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Transport energy modeling with meta-heuristic harmony search algorithm, an application to Turkey

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ABSTRACT

This study proposes a new method for estimating transport energy demand using a harmony search (HS) approach. **HA**rmony **S**earch **T**ransport **E**nergy **D**emand **E**stimation (HASTEDE) models are developedtaking population, gross domestic product and vehicle kilometers as an input. The HASTEDE models are in forms of linear, exponential and quadratic mathematical expressions and they are applied to Turkish Transportation sector energy consumption. Optimum or near-optimum values of the HS parameters are obtained with sensitivity analysis (SA). Performance of all models is compared with the Ministry of Energy and Natural Resources (MENR) projections. Results showed that HS algorithm may be used for energy modeling, but SA is required to obtain best values of the HS parameters. The quadratic form of HASTEDE will overestimate transport sector energy consumption by about 26% and linear and exponential forms underestimate by about 21% when they are compared with the MENR projections. This may happen due to the modeling procedure and selected parameters for models, but determining the upper and lower values of transportation sector energy consumption will provide a framework and flexibility for setting up energy policies.

1. Introduction

The transport sector is one of the major consumers of primary energy production in the world. It consumes about one-fifth of the primary energy in the world (Asmann and Sieber, 2005) and is responsible for almost 60% of the oil consumption in Organization for Economic Co-operation and Development countries with an increasing consumption in the developing world according to the International Energy Agency (IEA, 2005). One of the main reasons for the increasing demand for energy use may be due to the rapid increase in population, mobility, businesses, globalization and transport demand.

With respect to energy planning, the transport sector is crucial because, in most regions, it is either the largest and/or most rapidly growing consumer of liquid fuels. In many countries, the demand for transportation fuels tends to be rather unresponsive to changes in the price of crude oil because of the high level of consumer taxes (Wohlgemuth, 1997). When this high level of energy demand and price levels is considered, this sector takes one of the biggest shares in total energy consumption in many countries. Turkey may be a good example with 21% of the total energy consumption according to World Energy Council-Turkish National Committee (WEC-TNC, 2006).

Turkey expects a very large growth in energy demand in the future as its economy expands, especially for petrol in the transportation sector. Because of its limited energy resources, Turkey is greatly dependent on imported oil and gas, which is the most important diesel in Turkey, contributing 55% of Total Primary Energy Supply and importing 90% of its energy needs in 2004 (WEC-TNC, 2006). Passenger transport of Turkey increased by 2.5 times and goods transport increased by four times in the last two decades. The population increased by about 50% in the last two decades as well. Transportation demand increased more than gross domestic product (GDP) in Turkey when national economic parameters are compared to the transportation sector.

Modeling energy consumption in the transport sector is usually dependent on many factors such as vehicular usage, type of car, income, housing size, vehicular type and many other socio-economic parameters. Including all the parameters in sectoral energy modeling is a difficult task since it requires much detailed study and also much data, for which many of the data are unavailable. Therefore, it would be better to model transport energy consumption with simplified forms of mathematical expressions using available data. In addition, it would be better to provide a framework for integrating knowledge of transportation sector energy use trends with analysis of sectoral energy growth in a developing country.

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Much is known about energy modeling, but this is not so in transportation systems since it requires vehicular-related parameters. The transportation energy modelwould be capable of exploring alternative transportation systems in the developing worlds as a main priority for sustainable future. Any approach and method used to estimate the effects of policies and measures have to embody some assumptions regarding the way measures will affect sectoral trends on energy consumption and efficiency of the sector with technological development. Mathematical models are usually based on the assumption that methodology is chosen and formed according to the minimization of some objective values such as minimizing energy consumption values. Therefore, among the many meta-heuristic approaches, **HA**rmony **S**earch **T**ransport **E**nergy **D**emand **E**stimation (HASTEDE) models are proposed since it is considered as an effective and accurate mathematical approach in energy modeling studies. The HASTEDE models are in the form of linear, exponential and quadratic mathematical expressions that are solved with harmony notion. The HASTEDE models take population, GDP and vehicle ownerships as an input to estimate transport energy demand to forecast sectoral consumption until 2025 starting from 2006.

This paper has been organized in the following way. In the next section, some relevant literature review is given. Section 3 deals with the pHarmony search algorithm and problem formulation. Section 4 is on solution methods for the proposed energy modeling models. Sensitivity analyses (SAs) on harmony parameters are given in Section 5. Forecasting the future energy consumption in the transport sector is given in Section 6. Conclusions are drawn in Section 7.

2. Background and literature review

Energy studies were mainly carried out in the countries' own Department for Energy. Studies on energy forecasting in Turkey are planned by Ministry of Energy and Natural Resources (MENR) and State Planning Organization within 5 years' development planning periods. The MENR uses the Model for Analysis of Energy Demand model that requires very detailed and large number of data for the total and sectoral energy consumption (SEC) estimations. On the other hand, many models have been developed from many researches using various forms of mathematical formulations, which are directly or indirectly related to energy development models (Uri, 1980; Kavrakoglu, 1983; Yu and Been, 1984; Ebohan, 1996; Cheng and Lai, 1997; Ceylan and Ozturk, 2004; Canyurt and Ozturk, 2006; Say and Yucel, 2006).

Gilland (1988) developed an energy demand projection of the world for the years 2000 and 2020. Gungor and Arikan (2000) developed a method to compare natural gas, imported coal and nuclear power plants in terms of long-term production economy. Demirbas (2001) made a study about future developments and energy investments in Turkey. Ceylan and Ozturk (2004) first developed a genetic algorithm (GA) for estimating the energy demand using GDP, population, and import and export figures. Isik (2004) presented a study that shows the supply and demand situation in Turkey and examines its background. Ediger and Camdali (2007) made historical investigation from 1988 to 2004 to analyze energy and exergy efficiencies of Turkey. There are also other studies about energy demand forecasting of Turkey. Ediger and Tatlidil (2002) proposed an approach that uses the analysis of cyclic patterns in historical curves to forecast the primary energy demand in Turkey. Yumurtaci and Asmaz (2004) proposed an approach to calculate the future energy demand of Turkey, for the period of 1980 and 2050, based on the population and energy consumption increase rates per capita. Sozen et al. (2005) used artificial neural network (ANN) to forecast Turkey's net energy consumption. Toksari (2007) developed an ant colony energy demand estimation model for Turkey. Akay and Atak (2007) proposed an approach using grey prediction with rolling mechanism (GPRM) to predict Turkey's total and industrial electricity consumption. Sozen and Arcaklioglu (2007) developed the energy sources estimation equations in order to estimate the future projections and make correct investments in Turkey using the ANN approach.

Utlu and Hepbasli (2006) evaluated the energy and exergy utilization efficiencies in the Turkish transportation sector over the period from 2000 to 2020. In the study, energy and exergy analyses were performed for four transportation sub-modes and a comparison of Turkish transportation sector with the other countries was also presented. Similarly, Saidur et al. (2007) applied the useful energy and exergy analysis models for different modes of transport in Malaysia and compared the result with a few countries such as Turkey and their study. Results showed that the energy and exergy efficiencies of the Malaysian transportation sector are lower than that of Turkey.

Haldenbilen and Ceylan (2005) developed three forms of energy demand equations in order to forecast the transport energy consumption for future projections based on GA notion. They used population, GDP and Car Equivalent Approach as independent variables. Energy savings were also obtained under various scenarios. Similarly, Canyurt et al. (2006) developed GA approaches for the transport energy demand estimation using the socio-economic indicators, car, bus and track sales. Murat and Ceylan (2006) obtained that modeling the energy consumption may be carried out with ANNs with a lack of future estimation because ANN is good at solving current data, but is not good for forecasting.

It would be better to obtain vehicular ownership figures and their annual usage as a veh-km as well as socio-economic indicators since it shows the increase on vehicle ownerships on any country in order to estimate the transport energy demand. For example, Fig. 1 shows the rapid increase of motorization in Turkey between 1966 and 2004. Within this period, the fleet of cars, trucks and buses increased by about 40% according to General Directorate of Turkish Highways (GDTH, 2004). Energy consumption in the same period increased by about four times in this sector.

In 1970, energy consumption in the transport sector was 3208 Ton Oil Equivalent (TOE) and increased to a level of 13775 TOE in 2004 of Turkey annual final energy consumption (WEC-TNC, 2006). The energy needs in the transport sector in Turkey, which has a share of over 21% of the total energy consumption in the country, are totally met with gasoline, auto diesel and Liquefied Petroleum Gas.

At the same time, GDP, one of the main indicators for increasing vehicle ownership, can be seen in Fig. 2. It increased

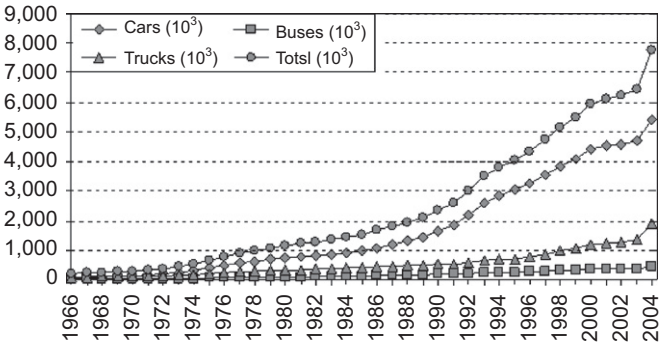

Fig. 1. Motorization figures in Turkey.