Applied Energy 135 (2014) 429–439

Contents lists available at ScienceDirect

Applied Energy

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

Incorporating travel behaviour and travel time into TIMES energy system models

Hannah E. Daly [a,b,*], Kalai Ramea [c], Alessandro Chiodi [a], Sonia Yeh [c], Maurizio Gargiulo [a,d], Brian Ó Gallachóir [a]

[a] Environmental Research Institute, University College Cork, Cork, Ireland
[b] UCL Energy Institute, University College London, London WC1H 0NN, UK
[c] Institute of Transport Studies, University of California, Davis, CA, USA
[d] e4sma s.r.l., Via Livorno, 60 – Environment Park, I-10144 Turin, Italy

HIGHLIGHTS

- We address the poor representation of travel behaviour in energy systems models.
- Modal choice modelled in TIMES energy system using novel TTB methodology.
- Case studies for California and Ireland are presented.
- In a mitigation/optimization scenario there is a shift to public transport usage.

ARTICLE INFO

Article history:
Received 11 March 2013
Received in revised form 12 August 2014
Accepted 14 August 2014

Keywords:
Modal choice
Travel behaviour
Energy systems modelling
Climate mitigation

ABSTRACT

Achieving ambitious climate change mitigation targets clearly requires a focus on transport that should include changes in travel behaviour in addition to increased vehicle efficiency and low-carbon fuels. Most available energy/economy/environment/engineering (E4) modelling tools focus however on technology and fuel switching and tend to poorly incorporate mitigation options from travel behaviour, and in particular, switching between modes is not an option. This paper describes a novel methodology for incorporating competition between private cars, buses and trains in a least-cost linear optimisation E4 model, called TIMES. This is achieved by imposing a constraint on overall travel time in the system, which represents the empirically observed fixed travel time budget (TTB) of individuals, and introducing a cost for infrastructural investments (travel time investment, TTI), which reduces the travel time of public transport. Two case studies from California and Ireland are developed using a simple TIMES model, and results are generated to 2030 for a reference scenario, an investments scenario and a CO_2 emissions reduction scenario. The results show that with no travel time constraint, the model chooses public transport exclusively. With a travel time constraint, mode choice is determined by income and investment cost assumptions, and the level of CO_2 constraint, with greater levels of public transport in the mitigation scenario. At low travel investment cost, new rail is introduced for short distances and increased bus capacity for longer distances. At higher investment costs rail is increasingly chosen for long distances also.

1. Introduction

Transportation contributes to 23% of energy-related CO_2 emissions globally. With increasing demands especially for light-duty vehicles, freight, and aviation, global transport CO_2 emissions are expected to double by 2050 [21]. Reducing greenhouse gas emissions from the transport sector will require complementary policies in improving the efficiency of vehicles, introducing low-carbon fuels and advanced vehicles technologies, and better travel demand management [32]. Most of the growth in demand for cars will come from developing countries, as car travel in developed countries essentially saturated, and is projected to remain flat in the next few decades. On the other hand, public transport and aviation already play an important role in many developed (especially Europe) and developing countries (Fig. 1). The importance of their role is expected to continue to increase given the need to

* Corresponding author at: UCL Energy Institute, University College London, Upper Woburn Place, London WC1H 0NN, UK. Tel.: +44 7729 36894; fax: +353 21 4901932.
E-mail address: hannah.daly@ucl.ac.uk (H.E. Daly).

http://dx.doi.org/10.1016/j.apenergy.2014.08.051
0306-2619/

Nomenclature

BKT	Bus Kilometre Travel	OM	Operation & Maintenance
CKT	Car Kilometre Travel	PKT	Passenger Kilometer Travel
E4	energy/economy/environment/engineering	TIMES	The Integrated MARKAL/EFOM System
IAM	Integrated Assessment Model	TKT	Train Kilometre Travel
ktoe	kilo-tonne oil equivalent	TTB	Travel Time Budget
LF	load factor	TTI	Travel Times Investment
mhs	million hours	VKT	Vehicle Kiometer Travel
MNL	Multi-Nomial Logit		

drastically reduce on-road transportation emissions in order to meet stringent climate targets [12,20].

However, while most of the integrated assessment models (IAMs) that governments rely on for developing climate mitigation policies have been able to project portfolios of advanced fuels and vehicle technologies given climate goals, bottom-up models are currently ill suited to examine potential travel demand changes and travel mode shifts given climate policies and changes in fuel prices, and most importantly the necessary investments needed to reduce vehicle travel, increase public transport shares, and non-vehicle infrastructure given climate goals [31]. Most IA models use scenarios describing future travel modal shifts without explicitly linking demand changes to drivers (e.g. fuel price changes) or infrastructure and technology investment decisions. This is evident in Fig. 1 and other studies [12,21]. This is despite the many studies which show that technological change is not sufficient for the transportation sector to develop in a way that is consistent with long-term climate targets [18,3,22,38].

A recent seminal paper by Schäfer [31] provides a critical review of the (lack of) modelling of behavioural changes in transportation in energy/economy/environment/engineering (E4) models, compares common methodologies employed in IA models, their shortcomings and gives recommendations for future improvement. This paper states that "Overall, introducing behavioural change in transportation into E3 models is feasible and intellectually rewarding. However, when pursuing holistic approaches to mitigating energy use and emissions, it is indispensable." Our paper explores some of the recommended methodologies and applies them for the first time in the bottom-up optimisation modelling framework using the TIMES model and implements this in two case studies based on the Californian TIMES model and the Irish TIMES model.

This paper describes the TIMES modelling framework and reviews the role of transport in energy models and key underlying concepts of travel behaviours and travel time budgets in Section 2, describes the methodology in Section 3, introduces and compares the case studies in Section 4, presents results in Section 5 and discusses results and concludes in Sections 6 and 7.

2. Transport modelling and energy systems models

Transport modelling is a very well established discipline used widely by decision-makers for planning infrastructure such as airports, roads and railways, for cost-benefit analyses, and environmental impact assessments. Transport planning models typically simulate travel trips by origin and destination, trip purpose, mode of travel and household demographies. Multinomial logit (MNL) modelling is often used to compute mode choice for trips between each origin and destination [10]. This methodology functions the utility associated with alternative modes and includes the variables that describe the attributes of alternatives, which influence the utility of all members of the population, and variables which influence people's preferences, or choices, among alternatives. Infrastructure and land use play a critical role in the patterns of travel demand, and accessibility to transport infrastructure is a strong determinant of mode choice and travel demand [23]. Therefore behaviour is a strong element of transport models, as

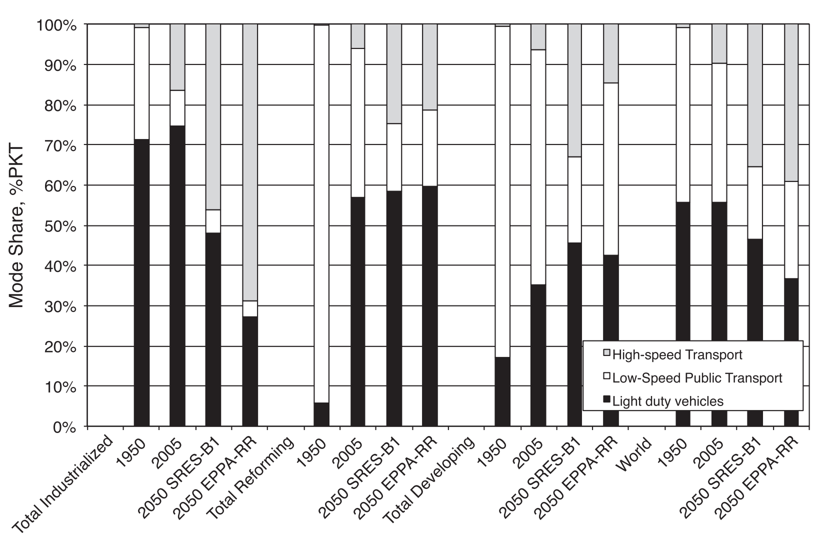

Fig. 1. Relative share of transport modes in the three meta-regions and the world, in history (1950 and 2005) and in projections (2050) based on various scenarios. SRES-B1: Special Report on Emissions Scenarios – SRES, rapid economic growth and advanced technology scenario. EPPA-RR: MIT Emissions Prediction and Policy Analysis (EPPA) CGE model. *Source:* Schäfer and Heywood [32].