Applied Energy 212 (2018) 265–282

Contents lists available at ScienceDirect

Applied Energy

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

Improving the representation of modal choice into bottom-up optimization energy system models – The MoCho-TIMES model

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HIGHLIGHTS

- Novel methodology for representing modal choice into energy system models is presented.
- Heterogeneity of transport users is introduced to differentiate modal perceptions.
- Preferences accounted through monetization of intangible costs.
- Value of time and level of service variables are accounted by the model.
- Approach paves the way to new policy analyses involving novel attributes.

ARTICLE INFO

Keywords:
Modal choice
Transport
Mobility behaviour
Bottom-up energy system modeling
TIMES-MARKAL

ABSTRACT

This study presents MoCho-TIMES, an original methodology for incorporating modal choice into energy-economy-environment-engineering (E4) system models. MoCho-TIMES addresses the scarce ability of E4 models to realistically depict behaviour in transport and allows for modal shift towards transit and non-motorized modes as a new dimension for decarbonising the transportation sector. The novel methodology determines endogenous modal shares by incorporating variables related to the level-of-service (LoS) of modes and consumers' modal perception within the E4 modeling framework. Heterogeneity of transport users is introduced to differentiate modal perception and preferences across different consumer groups, while modal preferences are quantified via monetization of intangible costs. A support transport simulation model consistent with the geographical scope of the E4 model provides the data and mathematical expressions required to develop the approach. This study develops MoCho-TIMES in the standalone transportation sector of TIMES-DK, the integrated energy system model for Denmark. The model is tested for the Business as Usual scenario and for four alternative scenarios that imply diverse assumptions for the new attributes introduced. The results show that different assumptions for the new attributes affect modal shares and CO_2 emissions. MoCho-TIMES inaugurates the possibility to perform innovative policy analyses involving new parameters to the E4 modeling framework. The results find that authority's commitment to sustainability is crucial for a paradigmatic change in the transportation sector.

1. Introduction

Transport is a key driver of economic development and it plays a fundamental role in supporting quality of life. However, it is also responsible for approximately 28% of total final energy use and for 23% of the world energy-related CO_2 emissions [1]. Transport is regarded as the most complicated sector to decarbonise, due to multiple reasons. Its rate of growth of energy use and CO_2 emissions is 2% a year, the highest among all the end-use energy sectors. Moreover, the global growth of transportation activity has been tracking that of GDP and is strongly linked to the increase of population and incomes [2]. Mobility demand per capita in non-OECD counties is still far below the levels in OECD countries, but is expected to grow at fast pace [3]. While the power and heat sectors have many efficient and renewable energy based

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https://doi.org/10.1016/j.apenergy.2017.12.050
Received 29 August 2017; Received in revised form 7 December 2017; Accepted 8 December 2017
0306-2619/

technologies available to enable a technology switch, the transportation sector lags behind. Some low-carbon technologies have appeared in the market [4], but they are still characterised by high investments costs that slow a large-scale deployment. Moreover, new transportation technologies have to face the slow turnover rate of the existing vehicle stock and the lock-in effect originated by the existing infrastructure. So far, the efforts to reduce transportation emissions by technological improvements and fuel standards have been offset by the increase of activity. The International Energy Agency (IEA) estimates in its baseline scenario a doubling of current transport energy use by 2050 and slightly more than a doubling of associated CO_2 emissions worldwide [5]. Experts agree on the strategy to pursue a reduction in transport externalities. The IEA suggests a combination of four technological and behavioural measures to promote concurrently: avoiding traveling, shifting to different modes, improving vehicle performance and switching to lower-carbon fuels [5]. Another set of measures suggested includes development of efficient technologies, changes in pricing and budgeting, changing attitudes, infrastructure supply, innovative institutional arrangements and development of new methods [6]. Given these premises, it is clear that the behavioural dimension plays a key role and that a behavioural change is a precondition for the decarbonisation of the transportation sector.

Energy system models are powerful tools for supporting long-term decision making and planning in the energy sector. In this paper we focus on a specific family of them, the TIMES/MARKAL models, belonging to the category of energy-economy-environmental-engineering (E4) optimization models. TIMES and MARKAL models have been used for more than three decades to identify least-cost resources and technology deployment pathways towards greenhouse gas (GHG) emission-free energy systems and exploring alternative scenarios under several constraints [7–12]. The major strength of E4 models lies in their ability to provide a detailed representation of the technological, economic and environmental dimensions of the integrated energy system and in their capability to explore decarbonisation pathways considering cross-sectoral dynamics and synergies. On the other hand, E4 models are still weak at depicting consumer behaviour [13–15]. This lack, to a certain extent, has reduced the credibility of E4 models' policy evaluations [16]. E4 models normally represent only a "system wide" decision maker, with perfect information and foresight and who takes rational decisions only based on pure economic criteria. However, individuals' preferences and behavioural attitudes are a fundamental aspect of decision making in the transportation sector. Therefore, the behavioural dimension shall be integrated in E4 models, to validate their application in transport policy analysis. This paper aims at filling this gap by proposing a new methodology, called MoCho-TIMES, that enables to incorporate modal choice (the choice that individuals make in selecting the means of traveling, e.g. car, public transport, bike or walk, for a specific trip) within E4 optimization models. Integrating modal choice within E4 models helps to identify the barriers limiting modal shift to zero- and low-carbon modes and to understand what kind of policies and regulation mechanisms can potentially trigger such modal shift. The theoretical basis of consumer choice is presented in Section 2, which reviews as well the representation of modal choice in transport and energy system models. Then, Section 3 presents all the aspects of this novel methodology. The results for the Business as Usual (BaU) scenario and for the alternative scenarios are analysed in Section 4, which also provides some insights on the capabilities of the approach. A discussion of the most innovative and critical aspects of MoCho-TIMES is provided in Section 5, together with recommendations for future research. Finally, Section 6 presents some concluding remarks of this study.

2. Theory and representation of modal choice

Modal choice consists of an individual facing two or more alternative transportation modes among which to choose. Given the finite and exhaustive set of mutually exclusive choice alternatives, modal choice can be represented by discrete choice models [17]. According to the classical formulation of discrete choice models [18,19], individuals choose among the available alternatives based on an index of preference, called utility, which depends on the characteristics of the alternatives and on the characteristics of the individual. Traditionally, in discrete choice models the utility is a linear function of parameters and attributes, plus an error term, which accounts for the fact that the modeller is able to capture only a subset of all the attributes affecting modal choice [19]. These attributes are generally socioeconomic variables, which account for diversity in modal perception across the population, and level-of-service (LoS) variables, defining the characteristics of the alternatives as perceived by the consumers. Moreover, alternative-specific constants (ASC) are used to take attributes that are not under the modeller's control into account. Discrete choice models calculate the probability that a consumer chooses a certain alternative from the choice set by comparing the utilities of the different alternatives. A rational consumer will choose the alternative from which he gets the greatest utility. The most popular technique for modeling modal choice has been through logit and probit models, because they are able to account for variation of preferences across the population [17]. An important characteristic of modal choice is that it is a spatial problem: the choice of the mean of transport for a trip strongly depends on the trip length, on its origin and destination and on the local availability of public transport and transport infrastructure.

A review of the LoS, socioeconomic and demographic attributes highly relevant for mobility behaviour has been performed. Table 1 recollects the attributes affecting modal choice in some transport models found in the literature [20–26].

Transport models have a long tradition of representing modal choice. Their structure generally consists in four steps: trip generation, trip distribution, modal choice and route assignment. In the third stage, modal shares are traditionally determined though multinomial logit model (MNL) or nested logit model (NMNL) accounting for many attributes describing the observed characteristics of the modes and the observed characteristics of the consumers. These types of transport models are normally characterised by a high level of population segmentation, with the rationale that behaviour is an individual feature and therefore attempts to capture it should be pursued to provide as much heterogeneity as possible. The population is traditionally segmented based on demographics and socioeconomic variables, which allow differentiating the LoS of the modes across consumer groups. More recently, the use of attitude-based consumer disaggregation is becoming popular [27]. Considering attitudes of the population as criteria for consumer segmentation, in particular travel behaviour and willingness to change behaviour, provides a better starting point for initiatives promoting sustainable transport. In fact, it allows for establishing priorities and targeting different groups of people with ad hoc policies [26,28]. Moreover, empirical results show a link between lifestyle and sustainability in travel behaviour, claiming a paradigmatic shift in transport regulation from demand management towards lifestyle adjustments [29].

In the field of energy system modeling, the improvement of the behavioural dimension of transport and the representation of modal choice is an innovative topic. Traditionally, in optimization E4 models the end-use mobility demands are specified exogenously for each mode. Several technologies compete to fulfil the projected mode-specific mobility demands. However, technologies compete within a mode, but not between modes, thus preventing endogenous modal shift [30]. This was a limitation, because modal shift is an efficient lever to cut CO_2 emissions in the transportation sector. At first, the contribution of modal shift towards GHG-emissions reduction was determined by means of "what if" analyses, which assess the effect of exogenously assumed levels of modal shift on the whole energy system and on the environment [5,31–33]. Recently, the interest of researchers is addressing the integration of modal choice [13,16]. A review of the