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Decarbonizing the Greek road transport sector using alternative technologies and fuels

Katerina G. Tsita, Petros A. Pilavachi *

Department of Mechanical Engineering, University of Western Macedonia, 50100 Kozani, Greece

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ABSTRACT

In this paper, a number of scenarios to decarbonize the Greek road transport sector are modeled using the Long-range Energy Alternatives Planning (LEAP) software for a variety of alternative technologies and fuels. Both light duty and heavy duty vehicles are considered. The scenario analysis time span covers years 2010–2050 with 2010 as the baseline year. The reference scenario includes all binding targets set out by the European Union and the Greek legislation regarding the development of renewable energies and the reduction of greenhouse gas emissions. At present transportation is dominated by internal combustion engines. Two alternative scenarios to the reference are presented. For all scenarios, the vehicle technologies and fuels proposed are the hybrid vehicles, electric vehicles, fuel cell vehicles, biofuels and gas engine vehicles. The analysis has shown that the Greek road transport sector can be decarbonized through various combinations of alternative technologies and fuels. Selecting specific options of fuels for year 2050 would be characterized with great uncertainty. This study proposes an increased penetration of biofuels, electric vehicles and gas engine vehicles. For the best alternative scenario as compared to the reference scenario, energy consumption is reduced from 5784 ktoe down to 4299 ktoe or by 26% for all vehicle stock, while CO_2 emissions are reduced from 16,995 ktons CO_2 down to 10,531 ktons CO_2 or by 38%.

1. Introduction

In the long term, the transport sector is expected to develop in the direction of replacing fossil fuels with fuels produced from renewable energy sources including biofuels, biomethane, biomethanol, synthetic gasoline, and hydrogen [1]. There is no shortage of alternative energy sources such as biofuels, renewable electricity and hydrogen or unconventional fossil carbon sources such as oil-sands, shale-oil and coal-to-liquids. Unconventional fossil carbon sources would produce less expensive fuels compared to renewable energy and even more compatible with the existing transport infrastructure, but would lead to increased carbon emissions [2].

Environmental issues are one of the major concerns in transportation. The rapid automobile growth phenomenon can induce significant greenhouse gas (GHG) emissions in urban environments where the majority of vehicles circulate daily. As a result gasoline consumption will increase while the average cruising speed is expected to be further reduced. High levels of air pollutants including tiny particles and nitrogen oxides emitted especially in diesel vehicle exhausts forced Mayors in some capital cities worldwide to ban all diesel vehicles by 2025. Current environmental policies in the main cities can be revised in a systematic way such as fuel quality improvements, better and more extensive public transport, promotion of alternative fuels and hybrid cars, enforcement of emission controls, variable working schedules to lower traffic peaks and better drivers education [3]. The public transport system is inadequate to meet the demand that results in a tremendous rise in personal vehicles; road space has not grown proportionately, longer travel time and more energy consumption is observed, which increases cost and pollution. All of the above problems are further aggravated due to the use of poor quality fuels and bad road conditions [4].

The design of the energy and transport policies requires the participation of all stakeholders, taking into account the interactions with the economy, society, environment and policy. Policy development process must be participatory and comprehensive to be accepted and promoted by all [5]. For each country, a feasible planning must be done to preserve the natural resources sustainability without negatively affecting the next generations. Existing city structures, building composition and transport fleets change

* Corresponding author.
E-mail address: ppilavachi@uowm.gr (P.A. Pilavachi).

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slowly over time. Large technological changes having considerable effect on new sources of energy supply or on demand patterns of new energy users, can only marginally affect global energy markets year-on-year since these changes take time to work. Although future energy supply, demand and energy mix, will depend on technological developments a number of these breakthroughs correspond to key uncertainties for global energy use and energy markets [6].

It will be mandatory to overcome the future challenges of road transport to secure sustainable person mobility and goods transport for the future, a basic requirement that humans will presuppose as self-evident also in the future [7]. At present transportation is dominated by Internal Combustion Engines (ICE). The development of complementary solutions will be the key to meet mobility demands over the next decades.

Energy produced from renewable sources, be it biofuels or bioelectricity increasingly becomes a possible fuel option especially in the developed world [8]. 1st generation biofuels have several constraints such as food-fuel competition, land use change, higher resource use, energy balance, particulates emissions and others besides having several other benefits like energy security issues and reduced carbon footprint [9]. Algal biofuels could be an answer for those constraints as they can grow very fast, are capable in production of several times higher biomass in comparison to terrestrial crops and trees, require marginal land and other resources, producing higher lipid and carbohydrate [10]. With the current demand for renewable fuels, especially for the transport sector, there is a need to develop a range of sustainable biofuel resources, as a step towards the replacement of fossil fuels [11]. Biofuels are expected to reduce greenhouse gas emissions and other pollutants, and revitalize the economy by increasing demand and prices for agricultural products [12]. Tsita and Pilavachi [13] evaluate next generation biomass derived fuels for the transport sector concluding that a stable, economically-sound and environmentally-friendly source of transportation fuel can potentially be a mix of bio-synthetic natural gas and electricity from biomass incineration.

The purpose of this paper is to evaluate various alternative technology and fuel scenarios for greenhouse gas emissions reduction employing the Long-range Energy Alternatives Planning (LEAP) software [14]. LEAP is an integrated modeling tool that can be used to track energy production and energy consumption in all sectors of an economy [15].

LEAP applications in energy and transportation appear widely in the literature. In their study, Das et al. [4] analyze the urban transportation system and its energy-environment implications for two mega cities of India, viz Delhi and Mumbai, while implications of various economic growth scenarios are examined on energy demand and emissions. The study assumes continuation of the current paradigm that relies on expansion of traveling mileages, vehicles and energy consumption with somewhat more efficient and less polluting vehicles in the future. The transport sector in Honduras is analyzed using LEAP [5]. Two scenarios are considered: a) a trend scenario, where no changes are applied and b) a desired scenario, where key policies are applied in different components of the energy sector, e.g. introduction of biofuels, improved energy efficiency, increase in the electricity consumption and introduction of hybrid cars, among others. It is concluded that policies that decrease fossil fuel use should be encouraged either by promoting the use of biofuels, by allowing the introduction of hybrid and electric cars or by encouraging the use of public transport. Feng et al. [16] study three alternative scenarios using the LEAP software to represent different development pathways of Beijing's energy future from 2007 to 2030. It is concluded that the implementation of alternative vehicle fuels such as compressed natural gas (CNG), electricity and hydrogen will reduce the dependence on fossil fuels. The main objectives of Cai et al. [17] study are to identify key emission sectors, assess important technologies and analyze the corresponding costs. These results will give insight to policy makers in creating feasible and practical climate policies. Ong et al., [18] summarize that there is an urgent need to adopt suitable energy policy to balance energy demand and reduce emissions in Malaysia transportation sector. A LEAP model extrapolates energy consumption, GHG emissions and pollutants emissions of Tianjin's urban passenger transport sector between 2010 and 2040 under four scenarios in order to analyze the reduction potential of various policy measures, and obtain some policy implications [19]. Apart from the base scenario, three alternative scenarios study the impact of different urban transport policy initiatives that would reduce energy demand and emissions in the transport sector of Rawalpindi and Islamabad [20]. The study has shown how the LEAP system, combined with appropriate detailed local data of total registered vehicles, energy consumption and emission factors, can provide a valuable tool for assessing future urban transport options in developing countries. Using LEAP Kemausuor et al. [21] examine the extent to which future energy scenarios in Ghana could rely on energy from biomass sources, through the production of biogas, liquid biofuels and electricity. Analysis was based on moderate and high use of bioenergy for transportation, electricity generation and residential fuel.

In our paper, a number of GHG emissions reduction scenarios in road transportation are modeled using LEAP for a variety of alternative vehicle technologies and fuels. In Section 1, introductory comments are given. In section 2, the LEAP software, the Greek road transport sector and alternative vehicle technologies and fuels are further discussed. In Section 3, the reference scenario and the proposed alternative scenarios are presented, while in Section 4 results are analyzed. The paper concludes in Section 5.

2. Materials and methods

2.1. The LEAP software

LEAP is an integrated software that simulates future energy demand and fuel trends. This software is useful in cases where the analyst wishes to determine the energy and environmental impacts of the proposed policies where the initial technology projection has already been predetermined [22]. LEAP is a widely-used software tool for energy policy analysis and climate change mitigation assessment, also adopted by many organizations in more than 190 countries worldwide. Its users include government agencies, non-governmental organizations, academia, consulting companies and energy utilities. It has been used in many scales ranging from cities and states to regional, national and global applications. Many countries have also chosen to use LEAP as part of their commitment to report to the United Nations Framework Convention on Climate Change [14].

An end-use driven scenario analysis is the central concept of LEAP. In the approach, a reference scenario is analyzed and alternative scenarios are simulated along with environmental emissions under a range of user-defined assumptions. Rather than being a single pre-set of statistically based energy demand model, the LEAP system is a powerful and flexible model-building tool that enables a wide range of models to be constructed [23]. It designs different scenarios of future energy demand and environmental impact based on how energy is produced, converted and consumed in a given region or economy under a range of values for parameters such as population increase, economic development, technology utilization and inflation [17]. Initially, LEAP is used to construct an inventory of fuels and GHG emissions for various vehicle types. Then, a reference scenario follows, projecting fuel use and emissions into the future under the assumption that no new policies