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Policy strategies and paths to promote sustainable energy systems—The dynamic In*vert* simulation tool

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Abstract

The European Union has established a number of targets regarding energy efficiency, Renewable Energy Sources (RES) and CO_2 reductions as the 'GREEN PAPER on Energy Efficiency', the Directive for 'promotion of the use of bio-fuels or other renewable fuels for transport' or 'Directive of the European Parliament of the Council on the promotion of cogeneration based on a useful heat demand in the internal energy market'. Many of the according RES and RUE measures are not attractive for investors from an economic point of view. Therefore, governments all over the world have to spend public money to promote these technologies/measures to bring them into market. These expenditures have to be adjusted to budget concerns and should be spent most efficiently. Therefore, the spent money has to be dedicated to technologies and efficiency measures with the best yield in CO_2 reduction without wasting money.

The core question: '*How can public money—for promoting sustainable energy systems—be spent most efficiently to reduce GHG emissions?*' has well been investigated by the European project In*vert*. In course of this project, a simulation tool has been designed to answer this core question. This paper describes the modelling with the In*vert* simulation tool and shows the key features necessary for simulating the energy system. A definition of 'Promotion Scheme Efficiency' is given, which allows estimating the most cost-effective technologies and/or efficiency measures to reduce CO_2 emissions. Investigations performed with the In*vert* simulation tool deliver an optimum portfolio mix of technologies and efficiency measures for each selected region. Within In*vert*, seven European regions were simulated and for the Austrian case study, the detailed portfolio mix is shown and political conclusions are derived.

Keywords: Dynamic bottom-up modelling; Promotion schemes; RES-CHP/DSM

1. Introduction

National and international targets, commitments and guidelines are claiming an increase of renewable energy sources (RES) as well as higher efficiency in the energy usage, as a result a decrease in CO_2 emissions.

However, all relevant political players are acting in a very sensitive area and feel the tension between environmental and political concerns:

- Environmental and energy policy goals may be in opposition.
- The taxation of energy, in particular of fossil energy, is not very popular (even in those cases where it would be the most efficient tool as the simulation runs with In*vert* and other investigations indicate). Therefore, it seems necessary to use public money to promote sustainable energy systems via promotion schemes. This fact results in the third challenge.

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- The promotion of renewable energy has to be harmonized with the budget-relevant goals of a government.

These reflections lead to the main question:

How can public money—for promoting sustainable energy systems—be spent most efficiently to reduce GHG emissions?

The European project In*vert* deals exactly with this question. The Altener project In*vert* 'Investing in RES and RUE technologies: models for saving public money' was led by the Energy Economics Group and combined seven international research institutes as well as five international energy agencies.

Within this project, the dynamic bottom-up Simulation Tool In*vert* was designed by the Energy Economics Group to answer the above question and evaluate the effects of different promotion schemes on the technology mix and the achievable CO_2 reductions in the building, electricity and transport (bio-fuel) sector till 2020.

This paper describes the special features of the In*vert* Simulation Tool to answer the key question and demonstrates the political strategies and paths, which can be derived from the simulation tool by showing the Austrian case study of the project In*vert*.

2. The dynamic In*vert* simulation tool

2.1. Introduction[2]

In*vert*[3] is a dynamic bottom-up simulation tool applicable on the existing building stock (for heating, cooling, domestic hot water systems (DHW)—including solar thermal systems,—rational use of energy (RUE), as well as RES according electricity supply (RES-E) and heat production (RES-CHP) and for bio-fuel production. In*vert* allows comparative and quantitative sensitivity analyses of the interactions between promotion schemes for RUE, RES-E, RES-CHP, and bio-fuels as well as corresponding greenhouse gas (GHG) reduction for each selected region.

2.2. Description of the model

2.2.1. Decision-making process in Invert

In*vert* models the decision-making process of the investors, taking into account market restrictions (e.g. RES-E market barriers, learning curves, consumer behaviour). However, basically two different approaches—depending on the sector—are used in In*vert*.

For the building sector (including DSM, heating, cooling, DHW, solar thermal) an *option*[4] *approach* is used. Within this approach, the decision-making process of various consumers and investors is modelled by comparing different options (e.g. heating systems). In contrast to the option approach in the RES-E, RES-CHP and bio-fuel sector, a *dynamic cost curve approach* is used. These two different approaches are depicted in the following sections.

2.2.2. Decision-making process in the building part of Invert (option approach)

In the building sector for each old system (= expired lifetime), different new system options exist. The decision maker (e.g. house owner, renter) selects a new technology option on the basis of the new system costs (a function of investment, operation and maintenance costs), the savings compared to the old system, the change in comfort and the promotion scheme support (e.g. investment subsidies). Now, the difficulty is to incorporate non-monetary comfort issues in the model and generate realistic simulations of the decision process. These considerations result in a system that is using factors (= Soft Barriers) modifying the pure monetary costs and gains. Theses 'Soft Barriers' are found by a calibration process comparing the real historical observed energy consumptions and the calculated monetary costs for each building type and investor group. The 'Soft Barriers' get adjusted in a way that the historical observed energy consumption matches the calculated energy consumption.

Before the model starts to simulate the actual decision-making process, the number of old systems (= expired lifetime) is determined. In*vert* uses a replacement rate on the basis of the lifetime of the existing equipment. This means 1/lifetime of a certain equipment specifies the number of equipment which can be replaced by a new option every year.

With these found 'Soft Barriers' and replacement rate impacts of different promotion schemes, energy prices and strategies can be simulated dynamically till 2020.[5]

The calculation of the 'option costs' is shown in Fig. 1. Starting with the technology data (investment costs, lifetime, OM costs, and efficiency), the risk evaluation of the future (Individual Payback Time)[6] and the fuel costs as

[2]For the simulations carried out for this paper, In*vert* was basically used to evaluate the effects of different promotion schemes (investment subsidies, feed-in tariffs, tax exemptions, subsidy on fuel input, CO_2 taxes, soft loans, and additional aside premium) on the energy carrier mix, CO_2 reductions and costs for society due to promoting certain strategies. Furthermore, different scenarios (price scenarios, insulation scenarios, different consumer behaviours, etc.) and the respective impact on future trends of renewable as well as conventional energy sources were performed.

[3]The model can be downloaded from the project homepage www.In-vert.at.

[4]A complete overview about considered technology options can be gathered from Kranzl et al. (2004).

[5]This approach assumes that the 'Soft Barrier' factors are constant over time, and the decision makers do not learn over time. This assumption will be removed in future versions of the model.

[6]The calculation of the Capital Recovery Factor is either based on the lifetime or individual payback time. The user of the model is able to *select* between 'Individual Payback Time' and 'Lifetime' of the equipment as basis for the simulation of the investors' decision-making process within the building part of In*vert*. If the user selects the 'Individual Payback Time,' the tool considers all costs and benefits (e.g. due to solar thermal systems and 'Insulation' as well as 'Windows') for the individual 'Payback Time'. With this approach, In*vert* is able to calculate the maximum yearly

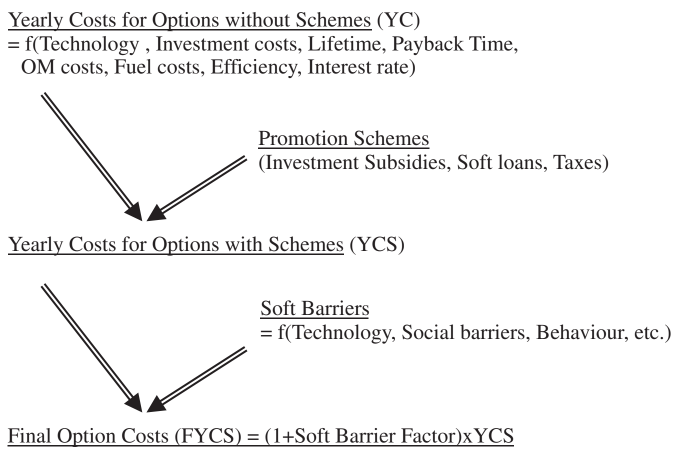

Fig. 1. Calculation of option costs in the building sector in In*vert*.

well as the average interest rate, the yearly costs for all possible replacement options get calculated.

Upon having calculated all option costs and using *no* promotion schemes as well as soft barriers, the option costs are represented by YC. The cheapest option in each consumer group (= building class in Fig. 2) will be used. This means for the example in Fig. 2 for the building class 1, option 4 and for building class 2 also, option 4 will be considered.

However, without promotion schemes, almost no RES or RUE measures may be applied because of high yearly option costs when compared to conventional energy systems and therefore it could be necessary to use promotion schemes. The yearly costs considering promotion schemes are represented by the dashed bars YCS in the example below. Because of the used promotion schemes, different options—compared to before—are the cheapest now (see Fig. 2: building class 1: option 3, and for building class 2: option 1).

However, the last step is to consider all other technical[7] and non-technical barriers[8] or incentives via the 'Soft Barriers'. As already pointed out, the decision-making process of the consumer is influenced by a variety of different technical and non-technical aspects (e.g. comfort, social barriers, education).

Other models apply the concept of varying interest rate for modelling the impact of consumer preferences. However, the methodology of applying soft barriers only partially refers to the type of consumer preference modelling in this paper. Rather, the concept applied in this paper refers to very technology-specific issues, especially of heating systems and corresponding comfort aspects. Actually, different types of heating systems cannot be regarded as homogenous goods for providing space heating. For example, single stoves in general are considered to be less comfortable than central heating systems. Furthermore, some authors use the concept of required time for the operation of heating systems. Again, this approach requires assigning a monetary value for the leisure time of people, which again raises methodological problems.

Therefore, In*vert* uses 'Soft Barriers' according to Fig. 1 to adapt the monetary yearly costs (YCS) to get the 'Final Option Costs' (FYCS) as the relevant decision criteria seen by the consumer (dotted bars in Fig. 2). The soft barriers have to be higher than -1. A soft barrier of zero means that the consumer recognizes exactly the monetary costs (YCS). A soft barrier >0 means that for this certain technology, technical or social barriers exist and therefore the investor recognizes a lower comfort or higher anticipated option costs.

Of course, the calibration of the soft barriers is one of the crucial steps within the simulation tool. This process is done by the use of historical empirical data for the actual penetration of various technologies. The results of the model are calibrated to these data. It gives the user the possibility to estimate a socio-economic interface between the investor and technology and allows simulating the Rebound Effect, which considers a rebound in energy consumption due to higher comfort levels after heating system upgrades (see also Haas and Auer, 1997).

Table 1 shows some representative soft barriers derived from the Austrian case study. The low comfort for wood and oil single systems results in positive soft barrier values of 0.4–0.2. In contrast to the wood and oil single systems, electricity single is very easy to install and handle and therefore the soft barrier factor results in zero in the Austrian case.

2.2.3. Decision-making process in the RES-E/CHP and bio-fuel part of Invert (cost resource curve approach)

For the simulation of the electricity (RES-E), grid-connected heat (RES-CHP) and bio-fuel sector, a dynamic cost resource curve approach is used. The different technologies are represented by the so-called 'bands' and sorted in a least-cost order. Each band summarizes technologies with a similar characteristic like possible application, size, efficiency, generation costs, availability, and so on.

In the RES-E, RES-CHP and bio-fuel part of In*vert* for each 'band,' the potentials and costs (short-term costs for already existing plants, and long-term marginal costs for possible future plants) for the electricity/heat as well as bio-fuel production are gathered and sorted in a least-cost order. Each 'band' is described by a certain set of parameters.

For example, wind—all wind farms/plants with the same full loud hour can be gathered and treated as one unique

(*footnote continued*)
costs seen by the consumer. Exactly these costs are the important decision-making parameters for the so-called Landlord problem. However, this approach corresponds with a risk evaluation of the future. For more information please see Stadler et al. (2004).

[7]For example, missing district heating grid, in urban regions, the problem of wood storage for wood heating systems, etc.

[8]For example, comfort, social pressure, education, beliefs, willingness to pay, etc.

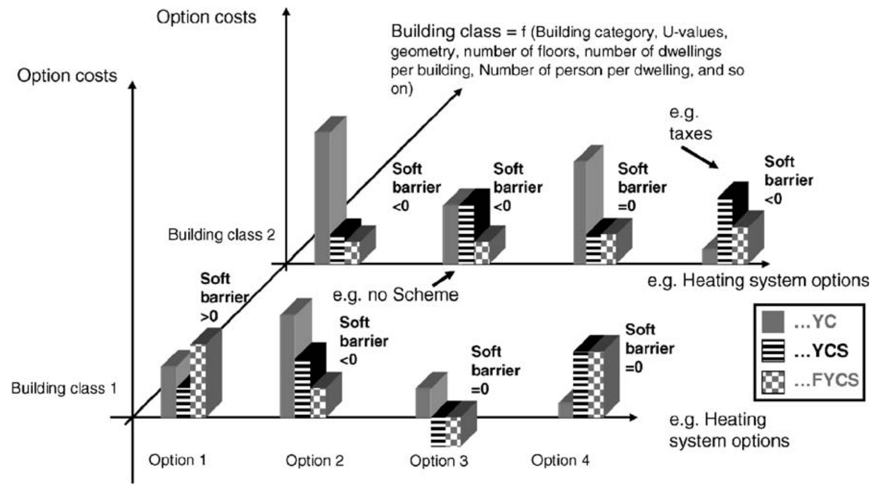

Fig. 2. Option-based approach in the building sector in In*vert*. Example: Heating options.

Table 1
Some 'Soft Barriers' for heating options derived from the Austrian case study

Building category	Soft barrier		
	Wood single	Oil single	Electricity single
Single dwelling (ch, dh)	0.3	0.2	0
Multiple dwelling (ch, dh)	0.4	0.3	0
Single dwelling (no ch, dh)	0.3	0.2	0
Multiple dwelling (ss, dh)	0.4	0.3	0
Multiple dwelling (of, dh)	0.4	0.3	0
Single dwelling (ch, no dh)	0.3	0.2	0
Multiple dwelling (ch, no dh)	0.4	0.3	0
Single dwelling (no ch, no dh)	0.3	0.2	0
Multiple dwelling (ss, no dh)	0.4	0.3	0
Multiple dwelling (of, no dh)	0.4	0.3	0

ch: combined heating system (heating plus DHW).
dh: district heating connection is in principle possible.
no dh: no available district heating connection.
of: one floor heating system; ss: single stove.

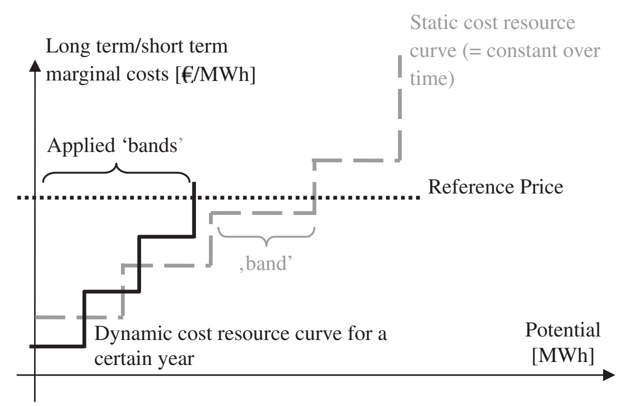

Fig. 3. Cost resource curve approach used in the RES-E, RES-CHP and bio-fuel part of In*vert*. See also www.Green-X.at and the Green-X simulation tool.

'band'. Of course, in reality, a continuous cost curve exists. However, for the modelling in In*vert*, we use stepped discrete functions as an approximation. Furthermore, up to now this would neglect the influence of time and learning effects. Therefore, the simulation tool also considers the effects of learning curves and market barriers, which lead to the concept of dynamic cost resources curves. These are applied in the simulation tool In*vert*.

The market barriers reduce the potential, and the learning curves reduce the costs of the static cost resource curve as indicated by the 'Dynamic cost resource curve for a certain year' in Fig. 3.

In contrast to the option-based approach of the building sector in the RES-E/CHP and bio-fuel part, no replacement rate is used. It is assumed that all RES-E/CHP or bio-fuel bands get installed or used when the costs (dynamic cost resource curve) for the electricity/heat or bio-fuel production are lower than the electricity or bio-fuel reference price as indicated in Fig. 3 (for further details regarding cost curves, see Resch et al. (2004) and Ragwitz et al. (2003)).

2.2.4. *Brief description of the implemented promotion schemes*

All currently[9] in In*vert*-implemented promotion schemes are shown in Tables 2 and 3.

At the electricity part, the promotion schemes are separated to RES-E and RES-CHP. In*vert* considers in this part only promotion schemes for renewables. Promotion schemes for conventional energy carriers can be considered only in the building part (heating, cooling, DHW).

The two major promotion schemes in the building sector (investment subsidy and soft loans) can be applied on each defined (by the user) building category (e.g. single family dwelling, multifamily dwelling) and defined technology for

[9]April 2005.

Table 2
Currently in In*vert* implemented promotion schemes, part one

Sector	Subsector	CO_2 tax	Investment subsidy	Soft loan	Feed in tariff
Building	Heating	√	√	√	
	DHW (including solar thermal)	√	√	√	
	Cooling	√	√	√	
	DSM		√	√	
	District heating	√	√	√	
Electricity	RES-E[a]	√	√		√
	RES-CHP[b]	√	√		√
	District heating	√	√		√
Bio-fuel	Bio-fuels	√			

[a]Renewable energy source—electricity.
[b]Renewable energy source—combined heat and power.

Table 3
Currently in In*vert* implemented promotion schemes, part two[a]

Sector	Sub sector	Tax exemption	Subsidy on fuel input	Additional aside premium
Electricity	RES-E	√	√	
	RES-CHP	√	√	
	District heating	√	√	
Bio-fuel	Bio-fuel	√		√

[a]A detailed description of policy strategies and promotion schemes in the European countries is given in Joergensen et al. (2004).

heating, cooling, DHW, solar thermal systems. Furthermore, it is possible to assign a certain Demand Side (DS) strategy for each defined building category and building part (walls, ceiling, floor, and windows).

3. Efficiency estimation of the spent public money

The basic idea for designing In*vert* is to estimate the efficiency of various promotion schemes and strategies to reduce CO_2 emissions in the different sectors as building, electricity and transport.

In this context, a 'Promotion Scheme Efficiency' (PSE) was defined to investigate the described issue[10]

$$\mathrm{PSE} = \frac{\sum_{i=1}^{n} \Delta \mathrm{CO_2\,Emissions}_i}{\sum_{i=1}^{n} \Delta \mathrm{Discounted\ Transfer\ Costs}_i}, \tag{1}$$

where ΔCO_2 Emissions$_i$ is the change in CO_2 emissions compared to the reference scenario [kton per year], ΔDiscounted Transfer Costs$_i$ is the *relevant* change in *discounted* transfer costs compared to the reference scenario [Mio € per year]. Why *Relevant* Change? Let us assume a simulation period till 2020. In case of investment subsidies and use of a new measure in 2019, the entire costs get considered, but the CO_2 reductions get only considered for two years (2019 and 2020). This circumstance results in an underestimation of the 'PSE'. Owing to this circumstance, only the relevant (2019 and 2020) discounted transfer costs are counted for the PSE and n is the number of simulation years

The PSE estimates the efficiency of a certain strategy compared to a Business As Usual (BAU) scenario by comparing the CO_2 emissions and necessary public transfer costs ($\approx$society costs for promoting a certain technology) of the BAU ($=$reference) scenario with the CO_2 emissions and necessary public transfer costs of the sensitivity scenario.

Efficient promotion schemes (second-best solution) are indicated by high decreases in CO_2 emissions and low increases of transfer costs compared to the BAU scenario. However, the most efficient schemes (best solution) are those reducing both CO_2 emissions and public transfer costs, which can be achieved by abolishing promotion schemes for conventional energy systems.

When it comes to the comparison of different promotion schemes, the PSE is only one important dimension for the evaluation of the most efficient promotion scheme to

[10]Note, in the In*vert* Simulation Tool, two different promotion scheme efficiency indicators are used. These two values (CPSE/LPSE) indicate the second-best promotion schemes by negative values. However, in this paper, we use the negative LPSE value and term it PSE. Negative CPSE/LPSE values indicate a CO_2 reduction accompanied with increased spent public money compared to the reference scenario. Therefore, the second-best promotion schemes are identified by negative CPSE/LPSE ($=+$PSE) values. Please see also Stadler et al. (2004, 2005a, b).

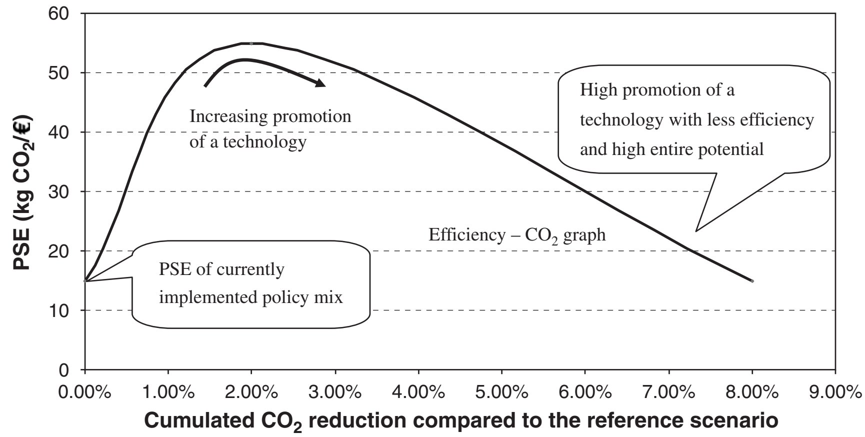

Fig. 4. Example for an Efficiency–CO_2 graph.

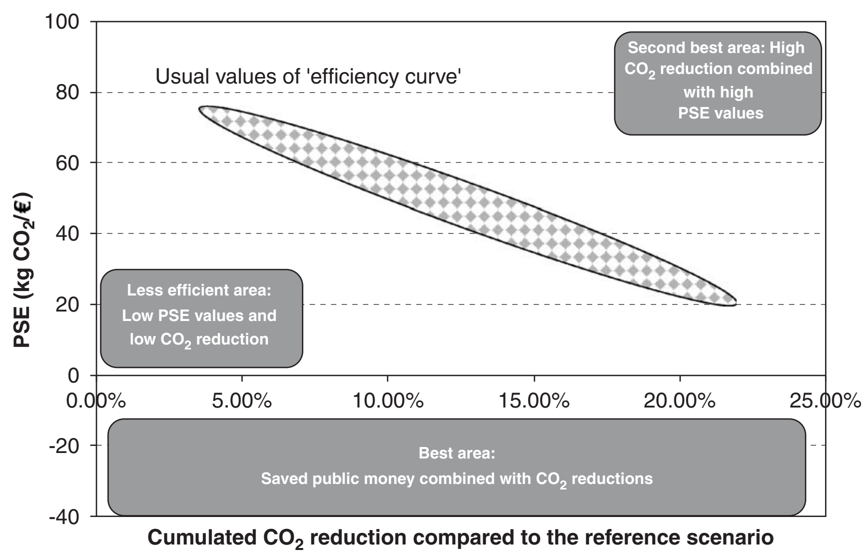

Fig. 5. Identification of best and worst area for promoting RES and RUE technologies.

reduce CO_2 emissions. The PSE indicates how efficient money is spent to reduce CO_2 emissions but does not reveal anything about the achievable entire CO_2 reduction. Therefore, it is also necessary to consider the total CO_2 reduction that can be achieved by a certain scheme. This second dimension is depicted in the Efficiency–CO_2 graphs as shown in Fig. 4.

The typical Efficiency–CO_2 graph has a decreasing PSE as shown in Fig. 4. In the figure above, only one promotion scheme (e.g. investment subsidy for district heating) is varied during fixing all other possible promotion schemes. While doing so for each possible promotion scheme, a set of different Efficiency–CO_2 curve shapes and maximums comes into being.

However, very important is that almost all efficiency curves have the same shape as illustrated in the figure above. Furthermore, the best area is indicated by reductions of CO_2 emissions and negative PSE (i.e. negative costs, e.g. by abolishing subsidies for conventional energy systems, see Fig. 5). The second-best area (area right top in Fig. 5) is indicated by a high efficiency and high CO_2 reduction potential. The usual efficiency curve shape is always between the second-best and the less efficient area, see Fig. 5.

The question of a PSE maximum in the shape depends on the already implemented level of promotion schemes and efficiency of energy usage. For example, if the existing building stock is distinguished by a high insulation quality, all new additional DS measures result in decreasing efficiency values because of the exiting high quality. Hence, countries (or regions) with a high level of building quality have to spend more money 'inefficiently' to reduce 1 kg CO_2 when compared to countries with low efficiencies in the energy chain.

A more detailed discussion is made in Section 4—Synopsis.

4. Political conclusions derived from the Austrian case study

4.1. Introduction

In course of the project In*vert*, seven different regions (case studies) were investigated:

- Vienna
- The province of Baden Würtemberg in Germany
- The small city of Jordanow in Poland
- The island of Crete
- Denmark
- Cornwall in UK and
- A solar thermal case in France

For the Austrian case study, different hypotheses for the heating of buildings (heat supply as well as RUE measures) according to the PSE as compared to a reference scenario (= BAU Scenario) were performed.

4.2. Basic data for the Vienna heating sector

The building stock in Vienna covers around 0.8 Mio dwellings. Owing to the very urban characteristic, more than 90% of them are multiple dwellings. About 42% of the dwellings have central heating systems, 34% heating systems covering one floor. Still, there is a share of 23% of all dwellings providing heating with single stoves. However, these systems have been strongly declining in the past two decades.

Gas and district heating are strongly dominating the energy mix for heating in Vienna. Around 58% of the total energy consumption for heating is provided by natural gas, more than a quarter by district heating (Fig. 6).

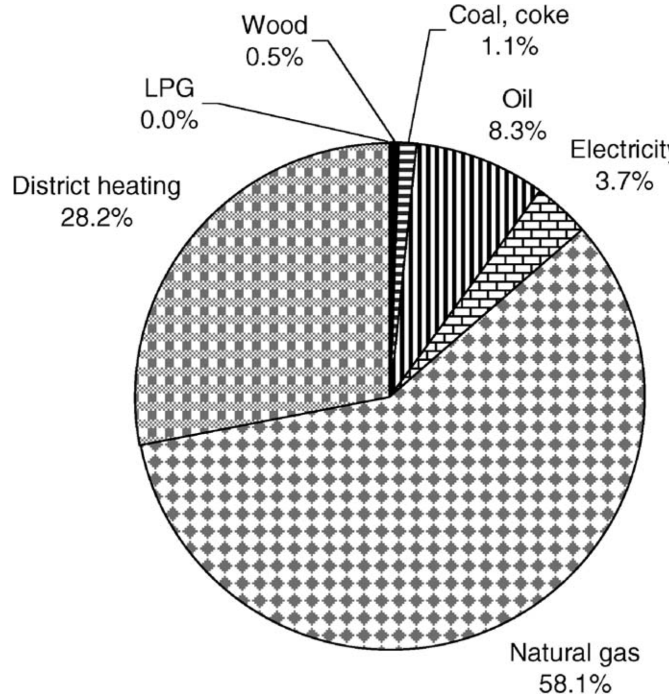

Fig. 6. Share of energy carriers on the final energy consumption for heating.

4.2.1. Promotion schemes in Vienna

A number of national energy policies have an impact on the situation in Vienna. The most important ones for the heating sector are[11] Energy taxes (e.g. for heating oil, natural gas, electricity, transport fuels).

On a regional level, the municipality of Vienna has adopted a number of energy promotion schemes targeting at the reduction of energy demand and the promotion of low-carbon technologies and renewable technologies. The most important ones are as follows:

- Thewosan: This program targets at the improvement of building quality. Depending on the level of building quality, which is achieved after refurbishment of the buildings and the amount of energy demand reduction, 30, 45, 60 or 75 €/m^2 are granted.
- Subsidy for biomass heating systems: According to the emission factors, grants are given between 20% and 30% of the eligible investment costs. Moreover, costs for maintenance of boilers during the first 2 years are granted.
- Subsidies for solar thermal systems (30% for DHW systems; 40% for combined systems space heating and DHW).
- Soft loans for window replacement (*U*-value lower than 1.9, no PVC windows).
- Support for installation of central heating systems and heating systems covering one floor.
- Subsidy for gas-condensing boilers.
- Support for low-energy buildings; requirement of energy efficiency standards for receiving general building construction subsidies.
- Subsidies for connection to district heating.
- Eco-electricity subsidy: Grants are given to PV systems up to 40% of the investment costs.

4.2.2. The Vienna reference scenario: assumptions and results

The reference scenario is defined to represent the 'BAU' development based on the existing promotion schemes. The main assumptions are the following:

- Moderate rise of fossil energy prices by approximately 1% per year (based on WIFO-baseline scenario Austria; see also Kratena and Schleicher (2001).
- moderate rise of wood price about 0.2% per year.
- Soft barriers for comfort (e.g. wood, coal single stoves), change of heat distribution system from single stove to heating system covering one floor, respectively, central

[11]The whole list of promotion schemes including RES-E and RES-CHP can be gathered from Ragwitz et al. (2005).

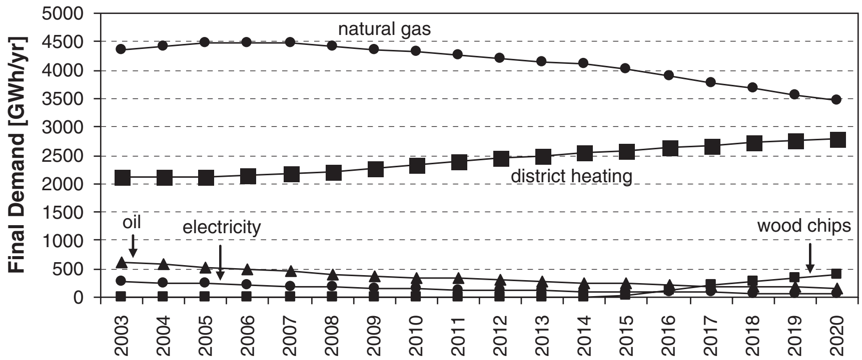

Fig. 7. Energy carriers for heating, reference scenario Vienna.

heating; additional building requirement (e.g. storage availability for wood chips); (especially, the soft barriers for central heating systems for the building categories with existing single stoves and heating systems covering one floor turned out to be essential. Moreover, biomass heating has proved to be not very popular in Vienna and hence has a higher soft barrier. This goes in line with the corresponding results of investigations about barriers for biomass heating systems in urban areas.),

- Current support schemes are kept constant until 2020 on the current level.

From these assumptions, we can gain the main simulation results characterizing the reference scenario. The development of the energy carrier mix is presented in Fig. 7.

- The figure shows a moderate growth of district heating. This is due to the promotion schemes granted for connecting to district heating and for corresponding building construction requirements. Since a large part of the energy price paid for district heating consists of a flat rate, rising energy prices (only variably in part) affect less the total costs for district heating to the consumers. A high share of the heating energy in Vienna's district heating grid comes from waste incineration and CHP. This supports the theses that the assumed moderate energy price increase of fossil fuels will affect the price of district heating less than oil and gas.
- There is moderate growth of natural gas in the beginning of the simulation period, afterwards slight decrease. In the beginning of the simulation period, natural gas in most building types is the least-cost heating option. However, owing to rising energy prices, these change in the second part of the simulation period.
- All other energy carriers decrease (especially oil, electricity, coal). This reflects the development in the past decade.
- Single stove switch mainly to systems covering one floor. This is mainly due to comfort requirements. The corresponding soft barriers were calibrated by historical empirical data and therefore this development reflects the development in the past decade.
- Wood chips get economically attractive in the last 5 years of the simulation period. This development is mainly due to the smaller energy price increase of biomass, compared to fossil fuels. Moreover, currently the municipality of Vienna has implemented promotion schemes for biomass. However, owing to high barriers and high investment costs, these have almost no impact until the year 2015.
- The share of solar thermal systems for DHW is neglectable for the whole simulation period. It turns out that the rise of energy prices (1% per year) and the current investment subsidies for solar DHW systems (30%) are not enough to provide a considerable incentive for these systems until the year 2020.

Fig. 8 shows that in the reference scenario, single stoves and heating systems covering one floor are increasingly replaced by central heating systems. Gas condensing systems increase especially in the first decade. In the second decade, their number stays stable. This is because the rising energy price is only partly compensated by subsidies for gas condensing boilers, currently granted by the municipality of Vienna.

The number of buildings refurbished is relatively low over the whole period. Building quality is increased for 5000–10,000 dwellings per year. This leads to a reduction of total useful energy by about 10% until 2020. However, owing to the change of single stoves to central heating systems, service factors increase. This is a typical case of a rebound effect, which leads to a partly compensation of energy reductions. Hence, the final energy demand only decreases by about 7%.

Reduction of CO_2 emissions due to insulation and window replacement amounts to around 190 kton CO_2 per year in 2020.

4.2.3. Comparison of various measures for further CO_2 reductions

For achieving higher CO_2 reductions *than in the reference scenario*, various different measures are possible. In the following, some of them are compared to each other:

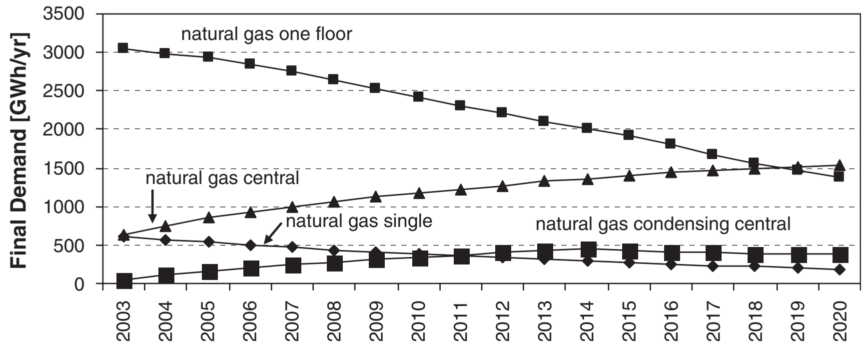

Fig. 8. Development of gas heating technologies, reference scenario Vienna.

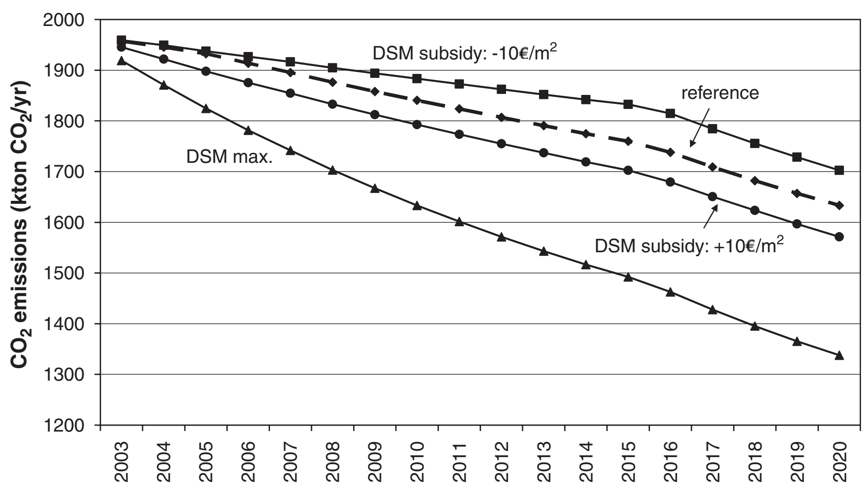

Fig. 9. Development of CO_2 emissions (heating and domestic hot water, Vienna) in various scenarios.

- *Raising subsidy for insulation and window replacement*:

The current promotion scheme for insulation and window replacement in Vienna is a subsidy where the level depends on the achieved energy savings. The subsidies are granted in Euro per living area of the concerned buildings.

Increasing this subsidy for insulation by 10 €/m^2 leads to a CO_2 reduction potential of about 900 kton (cumulated) until 2020. The amount of dwellings getting insulated doubles, compared to the reference scenario.

Fig. 9 shows the development of CO_2 emissions in various scenarios of different levels of DSM subsidy (building insulation and window replacement) compared to the reference scenario.

In a maximum DSM scenario, CO_2 emissions could be reduced by 4 Mton (cumulated 2020). For this scenario, it was assumed that all buildings getting refurbished replace their windows and insulate walls, ceiling and floor. It turns out that in the +10 €/m^2 subsidy scenario around 22% of this potential would be achieved.

The PSE of increasing DSM subsidy by 10 €/m^2 is 3.8 kg/€. Compared to other options, (see below) it turns out that the CO_2 reduction potential of this measure is quite high, and the PSE relatively low.

- *Raising subsidy for connection to district heating*:

In Vienna, there are subsidies for connecting to district heating and corresponding building construction requirements. As an option for a CO_2 reduction policy instrument, an increase of this subsidy was investigated in this paper. We could see that even in the reference scenario, with constant levels of district heating subsidy, there was a slight increase of district heating, in particular in the second part of the simulation period.

It turns out that by increasing the level of investment subsidy by 5% of the investment costs, this would lead to an additional CO_2 reduction potential of about 230 kton (cumulated until 2020). High PSE could be achieved by raising subsidy for district heating, which would result in a higher rate of connected buildings to the existing district heating grid (not assuming a stronger extension of the grid). The according PSE results in 56 kg/€.

- *Raising subsidy for biomass heating systems*:

Currently in Vienna, subsidies for small-scale biomass heating systems are implemented, but their uptake is relatively small and no strong development of biomass systems could be mentioned in the past.[12] So, an increase of biomass subsidies was investigated. It turns out that raising biomass subsidy by 5% of the investment costs would result in high a PSE of 84 kg/€. The crucial question for the actual CO_2 reduction potential that could be achieved is the question of acceptability and fuel transport. However, owing to this high level of PSE, biomass should be considered as relevant option in the outskirts of Vienna.

- *Raising subsidy for solar thermal DHW systems:*

Currently in Vienna, there are investment subsidies for solar thermal DHW systems at the amount of 30% of the investment costs. The development in the last decade shows that the impact of these subsidies is quite low and the number of installation is far below of what would be the technical potential.

Therefore, we investigated the impact of an increase to 50% investment subsidy. The result is that the total impact still is rather low at a level of 50% subsidy: In the maximum, about 1900 dwellings per year are supplied by solar thermal systems. Total transfer costs are less than 300,000 Euro per year, and CO_2 reduction is in the maximum about 500 tonCO_2 per year. This results in a PSE of about 5.6 kg CO_2/€ in the year 2020.

However, the technical potential for CO_2 reduction by solar thermal collectors is much higher, until 2020, over 100 kton CO_2 per year could be reduced. For achieving this potential, quite high level of subsidies (more than 75%) would be necessary to ensure economic attractiveness.

However, this is true for the assumed moderate price increase for fossil fuels of 1% per year. The sensitivity analyses carried out with respect to the energy price increase show that without any increase of the subsidy, a fossil price increase of 4% per year would lead to a strong boost of solar thermal systems beginning in the year 2015.

- *Extending subsidy for gas condensing boilers*:

The subsidy for gas condensing boilers existing currently in Vienna is restricted to those areas with no availability of district heating. Thus, it is not possible to obtain grants for gas condensing systems if you could connect to district heating. This refers to the strong commitment of Vienna's energy policy promoting the use of district heating.

Thus, we investigated whether there could be a positive impact of extending the subsidy to the whole area of Vienna.

This measure leads to a higher penetration of gas condensing boilers. The boilers provided 510 GWh of heat in 2020, compared to 410 GWh in the reference scenario.

However, the impact on CO_2 emissions is dubious. In the first years (until 2007), gas condensing boilers primarily replace conventional gas systems (compared with the reference scenario). This leads to a reduction of about 2 ktons CO_2 per year in 2007. In the following years (2007–2011), gas condensing boilers primarily replace district heating (compared to the reference scenario). Since the district heating in Vienna stems primarily from waste incineration and gas CHP, the related specific CO_2 emission factor is lower than from gas condensing systems. This leads to an increase of annual CO_2 emissions of nearly 4 ktons per year in 2011. The impact in the last period (2011–2020) is quite low, which is similar to the reference scenario: natural gas systems are getting less attractive.

[12]Due to high soft barriers resulting from comfort issues.

4.2.4. Synopsis

In Vienna, with the currently implemented promotion scheme mix (= reference scenario), 3.1 Mton-$CO_{2\text{cumulated}}$ as compared to a scenario without any promotion schemes can be reduced till 2020. This reduction is basically based on the fact that inefficient heating systems switch to gas and district heating systems. Furthermore, the current Thewosan program turns out to be quite effective and contributes also to this reduction in CO_2 emissions.

However, if we want to reduce the CO_2 emissions further, we have to increase the existing promotion schemes or have to use a different mix of schemes than in the reference scenario. In other words '*Which promotion scheme mix will be the best to reduce x%CO_2 emissions additionally, compared to the current reference scenario?*' This question will be answered by the Efficiency–CO_2 graph as shown in Fig. 10.

The point left in the *y*-axis indicates the currently implemented promotion scheme mix (= reference scenario) in Vienna. Starting at this point, the subsidy values for a certain set of strategies are changed, resulting in different PSE values. The first simulation point of an Efficiency–CO_2 graph always indicates no additional DSM subsidy and shows therefore the PSE for additional district heating and/or biomass subsidy only.

However, for the additional reduction of CO_2 emissions in the building sector till 2020, different options (increased district heating subsidy, increased DSM subsidy, and increased biomass subsidy) are available. The most efficient measures are the promotion of biomass and district heating, which constitute the envelope (highest PSE) in Fig. 10.

As a result of the quite ambitious Thewosan program, additional DSM measures are not very efficient. However, DSM measures are indicated by the highest CO_2 reduction potential and owing to this fact, DS measures have to be considered in Vienna to reach higher additional CO_2 reduction goals.

So, from Fig. 10, we can learn that the optimum promotion scheme mix depends strongly on the desired additional CO_2 reduction goal. A low additional CO_2 reduction ($<5\%$) can be efficiently achieved with higher biomass as well as district heating subsidies. If additional CO_2 reductions above 5% are favoured, it is absolutely necessary to consider higher DSM promotion schemes for the buildings that are indicated by low PSE values.

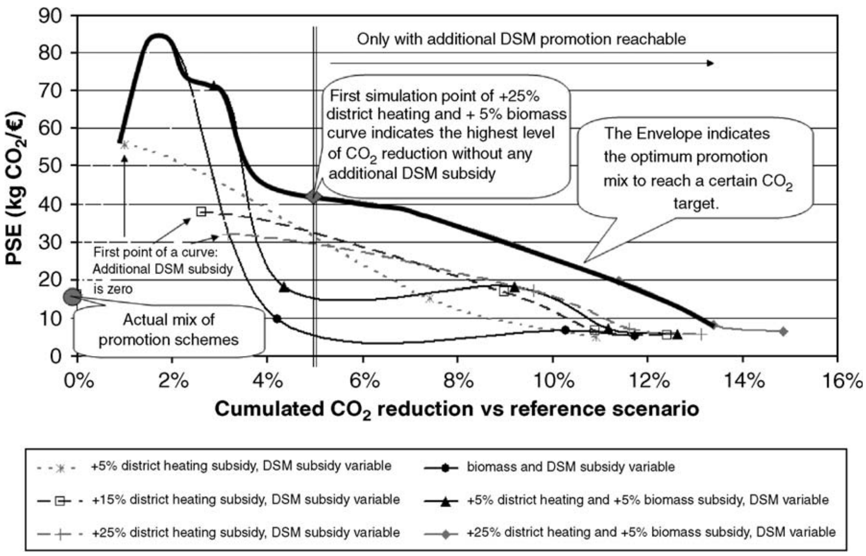

Fig. 10. Promotion scheme efficiency and the respective CO_2 reduction potential in the heating sector for different promotion schemes in Vienna.

5. Policy lessons learned

The investigations of the simulations performed show that CO_2 taxes[13] would represent a very effective instrument. Owing to the direct internalization of external costs, inefficiencies with respect to subsidy schemes can be reduced. Of course, the concept of PSE in terms of saved CO_2 emissions per public expenses (PSE) as has been applied in this paper is not applicable here. The impacts on the economy rather have to be investigated by macroeconomic models. As far as CO_2 taxes realized in a manner neutral to the total public budget, their realization is more a matter of political volition and power. In fact, energy taxations in political reality are not always easy to realize.

As long as CO_2 taxes or other forms of energy carrier taxes are not implemented in a level high enough fostering RES and RUE technologies, other incentives have to be set if the ambitious targets shall be achieved. The analyses within In*vert* as well as other projects have not shown any clear priority for a certain type of instrument like soft loans, subsidies or feed-in-tariffs. Rather, it is a matter of the right design of each instrument.

One of the core lesson learned is that for a comprehensive analysis and optimization of policy instruments, two aspects have to be considered: efficiency and effectiveness. The efficiency of a promotion scheme indicates how much of a target (e.g. CO_2 reduction) can be achieved by using a certain amount of public money in terms of kg CO_2/€. The effectiveness measures how much this instrument can contribute to reaching a certain target in absolute terms (e.g. kg CO_2 reduction). Both aspects have to be considered at the same time. Considerations of only one aspect may result to fallacy.

[13]Or taxes on the consumption of various energy carriers.

6. Conclusions

Optimizations neglecting social constraints as education or preferences (e.g. comfort issues) result in the problem that the calculated optimum is not easy to achieve. An optimization algorithm is capable to identify the best optimum, but does not easily reveal how to reach this optimum. Which political decisions are necessary to reach such an optimum? Is it possible to gain another optimum changing the social constraints? What are the effects of changing the social constraints by introducing information campaigns? All these questions can be answered by a simulation tool that simulates a certain selected strategy and its impact on future technology deployment as well as energy consumption and CO_2 emissions.

In*vert* is not capable to identify the best optimum solution, but it allows finding a way to introduce a certain strategy (e.g. CO_2 reduction goal) and to understand where the problems are.

The simulation runs in the seven different European regions have shown that the efficiency—and the corresponding CO_2 reduction—of the spent public money strongly depend on the already achieved efficiency potential in the region. In particular, the PSE for DS measures is very low in Austria due to the already high building efficiency, compared to other countries.

For Vienna, the most efficient promotion schemes are biomass and district-heating-related schemes. However, these schemes do not result in the highest CO_2 reduction potential (potentials are restricted) and therefore for more ambitious goals, the consideration of DSM measures is compulsory.

One of the most important conclusion derived from the simulation runs is that the optimum promotion mix depends on the desired CO_2 reduction and is not fixed for the entire possible range of CO_2 reductions. The policy makers have to know the exact CO_2 reduction goal and have to fix them to also constitute the best promotion scheme mix. Low reductions in the CO_2 emissions ($<5\%$, for Vienna) can be easily and efficiently achieved by increasing the biomass and/or district heating subsidy, without any change in the DSM subsidy. More ambitious goals ($>5\%$, for Vienna) have also been considered to increase DS subsidies, which will boost the spent public money due to the already high building efficiency.

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[14]For more information please take a look at www.Invert.at.