for power planning modeling. Hektor [129] proposed various energy planning models to apply for bioenergy. Bojic [130] developed a network of energy module based on dynamic programming procedure for the optimization of energy system. Many researchers including [131-140] applied MARKAL energy model for large scale energy planning. The EFOM energy model was used in different states including [141-148]. There are also other energy planning models including LEAP, New Earth 21 and National Energy Modeling Systems which have been established and applied in many countries including [149-156]. The MARKAL energy model was applied in many states and regions for sustainable development including [157-186]. Dalton et al. [187-189] used an energy optimization modeling systems to investigate the practical and economic feasibility of grid. Park et al. [190] established genetic Algorithm method to resolve the generation expansion planning problem. Suganthi and Williams [191] proposed an energy planning model to determine optimal allocation of renewable energies. Rozakis et al. [192] presented a MILP energy model to calculate the supply of energy from crops. Sun [193] established an output-energy model. Yokoyama and Ito [194] formulated an energy optimization model for the design of power systems. Frei et al. [195] developed an efficient bottom up and top down emerging model. Beccali et al. [196] proposed multi-criteria decision-making method for the optimization of renewable energy technologies at local scale. Cormio et al. [197] used BESOM model to recognize maximum mixing configurations of renewable energy resources. Iniyan and Sumathy [198] presented an OREM energy model for the planning of renewable energy resources in India. Zhidong [199] proposed an econometric energy model. QUEST model can be applied for short to long-term energy planning [200]. Antunes et al. [201] presented a MO-MILP model. Huber et al. [202] developed an energy model ElGreen which is applied for the simulation of numerous energy strategies and various renewable energy technologies. Agoris et al. [203] applied MARKAL and WASP-IV energy models. Kong et al. [204] presented a model to solve the problems associated with power planning. Nakata et al. [205] established an optimization energy models for the green electricity of rural areas of Japan.

Kranzl et al. [206] applied Invert system to achieve efficient sustainable energy systems. Tsioliaridou et al. [207] presented an energy simulation model to check the performance of various power systems Caselles et al. [208] developed a Dynamic Energy Simulation Model to check the effects of political, technical and economic variables on decision maker. Teri [209] applied a MARKAL energy model for Spanish energy sector. Cicek et al. [210] presented different policies to optimize bio energy production. Huang et al. [211] proposed energy planning procedures for sustainable development in Canada. Dagoumas et al. [212] proposed GTAP-E energy model to solve the global economic policy issues. Sirikum et al. [213] established a MINLP energy planning model to solve the GEP problems. Hawkes and Leach [214] discussed three micro-CHP energy technologies for the cost effective policies. Nguyen [215] inspected he economic effects of electricity production in Vietnam. Schulz et al. [216] applied MARKAL energy model for the assessment of methanation plant in Swiss. Endo [217] applied Markal energy model to evaluate the performance of fuel cells vehicles in Japan. Chang [218] employed MULTEEE model to investigation the maximum power energy mix judgment in Taiwan. Meza et al. [219] proposed MOLP energy model for long term GEP. Kannan et al. [220] applied MARKAL energy for the UK energy systems. Song et al. [221] applied LEAP model for the assessment of environmental and economic policies of South Korea. Pokharel [222] established econometric models for renewable energy situation in Nepal. Klaassen and Riahi [223] applied combination of MESSAGE energy model, bottom-up LP energy model and MACRO energy model to discuss the impacts of external expenses of power generation. Swider and Weber [224] used a Single-node energy model for power production in Germany. Zouliasand and Lymberopoulos [225] applied HOMER to optimize renewable energy technologies. Ostadi et al. [226] used a model for recognizing optimum power consumption arrangements in manufacturing factory. Beck et al. [227] developed an optimization technique for optimal planning of energy. Papagiannis et al. [228] employed LEAP2006 energy model in different European countries for energy planning. Jiang et al. [229] applied MARKAL energy model to assess utilization of natural gas in china. Mavrotas et al. [230] established a Building energy model for hospitals. Gan and Li [231] proposed an econometric energy model for Malaysia's economic policy and energy planning up to 2030. Du Can et al. [232] applied Leap model to estimate the energy consumption in households, industrial sectors, commercial and transport sectors worldwide. Melton [233] developed a hybrid energy-economy technique to mitigate the climate change in Africa, Middle East and Latin America. Blanco et al. [234] established a DSS energy model for micro-hydroelectricity plants. Frombo et al. [235] presented EDSS for energy planning of forestry biomass application. Khakbazan et al. [236] developed an experiment in Brandon, Manitoba for checking the influences of fertilizer organization on energy inputs and GHG emissions. Popescu et al. [237] proposed a simulation and forecast energy model for the consumption heat in buildings. Parikh and Ghosh [238] developed an energy model to model the national economic policy. Daniel et al. [239] developed a method for power system planning India. Drouet and Thénié [240] developed an ETEM Model to evaluate the policies for SD. Bujak [241] developed a model to find optimum energy consumption. Sharma and Bhattacharya [242] established LP energy model for long term generation expansion planning problems. Andreassi et al. [243] proposed an energy optimization model for the economics of electricity delivery arrangements. The HOMER model is applied for the design of hybrid systems by [244]. Lagorse et al. [245] presented multi agent approach for energy planning. An energy optimization model was developed by [246] for small scale power generation systems. Ehsani et al. [247] presented a MILP model for power production. Morais et al. [248] developed a MILP model for optimization of electricity production technologies. Dementjeva and Siirde [249] used Leap energy model to optimize the energy sector in Estonia. Dagoumas and Barker [250] applied macro-econometric E3MG energy model for low-carbon economic policy for UK. Anandarajah and Strachan [251] used the MARKAL energy model to develop the policies for UK. Jaehnert and Doorman [252] coupled market energy model EMPS with IRIE energy model to formulate the energy policies. Park et al. [253] applied SD energy model and Leap energy model to evaluate CO2 declination in the Korean petroleum oil purifying industry. Connolly et al. [254] comprehensively reviewed 37 energy models to classify appropriate energy planning model. Mizraesmaeeli et al. [255] presented MILP model for generation expansion planning. Muis et al. [256] proposed MILP model generation expansion planning at domestic level. Unsihuay-Vila et al. [257] established MILP energy model for long-term energy planning. Mejia et al. [258] presented a linear optimisation model for generation expansion planning. Zakerinia and Torabi [259] proposed a MO energy model for generation expansion planning problems. Tekiner et al. [260] developed a MO model for generation expansion planning. Banos et al. [261] conducted a review of energy optimization approaches used in energy planning and problems for sustainable energy development.

Zhou et al. [262] investigated the effects of various energy policies for renewable energy management. Dagher and Ruble [263] used LEAP energy model for Lebanon's power sector. Connolly et al. [264] applied Energy PLAN model to evaluate how Ireland's power system might be 100% renewable. Føyn et al. [265] used ETSAP/TIAM energy model to inspect the development of a worldwide renewable energy systems. Davies and Simonovic [266] introduced an integrated ANEMI model for various water manage policies. Han and Lee [267] applied MILP model for Generation Expansion Planning. Pereira et al. [268] developed MO-MINLP model for Generation expansion planning. Markovic et al. [269] categorized thirteen computer approaches according to various planning stratigies. Huang et al. [270] used LEAP energy model for an economic outlook for Taiwan up to 2030. Manfren et al. [271] presented a comprehensive review on generation system. Shammakh [272] established a MINLP model for the reduction of total energy system budget. Kannan [273] applied the Markal energy model for electricity demand and sustainable energy sources. Careri et al. [274] planned MINLP model for generation expansion planning. Unsihuay-Vila et al. [275] established MO model for generation expansion planning. Karali [276] proposed HERMES energy model for energy planning. Choi and Thomas [277] established MILP model for Generation expansion planning. Han et al. [278] proposed MO-MILP model for optimization of electricity systems. Sharan et al. [279] recommended MILP model for generation expansion planning of electricity systems. Daioglou et al. [280] developed an energy simulation model for household's application. Stoyan and Dessouky [281] used MIP model to improve energy systems. Rentizelas et al. [282] developed LP model for long term planning of energy. Mejía et al. [283] established LP model for the optimum GEP. Bakirtzis et al. [284] developed MILP model for the possible results of the centralized generation expansion planning problems. Mardan and Klahr [285] combined DES and ESO models for a non-existing systems. Sarica et al. [286] applied an energy optimization method to explore dynamics of theoretically optimized energy sector. Bautista [287] applied the Leap energy model to analyze current and upcoming energy situation in Venezuela. Weijde and Hobbs [288] used a model to define the multilevel nature of energy transmission. Promjiraprawat and Limmeechokchai [289] applied a based scenario analysis method to evaluate Thailand's renewable energy policies. Comodi et al. [290] used TIMES energy model to assess local renewable energy policies for the town of Pesaro. Devogelaer et al. [291] applied TIMES energy framework for the Belgian renewable energy systems to recognize and discover pathways for 100% renewable energy achievement. Bauer et al. [292] developed REMID-R model for energy management. Amer et al. [293] mentioned that scenario energy planning stimulates tactical thinking. Hunter et al. [294] presented TEMOA energy planning framework for conducting energy systems analysis. Zhang et al. [295] applied a multi-period energy optimization model to estimate optimum ways electricity sector. Kannan and Turton [296] created STEM-E model originating from TIMES model for power systems. Cho et al. [297] presented a distribution algorithm that reduces overall budget of power application in buildings. Safaei et al. [298] established a model for optimization of cogeneration and solar energy structures. Pereira and Saraiva [299] proposed a long term GEP model. Kwon et al. [300] examined the generation expansion planning problems of South Korea by using MILP model.

In Tables 1 and 2 various energy planning models has been listed. The tables show that large number of energy planning models are presented in the developed countries like USA, China, Italy, Brazil, Portugal, Canada and Greece. In under-developed countries most of the energy planning models are presented in India, Iran, Turkey, Saudi Arabia, Malaysia and Iraq.

Aliyu et al. [301] discussed present and upcoming expansion strategies in Nigeria by applying LEAP energy model. Cai et al. [302] applied LEAP energy model to simulate various electricity planning strategies in china. Pan et al. [303] used LEAP energy model for long term energy consumption and demand improvement of energy. Pan et al. [304] presented Leap energy model to evaluate the direct energy consumption in Nigeria. Matar et al. [305] established KAPSARC energy model to discussed the energy problems challenged by Saudi Arabia. Hedenus et al. [306] discussed POLES energy model for the comprehensive illustration of the worldwide energy systems. Chang and Li [307] utilized a model to find the optimum generation expansion planning of the Southeast Asian countries. Amorim et al. [308] applied TIMES model for electricity application in Portugal up to 2050. Poncelet et al. [309] utilized TIMES model to assess the effect of employing long-term models with low time-based resolution. Iqbal et al. [310] presented a comprehensive review energy optimization models for renewable energy sources. Halkos et al. [311] used Leap model to explore the national targets for energy and environmental related issues. Oscan et al. [312] coped Long term GEP of Turkey with integration of RES. By presenting an optimization energy model for African nations such as Ethiopia, [313] established other scenarios for the nation's energy demand up-to 2050. Prasad et al. [314] applied Leap energy model to discuss the prospective of biofuels in the transportation and power generation sector. Kale and Pohekar [315] utilized LEAP energy model to evaluate requirement and consumption scenarios. Poncelet et al. [316] established Island model for electricity. Aghaei et al. [317] developed an integrated model for the optimum GEP and TEP. Sinha and Chandel [318] evaluated 19 energy models for hybrid power energy systems planning. Welsch et al. [319] utilized TIMES-PLEXOS energy model for electricity. Batas and Rajaković [320] combined EnergyPLAN and GenOpt models to reduce the budgets in the domestic energy systems. Mahbub et al. [321] joined EnergyPLAN and MOEA models for energy planning. Tigas et al. [322] used multi-regional TIMES energy model to inspect the large scale saturation of RES in power sectors.

Tab. 1. Energy planning models used/presented in developed countries from 1977-2019

Sr. No	Model Name	Country	Reference no.
1	A simple energy model for solar energy economics	U.K	[42]
2	Synthetic model of primary energy replacement	Russia	[43]
3	Quasi-equilibrium model	USA	[44]
4	An LP model for supply and distribution system	New Zealand	[45]
5	A Monopolist energy model of Natural gas markets	USA	[47]
6	A dynamic energy planning model	Italy	[48]
7	Soft-system energy planning model	U.K	[49]
8	An integrated energy planning model	Taiwan	[51]
9	Oak Ridge Industrial Model (ORIM)	USA	[57]
10	NAPAP Integrated Model Set	USA	[62]
11	Application of Morkov Model	USA	[71]
12	A combined wind/hydro/diesel energy systems model	U.K	[79]
13	A VAV systems energy model for simulation of energy management	Canada	[82]
14	Daily Consumption Pattern energy models	Finland	[86]
15	Application of Monte Carlo simulation techniques	USA	[88]
16	A simulation energy model	Netherland	[94]
17	Resource Policy Screening Model (RPSM)	USA	[95]
18	Environmentally friendly energy system models	Japan	[98]
19	Modeling with MiniCAM 1.0	USA	[99]
20	Global energy systems model and power subsystem model	Greece	[104]
21	MARKAL model	Australia	[105]
22	An integrated energy planning model	USA	[106]
23	Input-Output model	Taiwan	[107]
24	An LP (Linear Programming) model	Sweden	[108]
25	Decision Support System—Operation Planning (DSS-OP)	Austria	[109]
26	validated computer simulation model	USA	[114]
27	Finnish EFOM model	Finland	[116]
28	MLP approach with demand side management (DSM)	Portugal	[117]
29	MODEST model	Sweden	[119]
30	Developed a software package KOM9	Japan	[121]
31	MESSAGE–MACRO linking	Austria	[126]
32	A mixed-integer linear optimization model	Germany	[127]
33	MARKAL model	Netherland	[131]
34	GHHAGA model	China	[133]
35	MARKAL model	USA	[134]
36	MODEST model	Sweden	[136]
37	UK MARKAL model	UK	[139]
38	MARKAL model	Netherland	[140]
39	The EFOM 12C energy supply model	Belgium	[142]
40	The MARKAL-EFOM energy model	Canada	[147]
41	LEAP model	USA	[151]
42	AEPSOM energy model	Australia	[153]
43	Dynamic New Earth21 model	Japan	[154]
44	Linear process model (MARKAL-Ontario)	Canada	[157]
45	IEA-MARKAL model	Sweden	[158]
46	Markal-Macro energy model	Switzerland	[161]
47	MARKet al.location model	Canada	[162]
48	Application of MARKAL	Sweden	[164]
49	MARKAL energy-system modeling tool	China	[167]
50	Markal model	Italy	[168]
51	R-MARKAL model	Italy	[169]
52	Markal model	China	[170]
53	Markal and CIMS models	Canada	[171]
54	Markal model	Italy	[173]
55	photochemical model (TAPOM-Lite) and technoeconomic model (MARKAL-Lite)	USA	[174]
56	Markal model	Netherland	[175]
57	Application of the IEA-MARKAL models	Italy	[176]
58	Markal model	Japan	[177]
59	Markal model	Sweden	[178]

Tab. 1. Energy planning models used/presented in developed countries from 1977-2019 – *continued*

Sr. No	**Model Name**	**Country**	**Reference no.**
60	Markal model	China	[179]
61	Energy system model MARKAL	Japan	[180]
62	MARKAL model	Japan	[181]
63	A linked set of three models	UK	[182]
64	MARKAL-MACRO-Italy model	Italy	[183]
65	The Global MARKAL-Model (GMM)	Switzerland	[184]
66	Energy assessment models, HOMER energy model and HYBRIDS energy model	Australia	[187]
67	HOMER	Australia	[189]
68	Bottom-up and Top-down energy planning model	Switzerland	[195]
69	Energy flow optimization model (EFOM)	Italy	[197]
70	Macroeconomic, energy and environment sub-models	China	[199]
71	European Commission's QUEST model	Belgium	[200]
72	A MILP energy model	Portugal	[201]
73	ElGreen energy planning model	Austria	[202]
74	R-MARKAL and WASP IV models	Greece	[203]
75	A simple linear programming model	China	[204]
76	Optimization model	Japan	[205]
77	Invert simulation tool, a computer model	Austria	[206]
78	Computer simulation tool INVERT	Greece	[207]
79	Dynamic simulation model	Spain	[208]
80	Fuzzy interval semi-infinite programming model	China	[211]
81	General equilibrium model (GTAP-E)	Greece	[212]
82	SWISS-MARKAL model	Switzerland	[216]
83	Energy system model based on Markal model	Japan	[217]
84	MULTEEE model	Taiwan	[218]
85	A long-term multiobjective model	Mexico	[219]
86	LEAP model	South Korea	[221]
87	MESSAGE-MACRO	Belgium	[223]
88	Application of a stochastic electricity market model	Germany	[224]
89	Mix of global optimization and agent-based models	Australia	[227]
90	LEAP2006 and WASP IV models	Greece	[228]
91	Economic optimization model MARKAL	China	[229]
92	Fuzzy programming model	Greece	[230]
93	Integrated assessment models	USA	[232]
94	Environmental decision support systems (EDSS)	Italy	[235]
95	Mixed-integer linear programming	Portugal	[248]
96	Leap model	Estonia	[249]
97	Application of a macro-econometric hybrid model E3MG	UK	[250]
98	Leap model	South Korea	[253]
99	MILP energy model	Canada	[255]
100	A long-term, multi-area and multistage energy model	Brazil	[257]
101	Bi-level optimization approach	USA	[262]
102	EnergyPLAN	Ireland	[264]
103	ETSAP-TIAM global energy system model	Denmark	[265]
104	Scalable infrastructure model	South Korea	[267]
105	Application of Leap model	Taiwan	[270]
106	Linear programming MARKAL energy system model	Switzerland	[273]
107	MESEDES model	Brazil	[275]
108	An electric power system optimization model	USA	[277]
109	A bottom up simulation model	Netherland	[280]
110	Stochastic Mixed-Integer Programming approach	USA	[281]
111	Power system planning model	Spain	[283]
112	MILP energy model	Greece	[284]
113	DES and ESO energy models	Sweden	[285]
114	A stochastic two-stage optimization model	U.K	[288]
115	Markal-TIMES	Italy	[290]
116	REMIND-R model	Germany	[292]
117	TEMOA energy model	USA	[294]
118	Swiss TIMES energy planning model	Switzerland	[296]

Tab. 1. Energy planning models used/presented in developed countries from 1977-2019 – *continued*

Sr. No	Model Name	Country	Reference no.
119	A model for energy demand	Portugal	[298]
120	A long term generation expansion model	Portugal	[299]
121	LEAP-China-Electricity model	China	[302]
122	Leap model	China	[303]
123	A TIMES energy model	Portugal	[308]
124	Leap energy model	Greece	[311]
125	An energy model (OSeMOSYS) was set up	Ireland	[319]
126	EnergyPLAN with GenOpt energy model	Serbia	[320]
127	Multi-objective energy model	Italy	[321]
128	An energy market model	Ireland	[324]
129	POLES energy model	France	[325]
130	SAMBA energy model	Brazil	[326]
131	CA-TIMES energy economic systems model	USA	[327]
132	MARKAL model	Taiwan	[332]
133	A generic model	Portugal	[335]
134	A model using mixed integer linear programming (MILP)	Belgium	[336]
135	Leap model	China	[337]
136	Bi-level integrated power system planning model	China	[339]
137	Multi-level, multi-objective optimization model	Croatia	[340]
138	ORCED energy model Version 9	USA	[341]
139	Mixed-integer bilevel optimization model	USA	[342]
140	Application of TIMES model	Norway	[347]
141	A long-term enrgy planning model	USA	[350]
142	MILP model	USA	[351]
143	Markal	Poland	[352]
144	MILP model	Poland	[361]
145	open-source energy modeling system (OSeMOSYS)	Germany	[364]
146	Multi-scale Renewable Energy, District Level and Regional Level Tools	USA	[365]
147	UK Times Model (UKTM)	U.K	[371]
148	POLES	France	[377]
149	A multi-objective model	Portugal	[381]
150	MILP energy model	USA	[386]
151	EPLANopt energy model	Italy	[391]
152	open source energy system model Balmorel	Denmark	[392]
153	A hierarchical MILP model	Japan	[394]
154	K-MILP model	Italy	[395]
155	REITSP model	China	[411]
156	Regional Energy Deployment System (ReEDS) model	USA	[413]
157	A dynamic energy model	China	[416]
158	A MINLP multi-objective optimization model	China	[431]
159	The classic short term energy model	China	[441]
160	A new stochastic optimization model	Canada	[442]
161	A FSDFP enrgy model	China	[446]
162	A multi-stage stochastic optimization (MSO) model	U.K	[450]
163	RETs based energy model	South Korea	[454]
164	An innovative multi-objective optimization energy model	Italy	[455]
165	New hard-linked, linear optimization model	Spain	[456]
166	A multi-criteria model	Canada	[457]
167	MILP energy model	Australia	[464]
168	A scenario-based robust investment planning model	China	[471]
169	A mathematical energy model	Portugal	[477]
170	Bi-Level energy model	Spain	[479]
171	A stochastic scenario-based approach	Brazil	[484]
172	MILP energy model	Brazil	[488]
173	A multistage convex distribution system planning model	Brazil	[490]
174	TEMBA energy model	Sweden	[362]
175	Stanford PILOT energy model	USA	[496]
176	WEM energy model	USA	[497]
177	TVA hydro scheduling model	USA	[498]
178	Load model	USA	[499]

Tab. 2. Energy planning models used/presented in under developed countries from 1977-2019

Sr. No	Model Name	Country	Reference no.
1	An energy sector optimization model	Pakistan	[46]
2	Huq's energy model	Bangladesh	[63]
3	A simple linear model	India	[75]
4	IESIE energy model	India	[76]
5	Mathematical energy planning model	India	[80]
6	AHP energy planning model	India	[84]
7	A multiple objective programming (MOP) model	India	[92]
8	Revisited energy model	Bangladesh	[96]
9	A modified model	India	[111]
10	A linear optimization and multi-attribute value energy planning models	Turkey	[112]
11	A linear programming energy model	India	[113]
12	An energy model for household's energy services	South Africa	[132]
13	Fuzzy linear programming approach	Iran	[148]
14	Leap Model	Tanzania	[150]
15	LEAP energy model	India	[156]
16	Indian MARKAL model	India	[163]
17	MARKAL model	India	[172]
18	MARKAL model	Vietnam	[186]
19	An optimization model	India	[191]
20	An optimal renewable energy mathematical (OREM) model	India	[198]
21	Planning production simulation model	Thailand	[213]
22	A non-linear programming model	Iran	[226]
23	A comprehensive econometric model	Malaysia	[231]
24	Simulation models	Romania	[237]
25	An energy planning optimization model	India	[239]
26	A proposed energy model for optimization of energy	Iran	[247]
27	MILP energy model	Malaysia	[256]
28	A multi objectives energy model	Iran	[259]
29	Monte-Carlo simulation	Turkey	[260]
30	LEAP energy model	Lebanon	[263]
31	A multiperiod mixed-integer nonlinear model	Saudi Arabia	[272]
32	An optimal expansion planning energy model	India	[279]
33	A simulation energy model	Turkey	[286]
34	KAPSARC energy model	Saudi Arabia	[305]
35	A dynamic linear programming model	Singapore	[307]
36	A genetic algorithm approach	Turkey	[312]
37	Leap energy model	Ethiopia	[313]
38	Leap model	India	[315]
39	A new probabilistic model	Iran	[317]
40	Pakistan's LEAP model	Pakistan	[330]
41	Leap model	Iran	[348]
42	Leap model	Iraq	[353]
43	OSeMOSYS model	Tunisia	[375]
44	A new optimization framework for power generation	Iran	[379]
45	A bi-level multi-stage TEP energy model	Iran	[382]
46	KAPSARC energy model	Saudi Arabia	[383]
47	An optimization energy model for long term planning	Iran	[397]
48	A CMOPSO optimization model	Turkey	[398]
49	Two-level stochastic micro grid planning tool	Iran	[432]
50	HGAPSO energy model	India	[436]
51	A robust optimization based approach	India	[447]
52	A capacity expansion planning model	UAE	[459]
53	A new and combined model	Iran	[472]
54	A robust model for multiyear distribution network	Iran	[481]
55	HOMER Model	Mauritania	[492]
56	A hybrid power system	Indonesia	[494]
57	A mathematical energy model	Iran	[495]

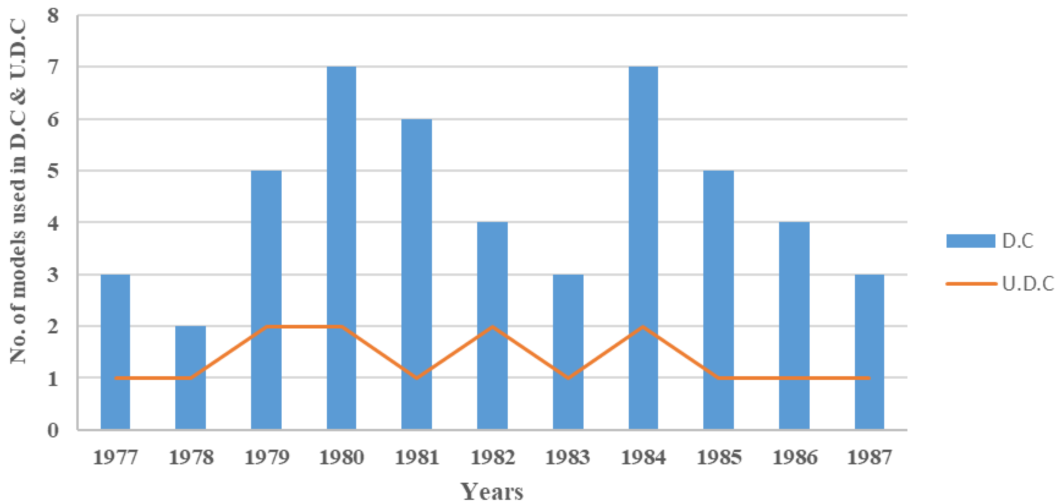

Fig. 1. Models presented in developed countries (D.C) and under developed countries (U.D.C) from 1977-1987

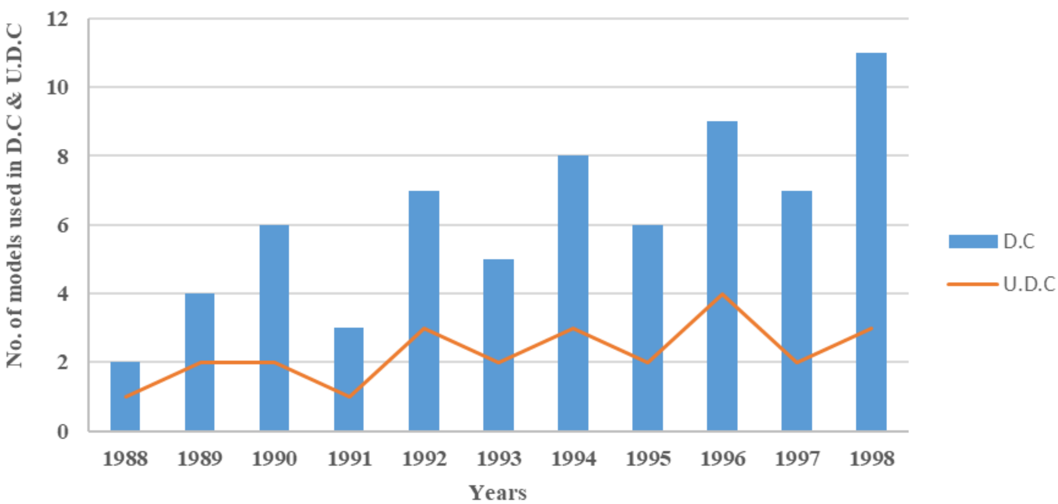

Fig. 2. Models presented in developed countries (D.C) and under developed countries (U.D.C) from 1988-1998

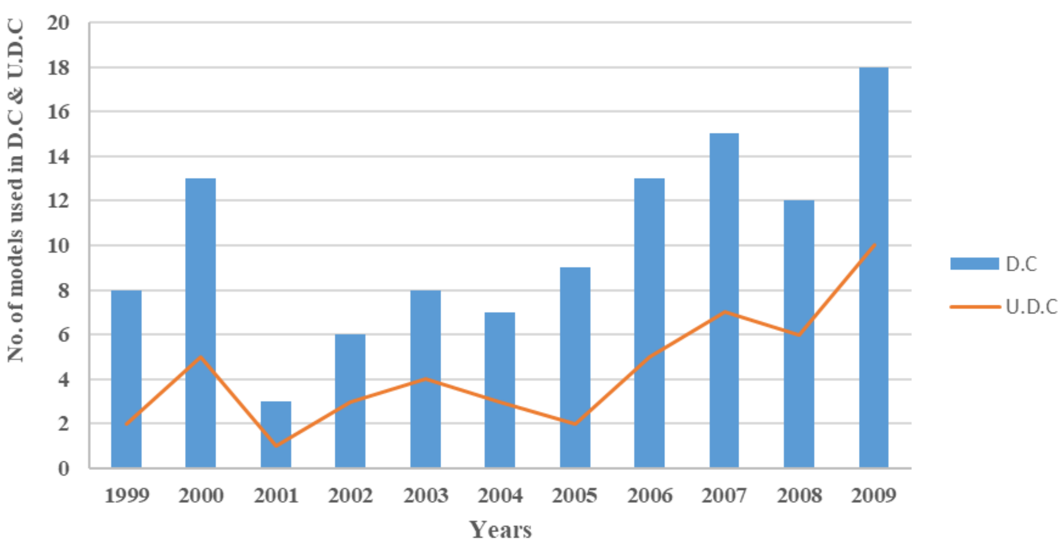

Fig. 3. Models presented in developed countries (D.C) and under developed countries (U.D.C) from 1999-2009

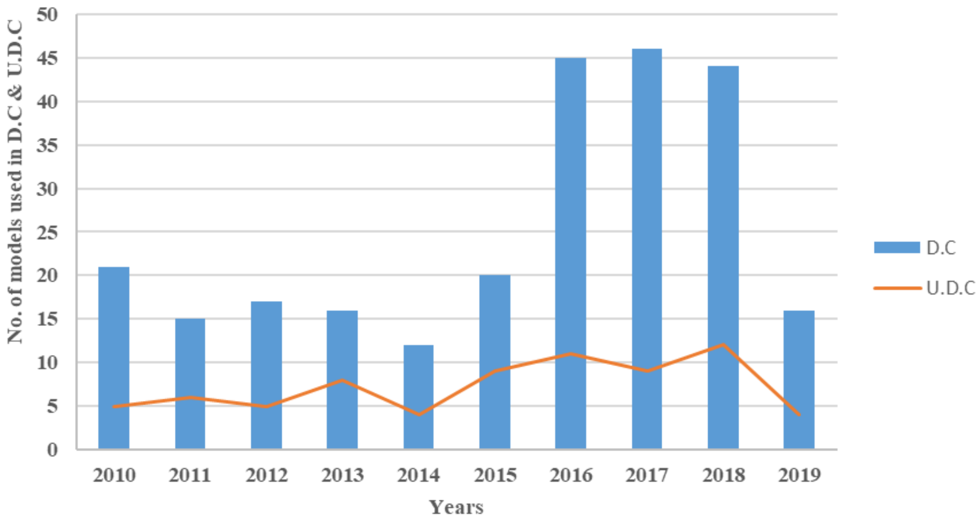

Fig. 4. Models presented in developed countries (D.C) and under developed countries (U.D.C) from 2010-2019

Wiernes and Moser [323] used an energy optimization model for generation expansion planning and TEP for upcoming European electric systems. Deane et al. [324] applied PLEXOS energy model to estimate the effects of integrating RE goals in domestic economic policies. Després [325] used combination of EUCAD and POLES energy models for power system optimization. Moura et al. [326] employed SAMBA energy model for South American energy planning system. The CA-TIMES optimization energy model has been used for California power System (v1.5) to know that how California can achieve the 2050 goals for GHG emissions [327]. Fitiwi et al. [328] presented a multi-node energy model for electricity. Munoz et al. [329] established a multi-node model for energy planning. Perwez and Sohail [330] used LEAP energy model to analyze alternative scenarios of energy in Pakistan. Lund et al. [331] presented a systematic review of various energy planning methods. By applying MARKAL model, Tsai and Chang [332] assessed Taiwan's greenhouse gas mitigation policies. Nowak et al. [333] established a model for evaluating the threat related to domestic RES goals. Mahumane and Mulder [334] applied LEAP energy model for energy planning. Stiphout et al. [335] proposed a model for storage and reserve requirements. Belderbos and Delarue [336] found the optimum power generation for various power technologies. Wu and Peng [337] used LEAP energy model to analyze the carbon emanations in power sectors of china. Kools et al. [338] developed a district electricity model. Zhang et al. [339] discussed the problems of RES to enhance energy application. Prebeg et al. [340] inspected the Long term energy planning for Croatian energy systems. The ORCED model was established [341]. Garcia-Herreros et al. [342] proposed a Mixed-Integer Bi-level energy optimization model for capacity planning. Wiser et al. [343] applied ReEDS for solar energy. Buonocore et al. [344] established EPSTEIN energy model to evaluate the impacts of emissions from electricity plants on human health. Pean et al. [345] applied PLEXOS for energy optimization. Berrill et al. [346] joined REMix model with THEMIS energy model to discuss various power scenarios for Europe up to 2050. Seljom et al. [347] established TIMES energy model for short term electricity planning. By using Leap energy model, assessments of various energy strategies implications have been conducted by [348]. Rajesh et al. [349] established a Multi-Stage Mixed Integer non-linear programming model for optimum GEP of power system. Park and Baldick [350] explored fluctuations in generation mix based on environmental and power policies. Go et al. [351] utilized MILP model for integration generation, storage and transmission planning. Jaskólski [352] used MARKAL energy model for Long- term energy planning. Saeed et al. [353] applied Leap energy model for the evaluation of sustainability in renewable energy of Iraq. By using the LEAP energy model, Kumar [354] evaluated the renewable energy potential in Southeast Asian nations. Using EnergyPLAN, Dominković et al. [355] used EnergyPLAN model to achieve 100 percent renewable energy system. Merrick [356] presented Single-node electricity model. Nahmmacher et al. [357] presented LIMES-EU energy model. Ploussard et al. [358] established a multi-node energy model. Wogrin et al. [359] proposed a Single-node energy model. Santen and Anadon [360] developed a generation expansion planning model. Wierzbowski et al. [361] presented an eMix energy model to focus on power sector. Taliotis et al. [362] used TEMBA energy model in the African power supply sectors. Nnaemeka et al. [363] utilized Leap model for power system until 2040. Löffler et al. [364] established a model for the worldwide power systems up to 2050. Tozzi and Ho [365] categorized 12 energy models on the basis their scales of applications.

Oree et al. [366] presented an assessment of generation expansion planning models. Moreira et al. [367] tested the energy co-optimization models. Emodi et al. [368] applied LEAP energy model in Nigeria to discover upcoming energy requirement and supply. Härtel et al. [369] proposed a Multi-Node transmission expansion planning model. Hemmati et al. [370] proposed an energy optimization model for optimum planning on RES. Nerini et al. [371] developed UK TIMES energy model to evaluate the UK's power systems. DeLlanoPaz et al. [372] presented a study on energy planning models. Ioannou et al. [373] provided a discussion of risk based energy models for sustainable power planning. Moradi et al. [374] presented a Single-node energy model for energy planning. Dhakouani [375] used OSeMOSYS energy model to the power of Tunisia. Lumbreras et al. [376] developed an optimum model for transmission network expansion planning. Després et al. [377] presented POLES energy model for simulation of electricity. Saiah and Stambouli [378] proposed upcoming scenario investigation for the Long term energy planning. Noorollahi et al. [379] discussed electricity GEP of Iran by proposing various RET. By applying genetic algorithm Sharifzadeh et al. [380] discussed the integration of RES from wind and solar energy. Luz et al. [381] suggested a Multi-Objective model for electricity generation expansion planning. Zolfaghari and Akbari [382] presented a Bi-Level energy model for TEP by wind investment. Matar and Elshurafa [383] applied KAPSARC Energy Model to assess the energy policy. Lopion et al. [384] studied the historic developments energy systems models. Kotzur et al. [385] established three single-node energy models. Lara et al. [386] presented a Multi-node energy model for Texas. Neniškis and Galinis [387] presented an electricity and heat energy model of Lithuania. Pineda et al. [388] developed a Multi-node energy model for Europe. Welder et al. [389] utilized a Multi-Node model for power-to-hydrogen energy. del Granado et al. [390] presented energy economic models for energy transition. EPLANopt model is applied for short term energy policy by [391]. Wiese et al. [392] established an energy model in GAMS concentrating on power sectors. Hilbers et al. [393] established a Single-node energy model of Great Britain. Yokoyama et al. [394] presented a building energy model. Zatti et al. [395] presented a district and building models for energy planning. Zhang et al. [396] suggested a Single-node model. Ahmadi et al. [397] established an energy optimization model for Long term energy planning. Deveci and Güler [398] proposed CMOPSO model for RE planning. Koltsaklis and Dagoumas [399] presented a comprehensive study on GEP problems. Sadeghi et al. [400] discussed GEP problems. Komiyama and Fujii [401] inspected massive integrations of variable Renewable Energy Sources into electricity-generation of Japan. Aryandoust and Lilliestam [402] applied a bi-level optimization model for German upcoming electricity systems. Flores-Quiroz et al. [403] proposed a methodology to discuss GEP problems. Garcia-Herreros et al. [404] suggested a Mixed-Integer Bi-Level energy optimization model for planning. Collins et al. [405] conducted a discussion for integration of short- term fluctuations of power systems to energy models. Alizadeh et al. [406] presented a study on classification of latest energy mechanisms in electric systems. Papaefthymiou and Dragoon [407] discussed the critical stages for building energy systems. Mikkola and Lund [408] discussed optimum ways for the management of the renewable energy systems. Palmintier and Webster [409] inspected the effect of working flexibility on generation expansion planning. An approach is presented by [410] for balancing market expenditures and requirements. Ji et al. [411] discussed power systems with various RE portfolio standards and capacity requirement setups. An approach is presented by [412] to measure the impacts of variables and intermittent Renewable Energy Sources on Long- term energy optimization. Krishnan and Cole [413] applied a linear programming model to measure the impacts of spatial resolution of power systems. Poncelet et al. [414] discussed the generation expansion planning problems. Pereira et al. [415] presented an energy optimization-based GEP model to calculate impacts of variable Renewable Energy Sources on efficiency of thermal power plants. Lu et al. [416] established a Multi-Year GEP model to analyze the RES investments. You et al. [417] proposed the coordinated generation expansion planning under high air flow rate. Blanchard [418] discussed the upcoming development of Macro-Economic models, with particularly emphasis on CGE models. Rasouli and Teneketzis [419] developed an approach for generation expansion planning. A review has been conducted by [420] of decision making models. Saavedra et al. [421] presented a study of applications of Sustainable development approaches in RE. Gravelsins et al. [422] discussed that how SDM can be applied in modelling the power systems. Najafi et al. [423] applied a novel approach for medium-term management of an energy system. Guler et al. [424] constructed a theoretical framework of regional energy hub. Wang et al. [425] developed an automatic and linear modeling methodology for energy optimization hub systems. Mohammadi et al. [426] applied various concepts and energy models for energy hub.

Hemmati et al. [427] suggested a sustainable development structure for optimum design of energy hub systems. Zhan et al. [428] established a stochastic model for solving the energy problems. Zhan et al. [429] developed a bi-level energy model to resolve generation expansion planning problems. Resener et al. [430] conducted a study of energy models for the solution of energy planning problems. Zheng et al. [431] developed a robust MINLP energy model that improves the alignment, sizing and operation of CCHP system. Hemmati et al. [432] presented a two-level energy planning algorithm. Rad and Moravej applied genetic algorithm technique for generation expansion planning. da-Silva developed [434] MOEA technique for generation expansion planning. Rastgou and Moshtagh [435] introduced Firefly algorithm technique. Sisodia et al. [436] applied hybrid algorithm model for resolving TEP problems. Guerra et al. [437] developed a combined energy model to resolve GEP and TEP problems. Moradi et al. [438] developed an algorithm technique to resolve the TEP problems. A social-spider algorithm is used by [439] to solve TEP problems. Rathore and Roy [440] introduced a STEP energy approach to discuss the impacts of plug-in electronic vehicles. Du et al. [441] determined that the electronic system flexibility is to be overvalued if no or basic operation restrictions are measured. A Risk-Averse Stochastic programming model has been introduced by [442] for grid power management. Wu et al. [443] developed TEP model for renewable energy. Yeo and Lee [444] introduced a sequences of various energy planning approaches for urban energy planning. Lu et al. [445] developed an Interval-Fuzzy programming model to enhance China's power management system. Zhang et al. [446] proposed a Fuzzy-Stochastic system model for supporting SD and management of power systems. Gupta and Gupta [447] introduced a robust optimization energy model for micro grid power planning. Falke et al. [448] proposed a Multi-Objective energy optimization and simulation model for the construction of RES. Muller et al. [449] introduced of a methodical modeling technique for multi-modal energy systems planning. Ioannou et al. [450] reviewed the influence of multi-modal power systems modeling on distribution and transmission grids. Saboori and Hemmati [451] discussed the optimum planning of ESU's as a Mixed Integer and nonlinear energy optimization problems to increase the benefit of supply companies. Li et al. [452] established a two-stages energy optimization model to solve the problems of ESU's and DGs. Guerra et al. [453] proposed MILP model for GEP in an interconnected energy system. Min et al. [454] applied a Stochastic optimization model for Long-term capacity expansion planning of energy systems. Mahbub et al. [455] used a new methodology for Long-term power planning. Khan et al. [456] suggested a partial equilibrium linear model. Parkinson et al. [457] developed systems analysis model by applying Multi-Criteria investigation methodology. Lv et al. [458] proposed an energy optimization model for planning of water-energy system. Saif and Almansoori [459] developed a MILP energy model to enhance long term capacity expansion planning. Smaoui and Krichen [460] applied an energy simulation-based model for optimum energy planning. Hickman et al. [461] used a Mixed-Integer model for optimum working of a system. Tomar and Tiwari [462] applied HOMER energy model for economic analysis of grid-connected power systems. Yang et al. [463] presented a review to address the sizing of battery for renewable energy system. A review has been conducted by [464] on existing models for the optimum design of PV-battery systems. Huang et al. [465] developed a Mathematical Decision-Making model for ideal storage ability in grid connected PV power system. Sani Hassan et al. [466] proposed MILP model linked with DER-CAM model to define maximum power flows. Grover-Silva et al. [467] applied power flow distribution grid planning model to address sizing and placement of supply grid connected battery system. Ehsan and Yang [468] established a distributed GEP model to decrease power losses. Ehsan et al. [469] proposed distributed generation investment model to enhance the value of power in distribution system. The investment planning model developed by Ehsan and Yang [470] uses DGP and storage arbitrage advantage to enhance distribution system operator's benefit. Ehsan and Yang [471] developed a MMIP energy model for energy planning. A particle swarm optimization model introduced by Hemmeti et al. in [472]. A Harmony Search Algorithm technique is in [473] for energy planning. Zhang [474] developed a Non-Dominated Genetic Algorithm Approach for energy planning. Zhang et al. [475] used a hybrid technique for energy planning. A Multi-Stage Long-term distribution planning model was proposed in [476,477]. A Multistage distribution model considering energy storage measures was developed by Shen et al. [478]. A bi-level energy model was introduced by Asensio et al. [479]. A Two-Stage Robust programming model was developed by Amjady et al. [480]. Ahmadigorji et al. [481] suggested a reinforcement GEP model. A MILP model was presented by Arias et al. [482]. A second-order conic chance-constrained energy model was proposed by [483]. Ortiz et al. [484] applied a MICP energy model for energy planning. An integrated energy planning model was developed by [485]. A deterministic energy model was introduced by [486]. A MILP energy model was presented by [487]. Dominguez et al. [488] proposed a robust two-stages short-term energy planning model. Lipu et al. [489] used HOMER for sensitivity investigation on hybrid renewable energy system. A stochastic mixed-integer convex programming model has been suggested by

Home-Ortiz et al. [490]. Peerapong et al. [491] applied HOMER energy model to maximize the electrification development in diesel based generator in Thailand. Soukeyna et al. [492] utilized HOMER energy model to achieve a viability study on generating energy from hybrid renewable system. Sadati et al. [493] used HOMER energy model for energy planning in Mediterranean area. Hantoro et al. [494] presented HOMER energy model to discuss the energy requirement and design of hybrid systems in Indonesia. Qolipour et al. [495] applied HOMER and MATLAB models to suggest a mathematical energy model for improving the renewable electricity expenses.

3. CONCLUSIONS

The different energy optimization models presented/applied in developed and under-devolved countries have been reviewed. The review show that large number of models have been presented and applied in developed nations like USA, China, Italy, Brazil, Portugal, Netherland, Japan, Sweden, Spain, France, Denmark, Germany, Belgium, Taiwan and Switzerland. Only a few numbers of energy planning models have been used in under-developed countries like India, Iran, Turkey, Malaysia, Iraq Saudi Arabia, Bangladesh and Pakistan. For sustainable development and renewable energy concerns, major factors for the application of energy planning models are life span of the energy system, consistency, alternating supply, geographical location, investment and community involvement.

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Biographical notes

Biographical notes were not provided by the authors.