On the road to energy-efficient mobility in Austria: An extended technology wedges approach

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Abstract

Energy and climate policy objectives require a fundamental restructuring of our energy systems, which affects energy services, final energy consumption and energy generation. One central area of change is mobility, which accounts for a significant and growing share in energy-related CO_2 emissions and energy demand.

In the research presented in this paper, an extended concept of technology wedges is used for Austria to illustrate options for technological and behavioural changes in the transport sector. Technology wedges are defined as options that achieve substantial reductions in final energy demand and emissions taking the effects on the entire energy cascade into account – i.e. changes in energy services, application and transformation technologies as well as primary energy. Energy service in mobility is defined as the access to persons, goods and services needed to connect all important functions and amenities of life. To simplify their measurability, energy services are expressed using the variables vehicle, passenger and tonne kilometres. Vehicle or passenger kilometres may, however, be reduced as an effect of the technology wedge, while still resulting in the same access to persons or goods. This particularly applies to options like improved spatial planning.

Introduction

Energy and climate policy objectives require a fundamental restructuring of our energy systems, which affects energy service, final energy demand and energy generation. Transport or mobility is one central area of change, which accounts for a significant and growing share in energy-related CO_2 emissions and energy demand.

In 2008, 26 % of GHG and respectively 30 % of CO_2 emissions in Austria were caused by the transport sector (Anderl et al., 2010). The greater part of transport emissions (98 %) originated from road transport, of which 55 % arose from passenger transport and 43 % from heavy and light duty vehicles. Between 1990 and 2008, transport GHG emissions rose by 60 % (Anderl et al., 2010). This significant growth in emissions is due, in particular, to an increase in freight transport. Between 1990 and 2008, GHG emissions from heavy duty vehicles increased by nearly 132 %. This trend in freight transport is a direct consequence of an increase in the international division of labour and the fragmentation of production.

In the research presented in this paper, an extended concept of technology wedges is used for Austria to illustrate options for technological and behavioural changes in the transport sector. Technology wedges are defined as options that achieve substantial reductions in final energy demand and emissions compared to a reference path taking the effects on the whole energy cascade into account – i.e. changes in energy services, application and transformation technologies as well as primary energy.

The technology wedges aim at three major effects. First, transport performance is reduced. Second, there is a shift in transport modes, for example, from cars to bicycles or walking. Third, there is an increase in efficiency (e.g. improved propulsion technology).

Our analysis of technology options follows three steps. First, we develop a reference path for energy demand and CO_2 emissions until 2020. The potential for savings from the implementation of individual technology wedges is then calculated and a portfolio of options is developed, accounting for interactions between wedges (e.g. reduced potential of bio-fuels due to reduced energy service demand). Finally, the economic impacts of the wedges are assessed, in addition to energy and emission effects.

Methodology

The methodological approach presented in this paper is based on the concept of stabilisation wedges by Pacala and Socolow (2004) which highlights the role of technologies in reducing greenhouse gas emissions. The original concept of stabilization wedges is extended and applied for Austria to illustrate options for technological and behavioural changes. The extensions include the integration of all wedges into a structural model of the Austrian energy system that starts with energy services and ends with primary energy flows, as well as an analysis of the economic impact of the implementation of different technologies.

Technology wedges are described using five central variables:

- S for energy service,
- u for useful energy intensity with
- U for useful energy (amount of useful energy U per service unit S, u=U/S), and
- f for final energy intensity (amount of final energy F per useful energy, f=F/U).
- F for final energy demand

The reductions in final energy demand and emissions depend on the development of energy services, as well as on changes in useful energy intensity and final energy intensity which depict technological and behavioural changes. The effects on emissions are caused by changes in the amount of final energy demand on the one hand and the structure of energy demand by energy source on the other[1].

Energy service in mobility is the access to persons, goods and services needed to connect important functions and amenities of daily life. According to this definition, the energy service is sought not to decline over time in all storylines. To simplify measurability, energy service (S) is expressed by means of the variables vehicle kilometres (vkm), passenger kilometres (pkm) and tonne kilometres (tkm). However, note that vehicle kilometres or passenger kilometres may be reduced or shifted in the storylines still leading to the same access to persons or goods with reduced energy consumption and reduced CO_2 emissions. This is particularly the case with improved spatial planning, where the same access is enabled using fewer passenger kilometres. We assume that demographic developments will give rise to more trips and more goods will have to be transported over time, thus S is increasing. The implicit final energy demand for providing the energy service is F. Effective useful energy (U) can be calculated by using the energy intensity factor for final energy f (F/U) for different transport modes and vehicle categories. The corresponding energy intensity for useful energy is u, i.e. U/S. The general assumptions underlying transport development – a decreasing share of public transport over time, a shift from diesel to gasoline engines, the latter being less efficient, and a decrease in the vehicle occupation rate due to demographic changes – lead to an increasing u, if there are no additional effects in the particular technology wedge influencing this indicator.

Technology wedges focus on the emission reduction potential of different technologies. The modelling of technology wedges therefore requires a reference scenario for the development of emissions as a starting point. This scenario represents the upper boundary of the reduction triangle, from which changes in emissions related to different portfolios of technology wedges are subtracted. The projection of final energy demand and CO_2 emissions in the transport sector by energy source is given in Figure 1. The reference scenario for final energy demand until 2020 follows the trends from past years and shows an increase of 2 % between 2008 and 2020. This is also reflected in the trend in CO_2 emissions. The dependency on fossil fuels is an indication of the challenges this sector has to meet.

Technology wedges for mobility

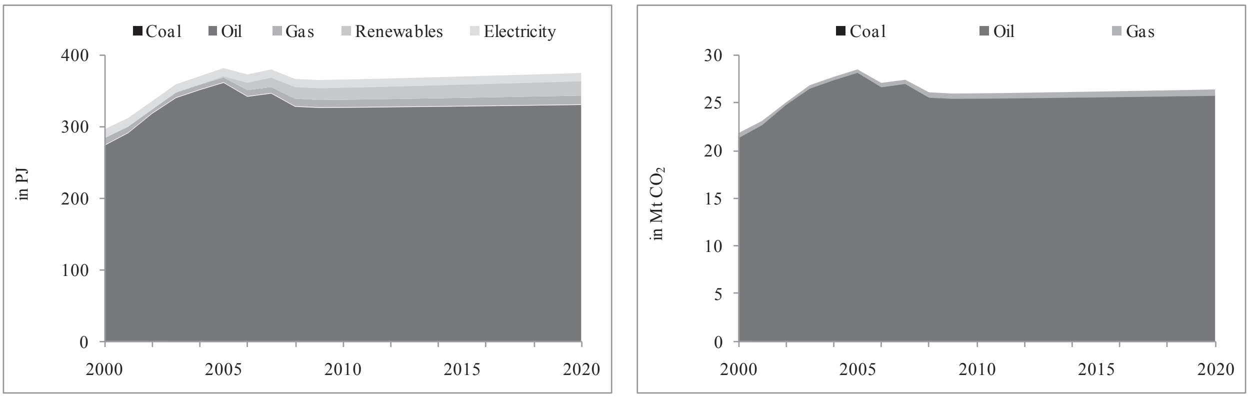
A CATALOGUE OF TECHNOLOGY WEDGES FOR MOBILITY

The determination of energy and emission reduction potentials for these different technology wedges is based on trends in motor vehicle stock and average mileage. Using recently observed transport performance in passenger transport (pkm) and freight transport (tkm) for the different individual passenger transport modes (motorised and non-motorised) as a basis, we calculate public transport and freight transport (rail and road) (Käfer et al., 2009) emission reduction potentials. The general assumptions for the technology wedges concern trends in vehicle stock (diesel vs. gasoline engines), modal share (in passenger and freight transport) and the occupation rate in passenger transport and loading rate in freight transport. Furthermore, the implementation of the EU regulation on 'setting emission performance standards for new passenger cars' (EC No 443/2009) is taken into account.

The technology wedges aim at three major effects. First, transport performance, such as person kilometres travelled or transport distances for goods, is reduced. Second, there is a shift in transport modes, for example, from energy wasting modes like passenger cars to energy saving modes like cycling and walking. Third, efficiency gains resulting from improved motor technology and/or decreased mass of vehicles are a source of change. The way in which these effects can be realised is analysed in storylines for the different technology wedges.

Eight technology wedges are developed for the transport sector, calculating the emission reduction potential and the associated investment effects. Transport studies as well as empirical research results are taken as a starting point for the calculations. The assumptions as well as the concrete implementation of each technology wedge are laid out in detail in Köppl etal. (2011):

1. A detailed description of the methodological approach is given in Köppl et al. (2011).



Source: Statistics Austria (2009a, b), UFCCC (2010); own calculations.

Figure 1. Reference scenario for final energy consumption (left) and CO_2 emissions (right) by energy source.

M-1: Efficient transport saving land use – Friedwagner et al. (2005) evaluated the transport effects of denser regions in the surroundings of Linz and Wels in Upper Austria. The results of Friedwagner et al. (2005) are scaled up to the Austrian level for this technology wedge.

M-2: Public transport – Based on studies on the modal split of Austrian passenger transport (e.g. BMVIT, 2007) it is assumed that the share of public transport increases by 3 percentage points until 2020.

M-3: Non-motorised transport – Research results from a Swiss study (INFRAS, 2005) are used in order to calculate the potential for a shift from motorised to non-motorised transport in Austria.

M-4: Alternative propulsion technologies – Referring to Pötscher et al. (2010) in 2020 about 210,000 EV and PHEV will be on the market. Following the forecast of Hausberger (2010) for the development of the vehicle fleet, this implies a market share of about 4 %. In the medium-term a distribution of 25:75 between EV and PHEV considering new registrations is assumed.

M-5: Freight transport – This technology wedge covers the promotion of intermodal transport and improvement of logistic systems using teleinformatics in transport. The emission reduction potential of freight transport, in particular the potential of shifting transport from road to rail, is based on Kapfer et al. (2005).

M-6: Efficiency increase of conventional vehicles by mass reduction – Among various possibilities for reducing the fuel consumption of vehicles, lightweight constructions can contribute significantly to an improved fuel economy. For the technology wedge an energy efficiency increase of 5 % is assumed until 2020, requiring a vehicle mass reduction of about 20 % according to an expert judgement by Hausberger (personal communication).

M-7: Alternative fuels – For the calculation of the reduction potential of the wedge only biofuels of the first generation are considered. The increase of the biofuel share was calculated following the trend scenario for Austria carried out by UBA and BMLFUW up to 2030 (Molitor et al., 2009).

M-8: Relocation of fuel consumption – The Austrian Environmental Agency (UBA) estimates that 24.7 % of the GHG emissions of 2008 are due to export of fuel in vehicle fuel tanks (Anderl et al., 2010). Currently, export of fuel in vehicle fuel tanks is estimated within a 15-30 % range of GHG emissions. For the technology wedge it is assumed that 15 % of the energy consumption in the road passenger and freight transport can be reduced by an equalisation of fuel prices and the resulting relocation of fuel consumption.

The technology wedges address passenger transport on the one hand and freight transport on the other. Each of the wedges assumes an increase in the energy efficiency of motorized individual transport. A further specific characteristic lies in the broad definition of technology wedges which comprises storylines based on behavioural rather than technological changes, for example, the shift towards public transport in M-2 or the shift towards non-motorised mobility in M-3. Measures to alleviate urban sprawl, such as those in technology wedge M-1, also broaden the narrow notion of "technology". Technology wedges M-4 to M-7 describe emission reduction potentials with a stronger focus on technology, such as the use of electric vehicles in M-4, the higher energy efficiency of trucks combined with a shift to rail transport in M-5, the effects of a change in material use (lightweight vehicles) in technology wedge M-6, and the emission reduction potential of an increased use of biofuels in M-7. Finally, M-8 assumes a reduction of "fuel tourism" (i.e. fuels bought in Austria and used abroad due to the price difference to neighbouring countries[2]).

The catalogue of technology wedges for transport presented here does not comprise all conceivable options for a transformation of the transport sector and is thus not to be interpreted as the only feasible transformation path. Other options to reduce transport demand include tele-working, internet-shopping or changes in production structures.

A FEASIBLE COMBINATION OF TECHNOLOGY WEDGES FOR MOBILITY

The emission reduction potentials of each technology wedge cannot be easily aggregated due to overlapping effects. Once reduced by better spatial planning, transport performance, for instance, can no longer be substituted by alternative propulsion technologies. Thus, the effect of each technology wedge, when used in combination, is smaller than when considered individually. In order to calculate the total emission reduction

2. Transport emissions are calculated based on fuel sales in a country. "Fuel tourism" thus leads to higher domestic emissions although the fuels are consumed in other countries.

Table 1. Final energy demand in the transport sector in 2020.

Technology Wedge		Energy savings in 2020 compared to reference path in PJ					
		Oil	Coal	Gas	Renewables	Electricity	Total
M-1	Efficient transport saving land use	-5.37	0.00	0.00	-0.27	0.03	-5.61
M-2	Public transport	-4.66	0.00	0.00	-0.22	0.49	-4.40
M-3	Non-motorised transport	-4.67	0.00	0.00	-0.23	0.00	-4.90
M-4	Alternative propulsion technologies	-2.08	0.00	0.00	-0.14	0.33	-1.88
M-5	Freight transport	-5.44	0.00	0.00	-0.33	1.35	-4.42
M-6	Efficiency increase of conventional vehicles by mass reduction	-5.86	0.00	0.00	-0.29	0.00	-6.15
M-7	Alternative fuels	-6.88	0.00	0.00	6.88	0.00	0.00
M-8	Relocation of fuel consumption	-53.40	0.00	0.00	-2.82	0.00	-56.22
	Total	-88.37	0.00	0.00	2.58	2.20	-83.59

Source: Statistics Austria (2009a, b); own calculations.

Table 2. CO_2 emissions in the transport sector in 2020.

Technology Wedge		CO2 reduction in 2020 compared to reference path in Mt		
		Combined wedges	Individual wedges	Individual wedges - no efficiency increase
M-1	Efficient transport saving land use	-0.40	-0.40	-0.50
M-2	Public transport	-0.35	-0.46	-0.59
M-3	Non-motorised transport	-0.35	-0.42	-0.52
M-4	Alternative propulsion technologies	-0.15	-0.15	-0.17
M-5	Freight transport	-0.40	-0.40	-0.40
M-6	Efficiency increase of conventional vehicles by mass reduction	-0.44	-0.50	-0.63
M-7	Alternative fuels	-0.51	-0.60	-0.70
M-8	Relocation of fuel consumption	-3.97	-3.97	-3.97
	Total	-6.56		

Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations.

potential of the transport sector, the potential of each technology wedge is determined step by step in logical order. First, the reduction potential of efficient transport-saving land use (M-1) is determined. The change in transport performance and modal split is used as the basis for the calculations of the next technology wedge, namely the improvement and enhancement of public transport (M-2). Next, the effects of non-motorised transport using the change in mileage from the previous technology wedge as new input data are calculated (M-3). The remaining transport performance in motorised transport is used to determine the effects of a shift from conventional vehicles to alternative propulsion technologies (M-4). In addition to passenger transport, the effects of improved freight transport are assessed considering a shift from road transport to rail and efficiency measures (M-5). Next, the reduction potential of an increase in efficiency of conventional vehicles through light-weight construction is determined (M-6). Finally, for the remaining fuel quantity required in passenger and freight transport, the share of biofuels is increased (M-7). The amount of reduced final energy demand and CO_2 emissions by relocating fuel consumption abroad, which is determined independently from the other technology wedges, is added (M-8). Altogether, through the eight technology wedges, final energy demand is reduced by 83.59 PJ in 2020 compared to the reference scenario. Accordingly, CO_2 emissions can be decreased by 6.56 Mt (see Table 1).

Table 2 shows the CO_2 emission reduction potentials for the technology wedges M-1 to M-8 in three ways: first, in a combined way; second, contrasted with the reduction potential when the wedges are not combined; and third, when the wedges are not combined and efficiency gains – i.e. the reduction potential of EU regulation (EC) No 443/2009 on emission standards for new passenger cars – are not achieved. Figure 2 illustrates the effects of the combined technology wedges on CO_2 emissions in the transport sector.

Economic effects

A multiplier analysis is conducted for the estimation of output and employment effects. This is complemented by an analysis of cost effects in the operating phase.

INPUT-OUTPUT EFFECTS

For the multiplier analysis, investment costs for the technology wedges have been compiled in a bottom up approach where quantification was possible. The input-output analysis is based on the additional investment costs of the technology wedges, i.e. investment costs exceeding the costs of the respective reference technologies. The use of additional investment costs ensures that only the effects induced by a transformation of the energy system are quantified. The assessment of the employment and output effects is based on average annual investments for the period 2009 to 2020 as well as investments in the year 2020.

The investment requirement for each of the technology wedges is listed in Table 3. The total additional investment costs for the combination of technology wedges on average amount to €1.1 bn p.a. over the period 2009 to 2020 and to €1.5 bn in 2020. The major part accrues to the sectors construction work, followed by the sectors 'trade of motor vehicles' and 'other transport equipment'.

The economic effects of the combination of technology wedges can be summarised as follows: On average, over the period 2009 to 2020, output effects of €1.7 bn and value added effects of €0.7 bn are generated. In terms of employment, 14,856 jobs and 13,923 full time equivalents (FTE) are related to the implementation of the technology wedges. The output multiplier and the value added multiplier for the efficiency portfolio are 1.51 and 0.74 respectively. This means that for each million Euro of additional investment output increases by €1.51 million and value added increases by €0.74 million, which is related to approximately 13 jobs. In 2020 output effects of €2.3 bn and value added effects of €1.3 bn are generated. Employment effects are 20,900 jobs or 19,376 FTE respectively. Higher output and employment effects in 2020 when compared to the twelve-year average mainly result from the higher additional investment costs in this year.

EFFECTS ON OPERATING COSTS

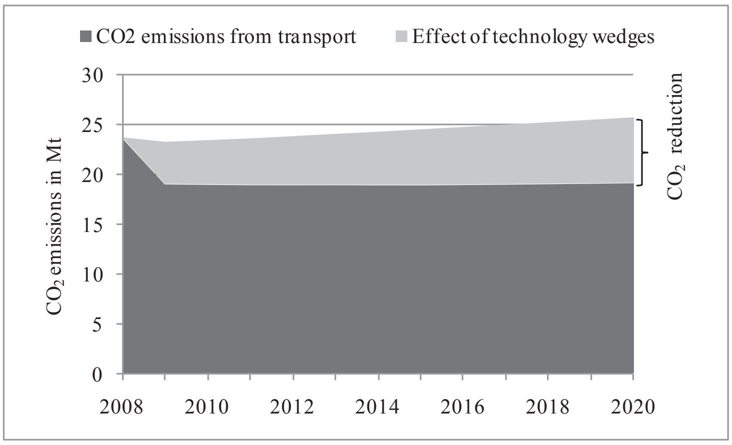
The implementation of the technology wedges also has considerable effects on the operating phase due to the energy savings achieved. In order to illustrate the difference in operating costs between the technology wedges and respective reference technologies, a similar approach to that used for the investment phase is followed. Total operating costs of the technology wedges are contrasted with respective additional operating costs in order to illustrate the effect of the technology wedge. Negative additional operating costs hence refer to cost savings compared to a reference technology.

Figure 3 illustrates the development of operating cost savings for the technology wedges which mirrors the diffusion path of the technology options. Figure 3 clearly illustrates the cumulative character of the operating cost effect. In 2020 operating cost savings amount to €372 million; average operating cost savings for the period 2009 to 2020 are €238 million respectively.

Conclusions

Our analysis of options for reducing energy use and emissions in the transport sector reveals a broad portfolio of technologies. In order to optimise the restructuring of mobility towards energy and emission efficiency, measures should first be implemented that reduce transport performance, e.g. through improved spatial planning. Subsequently, various technological options can be applied to satisfy the remaining mobility demand as efficiently as possible. These include a shift between transport modes, such as, for example, from cars to cycling or walking, as well as the deployment of more efficient technologies (e.g. lightweight vehicles, e-mobility).

The technology portfolio analysed delivers potential significant emission reductions of 6.5 Mt CO_2 in 2020 compared to the reference path. This corresponds to approximately 20 % of CO_2 emissions from transport. The restructuring steps – in particular the provision of infrastructure – are related to both ecological and economic effects. In addition to output and employment resulting from the required investments, it is important to stress that pronounced savings in operating costs can be achieved by deploying energy efficiency measures in mobility.



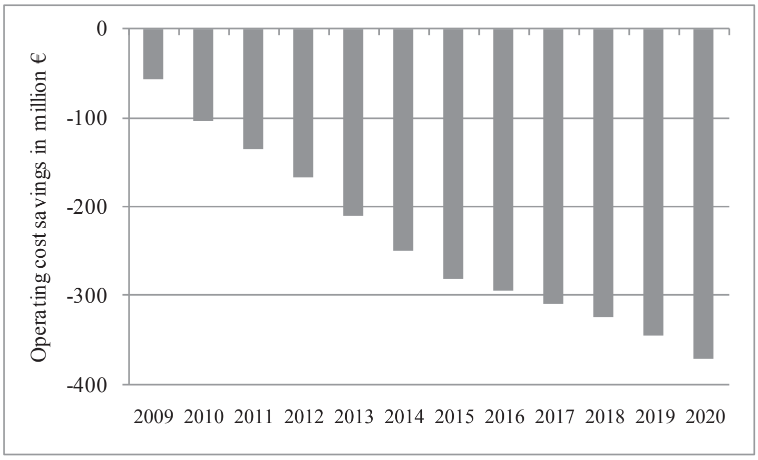
Source: Own calculations.

Figure 2. Effects of the technology wedges compared to the reference scenario.

Table 3. Investment requirement for the technology wedges.

		Investment Costs in million € for combination			
		Average 2009/2020		2020	
		Total	Additional	Total	Additional
M-1	Promotion of efficient transport saving land use	48	48	48	48
M-2	Improvement of public transport	835	835	835	835
M-3	Extension of non-motorised transport	45	45	45	45
M-4	Alternative propulsion technologies	453	191	1,430	583
M-5	Freight transport	33	33	33	33
M-6	Efficiency increase by lightweight construction of vehicles	2,645	0	4,829	0
M-7	Increase of biofuel additions	n.a.	n.a.	n.a.	n.a.
M-8	Relocation of fuel consumption	n.a.	n.a.	n.a.	n.a.

Source: Own calculations.



Source: Own calculations

Figure 3. Operating cost savings of the technology wedges.

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