Energy Policy 89 (2016) 36–51

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

An initiative towards an energy and environment scheme for Iran: Introducing RAISE (Richest Alternatives for Implementation to Supply Energy) model

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HIGHLIGHTS

- Combined cycle power plant is the best option to meet base load requirements.
- There's synergy between climate change mitigation and economic affordability.
- Power sector reacts to an emission cap by moving towards renewable energies.
- Instead of being exported, condensates should be refined by condensate refineries
- Iran's refining sector should be advanced by shifting to RFCC-equipped refineries.

ARTICLE INFO

Article history:
Received 10 October 2014
Received in revised form
16 October 2015
Accepted 17 October 2015

Keywords:
Sustainable development
Energy modeling
Climate change mitigation
Linear programming
CO_2 cap

ABSTRACT

Decision making in Iran's energy and environment-related issues has always been tied to complexities. Discussing these complexities and the necessity to deal with them, this paper strives to help the country with a tool by introducing Richest Alternatives for Implementation to Supply Energy (RAISE), a mixed integer linear programming model developed by the means of GNUMathprog mathematical programming language. The paper fully elaborates authors' desired modeling mentality and formulations on which RAISE is programmed to work and verifies its structure by running a widely known sample case named "UTOPIA" and comparing the results with other works including OSeMOSYS and Temoa. The model applies RAISE model to Iranian energy sector to elicit optimal policy without and with a CO_2 emission cap. The results suggest promotion of energy efficiency through investment on combined cycle power plants as the key to optimal policy in power generation sector. Regarding oil refining sector, investment on condensate refineries and advanced refineries equipped with Residual Fluid Catalytic Cracking (RFCC) units are suggested. Results also undermine the prevailing supposition that climate change mitigation deteriorates economic efficiency of energy system and suggest that there is a strong synergy between them. In the case of imposing a CO_2 cap that aims at maintaining CO_2 emissions from electricity production activities at 2012 levels, a shift to renewable energies occurs.

1. Introduction

During recent decades Iran's population, experiencing a 2.1% growth rate, has reached from about 38.9 million people in 1980 to 76.4 million in 2012 (WB Webpage). As a result, country's need to an efficient energy system has increased. On the other hand, with abundant natural resources, Iran's economy has always been reliant on foreign revenues from export of crude oil. Accordingly, Iran's energy sector has been the focal point of researchers as to "how" and "how costly" Iran could have an efficient energy system. In addition some newly emerged issues such as environmental concerns about growing Green House Gases (GHGs) emissions have posed more difficulties to the "problem of decision" in Iran.

In the following section, we explain the reasons having prompted us to develop a domesticated energy optimization model.

1.1. Backgrounds

There is a crucial need to a tool capable of quantifying decision space for Iran mainly because of the following bottlenecks:

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http://dx.doi.org/10.1016/j.enpol.2015.10.023
0301-4215/

Lack of a roadmap for end-use technologies: for decades, Iranian governments used to pay burdensome subsidies for energy that in turn has led to country's final energy intensity to soar up. In such an environment, any energy conservation measures wouldn't make sense until after 2011 subsidy reform plan. But the current dilemma is that the government does not have a deep insight on which end-use technologies to promote. Moreover, energy conservation measures and its extent for different end-use devices, has a trade off with business-as-usual supply of energy that is reflected in an energy model. This model can be used in prioritizing high potential conservation options and allocating presently limited and unplanned resources to these options.

The conundrum of natural gas: possessing 18% of world gas reserves, Iran is the top holder of this fuel (BP, 2013). Growing at a rate of 10.8% during 2001 to 2012 (Institute for International Energy Studies (IIES), 2012), natural gas is supposed to play a key role in any prospective development plans of the country but presently its utilization is limited to few traditional ways including burning to generate heat in demand side or power plants, and feedstock of petrochemical industry. Export (either through pipeline or LNG), conversion via GTL to produce petroleum products or conversion to hydrogen (which in turn could be used as the feed of many hydrogen-based technologies) are counted as other choices for natural gas planning not thought about seriously so far.

Diverse potent fuels: apart from oil and natural gas for which Iran is widely renowned, there are many other fuels and renewable potentials like coal, solar, wind and geothermal. Each of these resources has its own advocates and critics but it is not possible to dismiss or promote none of these options unless a prescriptive model suggests which one would excel the other.

Critical environmental situation: energy-related CO_2 emissions was 624 million metric tons in 2011, ranking Iran 8th in the list of top ten CO2 emitters (EIA Webpage). Such amount of carbon emission could presumably put Iran among countries with mitigation commitment in coming years and consequently lead to more complexity in decision making, since implications of such a shift to a low carbon economy are quit vague.

1.2. Motivations

Above mentioned reasons prove the need to develop an integrated energy model capable of capturing all discussed country-specific issues. On the other hand application of widely known energy models is usually linked with the following barriers:

Huge amount of resources, both human and financial, are required to have these models run and this is not what the country would be willing to afford.

For some of these models (e.g. MARKAL/TIMES), even if the resource limitations were lifted, it wouldn't be possible for the country to access a full package of them due to international sanctions. Even access to powerful solvers is limited and we must rely on freely available ones such as GNU Linear Programming Kit (GLPK) (GNU Webpage).

Many of these models do not allow modeler to access all modeling variables, leading to shortcomings in adding desirable constraints. Furthermore, Integration of these models with supplementary modules for further assessments (e.g. uncertainty analysis) if possible, is very difficult (Hunter et al., 2013).

The idea that led to developing RAISE (Richest Alternatives for Implementation to Supply Energy**)** and its feasibility is inspired by the brilliant work of Howells in which OSeMOSYS as an open source code for energy modeling in developing countries is introduced (Howells et al., 2011). OSEMOSYS's outstanding feature is that the level of modeling can be developed by adding functional blocks. Despite this advantage, its application in the modeling structure on which it is built upon, may be subject to shortcomings concerning the size of Mathematical Programming System (MPS) file and memory (RAM) it takes to reach the solution, what will be shown later in Section 3.2.

Additionally, our restriction as to being forced to use a freely available solver rather than a commercial one brings about this necessity that our model should be as numerically-smart as possible. So we found it useful to think about the ways that could make RAISE's modeling framework more efficient. Keeping in mind the advantages in modeling frameworks of OSeMOSYS (Howells et al., 2011), Temoa (Hunter et al., 2013) and MESSAGE (IIASA (International Institute of Applied Systems Analysis), 2001), we engendered the mathematical formulation of RAISE model such that it could serve these two objectives: (1) be able to include all country-related issues explicitly and (2) be as efficient as possible. Like OSeMOSYS, the programming language used to implement the model is GNUMathprog (Makhorin, 2010), a free open source tool which is as powerful as other model generators such as GAMS (Howells et al., 2011).

2. Underlying method

As is usually the case with many classic energy models, present work uses mixed integer linear programming, defined by: (1) an objective function denoting net widely discounted costs of energy system which is to be minimized and (2) a set of constraints defining feasible decision space as a proxy of different technical, physical, social and economic realities in place.

The key elements of RAISE model are technologies organized to extract, process, refine, convert, transport and distribute energy from upstream resources to end users, as is shown in Fig. 1. It is regarded as the Reference Energy System (RES) and is a useful conceptual model illustrating interactions that exist between technologies. In general, two key types of variables are defined for performance of technologies. The first one is a state variable denoting activity of the technology and the second one is the capacity of the technology which is a control variable limiting the first variable.

In a broad classification, fuels (services) are divided into 3 groups: *demand*, *intermediate* and *resource*. Since demand of some fuels (services) may be subject to seasonal or daily fluctuations, the model allows production of some fuels to be unevenly distributed throughout the year. These fuels are depicted in Fig. 1 by dotted lines. This is only the case for fuels placed into demand and intermediate categories but not resource (resource fuels do not have in-year variations). Having said that, there would be 5 types of fuels: (i) evenly-distributed demand (e.g. transport in Fig. 1), (ii) unevenly-distributed demand (e.g. lighting or heating in Fig. 1), (iii) evenly-distributed intermediate (e.g. gas oil in Fig. 1), (iv) unevenly-distributed intermediate (e.g. electricity in Fig. 1), (v) resource fuels (e.g. oil in Fig. 1).

Accordingly, technologies would be classified as follows:

Technologies producing fuels which are without seasonal or daily fluctuations. Since load management does not matter here, only 1 activity variable is simply assigned to each operation mode of technologies of this kind: $AO^{t,m,y}$ refers to annual aggregated output of technology t working on operation mode m in year y. In Fig. 1 these technologies are signified by rectangular boxes.

Technologies that at least one of their output fuels has in-year fluctuations and are shown by rhombic shapes in Fig. 1. Unlike the previous group, load management does matter here and for technologies lying in this category, it's necessary to define the same number of activity variables as the number of load regions: $O^{t,m,l,y}$ is the output of technology t working on operation mode m, in load region l and year y.

Technologies that are similar to the second group but their annual production pattern is fixed by the modeler. In fact he/she