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EnergyTransition 2012\2020\2050

Strategies for the Transition to Low Energy and Low Emission Structures (Executive Summary)

February 2011

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Abstract

The project EnergyTransition analyses options to comply with the targets of the EU Energy and Climate Package in an interdisciplinary approach. 25 storylines and technology wedges are developed and analysed in a bottom-up approach starting from energy services. The technology options are analysed with respect to their effects in the energy system as well as with respect to their effects on energy flows and emissions. The analysis of changes in the energy system is complemented by an economic analysis comprising an input-output analysis in order to reflect employment and output effects from the investment phase and an analysis of changes in operating costs due to the technology wedges. A microeconomic cost approach for selected technology wedges complements the analysis.

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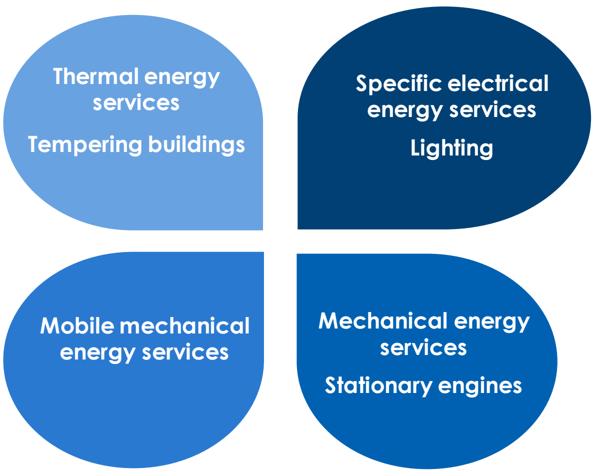
1 Introduction

The analysis of energy systems usually focuses on energy flows from primary energy sources to final energy demand by households and companies. It is, however, not the quantity of energy consumed by households and companies that is relevant for welfare but the energy services delivered. Hence, new concepts for the energy system are required that shift the focus from energy flows to energy services. The research project EnergyTransition[1] aims at expanding the analysis of energy flows through a closer look at energy service demand and technological options for application and transformation technologies.

The following energy services are distinguished for the analysis:

- Thermal energy services on different temperature levels that comprise low temperature applications in buildings (heating, hot water) and high temperature applications in industrial processes (e.g. industrial furnaces, kilns, etc.).
- Mechanical energy services to satisfy mobility needs on the one hand and for stationary engines in households and companies on the other hand.
- Specific electric energy services for lighting, electronics and other appliances.

Figure 1: Energy services



Source: Own illustration.

[1] The project EnergyTransition was funded by the Austrian 'Klima und Energiefonds' and was carried out within the research programme 'Energie der Zukunft'. The research programme 'Energie der Zukunft' was the result of a strategy process 'Energie 2050' of the Austrian Federal Ministry for Transport, Innovation and Technology. EnergyTransition as an interdisciplinary basic research project touches several thematic areas of the programme but has a focus on the area foresight studies.

Energy flows and thus the energy demand of households and companies depend on the application technologies used to provide the energy services. In buildings e.g. the energy required to deliver the energy service "well tempered living space" depends on the thermal quality of the building (thermal transmittance of walls, windows, roof etc.) and the heating system. With respect to mobility services the design of vehicles (e.g. lightweight construction using polymers) and the choice of the propulsion system (combustion or electric engine) are of relevance. Furthermore, a strong interrelation between energy services and selected material technologies for application technologies exists.

The application of (innovative) technologies and the respective investment decisions by firms or households depend on the one hand on prices for energy and for the technologies and on the other hand on institutional factors. Regulations (e.g. building codes, emission standards) or soft measures (e.g. mobility management) influence technological as well as societal or institutional innovations and technology choices. The amount of energy services consumed and the application technologies used in turn affect the requirements for primary energy supply and transformation processes for the generation of electricity and heat. Both, the transformation process and the distribution of energy entail losses. Thus, at this level decisions about transformation technologies, the primary energy sources used and the structure of the distribution network affect the efficiency of the energy system. Improvements and emission reductions can for instance be achieved by substituting stand-alone generation of heat or electricity by co-generation technologies or the increased use of renewable energy sources.

Regarding the restructuring of energy systems in order to be compatible with climate policy objectives three basic principles should be considered:

- *Low energy* needs to be dealt with as first priority in a restructuring process. It addresses any activities that aim at providing energy services with less energy flows. This includes the elimination of redundant energy services (e.g. in terms of person kilometres but not the access to goods and persons) just as well as innovations that improve the efficiency of transformation and application technologies.
- *Low carbon* aims at a controlled phase-out of fossil energy sources and serves climate policy objectives as well as energy supply security considerations. This, however, can only be achieved in combination with significant energy efficiency improvements. A complete substitution of fossil energy by renewables without reduction in demand is not feasible in the medium term.
- *Low distance,* finally, is related to the local/regional availability of renewable energy sources and distributed generation. This also requires new network and distribution structures for electricity and heat. Another relevant aspect in this context is the organisation of everyday life and avoiding redundant transport e.g. by improved spatial planning, tele-commuting etc.

EnergyTransition sets out a methodological frame for restructuring the energy system and integrates the idea of technology wedges by Pacala and Socolow (2004). It then applies the developed methodology – with a focus on energy services – to different areas in the Austrian energy system. The empirical application for the Austrian energy system implements the concept of technology wedges for the areas mobility, buildings, manufacturing and electricity and heat supply. For these areas storylines for each technology wedge describe the evolvement of energy services, energy flows, CO_2-emissions and technologies with a horizon until 2020. This is extended by technology specific investment and operating costs. Whereas the time span until 2020 comprises concrete calculations of energy and emission changes as well as investment and operating costs a qualitative outlook until 2050 is presented.

2 The extended technology wedges approach for Austria

Pacala and Socolow (2004), Socolow et al. (2004) show that a stabilisation of global greenhouse gas emissions[2] using existing technologies is possible in the next 50 years and that a broad diffusion of innovative technologies is required afterwards to reach the concentration goals. Each of the technology categories that are available in the short term can according to Pacala and Socolow (2004) make a significant contribution to the mitigation of emissions on a global level. A broad spectrum of options is considered that comprises energy efficiency improvements in buildings, transport and energy generation, a reduction of the emission intensity of energy generation (natural gas instead of coal, ...), carbon capture and storage as well as reforestation measures.

According to Pacala and Socolow (2004), the challenge is the broad application and a large scale up of the available technologies on the one hand, and in the initiation of climate-relevant research and development (R&D) on the other hand.

Pacala and Socolow (2004) offer a highly operational approach for analysing induced technological change. Concerned with technologies of the energy sector that have an impact on CO_2 emissions, they propose a restructuring of the global energy sector based on currently known and available technologies that would stabilise the level of carbon at seven billion tons of carbon per year (GtC/year) for the next five decades. Today we agree that a stabilisation in the next 50 years is not sufficient and new technologies have to be introduced immediately for further reductions of the emissions.

In the study EnergyTransition the concept of technology wedges by Pacala and Socolow is taken as a starting point and extended with respect to technology options for Austria.

One of the extensions of the concept of technology wedges concerns the focus on energy services discussed above. Three main areas are identified for the analysis:

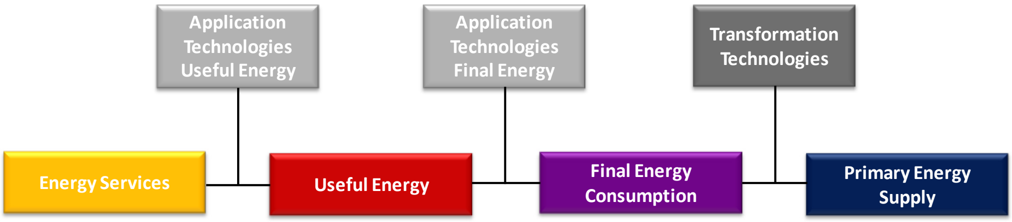
- buildings,
- mobility, and

[2] This corresponds to global emissions of about 42 Gt CO_2e. Business as usual forecasts assume a doubling of this value until the middle of the 21st century (Nakicenovic, 2005, Stern, 2006).

- manufacturing.

For these sectors desired energy services are defined (e.g. comfortable room temperature, person or ton kilometres). The analysis of the energy system contrary to common approaches thus starts at the "end" of the system: the welfare generating energy services. From there the whole energy cascade is traced back to final energy demand and primary energy supply. Application and transformation technologies used to generate energy services determine final energy consumption and primary supply (see Figure 2).

Figure 2: Structure of the energy cascade



Source: Own illustration.

Technology wedges are then defined for the energy services required and underpinned with a detailed storyline. The focus on energy services extends the notion of technological options as used in the original technology wedges concept: Behavioural changes as for example fewer kilometres driven due to altered preferences or changes in spatial planning are also explicitly considered as an option for reducing energy demand and GHG emissions just as e.g. electric vehicles. Thus, the technology portfolio deviates from the definition of technology in a narrow sense.

In the approach presented in EnergyTransition the concept of technology wedges is specifically applied to the Austrian energy system. Each technology wedge represents an option to reduce CO_2 emissions by a certain amount until 2020. The basic concept of technology wedges is extended in three ways:

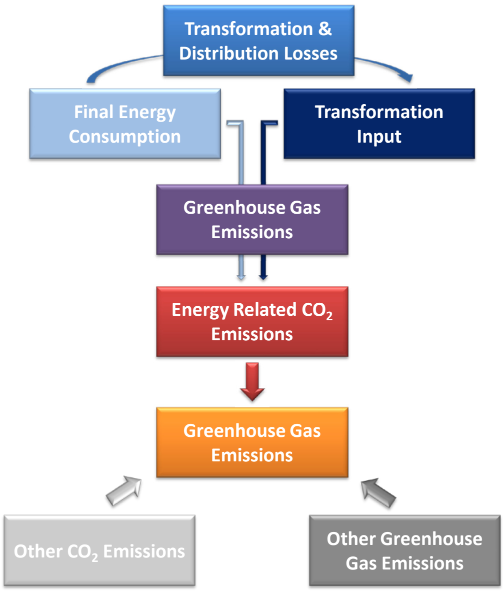
- The technologies are embedded into an integrated structural model of the Austrian energy system that starts from energy services and ends with primary energy flows. The quantity of energy flows depends on the application and transformation technologies implemented.
- The characteristics of all technologies are described in storylines in a uniform framework. The description includes economic parameters such as investment and maintenance costs and energy relevant parameters both in the investment and in the operating phase.
- Economic impacts from the implementation of different technologies are analysed for the investment and for the operating phase.

3 The reduction triangle for Austria

Technology wedges focus on emission reduction potentials of different technologies. Modelling of technology wedges therefore requires a reference scenario for the development of emissions. 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 starting point for the reference scenario is a projection of energy flows which reflects an extrapolation of historical trends based on forecasts of economic development[3]. The scenario consists of two components (see Figure 3). The first component (demand component) extrapolates final energy demand differentiating between economic sectors as well as between energy sources and energy use categories. The second component (supply component) builds on final energy demand and extrapolates transformation input in energy generation plants by energy source. Based on projected energy flows CO_2 emissions are calculated. In addition, non-energy related CO_2 emissions and other greenhouse gas emissions are projected for the emissions reference scenario based on historical trends.

Figure 3: The modelling approach for the reference scenario



Source: Köppl et al. (2009).

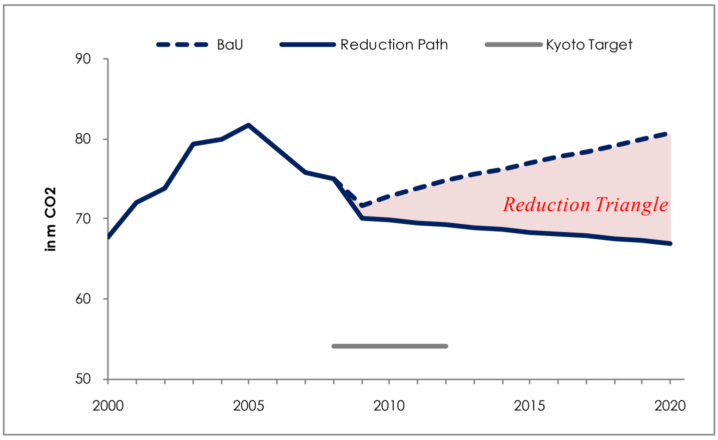
Figure 4 presents the reference path for Austrian CO_2 emissions as well as the reduction path according to the EU Energy and Climate Package (European Commission, 2008a, 2008b).

[3] The reference scenario represents a possible path for energy demand and emissions along past developments. It does not explicitly depict energy services as analysed in detail in the technology options for the areas buildings, mobility and industry.

CO_2 emissions are estimated to rise from 87 million t CO_2 in 2008 to 93 million t CO_2 in 2020 in the reference scenario.

According to the approach by Pacala and Socolow (2004) a reduction triangle for Austrian GHG emissions is defined in line with the EU Energy and Climate Package. The reference scenario and the reduction path - which is derived from the 2020 targets of the EU Energy and Climate Package – define the emission reduction requirement until 2020, the so called "reduction triangle". The methodology for developing the reference scenario as well as assessing the development of final energy demand, electricity and heat generation and GHG emissions until 2020 is described in detail in the full report of the project EnergyTransition. The reduction requirements until 2020 compared to 2005 GHG emissions and the reference path yield the reduction triangle as illustrated in Figure 4. The reduction requirement to comply with the EU targets is 8 million t[4] CO_2 compared to 2008. As we can observe a reduction of CO_2 emissions between 2005 and 2008 the reduction requirement with respect to the base year 2005 of the EU Energy and Climate Package is 15 million t CO_2. The difference in CO_2 emissions between the reference scenario and the emission target in 2020 is estimated to amount to 14 million t CO_2.

Figure 4: Reduction triangle for Austria (in million tons CO_2)



Source: Statistics Austria (2009a, b), UNFCCC (2010); own calculations. – The Kyoto target in this graph represents only the reduction requirements for CO_2 based on the assumption that the Austrian Kyoto target is equally distributed over all categories of greenhouse gases.

3.1 Methodological approach for implementing technology wedges

Technological and behavioural options to reduce final energy demand and associated emissions in the areas buildings, mobility and manufacturing constitute different potentials

[4] According to the calculation of CO_2 emissions in the EnergyTransition project. Deviations from official emission data are quantified and described in the final report of the project. The reduction requirement for CO_2 with respect to the base year 2005 in the EU Energy and Climate Package amounts to 15 million t CO_2. The significant difference in the reduction requirements with respect to 2005 and 2008 is the result of an overall decrease of CO_2 emissions of 6.7 million t between the two years.

and follow specific storylines. In order to illustrate the cascade of the energy system a common methodological approach for modelling the technology wedges for final energy demand is therefore needed.

The method developed in the project EnergyTransition uses five central variables for describing changes in final energy demand and in emissions for each technology wedge:

- *S* for energy service,
- U for *effective useful energy*,
- *u* for useful energy intensity (amount of effective useful energy[5] U per service unit S, *u=U/S*),
- *F* for final energy demand, and
- *f* for final energy intensity (amount of final energy F per useful energy, *f=F/U*).

The development of these central variables until 2020 is expressed in indices (2008 = 100). 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 hand (see below).

The central equation for the development of final energy demand over time t is:

(1) $$F_{w,t} = \frac{S_{w,t} * u_{w,t} * f_{w,t}}{10{,}000}$$

Final energy demand for a specific activity (*w*) in one year thus results from the amount of energy service demanded (*S*, e.g. living space, person kilometres) multiplied by useful energy intensity (*u*) and final energy intensity (*f*). In the storyline the shape of the diffusion path of technologies or behaviour changes is explicitly described.

Given a certain path for the demand for energy services (determined e.g. by behavioural changes) changes in useful energy intensity and final energy intensity determine energy demand. Variations in useful energy intensity occur through technological changes like an improvement in the building stock. Changes in final energy intensity result from improvements in transformation technologies such as engines or heating systems. These technological aspects are based on the storylines developed for various activities using a bottom up approach.

Based on equation (1) technology wedges for final energy demand can be expressed using the following variables:

- $\Delta a_{w,t}$ for changes in useful energy intensity and energy services, and
- $\Delta f_{w,t}$ for additional changes in final energy intensity.

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[5] Useful energy U is defined as the portion of final energy which is actually available after final conversion to the consumer for the respective use. In final conversion, electricity becomes for instance light, mechanical energy or heat. The effective useful energy used here considers efficiency factors of application technologies.

Changes in effective useful energy demand compared to 2008 that result either from the use of alternative application technologies (e.g. a building stock of higher thermal quality or lightweight vehicles) or from changes in life styles and behaviour ($\Delta a_{w,t}$) are calculated according to equation (2):

(2) $$\Delta a_{w,t} = \frac{s_{w,2008} * u_{w,2008}}{100} - \frac{s_{w,t} * u_{w,t}}{100} = 100 - \frac{s_{w,t} * u_{w,t}}{100}$$

A reduction in final energy demand could also result from an improvement in final energy efficiency. Changes in final energy efficiency ($\Delta f_{w,t}$) as for example a more efficient heating system that add to the changes in energy services and useful energy intensity ($\Delta a_{w,t}$) are calculated as in equation (3). Based on equation (1) $\Delta f_{w,t}$ can be defined as

(3) $$\Delta f_{w,t} = \frac{s_{w,2008} * u_{w,2008} * f_{w,2008}}{10{,}000} - \frac{s_{w,t} * u_{w,t} * f_{w,t}}{10{,}000} - \Delta a_{w,t} = F_{2008,t} - F_{w,t} - \Delta a_{w,t}$$

Based on $\Delta a_{w,t}$ and $\Delta f_{w,t}$ remaining final energy demand in a given year can be expressed for each technology wedge as presented in equation (4):

(4) $$F_{w,t} = F_{w,2008} - \Delta a_{w,t} - \Delta f_{w,t} = 100 - \Delta a_{w,t} - \Delta f_{w,t}$$

The reduction in final energy demand by the technology wedge is the sum of $\Delta a_{w,t}$ and $\Delta f_{w,t}$.

From the methodological approach of transforming information from storylines into a likely path for services, useful energy intensity and final energy intensity expressed in indices one can then convert the results into changes in absolute final energy demand (in TJ) compared to 2008 (the last year for which official energy statistics are available) as well as into changes compared to the reference scenario developed in the project EnergyTransition.

Changes in final energy consumption have to be split up by energy sources in order to assess implications for the energy mix as well as associated emission reductions.

Based on this information the emission reductions compared to the reference scenario and 2008 can be calculated using emission factors from UNFCCC (2010). Changes in CO_2 emissions ($\Delta C_{w,t}$) are calculated by multiplying changes in absolute final energy consumption with the corresponding emission factor (c_i) for each energy source:

(5) $\Delta C_{w,t} = \sum_i (c_i * \Delta F_{w,i,TJ,t})$, (TJ = Terajoule)

The common methodological approach for the areas mobility, buildings and manufacturing ensures the consistent integration of all technology wedges into the cascade of the energy system. A combination of technology wedges in order to achieve certain emission targets e.g. the emission target of the EU Energy and Climate Package then has to identify technology wedges that are additive. Combining e.g. a technology wedge "100% passive houses" in newly constructed buildings with a wedge "substitution of heating systems in conventional new buildings" is not feasible. In contrast "100% passive houses" in new construction and thermal improvement or substitution of heating systems in the building stock are fully additive.

For technology wedges in the area of energy supply a modified modelling approach is necessary as changes in the level of transformation input and in emissions are the result of changes in transformation output – which is driven by final energy demand – and in the fuel mix in the power and heat sector. Technology wedges that aim at the substitution of electricity and heat output from conventional plants by energy from low carbon technologies can be expressed by the following variables:

- $TO_{i,j}$ for transformation output from energy source *i* in plant type *j*,
- $TI_{i,j}$ for transformation input of energy source *i* in plant type *j*
- $e_{i,j}$ for transformation efficiency of plant type *j* using energy source *i* (amount of transformation output per transformation input, $e_{i,j}=TO_{i,j}/TI_{i,j}$).

The development of these central variables until 2020 is again expressed in indices (2008 = 100). Changes in transformation input depend on changes in transformation output on the one hand and changes in transformation efficiency on the other hand.

The central equation for technology wedges for energy supply hence can be written as

(6) $$TI_{w,i,j,t} = \frac{TO_{w,i,j,t}}{e_{w,i,j,t}} * 100$$

Equation (6) depicts the relationship of the three key variables. For a specific activity (*w*) transformation input of an energy source in a certain type of plant in a given year results from transformation output divided by transformation efficiency.

Although the modelling approach for energy supply deviates from the modelling of technology wedges in the other areas one can reconcile the common idea by interpreting final energy demand resulting from technology wedges in mobility, buildings and manufacturing as a proxy for *S*. Thus the potential or requirement for technology wedges in energy supply is not independent from activities in the sectors constituting final energy demand. The approach to relate the development of the central variables to the base year 2008 ensures that the relative changes versus 2008 can easily be translated into absolute changes versus 2008 as well as into absolute changes versus the reference scenario.

The extended technology wedges approach as applied in the project EnergyTransition extends the original method by Pacala and Socolow also with respect to economic analysis.

For the period until 2020 annual investment requirements[6] are estimated for each technology wedge and each storyline. In order to assess the domestic economic implications of the implementation of the technology wedges, investment costs are split up into sectoral investment shares as well as an assessment of the import share. The diffusion of technologies over time is defined by the storyline and can follow different paths: linear, exponential, stepwise or other.

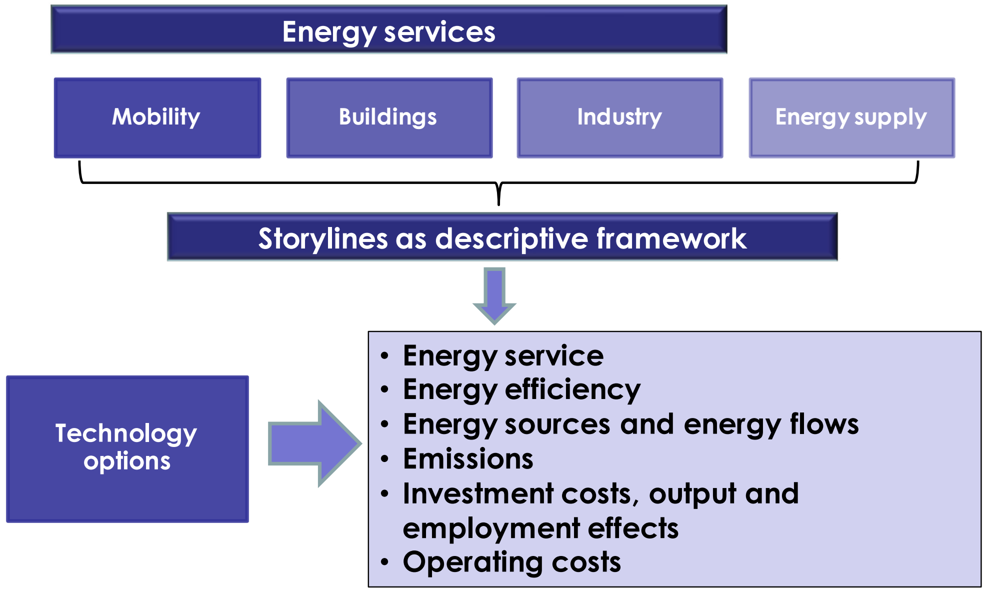
[6] Investment costs for the technology wedges are assessed as total costs as well as additional costs compared to a respective reference technology.

For the analysis of economic effects from investments related to the implementation of a set of technology wedges, the investment cost for an "average" year split up by sectoral shares for each technology wedge are the starting point for the static input output analysis. Thus, the direct and indirect effects of these investments are calculated.

The economic analysis of the investment phase in the transition of the energy system is complemented by data for the operating phase. These data cover cost categories like maintenance, personnel, insurance, fuels etc. The development of operating costs mirrors again the diffusion path of technologies. For the operating phase "additional costs" are calculated, which are the difference between operating costs of the respective reference technology (e.g. a conventional building) and operating costs of the wedge technology (e.g. a passive house). For many technology wedges these additional costs will be negative because of the energy (cost) savings resulting from the application of more efficient technologies as compared to the reference case.[7]

EnergyTransition follows the steps as outlined in Figure 5 in order to operationalise the concept of energy services. The figure illustrates that both the effects in the energy system as well as economic effects are captured.

Figure 5: Diagram of the project EnergyTransition



Source: Own illustration.

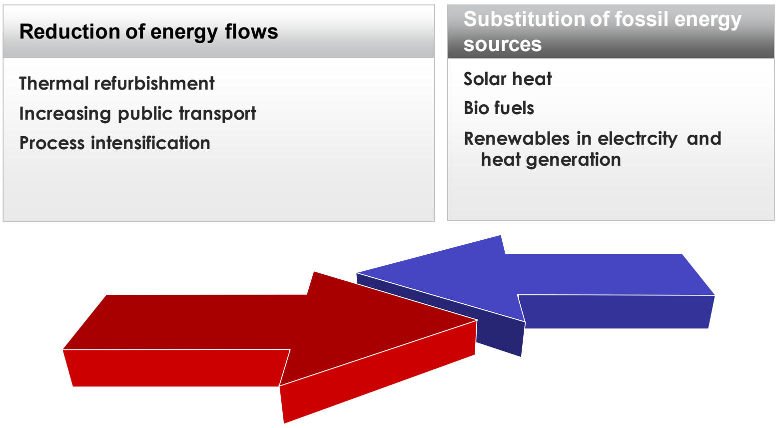
[7] Apart from the estimates of macroeconomic effects of the investment phase as well as changes in operating costs of the technology wedges, a sample of technologies is selected for which a microeconomic cost appraisal is conducted. This method enables a better comparison of the cost impacts of the technology wedges considered, allowing an integrated analysis of the investment and operating phase. These results can be found in the full report of the project EnergyTransition.

4 A catalogue of technology wedges for Austria

According to the concept of energy services as well as the common modelling approach described above concrete storylines and technology wedges for the areas mobility, buildings, manufacturing and supply of electricity and heat are developed.

Twenty-five storylines and technology wedges are analysed in detail in the project EnergyTransition. In principle two guidelines are available to translate the demand for energy services into lower energy flows or lower emission levels.

Figure 6: Guiding principles for emission reductions



Source: Own illustration.

The first guiding principle focuses more strongly on energy efficiency, whereas the second guideline stresses the emission reduction potential by reducing the emission intensity. Along these two principles the technology wedges are selected for the technology portfolios described in section 4.2.

With respect to the catalogue of technology wedges it has to be emphasised that the term "technology" also encompasses changes in energy services and resulting energy flows that follow from life style changes (e.g. change in place of residence in order to reduce daily travel distances). The catalogue illustrates well the systemic approach in EnergyTransition as one of the technology wedges in the sector electricity and heat supply is the result of lower energy demand in the sectors mobility, buildings and manufacturing. Finally it has to be mentioned, that for each sector feasible combinations of technology wedges are identified ensuring the additivity of changes in energy flows and emissions.

Figure 7: Catalogue of technology wedges

Mobility	Buildings	Industry	Energy supply
M1: Efficient land use	B1: Thermal refurbishment	P1: Energy demand industrial buildings	E1: Wind power
M2: Public transport	B2: Passiv House Standard	P2: Process-intensification	E2: Hydro plants
M3: Non-motorised transport	B3a: New heating systems	P3: Energy efficient engines	E3: Biogene CHP plants
M4: Alternative propulsion technologies	B3b: Solar heat	P4: Cogeneration heat and power	E4: Effects through reduced demand
M5: Freight transport	B4: Photovoltaic energy	P5: Substitution of fossil energy sources	
M6: Lightweight vehicles	B5: Energy efficient appliances	P6: Biomass for process heat	
M7: Bio fuels		P7: Solar heat	
M8: Relocation of fuel consumption			

Source: Own illustration.

4.1 Results for the technology wedges

Mobility

The energy service in mobility is the access to persons, goods and services needed for connecting important functions and amenities of daily life. According to this definition the energy service is sought not to decline over time. To simplify the measurability, energy service (S) is expressed by means of the variables vehicle kilometres, passenger kilometres and tonnekilometres. 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. In the transport sector energy and emission reduction potentials for different technology wedges are based on trends in motor vehicle stock and average mileage. Starting point is the recently observed transport performance in passenger transport (pkm) and freight transport (tkm) for the different individual passenger transport modes (motorised and non-motorised), public transport and freight transport (rail and road) when calculating emission reduction potentials (Käfer et al., 2009). Technology wedges in the storylines either refer to the total transport sector or only to segments of it (passenger or freight transport). For example alternative fuels concern both the passenger and freight transport sector, while for an enhancement of public transport only the passenger transport is relevant. Depending on the storyline and the segments considered energy indicators are calculated. They may thus refer only to these segments of overall transport.

The technology wedges aim at three major effects. First, transport performance (pkm or tkm) is reduced. Second, there is a shift between transport modes e.g. a shift from energy wasting modes like passenger cars to energy saving modes like bike and pedestrian. Third, changes come from efficiency gains because of improved motor technology and/or decreased mass of vehicles. These effects are described in the storylines for the different technology wedges.

Eight storylines and technology wedges are developed for the transport sector, calculating the emission reduction potential and the associated investment and operating cost effects. Table 1 summarises the emission reduction potentials of the mobility technology wedges, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 1: Key figures of technology wedges for mobility

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
M-1	Promotion of efficient transport saving land use	0.40	100	0.40	578	578	578	578	25	-205	25	-205
M-2	Improvement of public transport	0.46	76	0.35	13,167	13,167	10,018	10,018	581	278	442	212
M-3	Extension of non-motorised transport	0.42	83	0.35	648	648	540	540	2	-238	2	-198
M-4	Alternative propulsion technologies	0.15	100	0.15	5,435	2,295	5,435	2,295	119	-33	119	-33
M-5	Freight transport	0.40	100	0.40	396	396	396	396	n.a.*	n.a.*	n.a.*	n.a.*
M-6	Efficiency increase by lightweight construction of vehicles	0.50	88	0.44	36,062	0	31,734	0	4,956	-261	4,361	-230
M-7	Increase of biofuel additions	0.60	85	0.51	n.a.*	n.a.*	n.a.*	n.a.*	95	95	81	81
M-8	Relocation of fuel consumption	3.97	100	3.97	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*

Buildings

The building sector plays a central role in achieving the objectives of Austrian climate and energy policy. Its share in final energy consumption is almost 30%. Space heating and cooling consumed 314 PJ of final energy in 2008 *(Statistics Austria, 2009b)*. Energy and emission reduction potentials for different technology wedges described in the corresponding storylines are based on trends in energy demand for buildings. Starting point are data on energy demand in the building stock and in newly constructed buildings, existing heating systems as well as electricity consuming appliances.

As an approximation for services in the building sector surface area and energy demand per m² is taken (except for the technology wedge addressing efficiency potentials of electric appliances). The aim of the technology wedges is a reduction of the energy demand per service unit and thus an overall reduction of the energy demand of the building sector. This is to be accomplished by an improvement in the thermal quality of the building stock, a faster diffusion of passive houses in new construction, more efficient heating systems and a larger share of renewables including decentralised production of electricity, and finally savings in electricity demand through energy efficient appliances. For six technology wedges a detailed storyline is developed and underpinned with data.

- Thermal refurbishment of existing buildings according to Low Energy Standard
- Construction of new buildings according to Passive House Standard (PHS)
- Replacement of heating systems by more efficient ones based on renewables
- Intensified use of solar heat for space heating and hot water preparation.
- Increased power production from photovoltaics in zero energy buildings
- Energy optimised appliances, lighting and equipment

Table 2 summarises the emission reduction potentials of the building technology wedges, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 2: Key figures of technology wedges for buildings

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
B-1	Thermal refurbishment of existing buildings	1,18	100	1,18	55.682	38.985	55.682	38.985	302	-835	302	-835
B-2	Construction of new builidings according to Passive House Standard	0,28	100	0,28	47.051	7.457	47.007	7.450	74	-124	74	-124
B-3a	Replacement of heating systems by more efficient systems based on renewables	2,10	70	1,47	10.191	2.480	7.138	1.737	1.927	-421	1.350	-295
B-3b	Intensified use of solar heat for space heating and hot water preparation	0,35	70	0,25	14.294	11.447	10.006	8.013	669	-428	468	-300
B-4	Increased power production of builidings for own consumption	0,00	100	0,00	766	524	766	524	11	-50	11	-50
B-5	Energy optimised appliances, lighting and equipment	0,00	100	0,00	17.273	n.a.*	17.273	n.a.*	786	-527	786	-527

* not available.

Manufacturing

Despite an improvement in energy efficiency in the last decades energy demand from manufacturing in absolute terms has been increasing constantly. In 2008 the share of the production sector in total Austrian final energy consumption was 29%. Industry thus is the third area in the project EnergyTransition where a closer look at energy services is taken and where technological potentials for energy savings and emission reductions are analysed. The approach taken deviates from the more common sectoral analysis and starts from typical energy services in manufacturing. These are:

- Thermal energy services separated into three different temperature levels. The first temperature array is below 100°C, the second is between 100°C and 400°C and the third is above 400°C. Based on the Austrian Useful Energy Balances thermal energy services can be found in the categories space heating, steam production, industrial furnaces, drying and warm water supply.
- Mechanical energy services cover the provision of mechanical and kinetic energy. They are provided by engines which transform thermal, chemical or electrical energy into mechanical or kinetic energy. Generally production sectors have a considerable and increasing share of this service because of rising automation of technical processes. According to the Austrian Useful Energy Balances the useful energy categories stationary engines and traction belong to the mechanical energy services.
- Specific electrical energy services can only be provided by electricity. Energy services are provided by transforming electricity into other forms of energy like radiation (lighting). In this context, electricity is mainly used for illumination and electronics. The overall amount for this service shows no significant increase in the last years.
- Electrochemical energy services refer to electricity as part of a chemical reaction. Without this energy input the reaction would either not happen or in an uneconomic span of time.

Based on their technical potential eight storylines and technology wedges are developed with a time horizon until 2020. Table 3 summarises the emission reduction potentials of the technology wedges for industry, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) for the period until 2020. Impacts on operating costs are also depicted in the table.

Table 3: Key figures of technology wedges for manufacturing

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
P-1	Energy demand for industrial buildings	0,25	100	0,25	1.577	1.577	1.577	1.577	n.a.*	-171	n.a.*	-171
P-2	Process intensification and process integration	1,49	100	1,49	2.217	2.217	2.217	2.217	n.a.*	-739	n.a.*	-739
P-3	Energy efficient engines	0,06	88	0,05	704	704	616	616	n.a.*	-350	n.a.*	-306
P-4	Combined heat and power	-0,21	94	-0,20	331	319	312	301	44	-108	42	-102
P-5	Substitution of fossil energy sources with high emission-coefficients	0,84	67	0,56	65	-22	43	-15	423	-73	282	-49
P-6	Biomass for process heat	0,61	85	0,52	386	352	327	298	58	-143	49	-121
P-7	Solar thermal energy for process-heat and space heating	0,25	100	0,25	1.232	1.221	1.232	1.221	9	-72	9	-72

* not available.

Electricity and heat supply

Electricity and heat demand and hence transformation output from energy generation plants has been constantly rising in Austria. Fossil fuels still account for a large part in Austrian energy generation. The primary goal is therefore to develop technology wedges for reducing emissions from electricity and heat supply.

Emission reduction potentials in the energy sector generally include a shift to renewables or fossil fuels with lower emission factors and efficiency improvements, e.g. by the employment of co-generation plants instead of stand-alone technologies (see e.g. Öko-Institut – Prognos, 2009, Pacala – Socolow, 2004). Based on their technical potential in Austria for the power sector the following technology wedges are developed:

- a substitution of fossil electricity generation by wind power;
- a substitution of fossil electricity generation by run-off river plants;
- a substitution of coal based electricity generation and gas based heat generation by biomass and biogas based micro CHPs;
- a reduction in electricity and heat generation through reduced demand.

Table 4 summarises the emission reduction potentials of technology wedges for the sector electricity and heat supply, their possible combination, as well as the associated cumulated investment costs (total and compared to a reference technology) until 2020. In addition, impacts on operating costs are depicted.

Table 4: Key figures of technology wedges for energy supply

		CO_2 emission reduction			Investment costs in million €				Operating costs in million €			
		Total	Feasible combination		Cumulated 2009-2020		Feasible combination		2020		Feasible combination	
		in mt	in %	in mt	Total	Additional	Total	Additional	Total	Additional	Total	Additional
E-1	Substitution of fossil electricity generation by wind power	1.00	100	1.00	965	965	965	965	25	-43	25	-43
E-2	Substitution of fossil electricity generation by run-of-river hydro plants	1.00	100	1.00	1,044	1,044	1,044	1,044	26	-43	26	-43
E-3	Substitution of coal based electricity generation and gas based heat generation by biomann and biogas CHPs	1.00	100	1.00	738	738	738	738	117	-19	117	-19
E-4	Reduction in electricity and heat generation through reduced demand				n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*	n.a.*

* not available.

4.2 Technology wedge portfolios for the reduction triangle

Technology wedges filling the reduction triangle (see chapter 3) can be grouped into two categories:

- "efficiency wedges" and
- "fuel shift wedges".

"Efficiency wedges" are characterised by CO_2 savings resulting from lower final energy demand or from lower transformation input. Technology wedges achieving these reductions in energy consuming sectors (in this project: mobility, buildings and manufacturing) can originate either by a reduction of (redundant) energy services or by a decline in useful energy intensity (useful energy by service) or final energy intensity (final energy by useful energy)[8]. For electricity and heat generation, efficiency wedges imply a reduction in transformation input through an improvement in transformation efficiency.

"Fuel shift wedges" describe CO_2 emission reductions resulting from a shift to fuels with lower carbon content, e.g. an intensified use of renewables or a substitution of coal and oil by gas. Technology wedges can either concentrate on one of the two options or represent a combination of both, for example if coal based electricity generation is substituted by biomass based cogeneration. Given the uncertainty of the reference path – i.e. a potentially higher or lower effective reduction requirement in 2020 – it has to be emphasised that other combinations of technology wedges could also be implemented to comply with a higher/lower reduction target compared to the reference path.

Filling the reduction triangle can either have a stronger focus on "efficiency wedges" or on "fuel shift wedges". In the project EnergyTransition we present two different technology wedge portfolios are analysed, one focusing primarily on energy efficiency and one focusing mainly on changes in the fuel mix. The economic implications for each portfolio are analysed in an input-output setting.[9]

A technology wedge portfolio focusing on energy efficiency

This section presents a combination of technology wedges with a focus on energy efficiency. Hence, technology wedges from the areas mobility, buildings and manufacturing and their effects on the supply of electricity and heat are analysed. Table 5 presents the 18 technology wedges[10] considered to fill the reduction triangle and achieve an emission reduction of 14 million t CO_2 in 2020.

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[8] This includes the elimination of energy services (e.g. in terms of person kilometres but not the access to goods and persons) just as well as innovations that improve the efficiency of transformation and application technologies.

[9] The full report of the project EnergyTransition gives details on both technology wedge portfolios. Here a focus is given on the efficiency wedge portfolio.

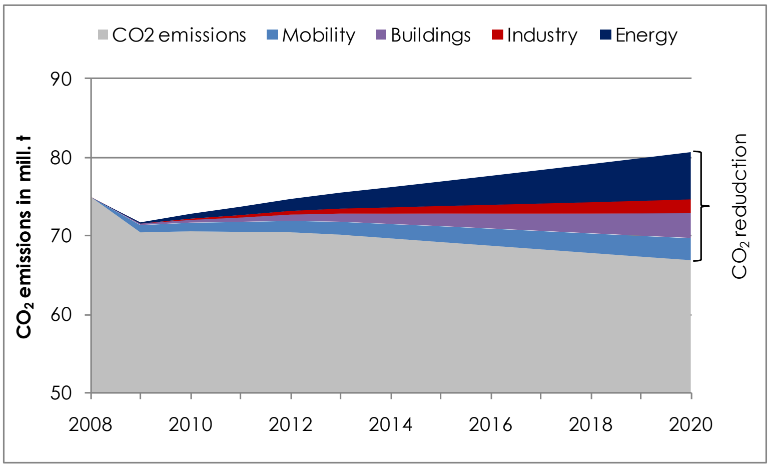
[10] The additivity of wedges is ensured.

Table 5: Technology wedge combination for the efficiency wedge portfolio

Technology wedge	
M-1	Promotion of efficient transport sav ing land use
M-2	Improv ement of public transport
M-3	Extension of non-motorised transport
M-4	Alternativ e propulsion technologies
M-5	Freight transport
M-6	Efficiency increase by lightweight construction of v ehicles
M-8	Relocation of fuel consumption
B-1	Thermal refurbishment of existing buildings
B-2	Construction of new buildings according to Passiv e House Standard
B-3a	Replacement of heating systems by more efficient systems based on renewables
B-3b	Solar heat for space heating and hot water preperation
B-4	Increased power production of buildings for own consumption
B-5	Energy optimised appliances, lighting and equipment
P-1	Energy demand for industrial buildings
P-2	Process intensification and process integration
P-3	Energy efficient engines
P-4	Combined heat and power
E-4	Reduction in electricity and heat generation through reduced demand

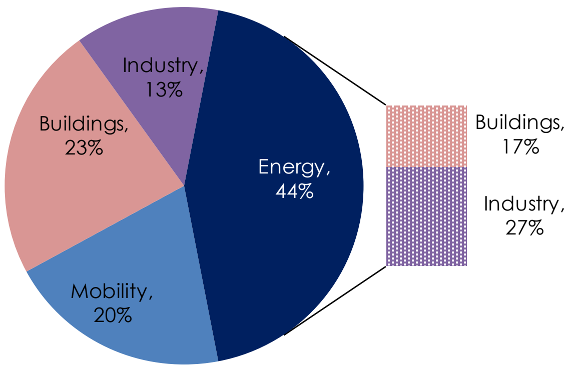
In Figure 8 the emission reductions are aggregated by sector and contrasted with the emission path of the reference scenario. Emission reductions from the mobility sector are 2.8 million t CO_2 in 2020. The technology wedges in the building sector achieve reductions of 3.2 million t CO_2 in 2020 compared to the EnergyTransition reference scenario. Emission reductions in the manufacturing sector amount to 1.8 million t in 2020 in this technology wedge portfolio. The largest emission reduction – 6 million t CO_2 in 2020 – is achieved by the energy sector. It has to be emphasised, however, that this emission reduction is exclusively the result of the lower heat and electricity demand resulting from the other sectors' efforts. A simple comparison of emission reductions by sector neglects this interrelationship of different levels in the energy cascade as explicitly considered in the project EnergyTransition (see Figure 9). The figure has to be interpreted as rough estimation. The emission effects from lower electricity and heat demand depend on the assumption which technologies and fuels are reduced for electricity and heat generation. Furthermore the additional electricity consumption in mobility is neglected.

Figure 8: Technology wedge portfolio focusing on energy efficiency compared to reference scenario



Source: Own calculations.

Figure 9: Sectoral emission reduction shares in the efficiency portfolio in 2020



Source: Own calculations.

The overall effects of the energy efficiency portfolio focusing on energy flows and emission reductions by energy source are illustrated in Table 6. Energy flows from final energy consumption and from transformation input in 2020 are 200 PJ lower than in the reference path. Oil use is reduced by almost 80 PJ, gas by 63 PJ. Coal contributes 45 PJ which translates into a relative reduction of almost 50% compared to the reference path. By reducing final demand the energy efficiency portfolio has an effect on all energy sources, thus also energy flows from renewables are slightly lower (2.8%) than in the reference scenario. The change in renewable has no relevance for the emission reduction of 14 million t CO_2.

Table 6: Change in energy flows and emission reduction by energy source – energy efficiency portfolio

Energy source	Final Energy Consumption and Transformation Input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	50.8	-45.4	-47.2	8.53	4.99	-4.4	-46.8
Oil	456.8	417.9	-79.2	-15.9	35.44	32.83	-5.7	-14.9
Gas	289.2	255.5	-63.2	-19.8	15.90	14.05	-3.5	-19.8
Renewables	380.5	418.6	-11.9	-2.8	2.87	3.13	0.0	0.0
Total	1,213.8	1,142.8	-199.6	-12.1	62.7	55.0	-13.6	-18.7

Source: Own calculations.

A similar approach as for the technology wedge portfolio focusing on energy efficiency is taken for the second technology portfolio focusing on low carbon fuels. This means that primarily technology wedges addressing a fuel shift in energy supply or in energy demand are considered. In order to fill the reduction triangle, however, some technology wedges that focus exclusively on improvements in energy efficiency need to be included.

For this technology portfolio only the overall changes in energy flows and emission are presented here[11]. Table 7 summarises the overall effects of the low carbon portfolio focusing on energy flows and emission reductions by energy source. Energy flows from final energy consumption and from transformation input in 2020 are 140 PJ lower than in the reference path. The low carbon portfolio thus yields lower changes in energy flows than the energy efficiency portfolio, although both portfolios achieve an emission reduction of 14 million t CO_2. Oil use is reduced by almost 100 PJ, gas by 47 PJ. Coal contributes approximately 40 PJ which is somewhat less than in the energy efficiency portfolio. The largest difference to the energy efficiency portfolio results for renewables, which showed a slight decrease in the efficiency portfolio compared to the reference path. In the low carbon portfolio energy flows from renewables exceed the reference scenario by 45 PJ (10%). Thus, in terms of producing not only emissions but also energy flows – irrespective of the energy sources – efficiency portfolios generate superior results.

[11] For further details on this technology wedge portfolio see the full report on the project EnergyTransition.

Table 7: Change in energy flows and emission reduction by energy source – low carbon portfolio

Energy source	Final Energy Consumption and Transformation Input				CO2 emissions			
	2008	2020			2008	2020		
	in PJ	in PJ	Difference to Reference		in mt	in mt	Difference to Reference	
			in PJ	in %			in mt	in %
Coal	87.2	55.5	-40.6	-42.3	8.53	5.45	-3.9	-41.9
Oil	456.8	399.9	-97.3	-19.6	35.44	31.35	-7.2	-18.7
Gas	289.2	272.0	-46.7	-14.7	15.90	14.96	-2.6	-14.7
Renewables	380.5	475.7	45.2	10.5	2.87	3.13	0.0	0.0
Total	1,213.8	1,203.0	-139.4	-8.4	62.7	54.9	-13.7	-18.9

Source: Own calculations.

5 Economic analysis

For the estimation of output and employment effects a multiplier analysis is conducted. These calculations show which demand effects follow an investment activity in a certain sector. The multiplier analysis represents a static input-output approach using the input-output table by ÖNACE categories as published by Statistics Austria (2009c).

For the economic analysis investment and operating costs for each technology wedge were compiled in a bottom up approach. The economic analysis within the project EnergyTransition comprises on the one hand economic effects of the investment phase for the two technology wedge portfolios based on an input output analysis. This is complemented by an illustration of the development of operating costs. On the other hand, for selected technology wedges a microeconomic cost appraisal is conducted[12] that – contrary to the macro perspective of the input output analysis – puts the focus on micro economic aspects.

In the following, the results for the technology wedge portfolio focusing on energy efficiency are presented. With respect to the input-output results these are comparable to the second technology wedge portfolio focusing on fuel shift, for which the results can be found in the full report to the project EnergyTransition.

5.1 Input-output effects of the efficiency technology wedge portfolio

For the period until 2020 annual investment requirements for each technology wedge are compiled in a bottom up approach. Total investment costs as well as additional investment costs are assessed[13]. Additional investment costs apply to cost differences compared to a

[12] The micro economic cost analysis can be found in the respective chapters on technology wedges for mobility, buildings, industry and supply of electricity and heat in the full report of the project EnergyTransition.

[13] For some technology wedges the assessment of investment cost was not possible and thus not all technology wedges could be considered for the quantification of the output and employment effects.

respective reference technology. In order to assess the domestic economic implications of the implementation of technology wedges, investment costs are split up into sectoral investment shares. The diffusion of technologies over time is defined by the storylines and can follow different paths: linear, exponential, stepwise or other.

The input-output analysis is based on the additional investment costs of the technology wedges included in the portfolio. The use of additional investment costs ensures that the effects induced by a transformation of the energy system along the energy cascade are quantified. That is, only the employment and output effects of the technology wedges that go beyond investments required for a reference technology or a reference path are calculated. As in terms of emission reductions for the portfolios only the combined wedges' reduction potential is taken into account. For the economic impacts, correspondingly, only the additional effort for transforming the energy system towards increased sustainability is considered. The assessment of the employment and output effects is based on an average annual investment for the period 2009 to 2020 as well as for investment in 2020.

Technology wedges chosen for the efficiency portfolio are listed in Table 8, showing the additional investment costs required for each wedge on average over the twelve-year period from 2009 to 2020 as well as in 2020. The additional investment costs follow the diffusion path of the technologies described in the storylines and are based on the feasible combination of technology wedges in the sectoral analysis to ensure the additivity of the wedges. The highest share in additional investment costs accrues to the building sector.

Table 8: Technology wedges and additional investment in the energy efficiency portfolio

	Technology wedge	Additional investment Average 2009/2020 in million €	Additional investment Average 2009/2020 in %	Additional investment 2020 in million €
M-1	Promotion of efficient transport sav ing land use	48,1	0,8	48,1
M-2	Improv ement of public transport	834,9	13,3	834,9
M-3	Extension of non-motorised transport	45,0	0,7	45,0
M-4	Alternativ e propulsion technologies	191,3	3,0	582,9
M-5	Freight transport	33,0	0,5	33,0
M-6	Efficiency increase by lightweight construction of v ehicles	n.a.	n.a.	n.a
M-8	Relocation of fuel consumption	n.a.	n.a.	n.a
B-1	Thermal refurbishment of existing buildings	3.248,8	51,8	4.826,0
B-2	Construction of new buildings according to Passiv e House Standard	621,4	9,9	1.085,7
B-3a	Replacement of heating systems by more efficient systems	144,7	2,3	188,9
B-3b	Solar heat for space heating and hot water preperation	667,8	10,6	541,2
B-4	Increased power production of buildings for own consumption	43,7	0,7	70,2
B-5	Energy optimised appliances, lighting and equipment	0,0	0,0	0,0
P-1	Energy demand for industrial buildings	131,5	2,1	143,4
P-2	Process intensification and process integration	184,8	2,9	201,6
P-3	Energy efficient engines	51,0	0,8	55,7
P-4	Combined heat and power	26,0	0,4	28,4
E-4	Reduction in electricity and heat generation through reduced demand	0,0	0,0	0,0
Total		**6.271,9**	**100,0**	**8.685,1**

Source: Own calculations.

Additional costs for the six technology wedges in the area buildings amount to 6,712 million € in 2020; average annual investment costs of these technology wedges for the period 2009 to 2020 are 4,726 million € respectively. Technology wedges for mobility have the second largest share in total additional investment costs amounting to 1,544 million € in 2020 and to an average of 1,152 million € p.a. for the period 2009 to 2020 respectively. Additional investments for the four technology wedges in manufacturing are 429 million € in 2020 and on average 393 million € p.a. over the twelve years respectively. For energy supply only Technology Wedge E-4 which comprises emission savings due to reduced final energy demand is considered in this technology wedge portfolio. For this technology wedge investment costs are zero as all investment costs are accounted for in the areas mobility, buildings and manufacturing.

The economic effects of the technology wedge portfolio focusing on energy efficiency are summarised in Table 9. On average over the period 2009 to 2020, the efficiency portfolio generates output effects of 9,498 million € and value added effects of 4,633 million €. In terms of employment 80,469 jobs and 76,129 full time equivalents (FTE) are related to the implementation of this technology wedge portfolio. The output multiplier and the value added multiplier for the efficiency portfolio are 1.51 and 0.74 respectively. This means that with each million € of additional investment output increases by 1.51 million €, value added increases by 0.74 million €, which is related to the protection or creation of approximately 13 jobs.

In 2020 output effects of 14,115 million € and value added effects of 5,955 million € are generated. Employment effects are 106,932 jobs or 99,512 FTE respectively. The higher output and employment effects compared to the twelve-year average mainly result from the higher additional investment costs in 2020.

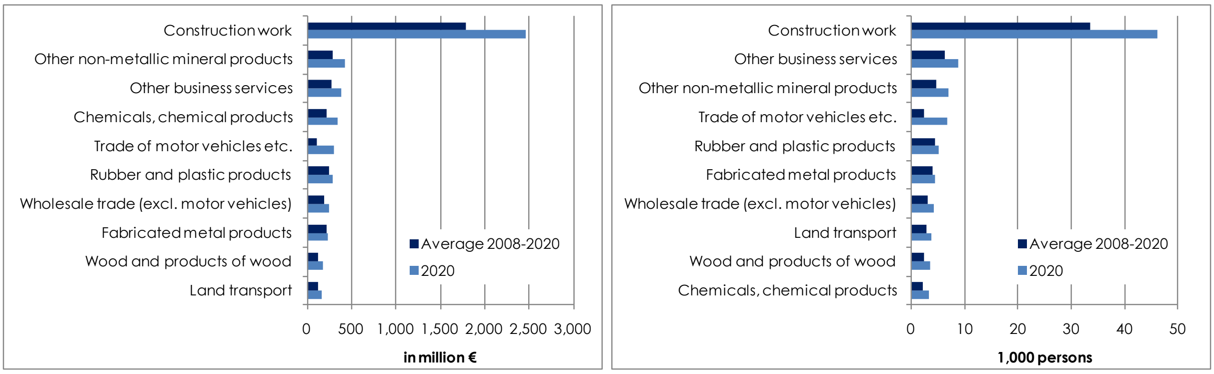
Table 9: Economic effects of the energy efficiency portfolio

		Average	2020
Output effects	mill. €	9,498	14,115
Value added effects	mill. €	4,633	5,955
Employment effcts	persons	80,469	106,932
	FTE [1]	76,129	99,512

Source: Own calculations. – [1] FTE stands for full time equivalents.

Figure 10 shows the sectoral effects of additional investment in the efficiency portfolio. Due to the large share in total additional investment the highest sectoral effects are found in the sector construction work. In addition, high value added effects can be observed for other non-metallic minerals, chemicals and chemical products and for other business services. Besides the employment effects in construction work, high employment effects result for the sectors other business services and for other non-metallic minerals[14].

Figure 10: Highest sectoral value added effects (left) and highest sectoral employment effects (right) in the efficiency portfolio



Source: Own calculations.

5.2 Operating costs in the efficiency technology wedge portfolio

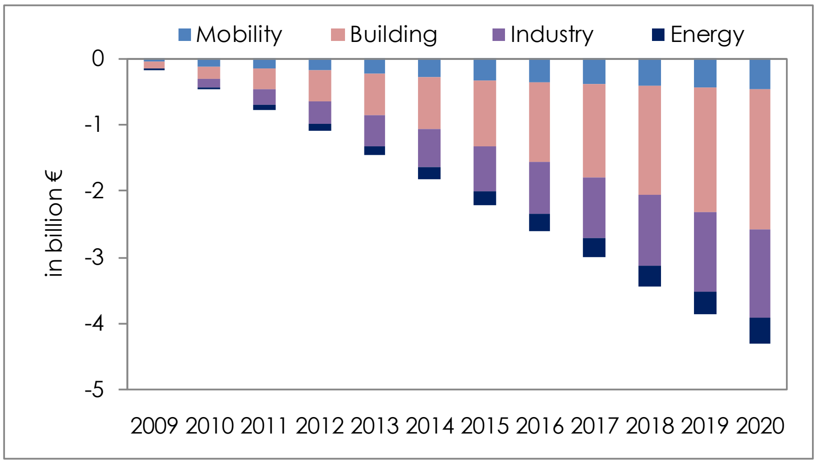
The implementation of the technology wedge portfolio described above has also considerable effects in the operating phase. In order to illustrate the difference in operating

[14] The results for the second technology wedge portfolio can be found in the full report to the project EnergyTransition.

costs between the technology wedges and respective reference technologies a similar approach is followed as for the investment phase: 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. In contrast to annual investment, operating costs as well as cost savings increase over time in line with the diffusion path of the investment and are thus cumulative.

Figure 11 illustrates the development of operating cost savings for the energy efficiency portfolio. Cost savings are quantified for the areas mobility, buildings, manufacturing and electricity and heat supply[15]. In line with the large contribution of the building sector to investments and emission reductions in this portfolio operating cost savings are highest in the building sector reflecting the significant energy savings. Figure 11 clearly illustrates the cumulative character of the operating cost effect. In 2020 operating cost savings amount to -4.3 billion €.

Figure 11: Operating cost savings of the energy efficiency portfolio



Source: Own calculations.

In general technology wedges realise operating cost savings compared to the respective reference technologies. A simple comparison between technology wedges with respect to the extent of cost savings, however, is not sensible as the simple focus on operating costs neglects the capital costs of the technology wedges and related relevant parameters like the service life of the technologies[16]. This perspective would be insufficient to

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[15] For some technology wedges a quantification of operating cost savings was not possible. Cost calculations for electricity and heat supply include savings in fuel costs only.

[16] A separate analysis for a sample of technology wedges implements these aspects in a microeconomic cost appraisal, that can be found in the full report of the project EnergyTransition.

comprehensively assess technological options as the focus on investment costs and payback times without accounting for effects over the whole service life[17].

6 Perspectives for 2050

The long term GHG reduction target in order to limit the risk of a global temperature increase of more than 2°C requires a further scaling up of the proposed measures and technologies as described in the storylines as well as continuous technological and social innovations. The long term perspectives until 2050 connect to the detailed recommendations for emission reductions until 2020 in the analysed areas mobility, buildings, industry and energy supply.

The decarbonisation of transport – seen from today's perspective – is likely to work along the very same technology wedges as given in the previous section for the 2020 time horizon, albeit at a different relative weight. Technology wedges directed most closely at the services themselves, such as spatial planning will gain in importance over time – if it is initiated early enough to enfold its long term impact. Given improved spatial planning, public transport and non-motorised transport can serve a broader share of the population, thus enhancing the impact of these two technology wedges in the long term. Vehicle efficiency already crucial in quantitative terms up to 2020 could be substantially exploited further. The same holds for lightweight technology.

In the building sector new design and technology concepts have to be implemented which meet the necessary requirements of low energy demand. The adoption of new technologies will go hand in hand with the implementation of enforced legal standards and codes regarding energy efficiency in the building sector. Energy demand of the new generation of buildings will be nearly zero, as it is already required by the new European Directive on Energy Performance in Buildings (European Commission, 2010a) and obligatory for all new constructed buildings in Europe after 2020. The future design of buildings is going towards the development and implementation of "zero energy" and "plus energy" buildings.

Zero Energy Buildings are based on the following principles: reduce energy demand, use energy gains and avoid installing active heating and cooling systems by implementing proper passive construction measures (e.g. shading to avoid overheating of buildings in summer). Any remaining (very low) demand for heating shall be supplied through low-temperature systems (heat pumps, solar heating & cooling – all in all "flameless" technologies instead of heating boilers in buildings, except in the case of co-generation systems) or use efficient ventilation and air conditioning systems (HVAC) and highly efficient equipment and lighting. Zero Energy Buildings differ to Zero Net Energy Buildings and Zero Carbon Buildings. Zero Net Energy Buildings are neutral over a year, they deliver as much energy to the supply

[17] The results for the technology wedge portfolio focusing on low carbon technologies can be found in the full report to the project EnergyTransition.

grids as they use from the grids. Zero Carbon Buildings are carbon neutral or positive and produce enough CO_2 free energy to supply themselves with energy over the year (IEA, 2008).

Plus-Energy Houses comply with the criteria of PHS and are characterised by active power supply and energy-saving equipment used by tenants/owners. The buildings are producing annually more energy than they require for own consumption. Roof and façades are actively used for e.g. photovoltaic plants. The solar power plant is feeding excess electricity into the local grid, or even charging batteries of electrical vehicles. Simultaneously these buildings become energy suppliers, e.g. for solar heating and cooling, photovoltaics etc.

The perspectives with respect to energy demand and emission of GHGs from industry in Austria in 2050 will largely depend on the following developments:

- economic development (GDP growth)
- industry structure (globalisation)
- development in other sectors (passive house instead of conventional houses, lightweight cars instead of SUVs, more electronics in all products, new communication technologies, etc.)
- specific energy input (improvements in energy efficiency)
- change in the mix of energy sources (driven by prices, regulations, availability, technological progress, etc.)

It can be assumed that the technology wedges defined for the period till 2020 will be valid until 2050. Radical changes are not ruled out, but unpredictable. The relative potential to contribute to emission reductions stems from various technical options:

- Cogeneration of low-temperature heat and power in medium sized units which leads to reduced energy demand mainly in the energy supply sector.
- Passive houses and energy-plus buildings for office buildings, production halls and storages resulting in an almost complete avoidance of room heating.
- Process intensification through new technologies, heat integration and process optimization for production processes in all sectors.
- Shift to renewable energy (solar process heat, biomass heating systems, biogas from waste, PV, etc.) mainly for low temperature processes, in selected cases with cogeneration; biomass refinery concepts for the utilization of the whole plant in the food chain.
- Improved efficiency in electrical applications (drives, cooling, etc.).
- Material substitution including a shift from steel to polymeric materials, concrete to wooden structures and more light materials in general.
- CCS technologies will still play a minor role in industries.

For the energy supply sector there are basically two fundamentally different approaches for developing perspectives: the supply focused approach and the demand focused approach.

Only an integrated approach that takes into account the interrelation between supply and demand is, however, capable of providing constructive insights into the potential futures of our energy systems.

Forecasting energy supply by looking into the future via the rear mirror of past trends is not viable. Instead of the future based on past developments a methodology of a backcasting from potential viable futures to the present should be applied.

The challenge in the project EnergyTransition lies in the proposition of concrete technological changes in the Austrian energy system until 2020 for the areas mentioned above along with alternative supply structures of energy that do not contradict a more long term perspective of the overall energy system in 2050. For energy supply this means to think of changes in infrastructure and fuel shifts in electricity and heat generation until 2020 that will not turn out as technological lock-ins or prove as sunk costs. Thus a guiding principle for the proposed technological changes in energy supply up to 2020 was to have the longer 2050 perspective in mind.

The expected structures of the energy system in about four decades determine the next steps to put the current energy system on a viable transformation path. The following guidelines for policymakers, companies and consumers can be derived:

(1) Viable energy systems will require a multiplication of current energy productivities.

(2) Higher energy productivity is coupled with higher energy quality. This mean, for example, there will be a lower demand for low temperature heat but a higher demand for electric appliances, electronics and motors.

(3) The energy supply mix needs to adjust to shifts in demand. The expected demand shifts in the quality of energy need to be reflected by a matching supply mix with a higher share of high exergy energy such as electricity and a lower share of low exergy energy as low temperature heat.

(4) The energy supply structure will become more decentralised.

(5) Primary energy is to be used and reused in a cascadic structure. Some feed stocks as crude oil but also biomass can be transformed both into materials (e.g. for producing polymers and other structures) and energy (e.g. heat and electricity). These feed stocks need to be used in the full cascade of their potential use, that priority is given to the use as materials which should be recycled and only afterwards used as input for the energy system.

Materials and material technologies will play an increasingly important role in the energy system, both in terms of significantly enhanced energy efficiency for specific energy services but also in terms of energy supply related to renewable energy technologies including the entire energy transformation chain. In terms of the longer-term perspective an important shift is envisaged in the role of materials in technology systems from simply being structural or functional materials for specific parts and components to a significantly stronger service oriented role, which aims at the enhancement of systems efficiency, effectiveness and functionality providing higher quality services. In other words, next generation materials will be developed and adapted to specific needs and functionalities with a much stronger focus on the optimisation of the systems functionality and performance. Among all material classes, polymeric materials, composites and hybrid materials offer the largest potential for tailoring novel materials towards specific multi-functional property and performance profiles.

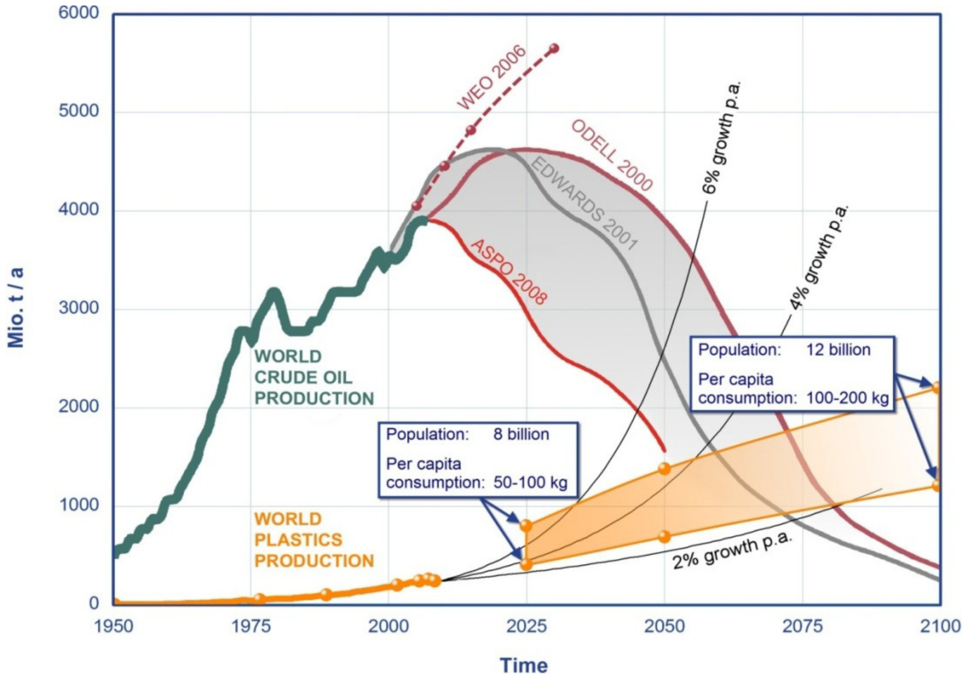
As to material performance improvements, it becomes increasingly apparent, that they play an important role in the overall energy efficiency improvements in existing technologies and applications. The most significant improvements in the future are again expected in the field of polymeric materials and advanced composites and hybrid materials. There are several key fields of energy technology functions in which materials play a major role in terms of improved energy efficiency and a higher quality of energy services. These include:

- In the field of enhanced energy efficiency:
    - Materials for thermal functions such as required in heating and cooling of buildings and the living environment.
    - Materials for structural and primarily mechanical functions in buildings and vehicles aiming at light-weight and ultra-light-weight constructions and designs.
- In the field of energy generation (i.e., harvesting of renewable energies) and energy transformation and transportation:
    - Materials for direct solar technologies (solar-thermal and solar-electrical),
    - Materials for indirect solar technologies (e.g., wind energy harvesting with wind mills of various designs and size scales from micro- to large-scale; high voltage DC cables for efficient electric energy transportation),
    - Materials for hydropower and wave-power energy generation, particularly also of small size scales (small and micro-turbines).
- In the field of energy storage:
    - Materials for batteries and capacitors of various size scales (e.g., large capacity light-weight batteries of high energy density for vehicles),
    - Materials for solar-chemical conversion technologies (e.g., conversion of atmospheric CO_2 into hydrocarbons or alcohols; electrolysis of water to produce hydrogen)
    - Thermal storage materials with significantly enhanced energy density compared to current water based sensible heat stores.

Considering the rising importance of polymers, the aspect of sufficient raw material availability for the next decades has been addressed most recently by Lang and Kicker (2010). Currently polymeric materials and plastics are produced predominantly from crude oil, consuming about 5% of the overall crude oil production annually.

Figure 12 combines various lower and upper bound scenarios in terms of future oil production and future plastics growth in a single chart. As "official" plastics growth scenarios up to 2050 by industry associations and alike are difficult to obtain, two approaches where followed in Figure 12. One approach is based on the crude oil need for current production volumes which were assumed to grow by rates in the range from 2 to 6 % p.a. (black solid lines in the illustration). The other is based on assumptions for population growth (8 billion in 2025, 12 billion in 2100), superimposed with lower/upper bound assumptions for the annual average per capita plastics consumption (50 and 100 kg per capita and year in 2025; 100 and 200 kg per capita and year in 2100).

Figure 12: Comparison of plastics growth and peak-oil scenarios



Source: Lang – Kicker (2010).

Based on such scenarios as illustrated in Figure 12 combined with considerations of technology and innovation opportunities for the fossil fuel and the plastics industry, in Lang (2006, 2010) it is concluded that the interests of the oil and gas industry and the solar industry will converge. Among other reasons, this will be the case also in order to secure for a sufficient raw material supply for higher value-added products such as polymeric materials. After all, many oil/gas production companies are also directly or indirectly (via ownership) involved in the production of plastics. In addition, alternative raw material resources for the production of renewable resource based polymers either in terms of biomass or by proper conversion technologies utilizing atmospheric CO_2 to produce hydrocarbons (e.g., methane) or alcohols (e.g., methanol) and alike will become increasingly important by 2050.

7 Conclusions

- **A new look at the energy system**

The overall target for energy and climate policy is to stabilise global warming below 2° Celsius. This target cannot be reached en passent i.e. when we follow a business as usual path with few measures and minor technological changes. Rather this target means that a substantial restructuring of the energy system needs to start immediately focusing on a broad diffusion of available alternatives and concurrently increasing R&D.

Common analyses of the energy system put a strong focus on the availability of primary energy sources and energy generation. This perspective entices one to overlook changes on other levels of the energy system. A fundamental change in energy systems that is suitable to achieve the political targets with respect to climate change, however, requires a different perspective. Only an integrated view of the whole energy cascade and furthermore the end of the energy cascade, namely from energy services, as a starting point are preconditions for overcoming path dependencies. Energy services are the crucial element for this new understanding of the energy system as not the level of energy flows consumed is welfare relevant but the welfare generating energy service, i.e. comfortable room temperature, access to goods and persons.

- **Energy services for mobility, building, industry, the role of materials and energy supply**

The study EnergyTransition is a concrete application of a new, "energy service based" philosophy. From the energy service perspective three sectors are of central importance: mobility, buildings, industry. Energy services can be provided by a broad range of technologies. In EnergyTransition technology options are developed in storylines for technology wedges until 2020: Each technology wedge is defined as an option to reduce Austrian CO_2 emissions by a certain amount by 2020. For the areas mobility, buildings, industry and electricity and heat supply technology wedges were developed that follow the common EnergyTransition methodology. The role of new materials is explicitly addressed in the areas buildings and mobility. The result is a catalogue of technology wedges that can be used in order to meet the Austrian GHG reduction targets as defined by the EU Energy and Climate Package.

- **The challenge of the 2020 targets**

The analyses of technological options in the project EnergyTransition and the reduction requirements resulting from the reference scenario and the policy objectives show that the implementation of a comprehensive bundle of measures is necessary in order to fulfil the Austrian energy and climate targets. Besides targeting all different levels of the energy system and all sectors an immediate realisation of emission reduction measures is essential. The deployment of energy efficiency options is preferable to low carbon technologies as the former not only reduce emissions but also energy flows. The challenge in both cases is ensure additivity of measures as well as to use technology options that do not lead into technological lock-ins. That means that a perspective beyond 2020 needs to be kept in mind.

- **Economic effects: investment and operating phase**

The restructuring of the energy system requires considerable investment efforts. Investment in the transformation of the energy system translates into an economic stimulus with corresponding output and employment effects. Quantified are the effects of additional investment that is investment costs of a technology wedge exceeding those of a reference technology. Whereas the stimulus effect of investment to the transformation period of the energy system, cost savings in the operating phase prevail over the whole service life of the technology. In general technology wedges realise operating cost savings compared to the respective reference technologies. A simple comparison between technology wedges with respect to the extent of cost savings, however, is not sensible as the simple focus on operating costs neglects the capital costs of the technology wedges and related relevant parameters like the service life of the technologies[18]. This perspective would be as insufficient to comprehensively assess technological options as the focus on investment costs and payback times without accounting for effects over the whole service life.

- **Central role of the building sector**

The great challenge for the building sector is a high quality renovation of the existing building stock and an intensified increase of the renovation rate to an extent, which up to now has not been implemented. The highest necessity for renovation lies in the building stock of the post war period. A highly important aspect is energy awareness and a changed user behavior, together with a significant reduction of the energy demand of living. Future buildings are characterized by nearly zero and plus energy buildings, which increasingly will contribute to decentralised energy supply.

- **Political framework**

While climate targets are usually acknowledged by decisions makers the transformation of targets into actual actions seems to fail due to differing political and institutional barriers. For example it may be that the emission reduction options and the impact on greenhouse gas emissions are simply not known, that there is resistance due to different interests of stakeholders or that the overall energy system is not considered by scheduling policy measures. The strength of the EnergyTransition framework is that (1) all relevant reduction options in different sectors are considered and quantified, (2) that interferences between different options within a sector but also across sectors are considered and (3) that changes in energy demand due to reduction options are balanced with energy supply thus considering the entire energy system. (4) Reduction options are considered on each step of

[18] A separate analysis for a sample of technology wedges implements these aspects in a microeconomic cost appraisal.

the energy cascade beginning with the energy service. Reduction options starting on this step of the energy cascade are most effective. The Energy Transition framework guarantees a more efficient scheduling and assessment of policy measures for decision makers thus increasing the possibility that climate policy meets its targets.

- **Long term perspectives – no technological lock in**

The 2020 emission reduction targets are an intermediate step towards the longer term perspective of de-carbonising the economy in order to limit global temperature rise to 2°C. When implementing measures for the required transition it is essential to keep this long term perspective in mind and avoid lock-in effects regarding technologies and associated infrastructure, social behavior and institutions. This long term perspective was also a guiding principle in developing the storylines for the technology options in EnergyTransition.

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