TIMES-DK: Technology-rich multi-sectoral optimisation model of the Danish energy system

As Denmark progresses towards a carbon neutral future, energy system models are required to address the challenges of the energy transition. This article describes design, input data and current usage of TIMES-DK, the first Danish energy system model that includes the complete national energy system, covering long-term technology investments. The article aims at explaining the modelling approach; highlighting strengths and reflecting upon limitations of the model; illustrating possible applications of TIMES-DK and inspiring new model developments. Some of the key strengths of the model include simultaneous optimisation of operation and investments across the complete energy system over the whole modelling horizon, explicit representation of the most important sectors of the economy, modular structure and the possibility of linking to a computable general equilibrium model for an additional insight on, e.g. public finance or CO2-leakage. TIMES-DK is being developed in close collaboration between an energy agency, a university and a consulting firm, to improve its robustness, relevance and impact on policy making. It allows for a wide range of applications including exploratory energy scenarios and policy analysis. To meet challenges of the future, further development of the model is needed and consequently the article provides references to ongoing projects addressing current development needs, such as improved representation of transport and flexible handling of the temporal dimension. To support a democratic and transparent process around decisions for the future Danish energy system, TIMES-DK should become available to interested parties.
Improvements in the representation of behavior in integrated energy and transport models

The inclusion of sociological aspects, as human behavior related to transportation, in energy–economy–environment (E3) models may enable an inclusive representation of the system under analysis, thus providing a more likely representation of reality. This article presents a review of integrated energy and transport models characterized by a detailed description of the passenger transport sector and by the presence of transport behavioral features. First, we propose a working taxonomy based on the level of integration of the energy and transport sectors. As the study underlines, a high level of integration is a precondition for incorporating the consumer behavior related to purchase decisions and use of transport technologies in energy and transport models. Second, we identify and review the recurring behavioral features related to transport included in current integrated energy and transport models: technology choice, modal choice, driving pattern, and new mobility trends. The main contribution of the paper resides in analyzing the modeling methodologies adopted in the literature to incorporate behavioral features in transport and in examining opportunities and challenges of each of them. We draw recommendations on model structure and relevant attributes to consider in relation to consumers’ choices in transportation.

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Organisations: Department of Management Engineering, Systems Analysis, University College Cork
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Web of Science (2017): Impact factor 1.892
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BFI (2016): BFI-level 2
A Long-Term Strategy to Decarbonise the Danish Inland Passenger Transport Sector

This study applies a novel modelling framework to assess how alternative policies may contribute to a fossil-free transport sector for Denmark and the potential contribution they may have to a well-below 2Â ºC world. The approach adopted consists of linking an energy system optimisation model, TIMES-DKMS, with a private car simulation model, the Danish Car Stock Model. The results of this study include the magnitude of CO2 abatement presented alongside the corresponding change in tax revenue generated through combinations of policies focusing on the derogation of motor taxes for low emission vehicles and banning the sale of the internal combustion engines. The resulting cumulative emissions from the Danish energy system are also compared to a range of national carbon budgets, calculated to adhere to various levels of global temperature rise at different levels of confidence. The results indicate that a ban on the sale of the internal combustion engines enforced in 2025 would enable the largest cut in cumulative greenhouse gas emissions of all the policies considered. However, none of the policies analysed comply with Denmark’s carbon budget capable of maintaining the increase of global temperature limited to 1.5Â ºC.

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Organisations: Department of Management Engineering, Systems Analysis, University College Cork, E4SMA
Contributors: Tattini, J., Mulholland, E., Venturini, G., Ahanchian, M., Gargiulo, M., Balyk, O., Karlsson, K. B.
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Global EV Outlook 2018: Towards cross-modal electrification

The Global EV Outlook is an annual publication that identifies and discusses recent developments in electric mobility across the globe. Combining historical analysis with projections to 2030, the report examines key areas of interest such as electric vehicle and charging infrastructure deployment, ownership costs, energy use, CO2 emissions and battery materials demand. The publication includes policy recommendations, learning from frontrunner markets to inform policymakers and stakeholders who aim to encourage electric vehicle adoption. The Global EV Outlook annual series is developed with the support of the members of the Electric Vehicles Initiative (EVI).

General information
State: Published
Organisations: Department of Management Engineering, Systems Analysis
Contributors: Bunsen, T., Cazzola, P., Gorner, M., Paoli, L., Scheffer, S., Schuitmaker, R., Tattini, J., Teter, J.
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Improving the representation of modal choice into bottom-up optimization energy system models - The MoCho-TIMES model

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 consumersâ€™ 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 CO2 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.

General information
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Organisations: Department of Management Engineering, Systems Analysis, University of California, E4SMA, University College Cork, Chalmers University of Technology
Contributors: Tattini, J., Ramea, K., Gargiulo, M., Yang, C., Mulholland, E., Yeh, S., Karlsson, K. B.
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Integrating realistic technology's retirement profile in TIMES models - The case of the Danish car sector

Policy analyses conducted with national TIMES models identified that the representation of retirement profile in the car sector is overly optimistic. In traditional TIMES models, the capacity of future installed technologies is constant until the end of the lifetime. However, analyses on cars' retirement profiles found out that the real-life retirement profiles are far from constant. They are characterised by a low decay in the first years after purchase and by a long tail in the distribution, meaning that few cars remain in the car stock for long time. A recent version of the TIMES code (TIMES v4.2.0) has been equipped with a novel attribute that enables to improve the representation of technology's retirement profile. This study utilizes such new attribute within TIMES-DKMS softlinked to DCSM (the Danish Car Stock Model), aiming at reaching a more detailed and realistic representation of the survival profile of car technologies. The study finds out that an early ban on sales and import of internal combustion engine (ICE) cars is not sufficient to decarbonise the Danish inland transportation sector by 2050, and that scrapping incentives are needed to replace ICE cars with low- and zero-emission vehicles, thus enabling the fulfilment of the Danish environmental targets in 2050.

Modelling transport modal shift in TIMES models through elasticities of substitution

Several efforts have been directed lately towards the endogenisation of transport modes competition in Energy/Economy/Environment/Engineering (E4) models. TIMES-DKEMS is a novel methodology paving the way for applying elasticities of substitution to incorporate transport modal shift into TIMES (The Integrated MARKAL-EFOM System) models. Substitution elasticities are defined for four transport demand aggregates, each corresponding to a different distance range class. Within an aggregate, modal demands can adjust their levels according to the defined substitution elasticity and in response to changes of their shadow prices relative to a reference case. The total volume of the transport demand over the aggregate is conserved and modal shift potentials are implemented to guarantee realistic dynamics. The behavior of TIMES-DKEMS is tested under an arbitrary environmental policy, an increasingly stringent bound on CO2 emissions. Modal shares are compared with the standard version of TIMES-DK. Results show that in 2050, 11% of car mobility demand is substituted by more efficient and less costly modes such as train and coach. A sensitivity analysis on the values of substitution elasticities indicates that higher absolute values correspond to larger modal shift. Finally, other model constraints, such as mode-specific travel patterns, interact with the substitution mechanism resulting in a modal shift containment.
Nordic EV Outlook 2018

The Nordic region is at the forefront of the global growth of electric mobility. The Nordic Electric Vehicle Outlook 2018 (NEVO 2018) aims to identify and discuss recent developments of electric mobility in the five Nordic countries: Denmark, Finland, Iceland, Norway and Sweden. The report assesses the current status of the electric car market, the deployment of charging infrastructure, and the integration with the electricity grid at country level. It analyses the role of European, national, and local policy frameworks in supporting these developments. The analysis also provides insights on consumer behaviour and includes an outlook on the progress of electric mobility in the Nordic region up to 2030.

NEVO 2018 has been developed in co-operation between the International Energy Agency (IEA) and Nordic Energy Research. It builds on the long-standing IEA engagement in the area of electric mobility, including the co-ordination of the Electric Vehicles Initiative (EVI) and the hosting of the Hybrid and Electric Vehicle Technology Collaboration Programme.

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

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.
The cost of electrifying private transport - Evidence from an empirical consumer choice model of Ireland and Denmark

There is a growing consensus that moving to a low carbon future within the transport sector will require a substantial shift away from fossil fuels toward more sustainable means of transport. A particular emphasis has been given to battery electric vehicles (BEV) and plug in hybrid electric vehicles (PHEV), with many nations investing in improving their charging infrastructure and incentivising electric vehicle purchasing through offering grant schemes and tax relief to consumers. Despite these incentives, the uptake of BEVs and PHEVs has been low, while some countries, such as Ireland and Denmark, are in the process of removing the tax relief currently in place. This initial retraction has already been met with a fall in sales of BEVs and PHEVs, which is expected to continue decreasing as these incentives are further reduced. This study develops a socio-economic consumer choice model of the private transport sector based off national empirical data for Ireland and Denmark to analyse the long-term effects of these subsidy retractions, and to further analyse the policy measures and associated cost of moving toward a low carbon private transport sector.

General information
State: Published
Organisations: Department of Management Engineering, Systems Analysis, University College Cork, University of California
Contributors: Mulholland, E., Tattini, J., Ramea, K., Yang, C., Gallachóir, B. P. Ó.
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Improving the representation of modal choice into bottom-up optimization energy system models

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Organisations: Department of Management Engineering, Systems Analysis, University of California at Davis, E4SMA, University College Cork, Chalmers University of Technology
Contributors: Tattini, J., Ramea, K., Gargiulo, M., Yang, C., Mulholland, E., Yeh, S., Karlsson, K. B.
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**Value of the interconnectors in the Nordic countries**

**General information**

State: Published  
Organisations: Department of Management Engineering, Systems Analysis, Energy Systems Analysis, Technical University of Denmark  
Contributors: Tattini, J., Gargiulo, M.  
Publication date: 2015  
Media of output: PowerPoint

**Event information**

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Location: Sophia Antipolis, France  
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Research output: Research › Sound/Visual production (digital) – Annual report year: 2015

**Projects:**

**Modelling of Transport Systems in Energy System Modelling Tools**

Tattini, J., PhD Student, Department of Management Engineering  
Karlsson, K. B., Main Supervisor, Department of Management Engineering  
Gargiulo, M., Supervisor  
Yeh, S., Supervisor  
Jørgensen, B. H., Examiner, Department of Management Engineering  
Ahlgren, E., Examiner, Department of Chemistry  
Schäfer, A. W., Examiner  
Schäfer, A. W., Examiner  
Forskningsrådsfinansiering  
01/07/2015 → 30/09/2018  
Award relations: Modelling of Transport Systems in Energy System Modelling Tools  
Project: PhD

**Activities:**

**Improving the representation of consumers’ choice in transport within energy system models**

Period: 30 Sep 2018  
Jacopo Tattini (Other)  
Department of Management Engineering

**Description**

PhD thesis  
Degree of recognition: International  
Documents:  
Phd Thesis Tattini

**Related organisation**

**Improving the representation of consumers’ choice in transport within energy system models**

Tattini, J. (Other)  
30 Sep 2018  
Activity: Other

**Promoting the uptake of electric cars - Lesson learnt from the Nordic experience**

Period: 24 Jun 2018
Jacopo Tattini (Other)
Department of Management Engineering
Systems Analysis
Degree of recognition: International
Documents:
Promoting the uptake of electric cars - Lesson learnt from the Nordic experience

Related event
Nordic Clean Energy Week 2018: How to speed up the introduction of Electro-Mobility and reach climate and energy targets
24/05/2018 → 24/05/2018
Copenhagen, Denmark
Activity: Other

Improving the representation of consumers’ choice in transport within E4 models
Period: 18 Jun 2018
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis

Description
Thesis brief
Degree of recognition: International
Documents:
Improving the representation of consumers’ choice in transport within E4 models

Related event
73rd semi-annual ETSAP meeting
17/06/2018 → 21/06/2018
Gothenburg, Sweden
Activity: Talks and presentations › Conference presentations

Improvements to the representation of technology’s retirement profile – The case of the Danish car sector
Period: 17 Jun 2018
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis
Degree of recognition: International
Documents:
Modeling technology retirement profile in TIMES

Related event
73rd semi-annual ETSAP meeting
17/06/2018 → 21/06/2018
Gothenburg, Sweden
Activity: Talks and presentations › Conference presentations

Nordic EV Outlook 2018
Period: 24 May 2018
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis

Description
This presentation describes the main findings of the International Energy Agency’s NEVO 2018 report, which analyses the status of electric mobility in the Nordic countries and the main policies enabling the successful uptake of electric cars in the Nordic region.

Degree of recognition: International

Documents:
Nevo 2018, IEA’s Nordic EV Outlook 2018

Related event

Nordic Clean Energy Week 2018: How to speed up the introduction of Electro-Mobility and reach climate and energy targets
24/05/2018 → 24/05/2018
Copenhagen, Denmark
Activity: Talks and presentations › Conference presentations

A long-term strategy to decarbonise the Danish inland passenger transport sector
Period: 5 Oct 2017
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis

Description
Presentation given at 12th SDEWES Conference in Dubrovnik
Degree of recognition: International
Documents:
Presentation A long-term strategy

Related event

12th SDEWES Conference
04/10/2017 → 08/10/2017
Dubrovnik, Croatia
Activity: Talks and presentations › Conference presentations

Improving the representation of modal choice into bottom-up optimization energy system models
Period: 13 Jul 2017
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis
Degree of recognition: International
Documents:
Improving the representation of modal choice into bottom-up optimization energy system models

Related event

36th International Energy Workshop
12/07/2017 → 14/07/2017
Washington DC, United States
Activity: Talks and presentations › Conference presentations

Poster presentation
Period: 3 Jul 2017
Jacopo Tattini (Other)
Department of Management Engineering
Systems Analysis
Degree of recognition: International
Documents:
Improving the representation of modal choice into bottom-up optimization energy system models
Related event
03/07/2017 → 04/07/2017
London, United Kingdom
Activity: Talks and presentations › Conference presentations

Modeling modal shift within TIMES energy system models
Period: 2 Dec 2016
Jacopo Tattini (Guest lecturer)
Department of Management Engineering
Systems Analysis
Degree of recognition: International
Documents:
Modeling modal shift within TIMES energy system models

Related event
1st AIEE Energy Symposium: Current and Future Challenges to Energy Security
30/11/2016 → 02/12/2016
Milan, Italy
Activity: Talks and presentations › Conference presentations

68th Semi-Annual ETSAP Meeting
Period: 23 Oct 2015
Jacopo Tattini (Speaker)
Department of Management Engineering
Systems Analysis
Energy Systems Analysis

Description
Presentation entitled "Values of the interconnectors in the Nordic countries"

Presentation at 68th Semi-Annual ETSAP Meeting
Documents:
Values of the interconnectors in the Nordic countries

Related event
68th Semi-Annual ETSAP Meeting
23/10/2015 → 25/10/2015
Sophia Antipolis, France
Activity: Talks and presentations › Conference presentations