Measuring Greenhouse Gas Abatement Costs in Upper Austria

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Introduction

Legally binding commitments for reducing carbon emissions arise in many countries of the world and are primarily based on the multilateral agreement of the Kyoto Protocol. The protocol applies mostly to industrialized countries in the period from 2008 to 2012 and provides for a reduction of six greenhouse gases (CO_2, CH_4, H_2O, HFC, PFC, SF_6) by approx. 5% in comparison to 1990. Moreover, the European Union decided to reduce greenhouse gas (GHG) emissions by at least 20% of 1990 levels by 2020. In addition, the European Union has offered to increase its emission reductions to 30% by 2020, contingent on the behavior of other major emitting countries in developed and developing countries. Within this framework, Austria was assigned a GHG reduction target of 13% by 2012 as compared to 1990. Given this setting, the question arises whether certain measures to reduce GHG emissions can be implemented cost-efficiently. The concept of marginal abatement costs (MACs) allows for the illustration of the marginal costs and the total emission abatement, indicating the ecological effectiveness with regard to a business-as-usual (BAU) scenario of certain GHG emission abatement measures. Strictly speaking, abatement costs are defined by a cost-benefit ratio which displays the monetary input necessary for the reduction of one ton of GHG emissions. Hence, this procedure can be used by policy makers to evaluate the implementation of certain abatement measures and assist decision-making at the international, national and regional level. By comparison, various countries have already carried out investigations in this field. For example, an in depth analysis was carried out in Germany (McKinsey & Company, 2007), which still represents a milestone in the analysis of abatement costs.

This paper presents the main results and conclusions of the scientific research project „Analysis of CO_2e abatement costs in Upper Austria". The assessment covers the quantification of abatement costs of certain GHG emissions (CO_2, CH_4, N_2O) of various energy efficiency and fuel switch measures, and puts special emphasis on the heat, electricity and transport sector in Upper Austria in the period from 2010 to 2030. The evaluated energy efficiency measures include, among others, thermal renovation activities, improving building standards, promoting efficient vehicles and enhancing domestic appliances. Additionally, the fuel switch measures incorporate the increased utilization of renewable energy sources for heating systems, for vehicles and for the generation of electricity. Furthermore, the absolute reduction potentials of the analyzed measures (in tons of CO_2 equivalents (CO_2e)) for each year and for the entire period from 2010 to 2030 were evaluated. To our knowledge, no other sector or measure-specific assessment has been conducted for Upper Austria up to now. Thus the multi-criteria approach of this paper reveals the economic efficiency and the ecological effectiveness of the considered methods with regard to (a) GHG emission reductions, (b) the improvement of the overall energy efficiency and (c) the competitiveness of a fuel switch towards renewable energy sources. In addition, the MACs resulting from 31 energy efficiency measures are compared to 25 technologies focusing on fuel switch measures. Thus, a direct comparison of energy efficiency concepts and the intensified utilization of renewable energy sources is possible. Furthermore, this enables the generation of a comprehensive overview and the prioritization of measures/technology changes. Drawing upon the findings of this study, policy recommendations can be elaborated and the necessary improvements of the regulative framework can be implemented.

The next section starts with an explanation of the concepts of MAC curves which focuses especially on the expert-based approach. In the following, the findings of the quantification of marginal abatement costs and the reduction potentials in Upper Austria are presented. In the section afterwards the idea of policy-making via MAC curves is addressed. Finally, the paper ends with conclusions and suggestions for future work.

The Concept of Marginal Abatement Costs

MACs cover those costs incurred by the reduction of a defined quantity of GHG emissions compared to a reference or BAU scenario. Accordingly, they provide a cost-benefit ratio and analyse the economic efficiency and ecological effectiveness for the evaluation of measures or technology changes.

Thus, the MAC curve displays the costs generated with the last unit of emission reduction for changing the quantity of reduced emissions. Consequently, a BAU scenario has to be derived in order to calculate the marginal abatement costs against this baseline abatement. As stated in Kesicki (2010), *"...a MAC curve allows one to analyse the cost of the last abated unit of CO_2 for a defined abatement level while obtaining insights into the total abatement costs through the integral of the abatement cost curve"*. The concept of MAC curves in general provides advantages with respect to the ability to derive the MACs for any given total reduction amount. Further, MAC curves display the total costs which are required to mitigate a defined amount of carbon emissions. On the other hand, MACs estimates are generally limited to one point in time, exhibit a lack of certainty because they focus on the future and do not consider ancillary benefits like improved energy security and the abatement of other GHGs. Thereby, two fundamental concepts for deriving MAC curves exist: (I) expert-based MAC curves based on a managerial approach and (II) model-derived MAC curves generated by energy and environmental policy models (Kesicki, 2010).

The latter is based on top-down models including endogenous economic reactions within the whole economy. Accordingly, conventional top-down models typically are deficient in details on present and future technological alternatives which may be important in regard to a suitable evaluation of different energy policies. Generally they do not provide for essential physical constraints such as the preservation of energy. These models offer great perception of the effects of policy measures such as taxes or subsidies causing market distortions. The second species are so-called bottom-up models which represent only the energy sector. They account for cost minimization or maximizing consumption and producer surplus in the focused sector and do not reflect macroeconomic reactions. Compared to top-down approaches, these models comprise more features of energy technologies along the conversion from primary to final energy (Shukla, 1995; Hourcade *et al.*, 2006; Böhringer and Rutherford, 2008).

In the following, the first manner to derive MAC curves - the expert-based approach – is described and the definitions as well as the interpretation of the derived results are given in more detail. Expert-based MACs are conceived through the evaluation and assessment of various technologies by experts who make assumptions for the BAU scenario, the CO_2 reduction potential and the costs for investment as well as energy prices at a single point in time. This concept of MACs, also known as technology cost curves, illustrates a ranking of the cheapest and most expensive technologies and therefore shows the potential of various measures/technology changes with respect to emission reductions.

According to the concept of expert-based MACs, the following formula is used for the quantification of specific abatement costs of GHG emissions based on a technology *i* with respect to a reference technology *j* (BAU situation without implementation of any measure):

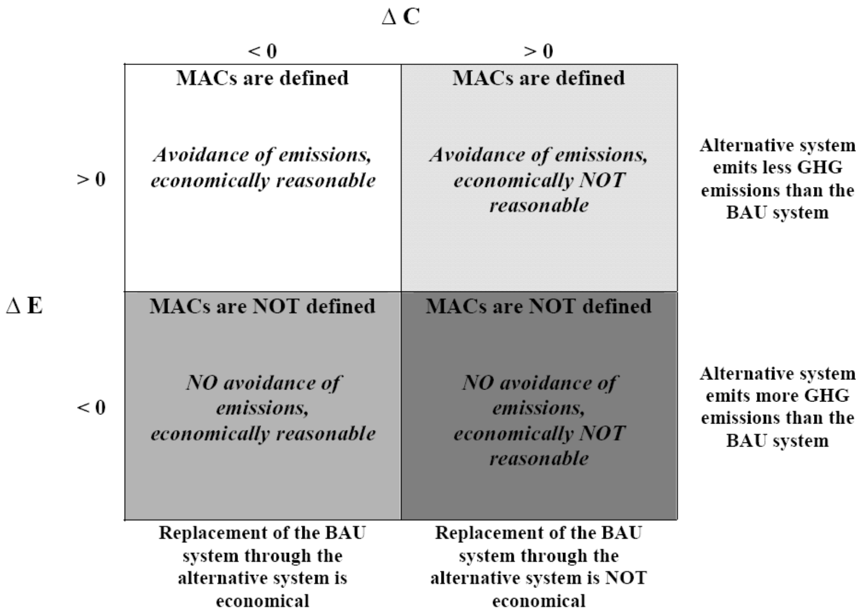
$$MAC_t^{i,j} = \frac{\Delta C_t}{\Delta E_t} \qquad (1)$$

with

ΔC_t (Total annual costs technology i [Euro] in t) – (total annual costs BAU technology j [Euro] in t)
ΔE_t (Total annual GHG emissions BAU technology j [tons] in t) – (total annual GHG emissions technology i [tons] in t)

As shown for a yearly observation in formula (1), the model can also be used to calculate the MACs for an extended time period.

After the quantification of the MACs of a measure or technology change, the outcome is classified. Figure 1 thus shows an evaluation model for MACs including the possible results and how those can be interpreted:



Δ E \ Δ C	< 0	> 0	
> 0	**MACs are defined** ***Avoidance of emissions, economically reasonable***	**MACs are defined** ***Avoidance of emissions, economically NOT reasonable***	**Alternative system emits less GHG emissions than the BAU system**
< 0	**MACs are NOT defined** ***NO avoidance of emissions, economically reasonable***	**MACs are NOT defined** ***NO avoidance of emissions, economically NOT reasonable***	**Alternative system emits more GHG emissions than the BAU system**
	Replacement of the BAU system through the alternative system is economical	**Replacement of the BAU system through the alternative system is NOT economical**	

Figure 1. Evaluation model for MACs.

In general, it can be said that negative marginal abatement costs for the case when ΔC<0 and ΔE>0 (and therefore MAC<0), indicate that cost-saving options exist. The combination of a positive total annual cost difference and a positive difference in GHG emissions, thus ΔC>0 and ΔE>0 (and therefore MAC>0), causes environmental effectiveness in terms of GHG emission reductions, but also higher costs. It should be noted that in regard to a positive total annual cost difference and a negative difference of GHG emissions, thus ΔC>0 and ΔE<0 (and therefore MAC<0), and a negative total annual cost difference associated with a negative GHG emission difference, thus ΔC<0 and ΔE<0 (and therefore MAC>0), no relevant conclusions regarding the marginal abatement costs can be derived, since no reduction of GHG emissions takes place.

Basically, when interpreting the values of the specific mitigation costs it has to be noted that neither the resulting cost difference nor the difference of emissions should be very low, so that the calculated values are comparable. Furthermore, the essentiality of consistent reference scenarios has to be pointed out as this provides the fundamental prerequisite for statements about the economic efficiency of GHG emission reductions. As a consequence of lower costs of the considered technology (alternative system) as compared to the reference system, and due to a minimal avoidance of emissions, high negative MACs result in an increased need for interpretation.

While the amount avoided (in tons CO_2e) reflects the effectiveness of each system in terms of meeting the aim of emission reductions, the specific avoidance costs (in Euro / ton CO_2e) are a measure regarding the efficiency of each activity and/or technology change. Hence, the expert-based MAC represents the cost-benefit ratio for the implementation of measures, since those costs display the monetary input necessary to avoid one ton of CO_2e. Accordingly, negative abatement costs are an indication for particularly efficient mitigation measures/technology changes.

MACs present the abatement costs required for any given total reduction amount, however they are generally limited to a certain time frame. The expert-based approach, which is examined in this paper in greater detail, considers individual technologies associated with specific details but neglects behavioural and learning aspects. Furthermore, the expert-based MACs conclude the possibility of different BAU scenarios which leads to an inconsistent perception. Due to these assumptions, the model is based on uncertain information, such as investment costs, efficiencies, etc.

Marginal Abatement Costs and Reduction Potentials in Upper Austria

General assumptions are discussed, before presenting the main results of the quantification of MACs and the reduction potentials in Upper Austria.As already mentioned, MACs can be quantified for an extended time period, in this case for the period from 2010 to 2030. Thus, the expert-based MACs for the period from 2010 to 2030 are calculated as follows:

$$MAC^{\,i,j}_{2010\text{-}2030} = \frac{\Delta C_t}{\Delta E_t} = \frac{\sum\limits_{t=2010}^{2030} C_t^i - \sum\limits_{t=2010}^{2030} C_t^j}{\sum\limits_{t=2010}^{2030} E_t^j - \sum\limits_{t=2010}^{2030} E_t^i} \qquad (2)$$

According to formula (2) ΔC_t represents the cost difference between the alternative system and the BAU scenario for the period from 2010 to 2030, and ΔE_t implies the spread between the GHG emissions through the BAU scenario as compared to the alternative system for the same period.

The quantification of MACs of GHG emissions includes the abatement costs for CO_2, CH_4 and N_2O emissions. The quantification of fluorinated GHGs is not feasible due to the lack of necessary data. In general, the observation of CH_4 and N_2O emissions allows for the quantification of GHG abatement costs. It should be noted that in the case of reduced CH_4 and N_2O emissions as a result of the implementation of a measure (in a situation of reduced CO_2 emissions), the CO_2e abatement costs are lower and therefore more positive than the abatement costs considering only CO_2. This can be explained by the fact that the same costs reduce more emissions.

The quantification of MACs, including CH_4 and N_2O emissions, is based on the global warming potential (GWP) of these gases in relation to CO_2. Table 1 contains the relationship between CO_2, CH_4 and N_2O.

Table 1. Global warming potential for a period of 100 years. Source: (IPPC, 2007)

Chemical compound	GWP for a period of 100 years in carbon dioxide equivalents
Carbon dioxide (CO_2)	1 CO_2e
Methane (CH_4)	25 CO_2e

Nitrous oxide (N_2O)	298 CO_2e

The separation of the quantification of the abatement costs for CH_4 and N_2O emissions does not seem appropriate, since the shifting the conversion and energy costs of a specific measure on these low distinctive types of emissions (compared to the level of CO_2) would distort the individual results too much. For this reason, the authors limit themselves to a representation of the total CO_2e abatement costs.

In terms of costs, a total cost approach is applied including end user costs as well as costs of public service, whereat costs for energy are also taken into consideration. Furthermore, it is assumed the investment into a measure/technology depreciates over the life span of the particular technology. Finally, in addition to the abatement costs of GHG emissions, this investigation also determines avoidance potentials of various measures until the year 2030.

Based on the definition of expert-based MACs within this assessment, 56 measures/technology changes were assessed. 31 of which concern the enhancement of energy efficiency. In the end, 25 of these evaluated GHG technology changes actually imply a fuel switch towards renewable or low-carbon technologies. The following areas of energy services were evaluated:

- Heating and Cooling (H)
- Electricity (E)
- Transportation (T)

Since, the BAU scenarios are an essential part within the concept of MACs, the following reference scenarios were defined for each segment within this assessment:

- Segment heating/cooling
    - Energy efficiency measures: individual scenario
    - Fuel switch measures: single-family house, with heating technologies based on fossil fuels
- Segment electricity
    - Energy efficiency measures: average new device/appliance
    - Fuel switch measures: four reference scenarios (European electricity mix, Austrian electricity mix, Upper Austrian electricity mix, electricity by a combined-cycle plant)
- Segment transportation
    - Energy efficiency: individual scenario
    - Fuel switch: vehicle with an average fuel consumption

The appendix contains detailed information on each abatement measure, in terms of the BAU, depreciation rates, energy consumption, investment costs, energy prices and so on. It must be stated that the quantification of individual measures is not very expedient. In contrast, the comparability of the measures with each other in order to design an expert-based abatement cost curve is far more significant. Therefore, the assumptions should simply be seen as general guidance for understanding the quantification of expert-based MACs (Table 4 to 6).

On the basis of the BAU scenarios mentioned, Table 2 illustrates the main results of the GHG reduction costs and potentials in Upper Austria through the 31 energy efficiency measures examined within this project. The evaluation represents the anticipated costs and reduction potentials in 2030.

Table 2. MACs and reduction potentials in Upper Austria by the year 2030, focusing on energy efficiency measures. Source: (Tichler *et al.,* 2010a; Tichler *et al.,* 2010b; Tichler *et al.*, 2010c)

Measure/Strategy	Energy Service	Annual GHG reduction costs in €/ton CO_2e	Amount of potential reduction of GHG emissions in Upper Austria in 2030 in tons CO_2e
Investigated measures to increase energy efficiency / reduce energy consumption in Upper Austria			
Carpooling	Transportation	-2,049	308,373
Energy-efficient street illumination	Electricity	-1,211	10,568
Efficient gasoline car	Transportation	-503	54,022
Energy-efficient heat pump including hydraulic enhancements	Electricity	-464	17,661
Energy-efficient ICT using heat recovery technology 60 kW	Electricity	-454	2,487
Energy-efficient ICT using heat recovery technology 7 kW	Heating/Cooling	-373	3,627
Reduced soil treatment in agriculture	Transportation	-365	3,303
Energy-efficient washing machine	Electricity	-353	4,110
Reduction of primary heating flow temperature in single-family houses	Heating/Cooling	-346	1,758
Energy-efficient LED-light technology	Electricity	-272	18,799
Energy-efficient freezer	Electricity	-196	10,159
Energy-efficient truck	Transportation	-196	370,644
Rolling road	Transportation	-149	3,870
Energy-efficient fridge	Electricity	-99	10,460
Energy-efficient diesel passenger car	Transportation	-95	140,736
Renovation of exterior walls in single-family houses	Heating/Cooling	-24	237,455
Renovation of basement ceiling in single-family houses	Heating/Cooling	9	68,028
Energy-efficient TV	Electricity	103	24,911
Replacement of gas boilers	Heating/Cooling	121	56,426
Multi-family house (30 households) on low-energy standard	Heating/Cooling	212	40,933
Renovation of upper floor ceiling in single-family houses	Heating/Cooling	227	47,491
Total renovation of commercial buildings on low-energy standard	Heating/Cooling	271	104,319
Thermal active building systems for heating assistance in single-family houses	Heating/Cooling	273	35,322
Passive houses instead of houses on low-energy standard	Heating/Cooling	420	61,233
Replacement of windows and exterior doors in single-family houses	Heating/Cooling	578	64,177
Energy-efficient DVD player	Electricity	759	1,335
Thermal waste heat absorption refrigeration system	Heating/Cooling	786	14,924
Row houses on low-energy standard	Heating/Cooling	837	6,317
Energy-efficient traffic signal systems	Electricity	838	1,913
Energy-efficient dishwasher	Electricity	1,331	12,493
Solar system for air conditioning	Heating/Cooling	5,490	27,866

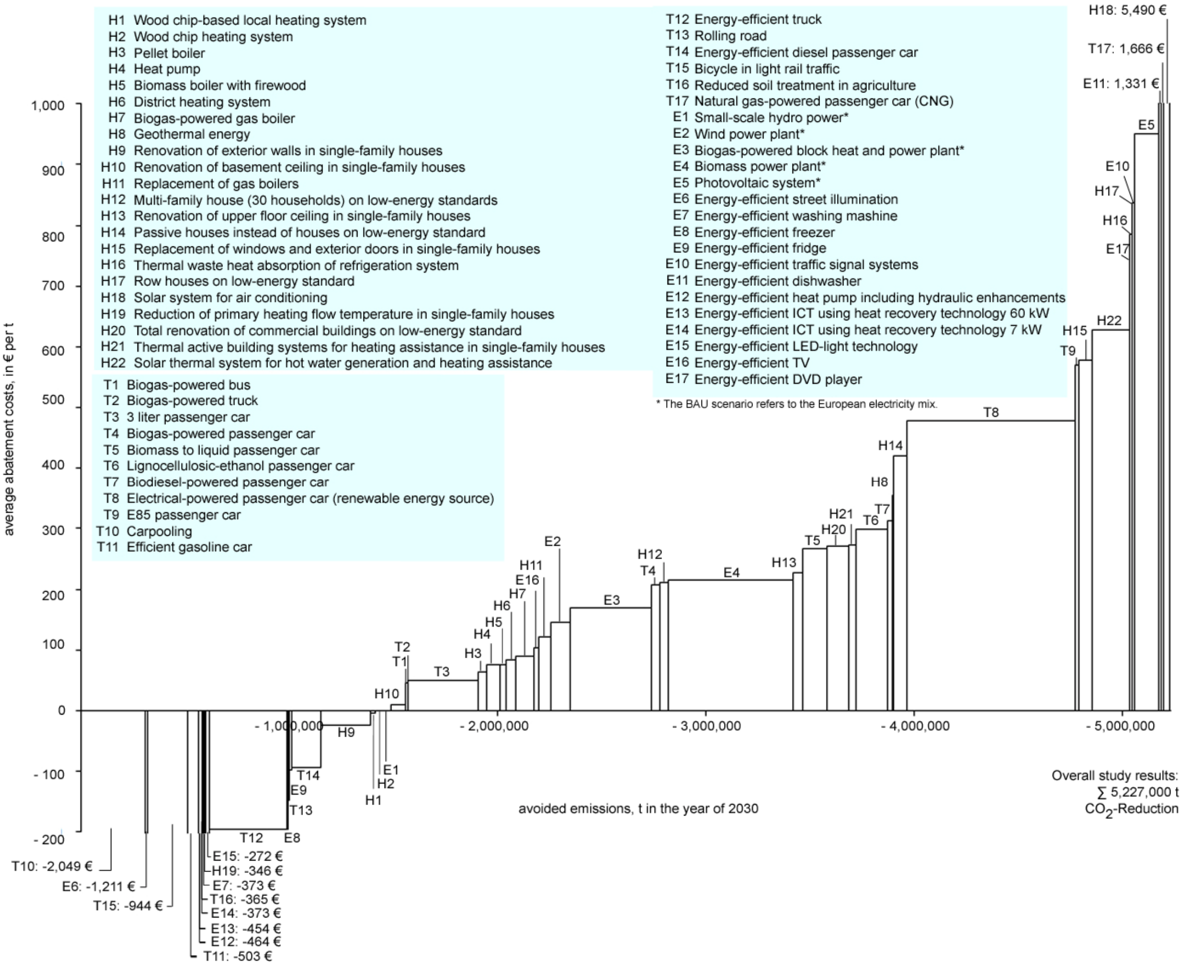
Finally, Table 3 displays the main results of the abatement costs and reduction potentials in Upper Austria that were generated by the 25 fuel switch strategies investigated within this project. The evaluation represents the anticipated costs and reduction potentials in 2030.

Table 3. MACs and reduction potentials in Upper Austria by the year 2030, focusing on fuel switch measures. Source: (Tichler *et al.,* 2010a; Tichler *et al.,* 2010b; Tichler *et al.*, 2010c)

Measure/Strategy	Energy Service	Annual GHG reduction costs in €/ton CO_2e	Amount of potential reduction of GHG emissions in Upper Austria in 2030 in tons CO_2e
Investigated measures to increase fuel switch in Upper Austria			
Bicycle in light rail traffic	Transportation	-944	190,712
Wood chip-based local heating system	Heating/Cooling	-5	26,450
Wood chip heating system	Heating/Cooling	-1	27,590
Small-scale hydro power *	Electricity	0	47,870
Biogas-powered bus	Transportation	45	7,958
Biogas-powered truck	Transportation	50	3,316
3 liter passenger car	Transportation	50	335,626
Pellet boiler	Heating/Cooling	63	43,814
Heat pump	Heating/Cooling	75	63,580
Biomass boiler with firewood	Heating/Cooling	76	25,500
District heating system	Heating/Cooling	84	50,924
Biogas-powered gas boiler	Heating/Cooling	90	83,809
Wind power plant *	Electricity	146	95,608
Biogas-powered block heat and power plant *	Electricity	169	388,068
Biogas-powered passenger car	Transportation	206	39,192
Biomass power plant *	Electricity	215	598,978
Biomass to liquid passenger car	Transportation	266	115,935
Lignocellulosic-ethanol passenger car	Transportation	298	148,649
Biodiesel-powered passenger car	Transportation	312	26,616
Geothermal energy	Heating/Cooling	355	5,613
Electrically-powered passenger car (renewable energy source)	Transportation	478	807,965
E85 passenger car	Transportation	569	16,910
Solar thermal system for hot water generation and heating assistance	Heating/Cooling	629	179,890
Photovoltaic system *	Electricity	951	114,729
Natural gas-powered passenger car (CNG)	Transportation	1,666	15,754
*BAU scenarios refer to the European electricity mix.			

Summarizing the economic efficiency of all evaluated measures, it is apparent that 19 out of the 56 strategies (which represent 34%) have negative abatement costs. Thus, even in the absence of other financial incentives it makes sense to invest in these measures as they pay off within their projected time of use or generate a positive cash flow. According to the assessment scheme in Figure 1, these measures are very efficient from an economic point of view and exhibit $\Delta C<0$ and $\Delta E>0$. The remaining 37 measures/technology changes (which represent 66%) generate positive abatement costs, which implies ΔC>0 and ΔE>0. Thus, although their ecological footprint is positive, it is not possible to justify an investment in these technologies from a purely economic point of view.

Figure 2 depicts a summary of the expert-based MACs of the evaluated measures in Upper Austria in the year 2030.



Note: H represents measures for the Heating/Cooling sector, T stands for Transportation, and E for Electricity.

Figure 2. MAC curve of the evaluated measures in Upper Austria in 2030. Source: (Tichler *et al.*, 2010c)

The assessment of the overall reduction potential of GHG emissions in Upper Austria shows that by the year 2030 a reduction of GHG emissions of 5.23 million tons CO_2e is possible. This represents 25% of the current GHG emissions of Upper Austria and 52% of the emissions outside the industrial sector which was not part of this analysis.

The possible reductions are by all means significant. Measures aimed at improving the overall energy efficiency account for a total of 1.76 million tons of CO_2e emission reductions (this represents 8% of the current GHG emissions or 18% of CO_2e emissions outside the industrial sector). On the other hand measures, which imply a fuel switch, are capable of reducing GHG emissions by 3.47 million tons CO_2e (which represents 16% of the current GHG emissions or 35% of the emissions outside the industrial sector).

In 1990, GHG emissions in Upper Austria accounted for 21.9 Mt CO_2e in Upper Austria, which means a required reduction to 19.1 Mt CO_2e by the year 2012. Based on the latest available figures from the Upper Austrian pollutant inventory in 2009, GHG emissions accounted for 21.3 Mt CO_2e (compared to 24.5 Mt CO_2e in 2008), of which 53% originate from the industrial sector. Even though the economic crises caused a slump of the industrial production, which is mainly responsible for the GHG reduction between 2008 and 2009 as it is the most relevant emission source, followed by transportation and housholds, , the province of Upper Austria is far away from achieving its reduction target (Environmental Agency Austria, 2011).

An overall vulnerability assessment for Upper Austria revealed good preconditions for coping with climate change, due to the fact of a highly adaptive capacity and moderate impacts of climate change to relevant sectors. However some crucial vulnerabilities can be identified, which mainly concern water management, forestry, transportation and energy production. Within the governmental working program 2009 to 2015 the federated government of Upper Austria has fixed severals sectoral mitigation measures and goals, focusing primarily on water management and forestry. Furthermore, climate change mitigation is addressed by the recent Upper Austrian Traffic Concept (promotion of public transport) and the Energy Strategy 2030 (reduction of GHG emissions of up to 65% by 2030) (Birngruber *et al.*, 2011).

Policy-making via Marginal Abatement Cost Curves

According to a generally accepted distinction between different policy instruments, incentive-based and non-incentive-based instruments are distinguished. The first category contains the most prominent climate policy approaches, namely the taxation of undesired pollution (e.g. carbon tax) and the limitation of overall carbon emissions (i.e. cap-and-trade). The second category includes instruments targeted at research and development, as well as command-and-control policies. Both types can be applied to different problem sets. However, from an economic efficiency point of view, market-based instruments are preferred. The various existing approaches can be further characterized by the measure/technology change under scrutiny. Here, a similar taxonomy according to Kesicki (2010) is used, which defines three categories of policy instruments that can be applied to different measures.

Furthermore, a group of economically viable technology shifts exists that will ultimately be implemented due to their (economic) advantage for the user (investor). These measures can be regarded to be best suited for command-and-control policies as the economic aspect of their implementation is already represented by their (negative) MACs. The second category involves market-based policies like carbon taxation and carbon permits. These measures typically exhibit positive marginal abatement costs, although they are also the most interesting category from a policy point of view. They require a profound mix of policy-instruments and thus are in great need of further research. The third and last category contains measures, technologies and strategies that result in (mostly large) positive MACs. These measures often require further research and development efforts in order to become economically viable.

The various policy instruments can thus be summarized into three groups, which are also depicted in Figure 3.

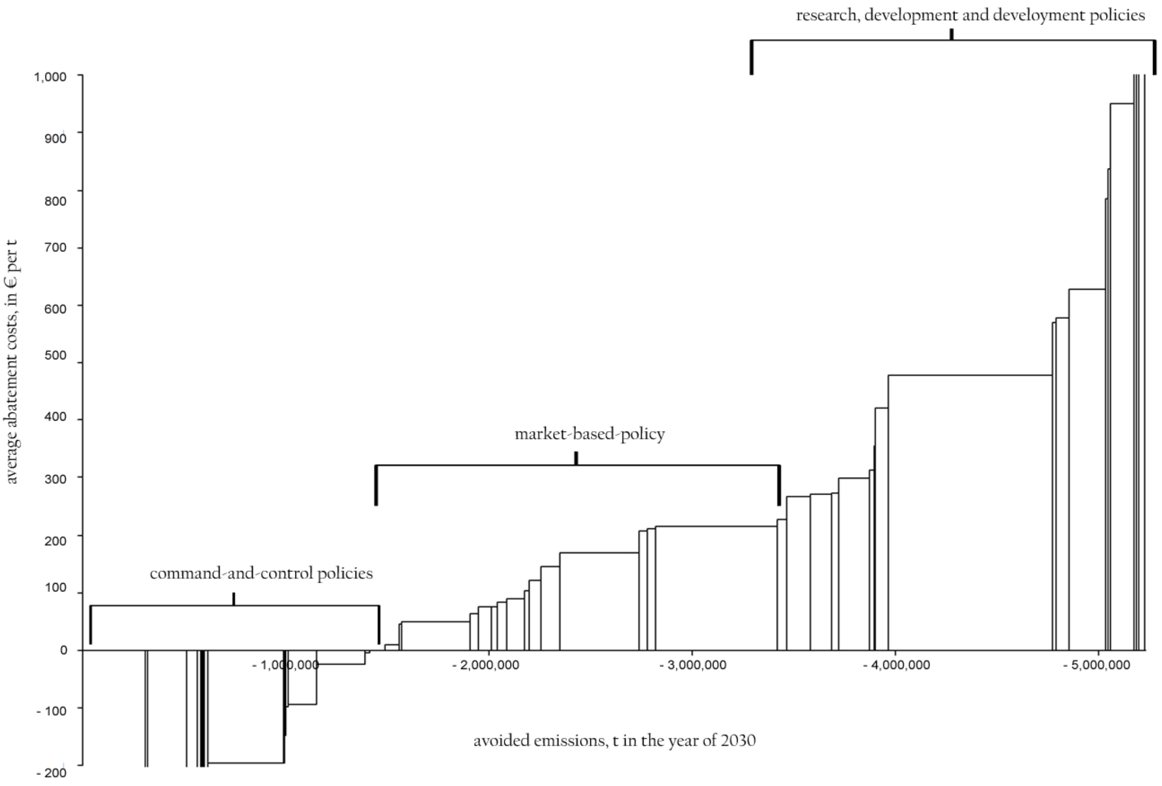


Figure 3. Application of various policy instruments due to expert-based MAC curves.
Source: (Kesicki, 2010; Tichler *et al.,* 2010c)]

Conclusions

In numerous international studies aimed at evaluating measures for the reduction of greenhouse gas (GHG) emissions, the concept of MACs is a frequently used procedure to illustrate the marginal costs and the total emission abatement, displaying the economic efficiency and ecological effectiveness of measures or technology changes. As demonstrated at a regional level, an expert-based assessment in Upper Austria (for the period from 2010 to 2030) shows a significant reduction potential of GHG emissions (25% of the current GHG emissions), consisting of 34% of energy efficiency measures and of 66% of measures focusing on fuel switch. These results can therefore be used by policy makers to promote the implementation of certain GHG abatement measures. Applied to Upper Austria the investigation can support the implementation of the governmental working program, as well as the Energy Strategy 2030.

The concept of MACs is generally limited to a certain time frame, furthermore the approach is based on several assumptions, such as investment costs and efficiencies. With regard to the expert-based MAC curve, future work should focus on creating different technological learning rates and on sensitivity analyses, since parameters such as investment, energy costs and the performance of new technologies have a deep impact on the shape of the MAC curve.

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Appendix

Table 4. Basic assumptions regarding the segment Heating and Cooling (H). Source: (Tichler *et al.*, 2010a; Tichler *et al.*, 2010b; Tichler *et al.*, 2010c)

Segment Heating and Cooling (H)					
Measure/Strategy	Reference scenario	Heat demand in kWh	Depreciation in years	Investment cost difference in €/year	Energy prices in €/kWh
H1 – Wood chip-based local heating system	100 single-family houses, with a heating technology based on fossil fuels	8,370 (per house)	21	+107,500	Wood chips: 0.026 Fossil: 0.072
H2 – Wood chip heating system	Single-family house, with a heating technology based on fossil fuels	8,370		+1,090	Wood chips: 0.026 Fossil: 0.072
H3 – Pellet boiler				+1,090	Pellets: 0.041 Fossil: 0.072
H4 – Heat pump				+1,070	Electricity: 0.183 Fossil: 0.072
H5 – Biomass boiler with firewood				+1,090	Fire wood: 0.038 Fossil: 0.072
H6 – District heating system	100 single-family houses, with a heating technology based on fossil fuels	8,370 (per house)		+107,500	District heating: 0.032 Fossil: 0.072
H7 – Biogas-powered gas boiler	Single-family house, with a heating technology based on fossil fuels	8,370		+640	Biogas: 0.098 Fossil: 0.072
H8 – Geothermal energy				+1,570	Electricity: 0.183 Fossil: 0.072
H9 – Renovation of exterior walls in single-family house	Single-family house from 1965, without renovation	Energy index reduction: 93 kWh/sqm	25	+1,330	Average heating: 0.067
H10 – Renovation of basement ceiling in single-family house		Energy index reduction: 27 kWh/sqm	25	+430	Average heating: 0.067
H11 – Replacement of gas boiler	Old atmospheric gas boiler	10,870	20	+530	Natural gas: 0.060
H12 – Multi-family house (30 households) on low-energy standard	Minimum standard, with an average heating technology	Measure: 148.500 BAU: 219.415	Building envelope: 30	+9,330	Average heating: 0.067
H13 – Renovation of upper floor ceiling in single-family house	Single-family house from 1965, without renovation	Energy index reduction: 19 kWh/sqm	25	+500	Average heating: 0.067
H14 – Passive house	Low-energy house, with an average heating technology	Measure: 1,860 BAU: 8,370	Building envelope: 30 Air conditioning: 17	+1,000	Average heating: 0.067
H15 – Replacement of windows and exterior doors in single-family house	Single-family house from 1965, without renovation	Energy index reduction: 25 kWh/sqm	25	+1,110	Average heating: 0.067
H16 – Thermal waste heat absorption refigeration system for commercial use	Electrical system	Cooling demand: 130 kW	17	+3,900	Electricity: 0.180 Waste heat: 0.010 and 29 €/kW Water/Waste water: 0.960/0.350 €/cbm
H17 – Row house on low-energy standard	Minimum standard, with an average heating technology	Measure: 9,000 BAU: 9,975	Building envelope: 30	+3,150	Average heating: 0.067
H18 – Solar system for air conditioning	Electrical system	Cooling demand: 1,125	19	+1,590	Electricity: 0.180
H19 – Reduction of primary heating flow temperature in single-family house	Single-family house, with a heating technology based on fossil fuels	8,370	only focusing on consumption cost	+0 (only focusing on consumption cost)	Fossil: 0.072
H20 – Total renovation of commercial building on low-energy standard	Commercial building (650 sqm), without renovation (134 kWh/sqm), average heating technology	Energy index reduction: 102 kWh/sqm	25	+9,690	Average heating: 0.067
H21 – Thermal active building systems for heating assistance in single-family house	Low-energy house, without thermal active building system	8,370	21	+650	Fossil: 0.072
H22 – Solar thermal system for hot water generation and heating assistance	Single-family house, with a heating technology based on fossil fuels	10,870		+980	Fossil: 0.072
Note: rounded values					

Table 5. Basic assumptions regarding the segment Electricity (E). Source: (Tichler *et al.*, 2010a; Tichler *et al.*, 2010b; Tichler *et al.*, 2010c)

Segment Electricity (E)					
Measure/Strategy	Reference scenario	Operating hours/year	Depreciation in years	Installed capacity in kW	Energy costs (Feed-in tariff) in €/kWh
E1 – Small-scale hydro power	European electricity mix, energy costs: 0.056 €/kWh	4,000	21	500	0.150
E2 – Wind power plant		2,000		2,000	0.097
E3 – Biogas powered block heat and power plant		6,500		500	0.165
E4 – Biomass power plant		8,000			0.150
E5 – Photovoltaic system*		880		5.5	0.365
Measure/Strategy	Reference scenario	Consumption in kWh	Depreciation in years	Investment cost difference in €/year	Electricity price in €/kWh
E6 – Energy-efficient street illumination	conventional HQI technology, consumption: 476 kWh/year	172	5	-34	0.180
E7 – Energy-efficient washing machine (Category: A)	inefficient washing machine; consumption: 266 kWh/year	234	12	0	
E8 – Energy-efficient freezer (Category: A)	inefficient freezer, consumption: 321 kWh/year	159	15	20	
E9 – Energy-efficient fridge (Category: A++)	inefficient fridge, consumption: 150 kWh/year	85		10	
E10 – Energy-efficient traffic signal systems	conventional traffic signal systems, installed capacity: 490 kWh	130	10	1,970	
E11 – Energy-efficient dishwasher (Category A)	inefficient dishwasher, consumption: 350 kWh/year	263	12	40	
E16 – Energy-efficient TV	conventional TV, consumption: 268 kWh/year	111	10	33	
E17 – Energy-efficient DVD player	conventional DVD player, consumption: 28,5 kWh/year	8,3		7	
Measure/Strategy	Reference scenario	Operating hours/year	Depreciation in years	Investment cost difference in €/year	Consumption in kWh
E12 – Energy-efficient heat pump including hydraulic enhancements	conventional heat pump system, consumption: 307 kWh/year	5,000	20	10	104
E13 – Energy-efficient ICT using heat recovery technology 60 kW	conventional ICT, consumption: 210.240 kWh/year	8,760		1,330	131,400
E14 – Energy-efficient ICT using heat recovery technology 7 kW	conventional ICT, consumption: 45.990 kWh/year				15,330
E15 – Energy-efficient LED-light technology**	conventional light bulb, consumption: 50 kWh/year	1,000		4	10

* Costs for a backup power plant are considered
** Focus on one unit
Note: rounded values

Table 6. Basic assumptions regarding the segment Transportation (T). Source: (Tichler *et al.*, 2010a; Tichler *et al.*, 2010b; Tichler *et al.*, 2010c)

Segment Transportation (T)					
Measure/Strategy	Reference scenario	Consumption per 100 km	Depreciation in years	Road performance in km/year	Investment cost difference in €/year
T1 – Biogas-powered bus	average new diesel-powered bus, consumption: 44.3l/100km	49.1 kg	15	100,000	2,990
T2 – Biogas-powered truck	average new diesel-powered truck, consumption: 33.5l/100km	39.2 kg	5	200,000	3,470
T3 – 3 liter passenger car	average new diesel/fuel-powered passenger car, consumption: 5.7l/100km	3.0 l	10	15,000	510
T4 – Biogas-powered passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	5.4 kg			540
T5 – Biomass-to-liquid passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	6.0 l			370
T6 – Lignocellulose-ethanol passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	8.1 l			350
T7 – Biodiesel-powered passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	6.6 l			240
T8 – Electrical-powered passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	20 kWh			1,470
T9 – E85 passenger car	average new diesel/gasoline-powered passenger car, consumption: 5.7l/100km	7.8 l			350
T10 – Carpooling (occupation of passenger car: 3 persons)	Occupation of passenger car: 1 person	6.0 l	5	Commuting distance: 2x15 km/day; commuting trips: 225/year	-4,950
T11 – Efficient gasoline car	average new inefficient gasoline car, consumption: 6.5l/100 km	6.1 l	10	15,000	-10
T12 – Energy efficient diesel truck	average new inefficient diesel-powered truck, consumption: 33.5l/100km	28.9 l	5	200,000	4,190
T13 – Rolling Road	Transport by 23 trucks (cargo: 23 t); consumption: 2,630 l diesel	7,200 kWh	no depreciation focused	760	-820
T14 – Energy-efficient diesel passenger car	average new inefficient diesel-powered passenger car, consumption: 5.2l/100 km	4.3 l	10	150,000	100
T15 – Bicycle in light rail traffic	average new diesel/fuel-powered passenger car, consumption: 5.7l/100km, road performance: 5.000 km; road performance by bicycle: 0 km	0.0 l		1,500 by bicycle, 3,500 by car	-1,950
T17 – Natural gas-powered passenger car	average new diesel/fuel-powered passenger car, consumption: 5.7l/100km, road performance: 5,000 km	5.4 kg		15,000	540
Measure/Strategy	Reference scenario	Agricultural crop land in ha		Depreciation in years	Investment cost difference in €/year
T16 – Reduced soil treatment in agriculture (diesel)	conventional soil treatment	67,000		21	only operating costs focused

Fuel prices:
Biodiesel: 0.93 €/l; Biogas 0.89 €/kg; BTL: 1.20 €/l; Diesel: 1.00 €/l; Diesel/Gasoline (50%/50%): 1.05 €/l; E85: 1.00 €/l ; Electricity: 0.18 €/kWh; Natural Gas: 0.85 €/kg
Note: rounded values