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Scenarios for a Sustainable Energy Supply Results of a Case Study for Austria

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***Abstract*—**A comprehensive discussion of feasible strategies for sustainable energy supply is urgently needed to achieve a turnaround of the current energy situation. The necessary fundamentals required for the development of a long term energy vision are lacking to a great extent due to the absence of reasonable long term scenarios that fulfill the requirements of climate protection and sustainable energy use. The contribution of the study is based on a search for sustainable energy paths in the long run for Austria. The analysis makes use of secondary data predominantly. The measures developed to avoid CO_2 emissions and other ecological risk factors vary to a great extent among all economic sectors. This is shown by the calculation of CO_2 cost of abatement curves. In this study it is demonstrated that the most effective technical measures with the lowest CO_2 abatement costs yield solutions to the current energy problems. Various scenarios are presented concerning the question how the technological and environmental options for a sustainable energy system for Austria could look like in the long run. It is shown how sustainable energy can be supplied even with today's technological knowledge and options available. The scenarios developed include an evaluation of the economic costs and ecological impacts. The results are not only applicable to Austria but demonstrate feasible and cost efficient ways towards a sustainable future.

***Keywords*—**Cost of CO_2 Abatement, Energy Economics, Energy Efficiency, Renewable Energy Technologies, Sustainable Energy and Development.

I. Introduction

ESPECIALLY in current times all Western countries are confronted with new challenges concerning the climate protection. Nowadays, the atmosphere's CO_2 concentration with 380 parts per million is the highest one in last 650,000 years and within the last 30 years the temperature of the ground level atmosphere increased by 0.6 degrees Celsius [1]. The Kyoto Protocol was signed by several states to tackle these climatic developments and to avoid a further temperature rising by decreasing the CO_2 emissions. Through the signature of the Kyoto Protocol the states are obliged to reduce the greenhouse gas emissions from 2008 to 2012 by 5.2%. The follow-up agreement from the year 2013 will be discussed and hopefully signed with new goals in Copenhagen in December 2009.

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In Austria, the greenhouse gas emissions in 2006 were 91.1 million tonnes CO_2 equivalents (see Fig. 1), which exceeds the allowed emissions of the Kyoto target of 68.8 tonnes by 19.1 million tonnes [2]. Therefore, far-reaching measures for climate protection have to be accomplished to reach the goals of the Kyoto Protocol.

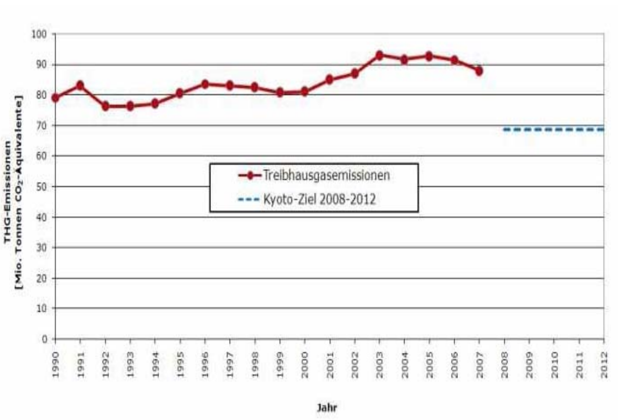

Fig. 1 Development of the greenhouse gas emissions in Austria 1990-2006 (red line) and the Kyoto Goal (green line); [2]

Generally speaking, there exist two ways of reducing emissions: on the one hand, the energy use can be reduced with the existing energy sources and on the other hand, the use of energy efficient technologies can lead to lower emissions. In an optimised setting, the two possibilities are combined and the demanded energy is produced by renewable resources.

The Austrian energy system can be characterised by several specialities: The fraction of renewable resources for electricity production is especially high due to the big share of hydro-energy with 59% of the overall production [3]. Moreover, since the Austrian citizens rejected in a referendum the construction of the first nuclear power plant in Zwentendorf in 1978, there is a strong commitment to a nuclear-power-free country. But the fact is often disregarded that people are using nuclear energy anyway, because the share of the imported nuclear electricity is about 5,8% on average [4], whereby the share of nuclear power depending on the electricity company's offer ranges from zero to 26% of nuclear power.

In Austria, there are four economic sectors which are responsible for about 86% of all greenhouse gas emissions:

the immense increase of emissions in the transport sector which has nearly doubled within fifteen years (emissions in CO_2 equivalents 1990: 12.7 million tonnes; emissions 2006: 23.3 million tonnes) and now, the share in the overall emissions increased from 16.2 to 25.5% [2]. According to the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management reducing the emissions of the transport sector is the biggest challenge to reach the goals of the Kyoto Protocol [5]. The Industry sector also faces big increases in CO_2 emissions of 14.3% in the same period, where the biggest polluters are the iron and steel production and the mineral processing industry. In this sector, 19.6 out of 25.3 million tonnes are covered from the emissions trading, for that reason the sector was not analysed in detail. In the energy producing sector, emissions increased by 12%, but are remaining the same level since 2004 due to an increase in using renewable energy sources which still possess a potential in producing electricity. The fourth big polluter is the field of heating where the biggest increase in demand was because of new buildings in the service sector. Nonetheless, the biggest challenges here are efficiency improvements in all buildings and heating systems.

As a matter of fact, facing these problems, there is a strong need to take activities to reduce greenhouse gas emissions and also to evaluate them economically. There exist various studies exploring and analyzing technical efficiency improvements and measurements for using more renewable energy sources but there is a lack of economic and ecological estimation of the impact of the new energy-efficient measures. Thus, this study aims to make a contribution to the economic evaluation of the cost of mitigation which exceeds the investigation of the costs of investment. The identified measures with their reduction potential of greenhouse gas emissions are combined with the evaluation how much it costs to abate CO_2 emissions. For this purpose, the method of marginal CO_2 cost of abatement curve is used. Moreover, the method was developed further by introducing a two step technique to avoid double-counting of abated emissions.

One of the results of reference [6] shows that CO_2 marginal abatement cost curves are an appropriate mean of detecting and evaluating different emissions reducing measures and that the cost curves are unique for every country. Nonetheless, the results are internationally comparable because they show ways for efficient energy use and its economic evaluation. By using and further developing this approach of marginal CO_2 abatement cost curves, this study analyses various scenarios of high impact to reduce emissions for the sectors households, services, transport and energy supply in Austria. The measures can be ranked by its effectiveness by the relation costs/tonne CO_2 and provide an empirical basis for decision-makers to determine which measures to implement first.

The paper proceeds as follows: Subsequent to the introduction, Section II describes the underlying method of marginal abatement cost curves and its application and further development and it gives some critical views about its weaknesses. Section III tells about the used data and Section IV presents the results and the further discussion in general and for the specific sectors more detailed. The paper ends up with the conclusions in Section V.

II. METHODS

In energy research, the static modelling of CO_2 marginal abatement curves are a common way to communicate results of studies regarding climate protection measurements and its costs [7]-[12]. One of the most important advantages of calculating Euros per tonne of abated CO_2 emissions is motivated by the convenient comparability because the curve gives the possibility to evaluate several measurements in its totality of their effectiveness.

Given the structure in Fig. 2, the CO_2 abatement costs are calculated by comparing a newly available technology demanding less energy or, in case of the energy supplying sector, replacing it by renewable energy sources, with the conventional technological solution which was used until now, also denominated as the status quo.

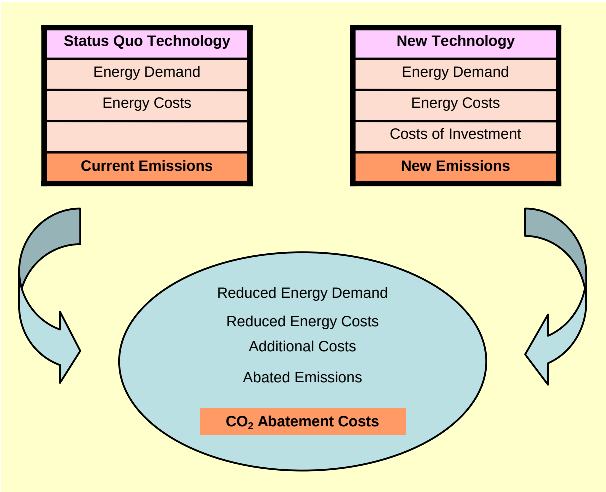

Fig. 2 Deriving the CO_2 abatement costs

A further factor for receiving the curve is the calculation of the overall additional costs which are yielded by the difference of the old and the new technology. A negative sign means a financial advantage of the new technology. This financial advantage arises in spite of the costs of investment due to the lower energy costs. If the additional positive or negative costs are divided by the CO_2 savings the CO_2 costs of abatement are derived. Therefore, a positive value of a single measure means that the life-long discounted costs of investment with the lower emissions are higher than the saved energy costs. The negative value describes a win-win situation where the new technology causes less emission and the sum of energy costs and the discounted costs of investment are less than in the case of the old technology. In this case, the introduction of the new technology leads to lower emissions and to a financial advantage. The calculation of the measures underlies the assumption that not the economically profitable potential but the technical potential is the crucial decisive point.

This study also makes a contribution to the advancement of the modelling of abatement curves in two ways: in an appropriate way of aggregating several measurements for one specific sector, for example the transport sector, the overlapping and double counting of CO_2 emission reductions could be avoided. This technique provides the advantage that the single measures can be added without providing a result which describes a saving potential that is too high through double counting. For the transport sector, it means that about sixty single measures were aggregated to two (one for cars and one for trucks) considering also a petrol to diesel shift and its implications for less emission reducing potential in case of diesel driven cars.

Another speciality was made by calculating saving potentials through a two step technique: in the household sector, single measures for single and multiple occupancies for building insulation were calculated by building period. After summing up the CO_2 saving effect because of the building insulation for the two dwelling types, the CO_2 reduction of the fuel switch of the heating system was calculated regarding the fact that an insulated building demands less energy and therefore the energy savings are lower than in the case of a non-insulated building. As a matter of fact, there have to be made assumptions how many of the single and multiple dwellings would change to which heating system. Therefore, for yielding the overall reductions in CO_2 emissions, it was necessary to calculate the emissions savings for insulation and then for changes in the heating system and to calculate the costs of abatement. The outcome after the aggregation is one result for each dwelling type.

One important advantage of cost of abatement curves is that different abatement technologies can easily be checked against the actual prices of CO_2 permit certificates. Given a certain price level for CO_2 permits policy makers can decide straightforwardly whether it is worth investing into some abatement technology or rather buy certificates in the market. In any case, the development of the market prices for CO_2 allowances has to be considered wisely because it undoubtedly implies uncertainty in the decision process. Therefore, the approach of marginal abatement cost curves is also used for determining permit prices and regional emissions [13] and for analyzing scenarios such as emission trading [14] with different countries and the use of market power in the gas market like Russia and Ukraine.

While thinking about the advantages of this information providing and therefore decision supporting methodology of calculating CO_2 abatement costs, the inherent structural weaknesses must also be considered [15]:

First of all, calculating a specific amount of money that should be invested to achieve a certain reduction potential does not consider difficulties in penetrating the ‘technology market’. It is quite obvious that such rate of innovation diffusion would play an important role on the overall effectiveness of the implemented measure (despite the fact of being very important, this problem will not be discussed in detail in this contribution).

Secondly, calculating with a (theoretical) 100% penetration rate of the new technology, it could be expected that the CO_2 emissions level decline exactly by the amount which engineers had calculated to derive the CO_2 abatement costs. Unfortunately, this is not the case. It is usually not considered that the production of certain energy efficient gadgets itself requires (a significant amount of) energy. The emissions induced by the production of the intermediate inputs (‘technologies’) also have to be considered when deciding on policy actions.

Thirdly, one methodological flaw consists of disregarding the change of the structure of the inter-industrial input relations over time. The resulting error of excluding such structural changes could be ignored in case of short to medium time horizons but would extremely gain importance when providing estimations over longer periods, e.g. 30 to 50 years.

Fourthly, if the energy prices change radically, which could be happen any time as the near past showed, the cost curve turns in case of increase to the left and makes it even cheaper to invest in a climate-friendly technology. The contrary happens with a decline in the energy prices: this development would lead to a shift to the right which makes the measurements more expensive and the financial incentive to investments weaker. This structural lack of robustness of such curves has to be considered when interpreting them [16].

III. Data

In order to make general statements about the options for the future of the Austrian energy system it was necessary to collect data at a national level. The used data are partly derived from primary data collection and expert interviews and data were also generated by literature study, research results about estimates of potential savings and specific data about building insulation [17] and costs of investment. In the household sector, it was not possible to find separated data about the emission of brown, cold and wet appliances on a national level. For that reason there could be made no comparison between the old and new technology but instead, data of the most inefficient new technology were compared with the best technology available. That explains the quite expensive measures in these cases but still the results are comparable to other research results [9]. The measures concerning the field of dwellings were conducted by calculating the saving potential by building phase and by considering single and multiple occupancies. Due to the structure of the model there was no consideration of new buildings like dwellings with passive house standard. There was also a lack of data in the service sector so that it was not possible to calculate some very cost and climate efficient measures like the use of low energy light bulbs for street lighting because until now, there exist no data about the amount of lighted street in Austria. In the energy sector, the energy saving measures were calculated by using the

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estimation about renewable energy sources available in Austria. The corresponding CO_2 saving potential results from less use of fossil energy production. The building of new big hydro power plants was not seen as an ecological alternative on the contrast to electricity from small hydro power plants. In the transport sector, there were found a lot of technical measures for less fuel demand for cars and trucks but alternatives like policy measures such as increased public transport or replacement of fossil fuels could not be regarded in this work due to its structure. Nonetheless, especially in this sector, not only technical improvements can lead to less greenhouse gas emissions.

IV. Results and Discussion

First of all, there will be made some explanations how to derive and draw marginal abatement cost curves. Fig. 3 shows such a marginal CO_2 abatement cost curve where the emission abated and the costs of mitigation for Austria are displayed. How to interpret Fig. 3 will be explained by using the box as an example: the upper border of the box (vertical distance B-C) displays the level of abatement costs per ton CO_2 (652 €/t), the horizontal length of the box stands for the potential amount of CO_2 that could be abated by this measure (distance A-B). In this case, 17.9 million tonnes could potentially be abated by implementing big scale photovoltaic electricity production.

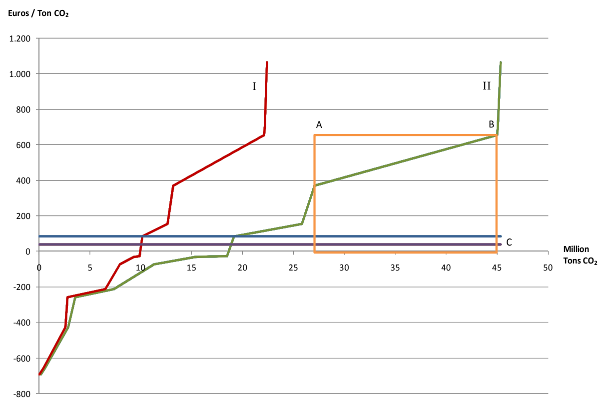

Fig. 3 Marginal CO_2 abatement cost curve in the medium (I) and the long run (II), respectively [15]

The calculated measures differ widely in their financial costs and in their magnitude of the avoided greenhouse gas emissions which is evident because of the different sectors considered and their inherent possibilities to mitigate CO_2 emissions. As a matter of fact, all measures under the zero degree line have negative costs of abatement. This means, as explained in Section II, that introducing the new technologies provide emission savings as well as monetary savings. For this reason, decision makers would be well advised to implement these measures first. The economically non rentable measures, this means, the measures above the zero degree line, could be made more attractive through governmental subsidies or through more research in technical possibilities to cheapen the costs of investment.

Curve I in Fig. 3 shows the same abatement level in a shorter period of time, namely for the year 2020. Due to a smaller discount rate the measures are even more expensive and there are fewer alternatives below the zero degree line. This would implicate that there has to be made an even stronger political enforcement to reach the same goal with less cost efficient possibilities than in the long run until 2050. Note again, that the cost of investment remain the same in the two cases! Therefore, the shift to the right of the long run curve II shows that to start now with the introduction of environment-friendly measures is even cost-efficient that economic rational agents have to advice to invest in these technologies.

The results will be described in detail for economic sectors households, services, transport and energy as follows.

A. *Household Sector*

Saving potentials were found in the field of building insulation, fuel switch in heating, efficient brown, cold and wet appliances and lighting which can be seen in detail in Fig. 4. The cumulated saving potential without overlapping emissions is 11.4 million tonnes CO_2 equivalent according to the underlying calculations. The biggest saving potential is the insulation of single dwellings followed by a fuel switch of the corresponding heating system (see measure 10 in Fig. 4) which reduces the greenhouse gas emissions by 6.6 million tonnes and the costs of abatement are calculated with 154€/t CO_2. Furthermore, an enormous reduction would provide the insulation and fuel switch of multiple dwellings with avoided emissions of 4 million tonnes CO_2 and costs of abatement of -72€/t CO_2. Due to the fact that this study is one of the first ones that calculated the emission reducing potential without overlapping emissions there do not exist any comparable data in other studies. As other studies as well it was found out that building insulation retrieved one of the highest saving potentials. Although the financial costs for single dwellings are positive (notice that there are negative for multiple occupancies) policy makers are well advised to invest in this alternative e.g. through financial incentives to make it more attractive for house-owners. In the case of Austria, there exist governmental subsidies for building insulation but experts doubt their overall effectiveness due to the small amount of money provided. If we look at the results of the single fuel switch measures there can be made the recommendation to change the heating system from electricity to biofuels (as example the calculation was made with pellets) and to replace heating oil through heating pumps. Other measures provide potentials for greenhouse gas saving but they are still an expensive option. If the price for fossil fuels increases the cost of abatement falls and makes it more attractive to invest in a more environment-friendly heating system. To stress out again that does not mean that the cost of investment are lower but the relationship between the saved emissions and the cost of abatement are more favorable. The most cost efficient alternative is the use of low energy light bulbs which could save up to 88% of energy and of the related emissions with one of the most efficient cost of abatement of -658€/t CO_2, although the avoided CO_2 emissions are calculated with 0.6 million tonnes. Nonetheless, based on these results, the prohibition of selling conventional light bulbs as it was introduced in Austria at the beginning of this year is – for obvious environmental reasons – a step into the right direction. The saving potential in the field of brown, cold and wet appliances is comparable low and sums up to 0.37 million tonnes (see measures 13 and 14 in Fig. 4) to very high costs of 702€/t CO_2 for brown appliances and 1063€/t CO_2 for cold and wet appliances. As mentioned in section three the high abatement costs are because of the lack of data for comparison reasons. Therefore, it can be assumed that the saving potential is higher because the old appliances are more energy-intensive than the most inefficient ones on the market nowadays which were used for the comparison and calculation of the cost of abatement. However, it should be a decisive criterion for all consumers to look at the energy consumption of the new appliances.

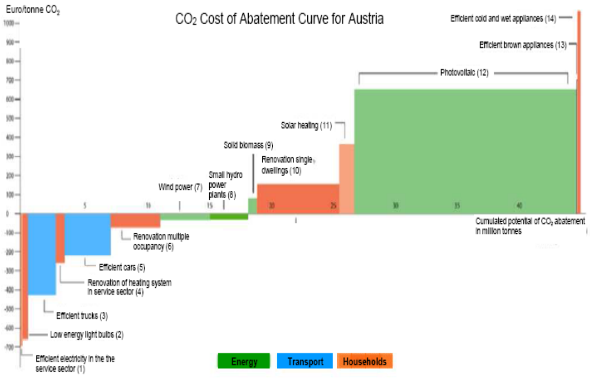

Fig. 4 CO_2 Cost of Abatement Curve for Austria

To sum it up, for the household sector an overall saving potential of 73% of all sector emissions was detected and 29% of the sector emissions can be avoided with negative costs, which are the measures of curve II below the zero degree line in Fig. 3. Through more information and political enforcement these measurement could be communicated and implemented easily because of their cost and emission reducing potential.

B. Service Sector

The most efficient measures are identified in the efficient use of management systems for electricity and the reconstruction of the heating system. The most benefit provides the introduction of efficient electricity systems with cost of abatement of -694€/t CO_2 and avoided emissions of 0.2 million tonnes (see measure 1 in Fig. 4). Through renovation of the heating system, 25% of energy use can be saved and it yields -258€/t CO_2 cost of abatement. Like other studies [18] it can be shown that measures for buildings in the service sector are amongst the most cost efficient ones. For sure, there is also an energy saving potential in the insulation of buildings but because there is no sufficient data available it was not possible to quantify the saving potential. The same holds for the field of electrical appliances in the office, lighting in buildings and streets and cooling systems [19] where no data is available for Austria. It can be assumed that the saving potential is much higher than it could be calculated and moreover, all private and public responsibilities are expected to minimize the costs of their organization by implementing the cost and energy efficient solutions.

C. Transport Sector

Only technical improvements concerning the efficiency and less fuel use were calculated for the CO_2 abatement costs. Political measures like the extension of public transport or any alternatives concerning a fuel switch of cars and trucks could not be considered in the calculations. All single measures for cars and trucks were summed up to one single measure without overlapping potentials and both show negative cost of abatement (trucks -428 and cars -216€/t CO_2; see measures 3 and 5 in Fig. 4). The emissions saved by full implementation are 10.2 million tonnes CO_2 from which we can draw the conclusion that even without any radical change of the transport system it is possible to save enormous amounts of CO_2. In addition with non technical measures, we would be able to make our motorized movements even more "greener".

D. Energy Sector

The results of the energy sector show that by using all potentials of renewable energy sources for production of electricity 25.8 million tonnes of CO_2 emissions could be avoided which is more than one quarter of the Austria's overall CO_2 emissions. Within the identified measures, photovoltaic has the biggest capacity to avoid emissions of 17.9 million tonnes CO_2 (see measure 12 in Fig. 4). Unfortunately, it is still one the most expensive alternatives with cost of abatement of 652€/t CO_2. It can be expected that this technology will get cheaper within the next years and that, thus, also the financial incentive to invest will increase. Electricity from small hybrid power plants is seen as one of Austria's future branches within this field. On the one hand, the cost of abatement with -29€/t CO_2 lead to the recommendation to invest in this technology, on the other hand small hybrid power plants provide an alternative for regional energy autarky. Further potentials are identified through wind power which also are calculated with negative costs of abatement of -31€/t CO_2 and it can avoid 4 million tonnes of CO_2.

E. Final Remarks

In 2006, the overall electricity consumption in Austria was 67.9 TWh [3] from which 38.2 TWh were produced by hybrid power plants. Through the implementation of the cost efficient small hybrid plants and wind power mills there could be produced 17.1 TWh per year in addition. This would lead to a percentage of more than 80% of the current electricity use which could be produced with renewable energy sources. Therefore, it is a contribution to a more independent and, in the long run, to a more stable energy system without the demand for fossil fuels or nuclear power plants and therefore a strong recommendation for policy makers to take their chance by investing in these technologies.

V. Conclusion

It is very common to argument that measures for climate protection are cost intensive and are no feasible alternative in times of crisis. By calculating CO_2 cost of abatement curves it can be shown which measures provide a high potential of avoiding greenhouse gas emissions and to which costs the environment friendly options can be implemented. In this study, eight measures with negative costs were identified that sum up a CO_2 emission saving potential of 18.5 million tonnes of CO_2. These results should give direction to more climate protection and should act as a basis for decision makers to take steps for a more sustainable development with more energy security by investing in these measures. In addition to the quantified options, there could be identified emission saving potentials in all sectors. For that reason, the overall greenhouse gas saving potential is even higher than calculated in this study and by doing further research on exact data it would be possible to achieve a more scientific basis for making statements about the economic and ecological impacts. Moreover, political action plans often are characterized by short term activities with a small impact on future developments. Especially in climate protection measures, it is unavoidable to make long term investments also in measures with positive cost of abatement but which though have a large impact on the cutting of CO_2 emissions. Besides, investments in more research and in more economically-friendly technology always have positive implications on other economic sectors as well, e.g. the employment market. Last but not least, this study wants to contribute to a scientific basis for decision makers, politicians as well as consumers, to more sustainable investments for the future.

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