



The role of energy-service demand reduction in global climate change mitigation: Combining energy modelling and decomposition analysis

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ARTICLE INFO

Article history:

Received 14 January 2011

Accepted 19 August 2011

Available online 3 September 2011

Keywords:

CO₂ emission reduction

Energy-service demand

Energy system modelling

ABSTRACT

In order to reduce energy-related CO₂ emissions different options have been considered: energy efficiency improvements, structural changes to low carbon or zero carbon fuel/technologies, carbon sequestration, and reduction in energy-service demands (useful energy). While efficiency and technology options have been extensively studied within the context of climate change mitigation, this paper addresses the possible role of price-related energy-service demand reduction. For this analysis, the elastic demand version of the TIAM–UCL global energy system model is used in combination with decomposition analysis. The results of the CO₂ emission decomposition indicate that a reduction in energy-service demand can play a limited role, contributing around 5% to global emission reduction in the 21st century. A look at the sectoral level reveals that the demand reduction can play a greater role in selected sectors like transport contributing around 16% at a global level. The societal welfare loss is found to be high when the price elasticity of demand is low.

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1. Introduction

Human beings demand energy in order to meet energy services such as heating, cooling, lighting, cooking, transport, or machine drive, via end-use devices, which consume final energy. In order to provide energy services (useful energy), conversion technologies (for example, power plants or refineries) and corresponding infrastructure are used to transform primary energy (for example coal) into final energy (for example electricity). End-use devices, such as light bulbs, refrigerators, or electric radiators, transform final energy into useful energy-services. Currently most of the primary energy sources used in the energy system are fossil fuels (hydrocarbons). Technologies are involved all the way from upstream to end-use sectors emitting CO₂ and other greenhouse gases by burning fossil fuels.

As a response to the challenge of climate change mitigation, there have been several research and modelling exercises carried out mostly discussing options like shifting to low carbon fuels, renewable energy and improving the efficiency of energy transformation and end-use technologies. Getting engineering right is not always enough, however; cultural and behavioural change affecting demand for energy services is necessary in order to meet the stringent climate change mitigation targets (Webler and Tuler, 2010). As human beings demand energy services, reducing energy-

service demands will, *ceteris paribus*, result in lower energy consumption and consequently reduce CO₂ emissions in the whole energy system. Moreover, demand reacts to price changes: an increased energy service price will result in a decreased demand for energy services and vice versa. This paper quantifies the role of energy-service demand reduction in meeting global CO₂ mitigation targets by decomposing the results of the TIMES Integrated Assessment Model (TIAM)–UCL global energy system model using the Logarithmic Mean Divisia Index (LMDI) as a decomposition technique. The term ‘demand reduction’ generally means reduction in final energy consumption such as gasoline, diesel or electricity. In this paper, demand reduction means reduction in energy-service demands due to increased prices for meeting those services. This paper does not include price-independent and income-dependent behavioural adaptations, such as a non-price-related reduction in thermal comfort or the reduction of speed limits on motorways. Neither does this paper study the price response of final energy consumption, such as gasoline, to price changes.

The overall objective of this paper is to examine the role of price-sensitive energy-service demand reduction in meeting global CO₂ reduction. We estimate the level of CO₂ emission reduction due to demand reduction at a regional and sectoral level and analyse the implications of demand reduction on societal welfare and regional emissions.

The remaining paper is structured as follows: Section 2 reviews the literature on CO₂ emission reduction and in particular on the role of energy-service demand. Section 3 presents the employed methodology, i.e. the TIAM–UCL model, demand reduction theory,

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and the decomposition technique used in this paper, while Section 4 defines the scenarios for the analysis. Section 5 discusses the results concerning the level of energy-service demand reduction in different end-use sectors, the contribution of demand reduction to CO₂ mitigation, and the impacts of demand reduction in terms of welfare cost and regional emission mix. Section 6 concludes the paper.

2. Literature review

In the context of global climate change mitigation a significant amount of literature has focused on possible ways to reduce carbon-intensive final energy consumption. Different ways to tackle rising carbon emissions include an increased energy efficiency, structural changes to low or zero carbon technologies, fuel switching, carbon capture and storage (CCS) and behavioural change. The last term can again be divided into price-related demand changes and those that are non-price related.

Several studies have looked at the possible contribution of energy efficiency to limit climate change (see e.g. Hanaoka et al., 2009; Ürges-Vorsatz and Metz, 2009). Further studies have reviewed the role of possible technology options, such as CCS, for the reduction of CO₂ emissions (den Elzen et al., 2008; Fisher et al., 2007; Gerlagh, 2006). Moreover, there are studies that discuss ways to reduce energy demand, such as electricity or gas consumption, i.e. on the final energy level. Toke and Taylor (2007) discuss the introduction of a demand reduction obligation in the UK non-domestic sector, Hinnells (2008) looks at technologies in residential and non-residential buildings to reduce final energy demand, while Sartori et al. (2009) have considered technological options to reduce final energy in the Norwegian building stock.

But there are limited studies available that look at energy-service demand reduction instead of final energy demand, particularly at a global level. Most of the studies on energy-service demand reduction used bottom-up, cost optimisation energy models such as MARKet ALlocation (MARKAL) or The Integrated MARKAL TIMES EFOM System (TIMES). Examples for studies relying on MARKAL are Anandarajah et al. (2008), Chen et al. (2007), and Kanudia and Shukla (1998). The TIMES model generator has been used in global studies by Vaillancourt et al. (2008), Syri et al. (2008), Loulou et al. (2009), and Ekholm et al. (2010). Next to model-based studies, there are other approaches that rely on the expert assessment of the emissions reduction potential. Pacala and Socolow (2004) considered reduced demand for car travel within the scope of their mitigation wedges, while Dietz et al. (2009) included demand reduction options for different energy service demands in household energy consumption as one possible option to reduce carbon emissions.

A review of those studies permits to conclude that demand reduction is an important factor to be considered as the level of demand reduction seems to be significant in low carbon scenarios. According to Kanudia and Shukla (1998) demand reduction contributes up to 10% of the CO₂ reduction in India in 2020. At a global level, Vaillancourt et al. (2008) found demand reduction in a climate change mitigation scenario to vary from 3% (for car travel) to 23% (for international aviation) in 2100. At a national level, demand reduction can be as high as 25% for the UK according to Anandarajah et al. (2008) and 30% for China according to Chen et al. (2007).

In summary, there have been many studies that examine possible contributions of technological and efficiency options in order to reduce carbon emissions. In addition, studies have focused on the reduction of final energy consumption and based on bottom-up energy models occasionally on the reduction of energy-service demands. To the best knowledge of the authors, no

study has so far translated a reduction of energy-service demands into a reduction of carbon emissions.¹ The present study fills this gap by combining energy systems modelling and decomposition analysis.

Research involving decomposition studies in the energy/emissions field has so far focused on the decomposition of historical data concerning energy consumption or CO₂ emissions. In this context, CO₂ emissions as an aggregate variable are decomposed into factors such as structural effects, carbon intensity or energy intensity (Diakoulaki et al., 2006; Zhang and Ang, 2001). Recently some studies have considered the development of underlying drivers of future emissions (Agnolucci et al., 2009; Kawase et al., 2006). To the knowledge of the authors, no study has so far analysed the role of demand reduction in meeting long-term CO₂ mitigation scenarios using decomposition techniques. A merit of using decomposition technique is that the contribution of demand reduction in meeting CO₂ emissions reduction target can be quantified in absolute or relative terms.

3. Methods

3.1. TIAM-UCL

The 16-region TIAM-UCL model has been developed under the UK Energy Research Centre (UKERC) Phase II project (Anandarajah et al., 2010b) by breaking out the United Kingdom (UK) from the Western Europe Region in the 15 Region Energy Technology Systems Analysis Programme (ETSAP)-TIAM model (Loulou and Labriet, 2008).² TIAM, an acronym for the TIMES Integrated Assessment Model, is a cost optimisation partial equilibrium model that minimises total discounted energy system cost in the standard version and maximises total societal welfare in the elastic demand version. Results of the optimisation include type and capacity of energy technologies, energy consumption by fuel, energy trade flows between world regions, energy system costs, the long-term prices for the energy carriers as well as the marginal costs of environmental measures. The model covers the time horizon from 2005 to 2100. The model horizon considered in TIAM-UCL is divided into periods of 10 year duration being represented by an average year.

In each region, TIAM-UCL describes the entire energy system with all essential current and future energy technologies from the primary energy supply over the processing, conversion, transport, distribution of energy carriers to the end-use sectors and the energy-service demands. These demands are linked to exogenous underlying drivers like population growth or GDP development via demand elasticities.

The primary energy resources and the petroleum processing sector are further divided in OPEC and non-OPEC sub-regions. The world regions are linked through trade in crude oil, hard coal, pipeline gas, liquefied natural gas (LNG), petroleum products (diesel, gasoline, naphtha and heavy fuel oil) and emission permits. On the resource side, the conventional and unconventional oil and gas reserves and resources in the different regions as well as various enhanced recovery methods are included in the model. Conventional oil is again divided into reserves, enhanced oil recovery reserves and yet-to-find resources. All different reserve and resource types of crude oil and natural gas are classified according to the regional structure of TIAM-UCL and divided into cost categories to account for varying supply costs.

¹ Kanudia and Shukla (1998) are an exception to this, but it is not clear how the estimation of the reduction in carbon emissions is derived.

² ETSAP-TIAM, originally developed by KanLo (www.kanors.com/DCM/TIAM).

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