Reaching carbon neutral transport sector in Denmark – Evidence from the incorporation of modal shift into the TIMES energy system modeling framework

Jacopo Tattinina,⁎, Maurizio Gargiulob, Kenneth Karlssona

a DTU Management Engineering, Produktionstorvet, Building 426, 2800 Kgs. Lyngby, Denmark
b E4SMA, Via Livorno, 60, 10144 Turin, Italy

ARTICLE INFO

Keywords:
Modal shift
TIMES model
Integrated Danish energy system
Transport
Behaviour

ABSTRACT

Energy/Economy/Environment/Engineering (E4) models have been rarely apt to represent human behaviour in transportation mode adoption. This paper contributes to the scientific literature by using an E4 model to analyse the long-term decarbonisation of the Danish transport sector. The study is carried out with TIMES-DK, the integrated energy system model of Denmark, which has been expanded in order to endogenously determine modal shares. The methodology extends the technology competition within the modes to competition across modes by aggregating the passenger modal travel demands into demand segments based on the distance range. Modal shift is based not only on the levelised costs of the modes, but also on speed and infrastructure requirement. Constraints derived from the National Travel Survey guarantee consistent travel habits and avoid unrealistic modal shifts. The comparison of model versions with and without modal shift identifies its positive contribution to the fulfilment of the Danish environmental targets. Four sensitivity analyses on the key variables of modal shift assess how their alternative realizations affect the decarbonisation of the transport sector and enable shifting away from car. The results indicate that less strict travel time budget (TTB) and increased speed of public bus lead to a more efficient decarbonisation by 2050.

1. Introduction

Transport is a fundamental driver of economy and society and it plays a primary role in supporting economic growth and quality of life. Nonetheless, transport is also responsible for many externalities at local, regional and global levels. At the local scale, transport is responsible for accidents, road damage, vibration, noise and congestion (Santos et al., 2010). At the regional scale, transport is responsible for emitting several air pollutants affecting human health. A widely discussed global externality is transport’s contribution to climate change. Since 1970 greenhouse gas (GHG) emissions from the transport sector have more than doubled, increasing at the fastest rate among all the end-use energy sectors (Sims et al., 2014). In 2010, transport accounted for approximately 23% of energy-related CO2 emissions worldwide (International Energy Agency, 2009) and about 36% in Denmark (Nordic Energy Research and International Energy Agency, 2016). So far, the efforts to reduce transport GHG emissions by improving powertrain efficiency and fuel standards have been offset by the increase of transport activity. Moreover, alternative fuelled vehicles (AFV) still require policy support to gain a significant market share (Mulholland et al., In preparation). An evidence is that the derogation of the vehicle registration tax (VRT) towards electric vehicles (EVs) in Denmark has seen a fall in their sale in 2016 (European Environmental Agency, 2017). Besides, the International Energy Agency (IEA) (2009) estimates that 2050 worldwide car ownership could triple, while freight transport by truck and aviation could increase four-fold, thus leading to a doubling of energy use in transport. In order to reverse this tremendous trend, the IEA proposes a combination of both technological and behavioural measures: avoid, shift, improve and switch (International Energy Agency, 2012). Avoid entails mitigating the mobility demands by, for instance, densifying the urban structure, teleworking and virtual mobility. Shift consists in increasing the market shares of low-carbon modes, fostered by e.g. improving the level of service (LoS) of public transport and deploying biking infrastructure. Improve focuses on enhancing the vehicle efficiency by decreasing its weight, increasing the occupancy and load factor and developing advanced engines. Switch consists in substituting oil-based fuels with low-carbon fuels.

In this paper, we investigate transport-related issues through the lens of an E4 optimization model, specifically a TIMES/MARKAL model. Such energy system models are valuable tools for long-term...
energy planning. Decision makers have been using them to perform policy analyses and to determine least-cost pathways toward low CO₂ emissions systems considering cross-sectoral dynamics and synergies. TIMES models are described as technology rich, because effectively representing the techno-economic dimensions of an energy system. However, TIMES models are still poor at representing consumers’ behaviour (Schäfer, 2012; Waisman et al., 2013; Cayla et al., 2011; Venturini et al., In preparation). Therefore, it is necessary to improve the representation of transport behaviour in TIMES and similar bottom-up (BU) E4 models to validate their application in transport policy analysis. For this purpose, this study develops a methodology that integrates endogenous modal shift into BU E4 models to analyse its potential contribution to the decarbonisation of the Danish transport sector. The approach is fully implemented and tested in the TIMES model of the Danish energy system, TIMES-DK (Balyk et al., In preparation).

This paper reviews how modal choice has been represented previously in transport and energy system models in Section 2. Then, in Section 3 an overview of the TIMES model generator is provided, followed by a detailed description of the methodology that enables endogenous modal shift. In Section 4 the novel approach is used to assess the benefits of modal shift in reaching a carbon-neutral transport sector, by comparing the results of two versions of TIMES-DK, one without and one with modal shift integrated. Then, four sensitivity analyses are conducted on the key variables of modal shift to assess how their different realizations affect the energy system and enable shifting away from car. Moreover, the most interesting outcomes of the study are used to suggest energy policies promoting modal shift. Section 5 discusses the main shortcomings of the model developed and recommends the direction of future research for improving the representation of transport behaviour in BU E4 models. Finally, Section 6 presents the conclusions.

2. Modal choice in energy and transport models

Modal shift implies a transfer of demand from one mode to another. The dynamics of modal shift result from modal choice changes, corresponding to an evolution in users’ preferences. In turn, users’ preferences are reshaped due to changes in socioeconomic status, subjective opinion, modal characteristics, infrastructure and policy.

Transport models are long-established tools for simulating modal choice. Their structure is composed of four steps: trip generation, trip distribution, modal choice and route assignment. In the third step, modal shares are determined via a multinomial logit model (MNL) or a nested multinomial logit model (NMLN). The MNL and NMLN models are based on a large number of attributes that describe the LoS of the alternative modes and the socioeconomic characteristics of the population. Thanks to their highly disaggregated population description and their ability to base decisions on many attributes, transport models depict realistically households’ modal choice, thus being a reliable tool to assess modal shift. However, the benefits of transport models cannot be directly replicated in linear optimization models due to incompatibilities between the two modeling frameworks. In fact, the MNL mathematical formulation of transport models based on exponential functions cannot be incorporated in linear optimization models. In the field of E4 models, the contribution of modal shift to CO₂ mitigation was initially evaluated through “what-if” analyses, which assess the effect of exogenously assumed levels of shift on the energy system and environment (International Energy Agency, 2009; GEA writing team, 2012). Lately, research interest is focusing on the endogenisation of modal choice (Venturini et al., In preparation). Thanks to the inclusion of simulation methods in the model structure, top-down (TD) (Karplus et al., 2013) and hybrid (H) (Pietzcker et al., 2010; Horne et al., 2005) E4 models are able to simulate modal choice through constant elasticities of substitution (CES) and MNL functions, which have been used for this purpose for more than four decades, thus being very reliable. Bottom-up optimization energy system models lag behind TD and H models concerning their ability to represent modal shift: the portfolio of technologies is endogenously determined only accounting for techno-economic parameters, e.g. capital costs, operation and maintenance (O&M) costs and fuel costs. CES and MNL functions do not directly fit in the optimization framework and thus for this class of models the research on new modeling techniques for representing modal choice is a cutting-edge topic. For BU optimization E4 models, a recent literature review (Venturini et al., In preparation) recognizes two main approaches to incorporate behaviourally realistic modal choice. One consists in linking the BU energy system model with an external transport simulation model that integrates the behavioural features and determines modal shares (E3MLab, 2014; Girod et al., 2012; Brand et al., 2012; McCollum et al., 2016). In the other approach, modal shift is assessed endogenously in the energy system model, by enlarging the traditional model structure to accommodate some transport-specific variables, such as TTB and transport infrastructure (Daly et al., 2014; Pye and Daly, 2015). While the latter method poses some limitations on the level of disaggregation and on the amount of model attributes, the benefits of representing modal shift directly within an energy system model are manifold. First, it enables assessing a much wider variety of policies directly within the energy system model. Then, it allows to analyse transport with an energy system-wide perspective, thus supporting the understanding of the reciprocal implications of decisions taken in the transport and energy systems. The analyses performed in this paper utilize a methodology belonging to the second category of the taxonomy described above.

3. Methodology

This section describes the methodology for incorporating modal shift in TIMES-DK. The approach develops upon previous works by Daly et al. (2014) and Pye and Daly (2015), as explained in detail in Section 5. This process forgoes changing the core modeling paradigm, only altering the conventional model structure (described in Section 3.1). Modal shift is based not only on the levelised costs of the modes, but also on new parameters, namely speed and infrastructure requirements. Moreover, some constraints derived from a National Travel Survey spatially consistent with the scope of analysis avoid unrealistic modal shifts in the model. Within the scope of this study, the soft variables influencing modal choice (Venturini et al., In preparation) have been neglected, and modal shift is endogenously determined via a suitably constrained socioeconomic optimization.

The methodology is developed within TIMES-DK, the TIMES model that represents the entire Danish energy system, from primary energy supply, through energy conversion, until transport, industry, residential and commercial end-use sectors (Balyk et al., In preparation). The transport sector in TIMES-DK includes the explicit representation of passenger and freight transport, both split in aviation, maritime and inland. In particular, inland passenger transport includes private car, bus, coach, rail (metro, train, S-train), 2-wheeler (motorcycle and moped) and non-motorized (bike and walk). Regarding time granularity, the transport sector is described at annual level, i.e. the model does not characterise intra-annual and intra-day variations. The new version of TIMES-DK that incorporates endogenous modal shift hereby presented is called TIMES-DKMS. In TIMES-DKMS, modal shift is limited to inland passenger transport. For national trips, ships and airplanes do not compete with inland modes due to Denmark’s small land surface area. Each mode competes with all others to increase its market share, being fixed the total travel demand. The car mode is an exception: its mobility demand can be replaced by any mode, but its maximum value in 2050 is limited to the baseline projection in TIMES-DK. This is due to the fact that the analyses in Section 4 focus on the long-term potential shift away from car.

Before describing the methodology in detail (Sections 3.2–3.6), Section 3.1 describes TIMES modeling framework and then compares
دریافت فوری متن کامل مقاله

امکان دانلود نسخه تمام متن مقالات انگلیسی
امکان دانلود نسخه ترجمه شده مقالات
پذیرش سفارش ترجمه تخصصی
امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
امکان دانلود رایگان ۲ صفحه اول هر مقاله
امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
دانلود فوری مقاله پس از پرداخت آنلاین
پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات