Optimization and Planning of Energy Systems using MESSAGE Code

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Abstract: This paper deals with energy system optimization and planning using message code. The problem is formulated as a mixed integer programming problem with constraints on activities and installed capacities. The objective function is the minimization of the total installation cost including the investment cost, the variable and fixed operation and maintenance costs, and the constraints violation cost. Various operation and environmental constraints are considered. The obtained results show the capability of message code to model and solve the complex energy planning problem considering different types of constraints.

Keywords: Energy planning, Mixed integer programming, Energy mix, MESSAGE code, Techno economic optimization.

1. INTRODUCTION

The energy demand and greenhouse gas emissions are proportionally increased with the industry development and demographic evolution [1, 2]. It can be satisfied by an appropriate energy planning process. This last can be defined as the process of developing long-range policies to help guide the future of a local, national, regional or even the global energy system [3].

However, each country has its own specific energy planning model depending on their natural resources, energy policy, population, industry and so on. Therefore, the energy planning problem modeling is a complex optimization problem that requires the mastering of the actual energy system structure, the energy resources and their reserves (fossil, fissile and renewable), the projected load demand and detailed techno economic data.

The IAEA proposes a set of free energy planning tools which each tool has its specific application [4]. The MESSAGE code is specialized in power supply planning and it is widely used by energy planning utilities and researchers [5-13]. It is based on the formulation of the problem as a mixed integer programming problem with constraints on activities and installed capacities. The objective function is the minimization of the total installation cost including the investment cost, the variable and fixed operation and maintenance costs, and the constraints violation cost. The integer decision variables represent the installation decision of installing such a technology, and the continuous decision variables represent the size of the technologies [14-15].

This paper deals with energy system optimization and planning using message code. The problem is formulated as a mixed integer programming problem with constraints on activities and installed capacities. The objective function is the minimization of the total installation cost including the investment cost, the variable and fixed operation and maintenance costs, and the constraints violation cost. Various operation and environmental constraints are considered. The obtained results are technically analyzed which show the capability of message code to model and solve the complex energy planning problem with satisfaction of constraints.

The rest of this paper is organized as follows: The long term energy planning problem is presented in section 2. The results of simulation are presented in section 3 and the gained conclusions are presented in section 4.

2. LONG TERM ENERGY PLANNING PROBLEM

In this paper, the energy planning problem is modeled and solved using MESSAGE code of the IAEA [15]. This last, was originally conceived at the International Institute for Applied Systems Analysis (IIASA) during the seventies (1970s). after that, the IAEA has enhanced it by adding of a user-interface to facilitate its application [15].

MESSAGE code can deal with the energy planning and optimization, analysis of power plants gas emissions, fuel cycle facilities, and so on. It is based on mixed integer linear optimization with constraints.

$$\min \sum_{j} \sum_{t}^{T} \left[d_t^0 \Delta_t X_{jt} \times i_{jt} + d_t^C \Delta_t Y_{jt} \times O_{jt} \right] \qquad (1)$$

Where,

- T= The number of period in the model
- J and t: technology and period, respectively
- and discount factors applied for operating and capital cost respectively.
- Δt: length of period t in years
- Xjt: fuel consumption of technology j in period t
- Yjt: capacity variables for annual new installation of technology
- Ijt: specific investment of technology j at period t
- Ojt: operating cost of technology j in period t.

The equality constraint of the optimization problem is presented as follows:

$$\sum \text{supply} \ge \text{Demand} \qquad (2)$$

or

$$\sum_{j=1}^{J} \sum_{i=1}^{I} \eta_{i,j,t} \times X_{i,j,t} \ge D_{i,t} \qquad (3)$$

With:

- t: period of study
- n: efficiency of plant
- X: installed capacity
- I: modeling years
- j: conversion technology
- D: Demand

Message requires detailed techniques and economics data related to the energy policy of the countries and the energy conversion facilities. Based on the modelling of the energy system as energy chain consisting various energy forms levels and energy conversion technologies.

Figure 1 presents an energy chain. From this figure, it can be seen that there are five energy levels (Resources, primary, secondary, final and demand).

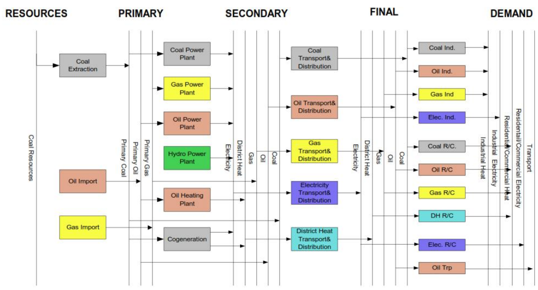

Fig.1: Energy chain [11].

Each level has at least one energy form, e.g. the level secondary has five energy forms namely: electricity, district heat, gas, oil and coal. The technologies are used in Message to model the energy conversion technologies used in the energy chain. It represents the link between two energy forms (levels). For more on information on the structure on the energy chain, the reader is invited to read the message manual [14-15].

3. SIMULATION AND RESULTS

Case Study

The slightly modified energy test system presented in DEMO_version5 is used in this paper. The energy system has two fossil power plants (oil and coal), two hydro power plants and a renewable power plant. The following table 1 shows the technical constraints considered in this planning problem. The projected load demand during the planning horizon is illustrated in figure 2. The energy planning results are illustrated in figure 3 and presented in table 2. From table 2, it can be seen that the balance of demand (presented in figure 2) and the total generation (presented in table 1) is satisfied considering 20% of losses of the Elec_TD (electrical transmission and distribution system). Furthermore, it can be remarked, also, that for the first years of the energy planning horizon, i.e. 2002 and 2005, the load demand is mainly supplied by more than 96% from Coal_PP and the left by the Oil_PP. Therefore, the Coal_PP is the cheapest option despite that it has more emission. This last is acceptable since it is not reached its upper limit (see figure 4). From 2010 to 2015, the share of fossil fuel is reduced and replaced by the Hydro power plants because of the retirement of four fossil power plants. It can be seen, also, that the share of renewable is limited in the first years because of its limit on new additional capacity.

The evolution of fossil power plant emission presented in figure 4 shows clearly that the limit predefined in table 1 is fully satisfied. Furthermore, the emissions are reduced in the period 2010-2020 because of the increased share of the hydro and the reduced share of coal and oil power plants. From 2020-2030, the emissions are increased another time because of the increased share of the fossil power plants (coal_pp and oil_pp).

Figure 5 shows the share of each power plant in the energy mix of 2025. From this figure, it is clear that the energy system is dominated by the hydro with almost 60% and the coal with more than 34%. However, the share of oil_PP is low because of its unavailability in the country (importation of oil). The same for the renewable, because of their relatively high investment cost in the first years of the planning horizon and the limit on its new installed capacity.

Table 1 Power plants technical constraints.

Technology	Type of constraints
Coal_PP	Bound on total installed capacity bdi=400 MW. Emission factor of SO2 is 0.089(kton per MWyr).
Oil_PP	Emission factor of SO2 is 0.039(kton per MWyr). Bound on activity for the importation of oil bda=125 MWyr.
Hyd1 and Hyd2	Bound on new capacity addition bdc=100MW from 2005.
Renewable	Bound on new capacity addition bdc=10MW for 2002 with a constant growth of 1.04 % each year.
SO2 emission	25,000 tons of SO2.

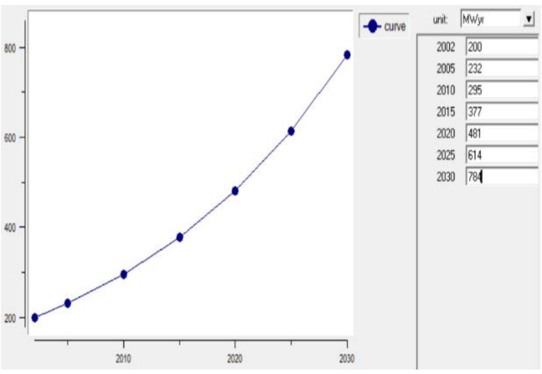

Fig. 2 Projected load demand.

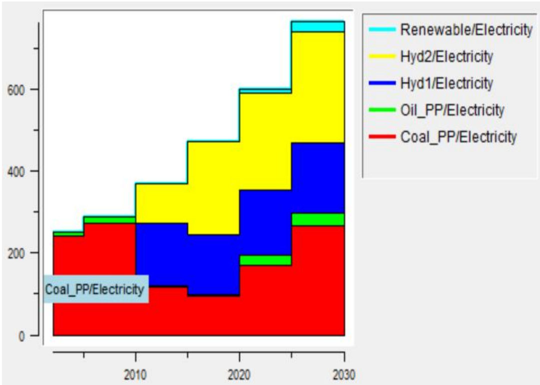

Fig. 3 Energy planning results.

Table 2 Energy planning results.

Years	Coal_PP (MWyr)	Oil_PP (MWyr)	Hydro1 (MWyr)	Hydro2 (MWyr)	Renew-able (MWyr)	Total (MWyr)
2002	242.22	7.78	0.00	0.00	0.00	250
2005	273.81	15.59	0.00	0.00	0.00	289.41
2010	117.25	2.35	152.00	97.76	0.00	369.36
2015	93.74	4.49	147.09	226.09	0.00	471.41
2020	169.46	26.11	159.00	238.00	9.08	601.65
2025	267.88	29.71	171.00	274.00	25.29	767.88

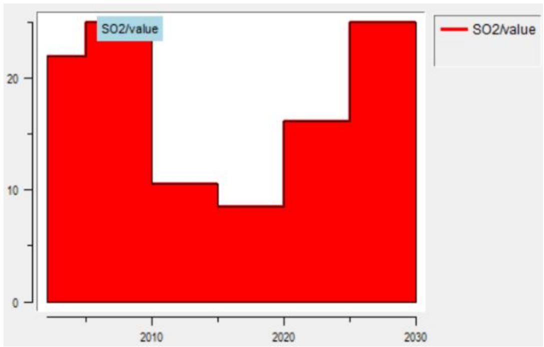

Fig. 4 Emission evolution.

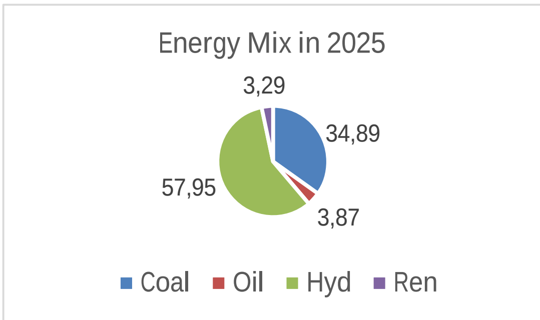

Fig. 5 Energy mix for 2025.

4. CONCLUSION AND FUTURE WORK

This paper presented the energy system optimization and planning using message code. The problem was formulated as a mixed integer programming problem with constraints on activities and installed capacities. Various operation and environmental constraints are considered. The obtained results showed the capability of message code to model and solve the complex energy planning problem considering various types of constraints. The modeling of detailed renewable energy systems and additional constraints related to environment, spinning reserve and grid flexibility will be considered in the future work.

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