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Marginal abatement cost curves for policy recommendation – A method for energy system analysis

Jan Tomaschek

Institute of Energy Economics and the Rational Use of Energy (IER) University of Stuttgart, Hessbruehlstr. 49a, D-70565 Stuttgart, Germany

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ABSTRACT

The transport sector is seen as one of the key factors for driving future energy consumption and greenhouse gas (GHG) emissions. In order to rank possible measures marginal abatement cost curves have become a tool to graphically represent the relationship between abatement costs and emission reduction. This paper demonstrates how to derive marginal abatement cost curves for well-to-wheel GHG emissions of the transport sector considering the full energy provision chain and the interlinkages and interdependencies within the energy system. Presented marginal abatement cost curves visualize substitution effects between measures for different marginal mitigation costs. The analysis makes use of an application of the energy system model generator TIMES for South Africa (TIMES-GEECO). For the example of Gauteng province, this study exemplary shows that the transport sector is not the first sector to address for cost-efficient reduction of GHG emissions. However, the analysis also demonstrates that several options are available to mitigate transport related GHG emissions at comparable low marginal abatement costs. This methodology can be transferred to other economic sectors as well as to other regions in the world to derive cost-efficient GHG reduction strategies

1. Introduction and background

In the Kyoto protocol the participating countries committed themselves to reduce greenhouse gas (GHG) emissions by 5.2% below the 1990 level by 2012. According to the IPCC Fifth Assessment Report (IPCC, 2014) the transport sector was responsible for about 14% (6.9 Gt CO_2e) of global GHG emissions in 2010, which is an increase of almost 50% since 1990. In the same timeframe the global oil demand increased by about 30% (IEA, 2012). This trend is likely to continue where the transport sector (especially in the emerging economies) is the main driver for increased GHG emissions (IEA, 2012).

The global reduction of GHG emissions can probably only be achieved if the economic burden is minimized. Marginal abatement cost (MAC) curves as graphical representations of the relationship between abatement costs and emission level have become a tool to determine the appropriate set of measures to reach the desired carbon reduction target. MAC curves have so far been applied to numerous demand sectors and regions in the world (see e.g., Kesicki, 2013, 2012a,b; McKinsey&Company, 2009; Remme, 2006; Schroten et al., 2012; Bockel et al., 2012; MacLeod et al., 2010).

In principle there are three levers for mitigating transport related GHG emissions: the first option is reducing demand for motorized transport (kilometers traveled per mode), e.g., by changing the modal split through enhancing public transport or freight mass transportation services (see e.g., Fiorio et al., 2013; Redman et al., 2013; Galilea and Medda, 2010; Buehler and Pucher, 2011; Albalate and Bel, 2010; John and Kurth, 1995). The second possibility lies in the reduction of vehicle emission intensity (i.e., tank-to-wheel (TTW) emissions) which can be achieved through increased vehicle efficiency (such as in hybrid electric vehicles) or by using alternative fuels (e.g., by using low-carbon fuels or by balancing carbon credits for biomass production). Finally, there is the possibility of decreasing the emission intensity of fuel provision (i.e., well-to-tank (WTT) emissions), e.g., through alternative fuel provision measures such as biofuels, natural gas or carbon capture and storage. Many studies are available analyzing either one or many of these aspects in more detail (see e.g., Bruchof, 2013; Özdemir, 2012; Flachsland et al., 2011; IEA, 2010; Gül, 2008).

This paper will demonstrate how to derive marginal abatement cost curves for well-to-wheel GHG emissions of the transport sector to demonstrate which measures should initially be applied and therewith to be supported through legislation. The analysis makes use of the energy system model generator, TIMES, and considers the full energy provision chain and the interlinkages and interdependencies within the energy system. To make the presented MAC curves more transparent this paper will also show the changes and substitution effects in marginal abatement cost curves by attributing sectoral effects in energy provision to energy use in the demand sector.

E-mail address: jan.tomaschek@ier.uni-stuttgart.de

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Symbols and indices

c	commodity
c_i	commodity of type i. Fuel products
c_{i*}	commodity of type i*. Feedstock for conversion process p_l^{CONV}
$c \in pcg\,(p)$	commodity which is element of the primary commodity group of process p
C_i	cost of technology i
C_{Ref}	cost of reference technology
CH_4	methane
CO_2	carbon dioxide
$CONV$	energy conversion sector
$DIST$	energy delivery and distribution
E_i	emissions of technology i
E_{Ref}	emissions of reference technology
$FLO\,(r, v, t, p, c, s)$	flow of commodity c of process p with vintage year v in current period t and time slice segment s in region r
g	type of primary energy provision process
GHG	greenhouse gases: CO_2, CH_4 and N_2O
i	fuel product (final energy carrier)
$i*$	feedstock for conversion process (primary energy carrier)
in	input
k	marginal abatement cost [EUR_{10}/t CO_2e]
l	type of conversion process
m	transport mode
n	transport powertrain
N_2O	nitrous oxide
out	output
p	process
$p \in p_l$	group of processes p_l of a similar type
p_l^{CONV}	conversion process for fuel provision of type l
p_m^{TRA}	transport processes by mode m
p_n^{TRA}	transport processes by powertrain n
$p_{m,n}^{TRA}$	transport process of mode m with powertrain technology n
pcg	primary commodity group
$PRIM$	primary energy provision
r	region
s	time slice segment
t	(current) time period
TEC	transport related energy consumption
TEP	transport related energy provision
TRA	transport sector
TTW	tank-to-wheel emissions
v	construction time period (vintage)
WTT	well-to-tank emissions
WTW	well-to-wheel emissions
wtt	well-to-tank emission factor
z	objective function
γ	transport share
$\eta(p_{c_i}^{DIST})$	efficiency of distribution process for commodity c_i, i.e. distribution losses

The analysis will be carried out for Gauteng Province, South Africa as an example. The South African government has committed to reduce greenhouse gas emissions by 34% till 2020 and by 42% till 2025 against a business as usual trajectory. A carbon tax based on CO_2 equivalents for all energy consuming sectors has been proposed in order to achieve this ambitious goal. However, the rate at which such a tax should be applied is still under discussion as well as possible exemptions for energy intensive industries (DNT, 2013).

The metropolitan region of Gauteng is the economic hub of South Africa with a third of the national GDP and a fifth of the population. The transport sector is responsible for about 25% of total GHG emissions, taking into account emissions from the energy supply (e.g., petroleum refining and synthetic fuels) (Tomaschek et al., 2012b). Gauteng Province sees an opportunity to be a forerunner for the South African climate protection strategy but has not yet developed a clear strategy how the transport sector could and should develop in future (DLGH, 2010).

The paper is structured as follows: Section 2.1 presents recent studies covering MAC curves. Furthermore, technology oriented bottom-up approaches using energy system models are described, where in both cases focus is given on those studies analyzing the transport sector or transport related issues in more detail. Section 2.2 presents the basic framework of the TIMES-GEECO model and its structure as well as technology detail in the transport sector and in the fuel provision sector. 1211Section 2.3 shows how MAC curves for the transport sector can be derived which incorporate fuel provision, interdependencies and interlinkages between options, transport related ancillary effects within the energy system as well as the substitution effects between options. The definition of the scenarios analyzed can be found in chapter 3. Chapter 4 presents the results of the model application and shows how to cost-optimally mitigate transport related well-to-wheel GHG emissions in Gauteng and in South Africa. Chapter 5 concludes and gives detailed policy recommendations.

2. Methodology

2.1. Literature review

Two fundamental approaches for deriving MAC curves can be distinguished: firstly, the calculation of marginal abatement costs of alternative measures against a reference and subsequent ranking (static approach) and, secondly, the application of mathematical models of the economy or energy system, i.e., computable general equilibrium (GCE) models or bottom-up approaches using energy models.

Static approaches calculate the GHG emissions (E) before and after the implementation of an alternative technology (i) and associate the emission abatement to the costs of the measure in comparison to a reference technology (Ref) (Eq. (1)).

$$MAC\,(i) = \frac{C_i - C_{Ref}}{E_{Ref} - E_i} \tag{1}$$

One of the most well-known presentations of such a MAC curves for the transport sector is probably the work of McKinsey&Company (2009) where they present abatement cost curves for different regions in the world and also a global MAC curve for the transport sector. The work of Schroten et al. (2012) laid its emphasis on the freight sector, and derived detailed MAC curves for heavy duty vehicles covering different delivery scenarios, distinguishing alternative powertrains, engine modifications as well as enhancements of vehicle aerodynamics and rolling resistance. An example for a sector wide MAC curve can be found in Wächter (2013) who identified some no-cost mitigation measures available for the transport sector of Austria but did not include emissions associated with energy provision. Telsnig et al. (2013) analyzed a broad set of abatement measures for the South African energy system based on a static approach. Static approaches are relatively easy to realize. In principle the analysis requires only the cost of two compared