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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Jalalimajidi, Mohsen/Seyedhosseini, S. M. (2017). Replacing renewable energy in Iranian industries using optimal models. In: International Journal of Energy Economics and Policy 7 (2), S. 109 - 112.

This Version is available at:
http://hdl.handle.net/11159/1176

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(2), 109-112.

Replacing Renewable Energy in Iranian Industries Using Optimal Models

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ABSTRACT

In this paper, in order to maximize optimization in Iranian industries, an optimal control modeling has been designed, and then optimal paths of replacing fossil fuels by renewable energy over time is plotted in industrial sectors of Iran. Moreover, a developed optimal control model is presented, and the data used is evaluated. Finally, the estimated energy demand in different industrial sectors of Iran and the costs of fossil fuel extraction is proposed.

Keywords: Iranian Industries, Optimization, Renewable Energy
JEL Classifications: C32, O13, O47

1. INTRODUCTION

Energy is an important input for social and economic growth of any country, particularly in industry. The activities within industry and economy are flourishing in each country so the need and demand for energy is consequently increasing. For a long time energy is divided into two categories: Renewable and nonrenewable, the latter being exhaustible. It is an essential and emergent need to move toward renewable energy and it is not an easy task to be carried out overnight. It needs to formulate some models able to optimize and use the energy as efficiently as possible. Building an energy model will aid to allocate appropriately the widely available renewable energy sources such as solar, wind, bioenergy and small hydropower to see the future energy demand in Iran. Recently, many models were proposed to meet the need. Hence a framework has been developed to examine the renewable energy replacement using optimal control modeling in the industrial sectors of Iran. The data are then evaluated to see the result.

2. RESEARCH METHODOLOGY

Chakrvrty et al. (2014) developed a model for determining the optimal path for replacement of fossil fuels with new energies in the energy sector. This model aims at the maximization of social welfare due to the constant supply of fossil fuels.

$$\text{Max}\int_{o}^{\infty} e^{-rt}\left[\sum_{j=1}^{j}\int_{0}^{\sum_{i=1}^{I} dij(t)} D_j^{-1}(\theta)\,d\theta - \sum_{j=1}^{J}\sum_{i=1}^{I}\frac{w_{ij}}{u_{ij}}d_{ij(t)}\right]dt \tag{1}$$

$$\dot{Q}_i(t) = -\sum_{j=1}^{J}\frac{d_{ij(t)}}{u_{ij}} \tag{2}$$

In the above model i shows the available resources (oil, coal, natural gas and wind and solar energy), j stands for economic sectors (residential, business and public, industry, transportation, agriculture, and electricity) and r represents the discount rate. The inverse demands function for the j^{th} energy, as a control variable, is as follows:

$$P_j(t) = D_i^{-1}\left[\sum_{i=1}^{I} d_{ij(t)}\right] \tag{3}$$

Since the process of converting resources (oil, gas, coal, solar and wind energy) is associated with energy dissipation, U_{ij} is the ratio of energy delivered to j to the total raw energy contained in a unit of resource i, and is known as the coefficient of performance. The d_{ij} is the net energy delivered from the source i to demand j from $q_{ij}(t)$ units of the source which is defined as follows:

$$d_{ij}(t) = u_{ij}q_{ij}(t) \quad (4)$$

q(it) contains estimated and proven reserves of oil, gas and coal, which are considered as a status variable. In the above model, total cost of the conversion and extraction are shown as below:

$$w_{ij} = c_i + z_{ij} \quad (5)$$

In which c_i is the final cost of (energy) resource exploitation and Z_{ij} is the cost of converting energy i according to demand j which equals the sum of operational, repairing and maintenance costs of the equipments used in resource conversion. In this study, it is supposed that renewable energy exploitation cost is zero, but its conversion cost is Z_b.

The continuous-time model with the above infinite time horizon is solved in the frame of optimal control problem. To do this, first the Hamiltonian present value for this problem is obtained as follows:

$$H = \sum_{j=1}^{J} \int_{0}^{\sum_{i=1}^{I} d_{ij}(t)} D_j^{-1}(\theta)\, d\theta - \sum_{j=1}^{J} \sum_{i-1}^{I} \frac{w_{ij}}{u_{ij}} d_{ij}(t) - \sum_{i-1}^{I} \lambda_i(t) \sum_{j=1}^{J} \frac{d_{ij(t)}}{u_{ij}} \quad (6)$$

λ_i is scarcity rents variable for energy resources *i* including (oil, gas and coal).

The first condition, which is one of maximum principle conditions, states that the supply of each resource (oil, gas, and coal) is divided by energy demand in different sectors (Chatzimouratidis et al, 2008). According to the second condition, the scarcity rent of fossil fuels will be increased through their amounts in the initial period (Dessai et al, 2003). The third condition, determines oil, gas, and coal consumption status in different sectors while the forth condition indicates the consumptions status of renewable energy in different parts (Coates et al, 2014). In fact, the third condition represents the optimum hostelling condition according to which the average price paid for energy (oil, gas, coal, solar, and wind, etc.) in different parts must exceed the total cost of exploitation, conversion, and fossil fuels scarcity rate in order for that sector to demand fossil fuel (Cleland, 2010). The forth condition completes the third one as a transition condition and the moving step from fossil fuel towards renewable energy (Martinot et al, 2012). According to this condition, when the average price paid by society in different sectors for energy equals the renewable energy conversion cost, only renewable energy is used, and this results in the reduction of fossil fuels' demand to zero (Fouquet, 2008). In this model, three scarcity variables are mentioned for oil, gas, and coal reserves which, like interest rate, increase consecutively over time. Exogenous variable is gross domestic product (GDP) of each year which, using the GDP in base year (Y_0) and past years GDP growth rate (g) and discounting rate (r), is calculated as follows (Energy Vortex, 2009):

$$Y = \frac{y.(1+g)^{t-1}}{(1+r)^{t-1}} \quad (7)$$

To estimate energy demand functions in different sectors, the Cobb-Douglas functional form was used in this study.

$$E = AP^{\alpha} Y^{\beta} E_{t-k}^{\gamma} \quad (8)$$

in which E is energy demand in year t, E_{t-k}, energy demand in k years ago, γ and A constants, Y is income (GDP) in year t, p weighted price of energy carriers in year t, α and β are short term price and income elasticity, and $\left(\beta = \frac{\beta}{1-\gamma}\right)$ and $\left(\alpha = \frac{\alpha}{1-\gamma}\right)$ are long-term income and price elasticity of demands.

Also in this form, energy demand in each part includes the total demand of (oil, gas, coal, solar, and wind) energy carriers, and the price paid in each part includes the weighted average of paid price in relation to oil, gas, coal, solar, and wind energy. Thus, assuming k = 1, the inverse demand function form used in equation model (1) is as follows (Knauer et al, 2014).:

$$P = \left(\frac{E}{e^{\theta} E(-1)^{\gamma} y^{\beta}} \right)^{\frac{1}{\alpha}} \quad (9)$$

3. FUNCTIONS OF ENERGY DEMAND IN DIFFERENT INDUSTRIALS SECTORS OF IRAN

In this part, using Dickey-Fuller test, the sustainability of demand and cost variables in different industrial sectors of Iran is investigated. Then, using regression method, the energy demand function in different parts is shown in logarithmic form as follows:

$$LDH = -12.52 - 0.03{*}LPH + 0.47{*}LY + 0.65{*}LDH(-1)$$
$$(-1.74)\ (0.6)\ (1.9)\ (6.1)\ R^2{=}0.90\ DW{=}1.88$$

$$LDP = -17.9 - 0.07{*}LPP + 0.67{*}LY + 0.4{*}LDP\ (-1)$$
$$(-2.6)\ (-1.60)\ (2.88)\ (3.89)\ R^2 = 0.75\ DW = 1.5$$

$$LDI = -7.43 - 0.004{*}LPI + 0.3{*}LY + 0.59{*}LDI(-1)$$
$$(-1.85)\ (-1)\ (2.04)\ (2.98)\ R^2 = 0.93\ DW = 1.82$$

$$LDT = -8.54 - 0.002{*}LPT + 0.33{*}LY = 0.62{*}LDT(-1)$$
$$(-2.18)\ (-12)\ (2.26)\ (3.4)\ R^2 = 0.98\ DW = 1.83$$

$$LDA = -5.63 - 0.11{*}LPA + 0.34{*}LY + 0.31{*}LDA(-1)$$
$$(-0.93)\ (-2)\ (1.64)\ (2.08)\ R^2 = 0.34\ DW = 1.93$$

$$LDE = -8.47 - 0.002{*}LPE + 0.31{*}LY + 0.73{*}LDE(-1)$$
$$(-1.74)\ (-2)\ (1.80)\ (4.99)\ R^2 = 0.98\ DW = 1.2$$

in which LDH, LDP, LDI, LDT, LDA and LDE respectively stand for energy demand logarithm in different sectors industries, and LPH, LPP, LPI, LPT, LPA, and LPE are the logarithm of the paid price for energy in different parts, and LY is the GDP. Also LDH−1, LDP−1, LDI−1, LDT−1, LDA−1 and LDE−1 are energy demand logarithm in (1) Production, (2) business and public, (3) small industries, (4) transportation, (5) services, and (6) electricity sectors respectively with an inactivity period.

The price and income elasticity in different industrials sectors of Iran has been calculated using the estimated functions.

3.1. Cost Functions of Oil, Gas, and Coal exploitation

Oil production cost is the sum of exploitation, development, and production operational costs. c_t is oil production total costs while Qo_t is the amount of oil production.

$$c_t = 1.2(0.46Qo_t + 0.7714Qo_t^{-0.2423}) \quad (10)$$

Functions of gas and coal exploitation costs are respectively as follows:

$$TC_t = 63Qg_t - 0.0025Qg_t^2 + 5.44 - 10^{-18}Qg_t^3 \quad (11)$$

$$TC_t = 8.9Qc_t - 4.99* - 10^{-6}Qc_t^2 + 8.74*10^{-13}Qc_t^3 \quad (12)$$

Qg_t is the amount of natural gas production and Qc_t is the level of coal production (Department of Energy, 2016).

3.1.1. Conversion cost

The conversion cost is the total of annual operative and investment costs. For the new energy replacement model, the cost of electricity produced from the conversion of renewable energy, and also the cost of transmitting electricity from power plants to various demand sectors are taken into consideration. The cost of renewable energy as a result the average cost of converting 1 KW/h will be 3800 rail's (1055 billion rails per Pet J). Table 1 shows The price and income elasticity in different industrials sectors of Iran in 2016.

3.1.2. Social welfare cost

According to the Human Development Report, the United Nations, Iran had 1.5% of the global emission of CO_2 in 2016, and it has 13th rank in releasing carbon dioxide. In this research, by incorporating the social costs resulting from the consumption of fossil fuels in various sectors of the Iranian industry, the reduction of social welfare surplus examined. Social cost of carbon emissions was 80,000 rail's per-ton in 2010 that using the price index adjusted to 400,000 rail's in 2016.

Table 1: The price and income elasticity in different industrials sectors of Iran

Sector	Short-term price elasticity	Short-term income elasticity	Long-term price elasticity	Long-term income elasticity
1	−0.03	0.47	−0.08	1.3
2	−0.07	0.67	−0.11	1.1
3	−0.004	0.2	−0.009	0.48
4	−0.002	0.33	−0.005	0.86
5	−0.11	0.34	−0.15	0.49
6	−0.002	0.31	−0.007	1.1

4. REPLACEMENT OF RENEWABLE ENERGY INSTEAD OF FOSSIL ENERGY IN DIFFERENT SCENARIOS

4.1. First Scenario

The results show that with the assumption of constant conversion costs of renewable energy, respectively, public and business sectors after 25 years, transportation sector, after 27 years, the services after 30 years, the power sector after 35 years, production sector after 41 years and small industrials sector after 77 years will change their demand from fossil fuels to renewable energy.

4.2. Second Scenario

Assuming a 10% reduction in the cost of renewable energy conversion in every decade, in businesses and public sector after 21 years, in the Department of Transportation after 23 years, in the services sector after 26 years, in the electricity sector after 30 years, in the production sector after 33 years and in the small industrials sector after 54 years, transition from fossil fuels renewable will take place. According to the second scenario fossil energy demand in different sectors will be zero in 54 years and moving toward renewable energy will be complete.

4.3. Third Scenario

Assuming a 30% reduction in the cost of renewable energy conversion in every decade, in public and commercial sector after 18 years, in transportation sector after 20 years, in the services sector after 21 years, in the power sector after 21 years, in the production sector after 25 years and in the small industrials sector after 30 years, transition from fossil fuels to solar and wind power will be done.

4.4. Fourth Scenario

Assuming a 50% reduction in the cost of renewable energy conversion, businesses and public sector after 13 years, transportation sector after 16 years, the services sector after 18 years, power sector after 20 years, production sector after 20 years and small industrials sector after 20 years will change their demand from fossil fuels to renewable energy.

5. CONCLUSION

This research claims that energy planning processes under sustainable development criteria can maximize the optimization in Iranian industries using optimal control models.

The analysis of these methodologies and tools is useful to highlight their main advantages and to harness them in the proposal of combined planning methods involving different approaches. Findings reveal that estimated energy demand in industrial sectors of Iran can be useful for replacement of new energy in future step by step and the programs have to be designed accordingly.

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