Energy Policy 96 (2016) 78–92

Contents lists available at ScienceDirect

Energy Policy

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

Transport energy demand in Andorra. Assessing private car futures through sensitivity and scenario analysis

Oriol Travesset-Baro [a,b,*], Brian P.Ó. Gallachóir [c], Eric Jover [b], Marti Rosas-Casals [a,d]

[a] Sustainability Measurement and Modelling Lab (SUMMLab), Universitat Politècnica de Catalunya (UPC), EET-Campus Terrassa, 08222 Barcelona, Spain
[b] Observatori de la Sostenibilitat d'Andorra (OBSA), Plaça de la Germandat 7, AD600 Sant Julià de Lòria, Andorra
[c] Energy Policy and Modelling Group, Environmental Research Institute, University College Cork, Lee Rd., Ireland
[d] Research Institute in Science and Technology for Sustainability - IS.UPC, Universitat Politècnica de Catalunya (UPC), Campus Nord - TG Building, 08034 Barcelona, Spain

HIGHLIGHTS

- A private car energy model is built using aggregated available data.
- Andorra's current car fleet energy consumption is estimated and forecasted to 2050.
- Potential energy savings have been estimated using sensitivity and scenario analysis.

ARTICLE INFO

Article history:
Received 22 September 2015
Received in revised form
14 May 2016
Accepted 24 May 2016

Keywords:
Transport
Energy demand
Andorra
Private car fleet
Sensitivity analysis
Scenario analysis

ABSTRACT

This paper presents a model which estimates current car fleet energy consumption in Andorra and forecasts such consumption as a reference scenario. The base-year model is built through a bottom-up methodology using vehicle registration and technical inspection data. The model forecasts energy consumption up to 2050, taking into account the fleet structure, the car survival profile, trends in activity of the various car categories, and the fuel price and income elasticities that affect car stock and total fleet activity. It provides an initial estimate of private car energy demand in Andorra and charts a baseline scenario that describes a hypothetical future based on historical trends. A local sensitivity analysis is conducted to determine the most sensitive input parameters and study the effect of its variability. In addition, the scenario analysis explores the most uncertain future aspects which can cause important variability in the results with respect to the Reference scenario and provides a broad estimate of potential energy savings related to different policy strategies.

1. Introduction

Global energy use in the transportation sector has grown 132% since 1973, a growth that surpasses the overall total energy consumption (92%). Apart from industry, transport is currently the most energy-consuming sector in the world. Although projections to 2035 suggest a more moderate future annual growth (1.4% per annum according to the IEA New Policies Scenario), this figure is far from the stabilization levels required to follow the IEA 450 Scenario, which establishes policies to limit the average global temperature increase to 2 °C (IEA, 2014). Within the European Union framework, the transportation sector accounts for 32% of the final energy consumption and is responsible for almost a quarter of the total carbon dioxide (CO_2) emissions produced, being the sector with the highest growth in both areas since 1990 (European Commission, 2014a). Emissions from the transport sector increased by 33% in the period from 1990 to 2007. However, the recent economic downturn has prevented sustained growth since then. More than two thirds of transport-related GHG emissions are from road transport, contributing approximately 20% of the EU's total CO_2 emissions (European Commission, 2014b). Private cars, as the predominant mode of road transport, have a key contribution to make in decarbonising both European and global economies.

This context points to the need for countries to dedicate greater efforts in defining and implementing effective policies that focus on transport and, more specifically, on minimising energy-related CO_2 emissions. Top-down and, particularly, bottom-up models that quantify the impact of specific governmental policies are widely

* Corresponding author at: Observatori de la Sostenibilitat d'Andorra (OBSA), Plaça de la Germandat 7, AD600 Sant Julià de Lòria, Andorra.
E-mail address: travesset@gmail.com (O. Travesset-Baro).

http://dx.doi.org/10.1016/j.enpol.2016.05.041
0301-4215/

used to inform and support decision-making processes (Nakata, 2004). In this sense, Bandivadekar et al. (2008) evaluate the potential effects of new technologies in the United States using a vehicle fleet bottom-up model. The model examines future vehicle-fuel use based on sales, retirements, fuel consumption and miles driven per year. A similar approach is used by Pasaoglu et al. (2012), implementing a model that analyses the evolution in energy savings, emission reductions and cost aspects of future vehicle options in the EU-27 under various vehicle penetration scenarios. Siskos et al. (2015) assess CO_2 and energy efficiency car standards in the EU in the context of a decarbonisation strategy using the PRIMES-TREMOVE energy economic transport model. Daly and Gallachóir (2012) use a technological model of Ireland's future car stock to simulate the impact of a range of policy strategies that focus on vehicle efficiency, fuel switching and behavioural measures. Local policies such as fiscal measures (i.e. vehicle and fuel taxation) are evaluated in national-scale models such as that used in the UK Transport Carbon Model (Brand et al., 2012) or in Kloess et al. (2011) where the Austrian passenger car fleet is simulated. *Ex-post* analysis of car taxation policies has also emerged with case studies being completed in Ireland (Rogan et al., 2011) and in France (D'Haultfœuille et al., 2014).

Most of the studies developed in this field are concentrated in countries where the availability of data is very high and where there is previous research that can support the construction of new models. In countries where available data is more aggregated in their original form, simplifications and estimates are required in order to build these models. This paper focuses on this challenge in energy modelling research. The variability in the model outputs, associated with uncertainties in input parameters, may be even greater in these cases. In this sense, greater emphasis on analysing possible output variability is needed to give policymakers greater confidence in the forecasts derived from such models.

This paper builds an energy model for the private car stock in Andorra. Its purpose is to demonstrate how a useful modelling tool can be developed and applied in the presence of more aggregated data. The approach adopted here has the potential to be replicated in other regions that require further evidence to underpin policy decisions. The model estimates current and future car transport energy demand in Andorra. It builds a reference scenario and shows the subsequent steps that are required to enable additional scenario analysis, so that the model can be used to support national policy decision-making processes by quantifying the impacts of various energy policy measures.

Andorra is a small, mountainous country located between France and Spain, with a population of approximately 70,000 inhabitants in 2015 and an area of 468 km^2. Andorra is highly energy import-dependent. Only 4% of the energy used in the country derives from locally generated electricity. The remaining 96%, including all hydrocarbon fuels used in transport sector, is imported from France and Spain. Despite this high dependency on energy imports, electricity and hydrocarbon fuels are cheaper than in neighbouring countries due to Andorra's fiscal policy. The ratio of private cars per population is among the highest in the world (686 cars per 1000 inhabitants). Despite the decline in car sales since 2005, the total car stock has continued to rise, undeterred by the economic downturn (Department of Statistics, 2014). This case study is particularly relevant, as in Andorra, the transport sector is the main energy consumer (50% of the final energy consumed in 2013) and the leading source of GHG emissions, representing 69% of energy-related emissions (Miquel et al., 2014). Its location, in the middle of the Pyrenees, means that transport energy demand is entirely focused on road transport. Moreover, nearly 8 million people visit Andorra by road every year, representing an important contributor to national fuel consumption. Although there is no previous research addressing this aspect, according to the vehicle fleet structure, private cars (72% of the fleet) seem to have a major impact on transport energy demand. Thus, it is particularly critical to quantify the importance of private car energy demand, improve understanding of the country's drivers and show possible future trends in order to deal with energy challenges in the coming years.

The private car energy model implemented in this paper follows essentially that proposed by Daly and Gallachóir (2011a), but it has been modified and adapted to account for aggregated data, such as those found in the case of Andorra. It can be classified as a bottom-up simulation forecasting model, where energy demand is driven by the technological composition of the car stock and the behaviour of private car users. A demographic model of the car stock has been created and the technological characteristics (fuel type, engine size and car age) have been disaggregated by year.

The paper is organised as follows. The methodology and assumptions are presented in Section 2. Section 3 provides the results and discussion. Finally, conclusions, policy implications and some prospects for future work are presented in Section 4.

2. Methods

The model presented in this paper has been developed in two main steps. Firstly, a technological stock model of private car energy demand has been built. Andorra's current private car fleet has been modelled, including highly detailed vehicle technological characteristics, to provide energy demand results for the year 2013. Then, the stock model has been projected for each year up to 2050, based on historical trends and guided by economic factors and technological innovation. Finally, the effect of the variability in input parameters has been studied through a sensitivity analysis and different scenarios have been analysed in order to quantify the potential of technology- and behaviour-focused policies.

2.1. Car fleet model

This model represents Andorra's current car fleet. It is a technological car stock model built through a bottom-up methodology using the country's vehicle registration data (Daly and Gallachóir, 2011b). It uses fleet structure, mileage profile (km/year) and specific energy consumption (MJ/km) as explanatory variables (Fig. 1). The private car fleet in 2013 is disaggregated into different categories according to fuel type, engine size and vintage (car age). Subsequently, a mileage profile for different car categories has been defined, based on data from vehicle technical inspections. Each category has a specific energy consumption value, which takes into account official fuel consumption test data, on-road factor (to reflect the gap between real and test vehicle efficiency), and ageing factor (to include vehicle vintage in car consumption).

2.1.1. Car fleet structure

Andorra's 2013 private car fleet is built using data compiled from the National Vehicle Registration bureau up to the end of 2013 (Department of Industry, 2014). Although the database contains technological details from all vehicles registered since 1951 still remaining in the car fleet, it does not include any information on the fleet structure for years before 2013 or historical scrapped vehicles. Fig. 2 shows Andorra's 2013 private car fleet. All cars registered after 1984 (49,691 individual records) have been filtered and disaggregated into different categories according to fuel type (petrol or diesel), engine size (<1400 cc, 1400–2000 cc, >2000 cc) and vintage (0–29 years), factors that have a major influence on energy consumption.

The entire fleet is distributed into diesel and petrol cars, since other technologies are not relevant in the current car fleet. Electric vehicles are not considered in the model due to their low