Contents

ANNEX 1:

EU-objectives

on climate change and renewable energy

for 2020 in Belgium[1]

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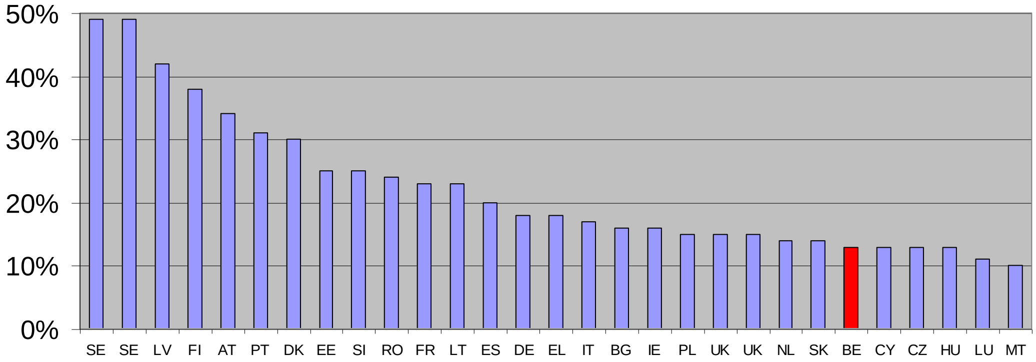
[1] This research has been funded by the Belgian Science Policy, (SSD III) project 'TUMATIM, Treating Uncertainty and risk in energy systems with TIMES'. It has also benefited from the development of TIMES and the associated software VEDA within the EU research project 'NEEDS' (NEEDS 2008)

INTRODUCTION

In this paper we analyze the impact for Belgium of the EU-objectives for climate change and renewable energy for 2020. In January 2008, the European Commission published its impact assessment on the EU-objectives for climate change and renewable energy for 2020. The European Commission decided, in its "Climate action and renewable energy package" (EC, 2008), to reduce the EU GHG emissions by 20% by 2020 in comparison to 1990, to have a 10% share of biofuels in transport and a 20% share for renewables in 2020.

For climate change, a distinction is made between the ETS sectors with the emission trading system at EU level and the non-ETS sectors with targets at country level. The EC has decided on an EU target for the ETS with auctioning of the permits and a burden sharing between countries for the non-ETS sectors to reach the overall 20% reduction target. The renewable target is also allocated between countries. The specific targets for Belgium are a reduction of 15% CO_2eq in 2020 compared to 2005 for the non-ETS sectors and a renewable target share of 13% in 2020 (figure 1). In addition, there is a target for renewable energy in the transport sector of 10%[2].

Figure 1: Renewable target for EU countries in 2020



This paper analyzes the renewable energy target for Belgium and its interactions with the climate policy targets. The issue is studied with the Belgian TIMES model.

In the first section of this paper, the model is explained, in the second section, the different scenarios developed for this analysis are described. In a third section the results are analysed and the final section concludes.

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[2] In this analysis simplified to a biofuel target

MODEL AND METHODOLOGY

TIMES is a techno-economic optimisation model which assembles, in a simple market context, technological information (conversion efficiency, investment and variable costs, emissions, etc.) for the entire energy system. The model is developed within an IEA Implementing agreement, ETSAP, in which Belgium participates (Loulou R. et al, 2005). The Belgian version of the model was developed by CES-KULeuven and VITO with the financing of the Belgian Science Policy Office (Van Regemorter D. and Nijs W., 2007 and 2008)

The model maximises the sum of consumer and producer surplus inside the energy system using linear programming. It can simulate the energy demand and supply activities with technological detail for a country and also provides information on associated emissions and environmental damage. The model uses a horizon of up to 40/80 years. In the Belgian version, the time horizon is 2050. The demand functions for energy services are a function of the activity levels per sector and the cost of energy services. The energy services (passenger car km or steel) are produced in the most cost effective way, combining demand side technologies (more energy efficient light bulbs, more efficient car engines etc.) and supply side technologies (better power stations or refineries). In this way one is able to simulate the potential role of new technologies in the energy supply and demand in a sector.

The model is dynamic and forward looking in the sense that all choices (use of energy services as well as types of technologies) take into account the costs and benefits over the whole lifecycle. The discounted welfare includes the benefits to all users and producers of energy as well as all variable and investment costs of delivering energy.

GENERAL ASSUMPTIONS AND REFERENCE SCENARIO

Background Assumptions

The starting point is the construction of the reference scenario. It is important to stress the role of this scenario for policy analysis with the TIMES model. The reference scenario has not as objective to forecast the development of the energy system. It gives a consistent development path for the energy system, using a cost optimisation approach and the simplified representation of the energy users and suppliers behaviour in TIMES. The reference scenario serves as basis to evaluate the cost of policies and their impact on the technological choices in the energy system. The reference scenario can therefore deviate from the evolution of the energy system in recent years which reflects the real behaviour of the economic agents, their expectations and the dynamic adjustment of the energy system. The main advantage of our approach is therefore a consistent treatment of the technologies for policy evaluation.

The construction of the reference scenario is based on assumptions regarding the macroeconomic evolution for Belgium and the World energy prices evolution till 2050 complemented with energy policy assumptions.

Macroeconomic assumptions

The macroeconomic background for Belgium was derived with GEM-E3, a general equilibrium model for the EU countries. It gives the economic growth rates used for deriving the energy service demands in the reference scenario. The demand functions are obtained by applying assumptions on the elasticity of the sectoral demand with respect to the macroeconomic evolution. The international energy prices are those derived in July 2007 with the POLES World energy model by IPTS (Russ et al, 2007), a research centre of the European Commission, updated with the assumptions in the PRIMES model for the EU impact assessment.

Table 1: Macroeconomic Assumptions for Belgium and international energy prices

	Unit	2010[3]	2015	2020	2025	2030	2035	2040	2045	2050
Population	%/y	0.2%	0.2%	0.2%	0.2%	0.2%	0.1%	0.0%	-0.1%	-0.1%
GDP	%/y	2.2%	2.4%	2.2%	1.8%	1.7%	1.6%	1.5%	1.3%	1.2%
Import price crude oil	€/GJ[4]	7.8	8.6	9.1	9.6	10.5	11.3	11.7	12.7	13.6
Import price natural gas	€/GJ	4.1	4.9	6.1	7.5	7.6	8.2	9.1	9.6	10.9
Import price coal	€/GJ	2.0	2.1	2.3	2.5	2.6	2.8	3.0	3.2	3.4

Renewables potentials

Potentials for renewable resources are an important element in the evaluation of the EU targets. The production potential of the different renewables used in the model are those proposed by J. De Ruyck for the 'Commissie Energie 2030' (De Ruyck J., 2006). For biomass, it is assumed that 10% of the arable land in Belgium can be used for the production of biocrops, such as wheat or rapeseed and 30% of the forest for the production of wood. Both types of biomass can also be imported. A limit is imposed on their imports though Belgium as a small country could benefit from an unlimited supply. Moreover, the supply is assumed to be available at an increasing cost by considering two price steps to reflect the pressure of demand when a climate policy would be applied in the whole EU.

For wind energy a distinction is made between on and off shore. The cost of the grid expansion needed for the implementation of the full potential of offshore is included in the cost of the power plants[5]. The data related to the wind technologies and the potentials were also checked with (Devriendt N. et al., 2005).

The table hereafter summarizes the potentials assumed for the different sources.

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[3] The years actually refer to a period in which all model years are equal, in this case: 2008-2012

[4] All costs and prices in this paper are in €2010

[5] As TIMES is not running in mixed integer mode, binary investment options are not possible. The cost is therefore included as a cost per Kwe installed; therefore the cost computation is only correct if the full potential is installed.

Table 2: Potential for energy sources

		Domestic	Import
Biomass (PJ)	Woodresidue	10.8	
	Wood	22.7	25-83
	Biocrops (wheat & rapeseed)	16.5	25-83 for each crop
Wind (GW)	Onshore cat1	0.63	
	Onshore cat2	0.92	
	Onshore cat3	0.47	
	Offshore cat1	0.60	
	Offshore cat2	0.30	
	Offshore cat3	2.90	
Solar (GW, GWth)	PV	10	
	Hot water	3	

Carbon capture and storage could be an important option when a high reduction target is imposed. Geological disposal in deep aquifers and coal sinks is modelled for the storage of the removed CO_2. A maximum cumulative potential of 100 Mt of CO_2 at a distance less than 20km and of 1000 Mt at higher cost is considered. This potential is present in Belgium (Laenen B. et al., 2004). The 100 Mt can be captured with high certainty in Belgium; 1000 Mt is uncertain (although, if not in Belgium, this could represent foreign sinks).

General policy assumptions

In the reference scenario, there are no major changes expected in the Belgian economic, energy and environmental policies. The nuclear phase-out is implemented. The EU emission trading system (ETS) is assumed to be in place and to impose a price of 24 €/ton CO_2 after 2015. It has been assumed for this modelling exercise that the sectors covered by the ETS would include all the industrial sectors and the electricity sector as this seems to reflect the actual tendency of enlarging the sectoral participation[6]. This leaves for the non-ETS sectors the residential, service and transport sectors.

In all scenarios, the discount rate is fixed to 4%, reflecting the public sector approach in the policy evaluation with TIMES. Policy measures like subsidies for energy efficient investment or similar measures implemented in the different regions are not explicitly accounted for. We do this to guarantee a consistent comparison of the technologies. It must be mentioned that in the reference scenario, the perfect foresight/optimisation approach in TIMES can already induce the use of some of the policy-promoted options even in the absence of any carbon constraint, as long as they are cost-efficient (the 'no-regret' options). Moreover, the assumption regarding the carbon value for the ETS in the reference induces also a shift towards less carbon intensive technologies.

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[6] The model does not allow to make a distinction between small and large installations in the non energy intensive sectors.

The Reference Scenario

Given the demand functions for energy services, TIMES optimizes the choice of energy processes, the energy efficiency, the choice of fuel by the energy users as well as the choice of energy production processes by the energy sector. The choice is based on the information on the present and future availability of energy technologies, their costs and performance at the level of the energy user and at the level of the energy producer. It is clear therefore that the energy path as derived from this optimisation process, takes into account all the no-regret options and may therefore slightly underestimate the real growth of the energy demand. Other criteria besides cost minimisation driving consumer behaviour are not reflected in this reference.

The primary energy consumption grows on average at 0.5%. There is a shift to solids when coal power plants replace the nuclear power plants. Oil products keep a relatively high share of the energy market because they remain the dominant fuel in the transport sector. Renewable energy , with a market share of 0.8%, does not really penetrate and is actually lower than today's share of renewable energy because the model is calibrated to the 2000 data. In Flanders, the share of renewable energy was about 2.9% in 2009 of which 1.0% green electricity, 1.3% green heat (mainly wood stoves) and 0.6% biofuels (Aernouts K., 2010).

Table 3: Primary Energy Consumption in the reference scenario
(abs. in PJ and % share)

	2010	2020	2030	2040
Coal	377	683	1013	1133
Oil	1123	1145	1264	1381
Natural gas	645	583	569	523
Nuclear	505	350	0	0
Hydro, wind, photovoltaic	8	14	14	14
Other renewables	12	12	12	12
Waste	16	20	21	23
Total	2685	2808	2893	3085
Coal	14.0%	24.3%	35.0%	36.7%
Oil	41.8%	40.8%	43.7%	44.8%
Natural gas	24.0%	20.8%	19.7%	16.9%
Nuclear	18.8%	12.5%	0.0%	0.0%
Hydro, wind, photovoltaic	0.3%	0.5%	0.5%	0.4%
Other renewables	0.4%	0.4%	0.4%	0.4%
Waste	0.6%	0.7%	0.7%	0.7%

The evolution in the primary energy consumption implies that the CO_2 emissions linked to energy increase. In 2020, they are 26% above the level of 2005 and continue to increase thereafter, especially after 2025 when coal power plants should replace the nuclear power plants. Industry and transport remain the biggest emitters in the first period but the electricity sector becomes an important polluter when new coal power plants are installed.

Table 4: CO_2 emissions in the reference scenario (Mio.ton and %)

	2010	2020	2030	2040	share 2010	share 2020	share 2030	share 2040
Industry[7]	48	59	64	70	40%	39%	35%	35%
Hous, Com & Agr	27	23	22	19	22%	16%	12%	9%
Transport	25	26	28	31	20%	17%	15%	15%
Electricity	17	37	67	76	14%	25%	36%	38%
Other supply	5	5	5	5	4%	3%	3%	2%
Total emissions	122	149	186	200	100%	100%	100%	100%

CONSTRUCTION OF THE SCENARIOS

To evaluate the effect of the EU targets for Belgium, we consider 4 scenario's, including the reference scenario. The Belgian Kyoto target and the nuclear phase-out are imposed in all scenarios. It is assumed that 7% of the reduction target in 2010 is achieved by buying permits abroad. Only CO_2 emissions are considered as the other GHG are not yet modelled and the energy system is only responsible for a small part of the other GHG. Some variants have also been considered for the analysis, but they are only mentioned further in the text for reasons of clarity. **Table 5** reproduces the definitions and the specific assumptions for the different scenario's.

Table 5: Scenario definitions and assumptions

Scenario	**Definition**
REF	Reference scenario with a CO_2 price for ETS-sectors of 24 €/t after 2020
REN	Same as REF + 10% biofuel target + 13% Renewable target
CLIM	A CO_2 price for ETS sectors of 39 €/t in 2020 and a CO_2 emission constraint for non-ETS sectors
CLIM_REN	Same as CLIM + 10% biofuel target + 13% Renewable target

Scenario	**Assumptions**	**Years**		
		2010	2020	2050
REF and REN	CO_2 price for ETS sectors (€/ton)	20	24.2*	24.2*
CLIM and CLIM_REN	CO_2 price for ETS sectors (€/ton)	20	39.1*	208
	CO_2 constraint non-ETS sectors (ref = 2005)	-8%	-15%	-39%**
REN and CLIM_REN	Biofuels target		10%	10%
	Renewable energy target		13%	15%

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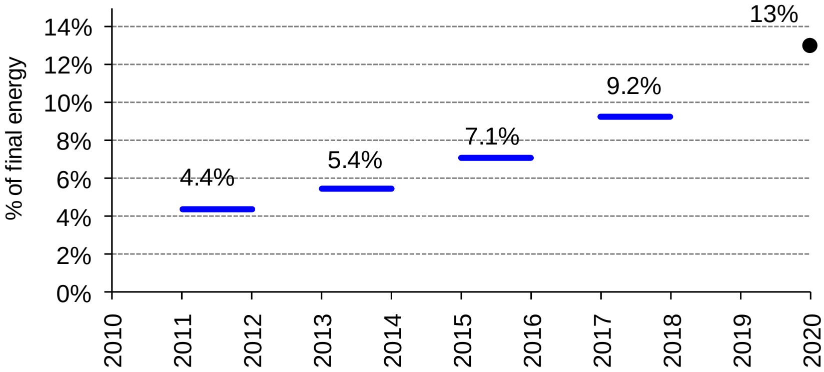
[7] Includes emissions from cogeneration plants

* These values come from the Impact Assessment report of the European Commission on the Climate and Renewable Action Plan (EU, 2008); **Corresponds to 8 Mton extra reduction in the non-ETS sectors in 2050, compared to 2020

"REN" refers to the biofuel and renewable target imposed. Figure 2 gives the renewable target for Belgium from the EU and the minimum trajectory. In the model, targets were explicitly modelled only for 2015 and 2020. The formula for the computation of the renewable target % in the model is:

- As numerator: electricity and heat (from CHP) produced by renewable technologies + renewable energy (not electricity or heat) in the final demand sectors
- As denominator: total electricity and heat (from CHP) produced and total final demand (not electricity and heat)

Figure 2: Renewable target for Belgium and minimum trajectory



For technologies such as heat pumps, the implicit energy from air or ground was not taken into account although this energy is considered as green energy in the renewables Directive. However, the advantage of reducing the final energy by increasing the share of heat pumps, is incorporated in the model.

The scenario "CLIM_REN" is close to current EU climate policy. In this scenario, the targets for the non-ETS sectors have been implemented. The model assumes an EU-wide CO_2 price for the ETS sectors in line with the EC impact assessment (EC, 2008) in which a European model was used.

As TIMES is a perfect foresight model, it is important to take into account the future beyond 2020. It was assumed that the effort for GHG reduction would continue, given the EU objective of limiting the temperature increase to no more than 2° Celsius. A carbon value gradually increasing to 208 €/ton CO_2 in 2050 was imposed on the ETS sectors and a reduction target of

37% for the non-ETS[8] compared to 2005. For the renewable target, a share of 15% was imposed after 2020 while the biofuel target remains at 10%. The importance of these two specific targets decreases with the stringency of the climate target, as will be seen in the results.

RESULTS

The energy system welfare cost

The total welfare cost of the alternative scenarios is shown in table 6 and 7. The cost is the additional cost of alternative scenarios in comparison with the reference scenario. As the level of demand for energy services can change, the welfare cost equals the change in the sum of consumer and producer surplus. It does not take into account possible side benefits through the reduction of other external costs linked to energy use. Neither does it include the derived effects on other markets which depend on the policy instrument used[9].

The result in the first column of table 6 is the relative change of the total discounted energy system cost in TIMES over the entire modelling period until 2050. The result in the second column shows this cost as a ratio to the estimated GDP for Belgium in 2010 (Eurostat).

Table 6: Total discounted welfare cost (loss of consumer/producer surplus), compared to REF

	%DIF	%GDP2010
REN	1.4%	5.5%
CLIM	4.2%	16.2%
CLIM_REN	4.5%	17.5%

Another way of representing the additional cost is to annualise it with a discount rate of 4% and then relate it to the estimated GDP of 2010, as shown in the next table. This is a yearly equivalent annual cost. The additional cost varies from year to year as shown in the last columns.

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[8] The target for non-ETS and the ETS carbon value were fixed such as to achieve a certain convergence between the non-ETS and ETS carbon value by the end of the horizon.

[9] Changes in the tax revenue and the costs specifically associated to the change in market distortions in other sectors - Cf. double dividend literature.

Table 7: Total annualised (averaged) welfare cost and undiscounted welfare cost

			Undiscounted cost [M€/an]		
	Annualised [M€]	Annualised %GDP2010	2020	2030	2040
REN	853	0.25%	1702	1736	2008
CLIM	2518	0.73%	1898	5860	8610
CLIM_REN	2719	0.78%	2770	6171	8803

It can be seen from the results that the CO_2 reduction scenarios CLIM and CLIM_REN are close in terms of cost. Imposing a renewable target on top of the climate target increases the total system cost but the additional cost is limited. The cost increase is not more than 0.05 % of GDP2010 in annualised terms (see table 7). This additional cost corresponds, on average, to an increase of the energy system cost by some 8%. In terms of the annual system cost in 2020, the cost increase is much higher. The additional cost in 2020 increases from about 1.9 B€ to 2.8 B€, an increase of nearly 50%. However, it still represents only 4% compared to the reference in 2020. After 2020 the annual additional costs remain small.

This is also reflected in the renewable shadow price in table 8. For 2020, the marginal cost of the renewable target is in "CLIM_REN" almost equal to the marginal cost in the scenario "REN" where there is no climate constraint. The renewable target of 13% is clearly dominating the climate target here. The CO_2 price for the non ETS sectors (the shadow price of the CO_2 constraint) is even zero in 2020. The reason is that the renewable target is forcing the CO_2 emissions below the target for the non-ETS sectors. If there is no renewable target, the shadow price of the non-ETS target has a price of 22 €/t CO_2. Apparently, there are some cheap options in the non-ETS sectors for the renewable target, mainly reducing the final energy demand in the commercial sector. The CO_2 price for the ETS does not change as it was assumed fixed.

After 2030, the renewable shadow price is very low. The reason is that renewable energy is, in the longer term, a cost efficient option when climate policy is the only objective.

Table 8: Shadow price of the targets and CO2 price imposed in the ETS

	2010	2020	2030	2040
Shadow price of renewable target (€/MWh)				
REN	0	55	46	63
CLIM_REN	0	56	0	2
Shadow price of CO_2 constraint non-ETS (€/t CO_2)				
CLIM	29	22	117	150
CLIM_REN	30	0	92	159
Shadow price of biofuel target (€/MWh)				
REN, CLIM, CLIM_REN	0	0	0	0
Price of CO_2 ETS (€/t CO_2)				
REN	20	24	24	24
CLIM	20	39	103	155
CLIM_REN	20	39	103	155

The shadow price of the biofuel target is zero: the share of biofuels reaches 12.7%, so above the 10% target. A scenario with only the 13% renewable target and without biofuel target gives the same results. Increasing the share of biofuels is a good option for reducing the CO_2 emissions (shadow price zero in CLIM) and for increasing the renewables share when more stringent renewable targets are imposed. A variant of the CLIM_REN scenario was created with only the biofuel target, thus without the overall renewable energy target. In this variant, the biofuel target is binding and the shadow price of the constraint amounts to 36 €/MWh in 2020.

A second variant of the CLIM_REN scenario has been constructed to test the assumption of distinguishing ETS and non-ETS sectors. Imposing an overall CO_2 price instead of distinguishing ETS and non-ETS sectors does not influence much the cost. This is an indication that the target of 15% reduction for the non-ETS sectors is close to an overall cost efficient solution. The renewable value decreases from 56€/MWh to 31€/MWh in 2020, because in this variant, the CO_2 emissions of the non-ETS sectors have a price in 2020. The differences disappear rapidly after 2025.

CO_2 emissions and energy consumption

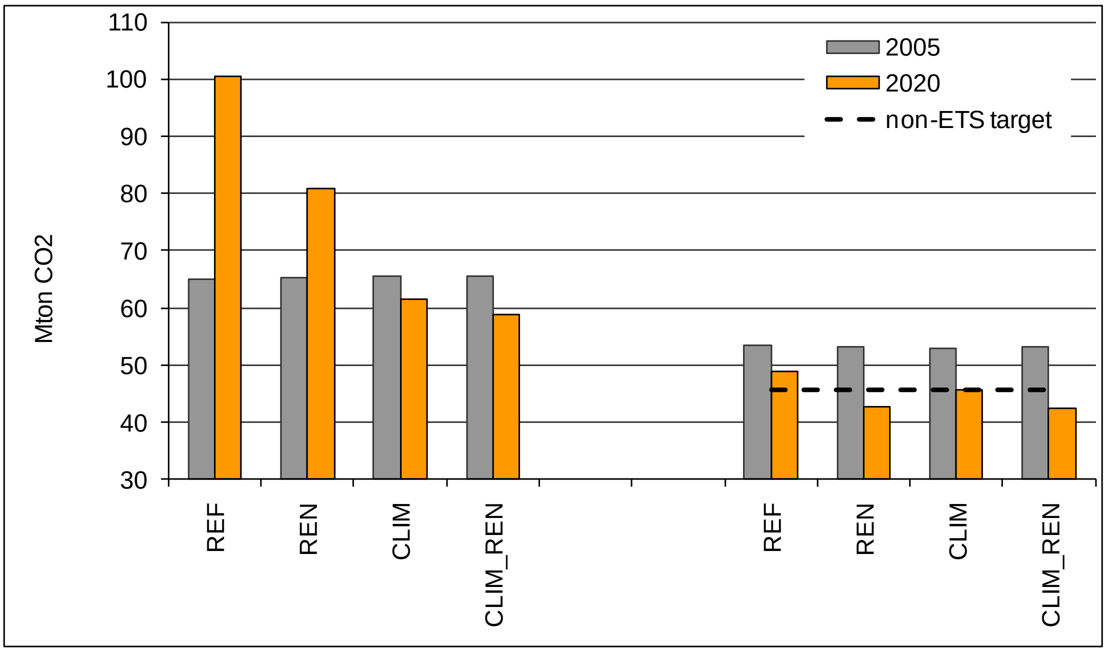
The CO_2 emissions for the different scenarios are given in the table below. The CO_2 emissions are not reduced much when only the renewable and biofuel targets are imposed without any climate target, especially in the long term. A policy targeted only on renewable energy alone is not enough for the climate target as it does not induce a sufficient CO_2 emissions reduction. Adding the renewable target to the climate policy reduces the emissions in 2020 with an additional 4%-point.

Table 9: CO_2 emissions in the different scenarios (in Mio.t and percentage reduction)

	2010	2020	2030	2040
REF	122	149	186	200
REN	121	124	161	173
CLIM	119	107	89	80
CLIM_REN	119	101	87	79
REN	-1%	-17%	-14%	-14%
CLIM	-3%	-28%	-52%	-60%
CLIM_REN	-3%	-32%	-53%	-61%

The contribution of ETS and non-ETS sectors in these emission reductions is analysed in the figure below. Both ETS and non-ETS sectors contribute to the reduction target, except in the REN scenario.

Figure 3: CO_2 emissions in the ETS (left) and non-ETS sectors (right)



The primary energy consumption decreases with the climate target and there is a substitution away from coal to gas and renewables. The shift towards renewables is more pronounced when there is a specific renewable target.

Table 10: Primary energy consumption (PJ)
(difference compared to reference)

	CLIM				CLIM_REN			
	2010	2020	2030	2040	2010	2020	2030	2040
Coal	-15	-422	-799	-958	-15	-430	-813	-970
Oil	-24	-12	-53	-99	-24	-65	-72	-100
Natural gas	20	213	368	443	20	84	340	412
Nuclear	0	0	0	0	0	0	0	0
Biomass, hydro, wind, photovoltaic	0	48	164	248	0	240	256	273
Waste	0	0	0	-1	0	0	0	0
Total	-18	-173	-319	-366	-19	-171	-289	-386

The share of renewables (as computed for the renewable target) is given in the table below. Here again one can see the impact of the renewable target in 2020 where the share is more than doubled. After 2020, the climate target leads by itself to an increase in the renewable share without however going much beyond 13%.

Table 11: Share of renewables
(computed as for the renewable target)

	2010	2020	2030	2040
REF	1.1%	1.4%	1.3%	1.3%
REN	1.2%	13.0%	13.7%	14.4%
CLIM	1.2%	4.3%	9.8%	12.7%
CLIM_REN	1.2%	13.0%	13.7%	14.4%

Technological options for renewable energy

Imposing a renewable target leads mainly to a more rapid penetration of the technologies based on renewables, such as biomass for heat and CHP. In the electricity sector, the full potential for wind off shore of 3800 MW_{el} is used from 2020 onwards. A very high growth rate of the capacity of wind turbines off shore is needed in such scenario. In the absence of a renewable target, part of the emission reductions in the electricity sector were obtained through carbon capture and storage and these are replaced by emission reduction through renewables whenever a renewable target is imposed.

When the target for renewable increases, biofuels for transport are penetrating more rapidly, first ethanol and then biodiesel[10], until the maximum potential is used.

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[10] Mixing biofuels with oilfuels can be seen as a first step to a more generalised use, cars on biofuels being more efficient.

The potentials imposed on domestic production for biocrops and wood play an important role in these results and should be further examined with sensitivity studies.

Table 12 gives the results for the CLIM_REN scenario with a 13% and 20% share of renewable energy. The tables makes a distinction between green electricity (ELC) and other green energy (Non-ELC), thus green heat and biofuels.

Table 12: Technological option for renewable in a CO2-scenario with 13% and 20% renewable target in 2020 (PJ)

Scenario	CLIM_REN13		CLIM_REN20	
Process	ELC	Non-ELC	ELC	Non-ELC
CHP Steam Turb. condensing WOOD Chemistry	0.1	0.2	0	0
CHP Steam Turb. condensing WOOD Non Ferro	2.6	4.5	1.5	2.6
CHP Int. Combust. Biogas Other	0	0	0.3	0.5
CHP Steam Turb. condensing WOOD Other	24.1	42.0	7.4	12.9
CHP Int. Combust. Biogas Paper	0.4	0.5	5.9	7.6
CHP Steam Turb. condensing WOOD Paper	4.1	7.1	0	0
CHP Int. Combust. Biogas Refineries	0	0	0.1	0.1
CHP Steam Turb condensing WOOD Refineries	0	0	2.3	4.0
Hydro	1.6	0	1.6	0
Hydro New	0.9	0	0.9	0
PV Plant Size	0	0	31.0	0
Wind Base-year	0.1	0	0.1	0
Wind Offshore Close	6.9	0	6.9	0
Wind Offshore Medium	3.5	0	3.5	0
Wind Offshore Far	33.4	0	33.4	0
Wind Onshore High	5.5	0	5.5	0
Wind Onshore Medium	5.6	0	5.6	0
Wind Onshore Low	1.5	0	1.5	0
Industrial Wood Heating	0	1.5	0	73.0
Residential Wood Heating	0	8.0	0	0
Biodiesel for Transport	0	0.0	0	41.0
Ethanol for Transport	0	44.9	0	44.9
Total Electricity and non-electricity	**90.2**	**108.7**	**107.4**	**186.6**
TOTAL		**198.9**		**293.9**

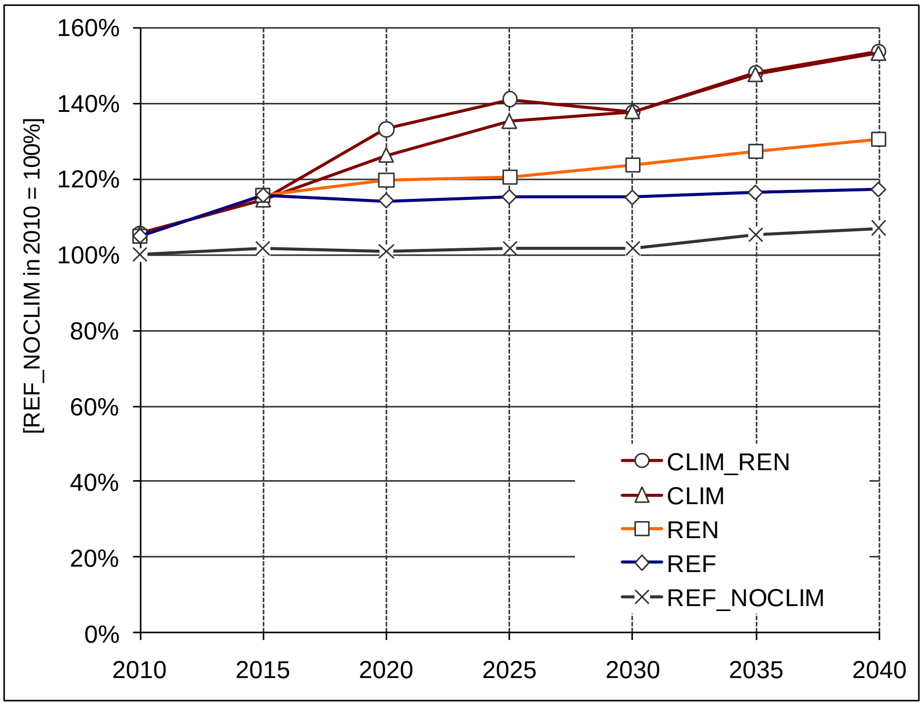
Impact on electricity price for households

As an example of the impact of the climate and energy policy on the energy price, the evolution in the electricity price in the residential sector is reproduced in the table and graph below. A fix transport and distribution cost is assumed. The total electricity price increases with the stringency of the targets and here again the impact of the renewable target is reflected mainly in 2020 and 2025. The impact of the renewable target is lower than the impact of having the climate policy alone. In contrast to REF, REF_NOCLIM is a scenario without a tax for CO_2.

Table 13: Electricity price for households (compared to 2010 if no climate policy)

	2020	2030	2040
REF_NOCLIM	2%	2%	5%
REF	16%	15%	16%
REN	16%	21%	27%
CLIM	14%	35%	48%
CLIM_REN	15%	41%	48%

Figure 4: Relative electricity price for households (compared to the price in 2000)



Impact of the renewable target

For a specific evaluation of the renewable target for Belgium, different runs of the CLIM_REN scenario were done with a renewable target going from 10% to 20% in 2020. For the period after 2020, the target is slightly increased as can be seen in the table below. The other policies are assumed fixed.

Table 14: Share of renewable energy

	2010	2020	2030	2040
CLIM_REN10	1.16%	10.0%	10.9%	12.7%
CLIM_REN11	1.16%	11.0%	12.4%	13.7%
CLIM_REN12	1.16%	12.0%	13.0%	14.0%
CLIM_REN	**1.16%**	**13.0%**	**13.8%**	**14.4%**
CLIM_REN15	1.20%	15.0%	15.0%	15.0%
CLIM_REN17	1.21%	17.0%	17.0%	17.1%
CLIM_REN20	1.15%	20.0%	21.7%	23.4%

With the increasing target on renewable, the share of biofuels (which are one of the available options) increases also, as seen in the next table. For a renewable target of 13% or more, the cost efficient share of biofuels is more than 10%. For a renewable target of 12% or less, the cost efficient share of biofuels is less than 10%.

Table 15: Share of biofuels in transport

	2010	2020	2030	2040
CLIM_REN10	0%	10.0%	10.0%	13.6%
CLIM_REN11	0%	10.0%	10.6%	13.6%
CLIM_REN12	0%	10.0%	10.0%	13.6%
CLIM_REN	0%	12.7%	12.3%	13.6%
CLIM_REN15	0%	15.7%	13.1%	13.6%
CLIM_REN17	0%	16.9%	13.8%	13.7%
CLIM_REN20	0%	24.8%	25.3%	26.2%

Table 16 shows the shadow price of the non-ETS CO_2 target. With a renewable target above 13%, the increase in the shadow price of CO_2 is shifted towards the later periods.

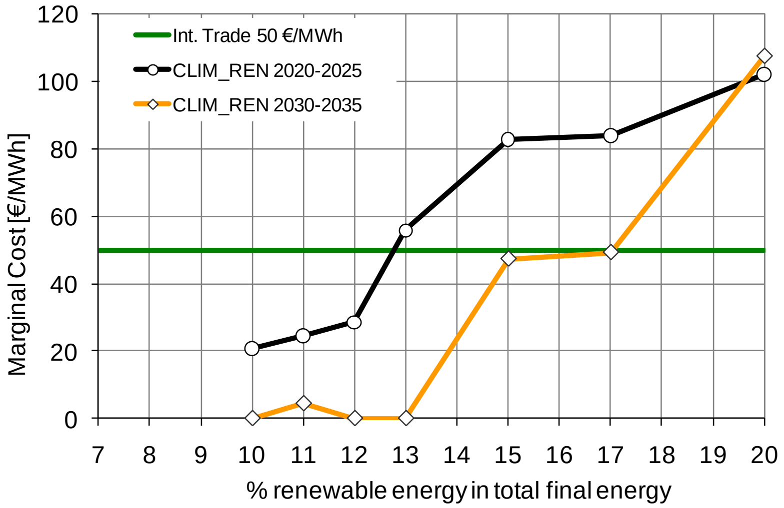
Table 16: Shadow price of the non-ETS CO_2 target (€/ton CO_2)

	2010	2015	2020	2025	2030	2035	2040
CLIM_REN10	29	40	0	39	109	134	157
CLIM_REN11	29	41	0	37	100	133	157
CLIM_REN12	29	41	0	31	110	133	156
CLIM_REN	30	42	0	0	92	133	159
CLIM_REN15	26	35	0	0	35	72	158
CLIM_REN17	26	29	0	0	25	67	161
CLIM_REN20	26	27	0	0	0	0	0

The shadow prices of the renewable constraint are illustrated in Figure 5. The shadow prices increase from 20-30 €/MWh to 90-100 €/MWh when increasing the target to 20%. Beyond 2020, it becomes very costly to impose a target above 13%. Numbers are averaged for the period 2020-2025 and for the period 2030-2035. They represent the marginal cost of an extra MWh of renewable energy that is imposed, given that there is already a CO_2 constraint. The marginal cost decreases over time because of the assumed policy for CO_2, except for a stringent renewable target of more than 17%.

One can also compare these results with assumed prices for a EU-green certificate. Assuming a liquid market in guarantees of origin for renewable energy, there would be one price for a EU-green certificate. For example with an international price of 50 €/MWh, it would be cost efficient to have 13% and 17% of renewable energy in Belgium in respectively 2020-2025 and 2030-2035, given the climate policy imposed.

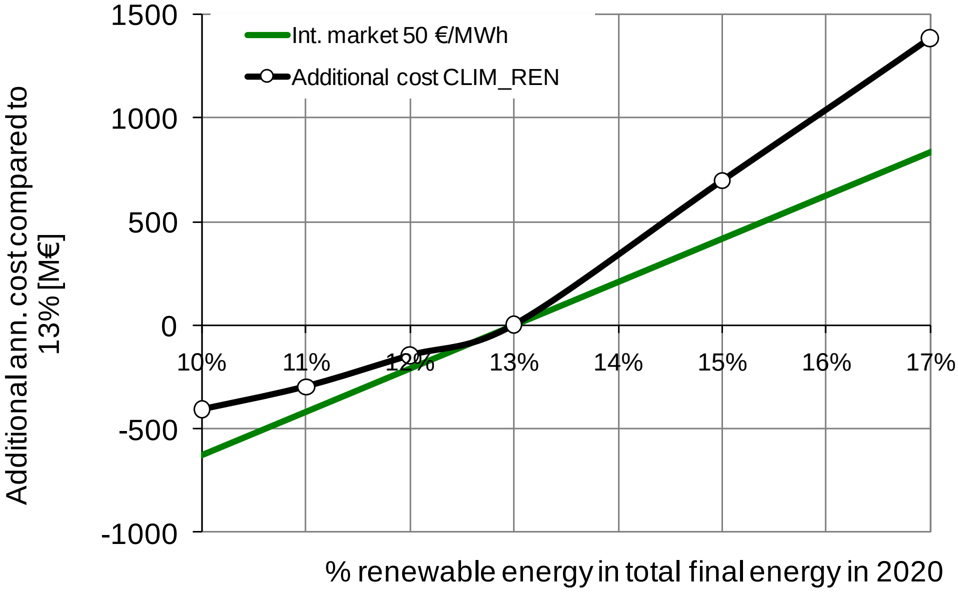
Figure 5: Shadow price of renewable target for the scenario CLIM_REN averaged for 2020-2025 and 2030-2035



In Figure 6, the black line represents the additional annual cost in the year 2020 compared to the situation where a 13% target is imposed. The other marginal cost curve is linear and represents the opportunity cost assuming an international price of a green certificate of 50 €/MWh. The cost of a target for a Member State is after all the price of an international green certificate multiplied with the target. With renewable shares that are higher than 13%, the average additional annual cost for one extra percentage of green energy amounts to 350 M€ (rounded). This conclusion is only valid for 2020, since it has been shown that the marginal cost decreases rapidly after 2025.

These computations have been based on the CLIM_REN scenario that assumes a fixed, exogenous price for the ETS sectors. A fixed price of carbon for the ETS sectors is an important assumption in our policy scenarios where policies overlap. An endogenous carbon price (at EU level) generates different results. Sensitivity analysis with the Belgian model shows that the additional cost of a 20% renewable target is 20% lower. It also shows that the results on the marginal cost for renewable energy are not very different when the carbon price is made endogenous.

Figure 6: Additional annual cost in the year 2020 compared to the proposed 13% renewable target



CONCLUSIONS

The conclusions in this paper are clearly dependent on the modelling assumptions and on the cost and technology assumptions used.

For the total period (2010-2050), the addition of a renewable and biofuel target on top of the climate target increases only slightly the total cost of a climate only policy. This increase is however mostly concentrated around 2020 and can then be substantial compared to the no renewable case. The addition of the renewable target represents an increase of the annual cost of the energy system of some 4% compared to the reference in 2020.

The imposition of the renewable target implies that the non-ETS CO_2 target is achieved without any specific CO_2 emission additional reduction efforts in this sector.

After 2020, the policy for renewable energy only increases slightly the cost of achieving the Belgian climate target as a limited introduction of renewables is part of a cost effective climate policy. As renewable technologies are still in their development phase, the renewable targets could contribute to more innovation in renewable energy and contribute as such to future more stringent climate targets. It could also induce other external benefits (air pollution etc).

When renewable certificates become tradeable and one can rely on a long-term European price for green energy certificates of about 50 €/MWh, it would be cost efficient to have 13% and 17% of renewable energy in Belgium in respectively 2020-2025 and 2030-2035, given the climate policy imposed.

The biofuel target in transport is only binding when imposed without the renewable or climate target, the biofuel option being one of the options to reach the renewable target. Its share reaches approx 12% with the renewable target. Though the assumptions regarding the potential for biofuels for Belgium are rather conservative, the side effects of the use of biofuels in terms of biodiversity, food production, etc. if extended at EU/World level need further examination.

A policy targeted on renewable energy alone is insufficient to reach the climate target.

We have shown that the climate and renewable policies interact and that the cost of additional climate or renewable efforts can only be specified when both constraints are clearly specified. While both the climate target and the renewable target contribute to the reduction of the CO_2 emissions, the technological choice they induce can be different, e.g. carbon capture versus electricity production from renewables.

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ANNEX 2:

Residential energy demand elasticities: what lessons can be learned from bottom-up and top-down methodologies.

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Abstract

In standard MARKAL, substitution between capital and energy is represented by a set of technology options and energy price shifts resulting in an opposite energy consumption movement, while keeping the energy service constant. Standard MARKAL does not count for non-technical solutions such as price driven behavioural changes. MARKAL-ED (Elastic Demand) includes a functionality to account for such behaviour. The energy service demand is then price sensitive. In this article we consider the case of residential fuel consumption and search for empirical evidence to quantify the energy service elasticity.

Keywords: energy demand elasticity, energy service elasticity, MARKAL, TIMES, bottom-up, top-down

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1. INTRODUCTION

Techno-economic optimisation models, like Markal, TIMES and Message and which we will further refer to as optimisation models are used worldwide for energy policy analysis and energy scenario development. These models are offered to potential users as a software package, providing facilities for building a national energy system by entering technology data, demand scenarios and system parameters. Besides the parameters characterising the technologies implemented in such models; these models need also parameters reflecting more the behaviour of the economic agents, regarding e.g. their reaction to change in the price of energy services.

Energy econometric models are also widely used for energy and GHG scenario and policy analysis, but have a different nature. Technology choices and economic behaviour are reflected in econometrically estimated parameters, such as price and income elasticity of energy demand or technical progress. They however donot give any indication on the energy service price elasticity needed for the energy optimisation models.

In this paper we investigate through an econometric approach if we can provide some guidance in quantifying energy service price elasticities. Answering this question requires first some clarification.

First, energy service price elasticities are difficult to observe econometrically, mainly due to lack of data for energy services demand and energy service prices. The econometric literature as well as our analysis focuses on energy demand elasticities. The difference between the two conceptis elaborated in the following section.

Second, optimisation models, with their presence of the capital stock, are relevant for developing long term scenarios, with a horizon from 10 up to 40-50 years. They need therefore estimated parameters reflecting this focus on the long term. Before the nineties, econometric research mainly focussed on short or medium term, not only because of the Neo-Keynesian nature but also due to lack of a sound theoretical background for quantifying long term effects. The concept of coïntegration and error correction specification presented by Engle and Granger (1987) was a conceptual breakthrough. Nowadays coïntegration analysis is a standard methodology for deriving long term elasticities.

Third, quantifying price reactions is a core business of any economic modelling activity but the way this is implemented in optimisation models and in econometric models is completely different as is illustrated in table 1. One fundamental difference is the 'historical' relation, i.e. econometric models rely on past dataand optimisation models on actual and future technology deployment. Technological improvements might explain both energy efficiency improvements and shifts in price reactions. Another important difference is that optimisation models usually assume a perfect competitive market, whereas models estimated on historical observations reflect also past market imperfections.

	Optimisation models	Econometric models
Representation	Price induced technology shifts	Single parameter
Historical relation	Future technology deployment	Historical data
Rationale	Economic reasoning	Historical observations
Market imperfections	Competitive market	Historical market imperfections

table 17: Key characteristics for modelling price reactions in optimisation models and in econometric models

In this paper we derive residential fuel price elasticities both using a bottom-up optimisation model and a panel coïntegration approach. In the following section we introduce some useful concepts allowing for a better understanding of price elasticities in techno-economic optimisation models. Then, in section 3 we present the techno-economic optimisation approach and in section 4 the econometric approach. In the final section we conclude and derive some guidance rules for the use of econometric estimations results in bottom-up optimisation models.

2 ENERGY DEMAND AND ENERGY SERVICE PRICE ELASTICITIES

Energy demand price elasticities express a relationship between the amount of energy consumed and the price of energy.

Energy service demand price elasticities express a relationship between the amount of energy service and the price (or cost) of the energy service

Optimisation models focus on technologies and the structure is based is on physical evidence. Energy demand results from various uses. The driving factor is the so called "energy-service" demand, a concept closely related to the utility provided by the energy. Typical energy services are: the comfort of having a space room temperature of 20 ° C, the light produced by lightbulbs, the entertainment provided by a television, clean clothes provide by the washing machine. The energy demand, or energy consumption, results from the choice of different technological options providing the required service level. The price elasticity of energy demand, *EDE*, can be linked to the price elasticity of energy service, *ESE* assuming a 'technological relation between ES and ED.

We first consider that the energy service is provided by a Leontief technology. In optimisation models the energy service is provided by one technology using capital and energy. In this case the relationship between the energy demand elasticity and the energy service price elasticity is given by (1) in which δ represents the budget share of energy in the overall spending for the service.

$$EDE = ESE * \delta \quad \text{or} \quad ESE = EDE/\delta \qquad (1)\ (1')$$

By definition $0 < \delta < 1$ and obviously in absolute terms $|EDE| < |ESE|$.

In the more general case, when different technological options are available, then the relationship is given by (2) where σ represents the substitution elasticity between energy and the other production factors. This equation is derived in appendix for a CES production function but it is generally true in a range when the substitution elasticity is assumed to be constant.

$$EDE = ESE * \delta - \sigma(1 - \delta) \quad \text{or} \quad ESE = (EDE + \sigma\ 1 - \delta\ )/\delta \quad (2)\ (2')$$

Both *EDE* and *ESE* are negative, as required by economic theory. It is easy verified that now $|EDE| <> |ESE|$ depending on the values of σ and δ. We can argue that $|EDE| > |ESE|$ if the substitution elasticity is high and the budget share of energy in the overall spending for the energy service is small.

3. BOTTOM-UP METHODOLOGY

Presentation of the model

The model is a MARKAL application for the Flanders region in Belgium[12]. The existing stock of houses is represented by 24 main categories (single houses and apartments, age structure, heating system) and differentiates between different levels of insulation for roofs, walls, floors, and windows. Furthermore the model differentiates between old boilers and more efficient

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[12] http://www.emis.vito.be/environmental-costing-model

boilers. The model structure incorporates the possibility of additional insulating measures on different building components and some level of trade off between efficient boilers and insulation, as represented in figure 1. Technological options are characterized by the investment cost, efficiency and the degree of past implementation (in case of insulation). For each category, the models considers 2 boiler types, 3 levels of roof insulation, 3 glass qualities, 2 types of walls, 3 levels of floor insulation and an option for solar boiler for sanitary hot water production, leaving 215 options for improvement for houses with the lowest energy efficiency. However, most houses do not start from the lowest efficiency levels as a number of measures have already been implemented. Endogenous demolition of houses is not considered. For new houses there are options for different levels of energy efficiency, starting by the minimum requirements defined by the Flanders energy efficiency legislation going to passive houses, without specifying the details of the different building components.

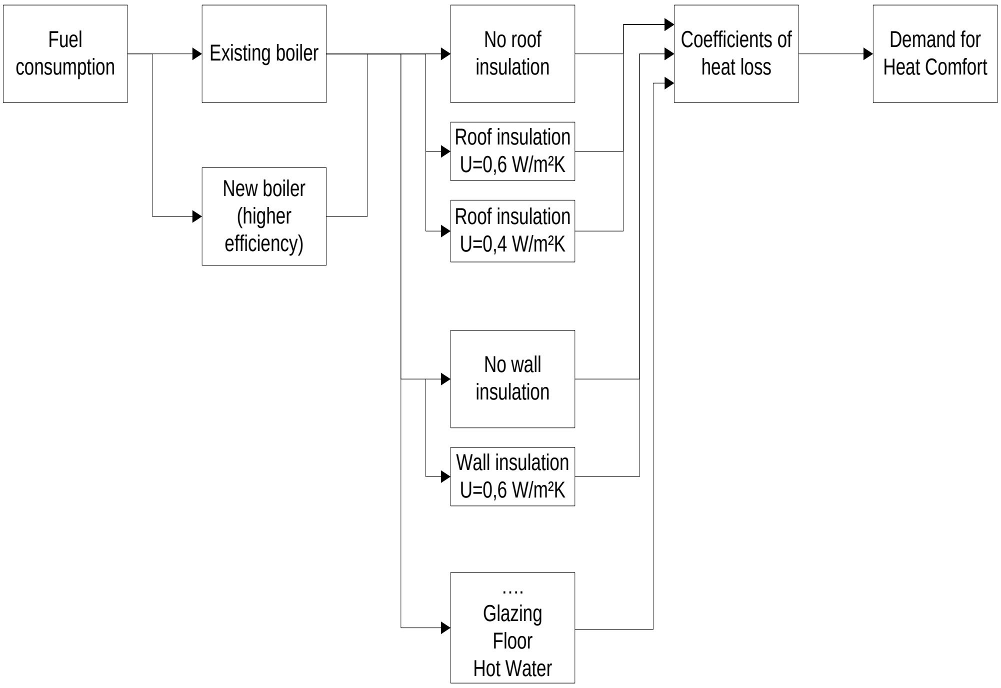

Figure 7: Simplified representation of the optimisation model for the residential sector Starting from the worst case, this structure has 11 options to improve energy efficiency for a house with the lowest energy efficiency level.

The flexibility of the model can also be translated into a CO_2 abatement curve (see fig 2)[13]. The latter has been derived using increasing levels of CO_2 tax using a social discount rate of 4 %. At current energy prices, roof insulation and better glazing have negative marginal reduction costs.

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[13] Negative CO2 reduction costs have been derived from the total system cost and the reduced cost of limiting cost efficient measures. Positive CO2 reduction costs have been derived by increasing levels of CO2 tax.

The efficiency gap is approximately 10%, either expressed as CO_2 emissions or fuel consumption. The existence of no-regret measures is a market anomaly which has been observed in different studies on energy-efficiency in the residential sector. Studies released in the early 80ts often explain this phenomenon by high implicit discount rates in energy efficiency investment, pointing to levels of 30 % and more. Hasset and Metcalf (1993) found a more rational explanation by introducing real options theory in their analysis and pointed out that uncertainty in future energy prices and the fact that energy saving investment is irreversible could explain a factor four between the market rate and the discount rate applied for energy saving investment. However Sanstad et all (1995) argued that real options theory was not able to explain 25 % observed implicit discount rates but only a an increase of the order 1%-2 %. Howard and Sanstad (1995) argued that high discount rates in energy related decisions are difficult to reconcile with standard models of rational choice and found that market failures related to asymmetric information, bounded rationality and transaction costs are major contributors to the so called "efficiency gap".

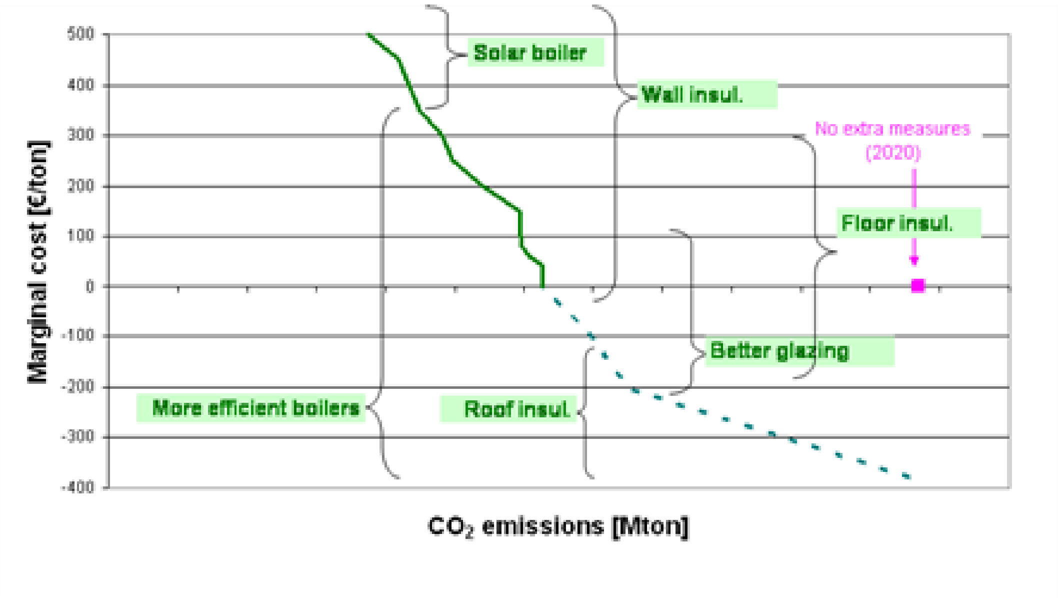

Figure 8: Marginal CO2 abatement cost curve for the residential sector in the

In order to fill the efficiency gap a sector specific hurdle rate of 15 %.has been used. The latter can be thought as representing a rational private discount rate, the Hasset and Metcalf effect, market failures that can be expressed as a fraction of capital spending (transaction costs, lack of capital), older people comparing life-expectations and investment pay-back time and many other unobserved issues.

PRICE ELASTICITIES

In order to derive fuel price elasticities (*EDE*) we have introduced a once and for all price increase of 20% of the 2010 price level for different values of *ESE* price elasticity of 0 and -.20. The results presented in table 2 are for the year 2025, i.e. 15 years after the introduction of the price increase. This period has been chosen in concordance with the time dimension in the econometric section below. Using a price increase of 20 % a *EDE* elasticity of -.63 is observed for *ESE* = 0 and -.78 for *ESE* =-.2. The price sensitivity is much higher for new houses than for existing ones, which can be explained by the fact that it is easier to reach higher energy efficiency levels when considered at the conceptual phase. Table 2 also provides figures for the budget share and the substitution elasticity. These have been calculated by substituting the *EDE* results with *ESE* 0 and *ESE* -.2 back in equation 2[14]. The budget shares are relatively high, which is explained by the fact that only incremental investment costs above standard technologies are represented.

Hurdle rate: 15 %, Energy price increase: 20 %				
		Total	Existing	New
ESE = 0	EDE	-0.63	-0.25	-1.43
ESE =-0.2	EDE	-0.78	-0.42	-1.53
	δ 23	0.75	0.86	0.50
	σ	2.52	1.76	2.84
Hurdle rate: 15 %, Energy price increase: 100%				
		Total	Existing	New
ESE = 0	EDE	-0.23	-0.16	-0.38
ESE = -0.2	EDE	-0.39	-0.31	-0.54
	δ	0.78	0.76	0.82
	σ	1.04	0.65	2.13

table 18: Observed energy demand elasticities in the optimisation model.

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[14] Values for the budget share parameter and the substitution elasticity can be derived from these results. Using ESE_1 for ESE =0 and ESE_2 for ESE=-0.2 and the corresponding symbols for EDE, δ is calculated as $(EDE_2-EDE_1)/(ESE_2-ESE_1)$ and σ is calculated as $(EDE_1- \delta.ESE_1)/(1-\delta)$

The second part in table 2 presents the results for a price shock of 100 %. For *EDE* we now observe lower values but the drop is significantly higher for new houses, although more energy-efficient options are available but the 15 % hurdle rate makes these very expensive. Higher capital spending in existing houses results in a lower budget share for energy. However, for new houses the price increase results in an increase of the budget share.

4. ECONOMETRIC APPROACH

4.1 Review of relevant literature

Contrary to bottom-up modeling, there is an extensive amount of scientific literature defining rules and standards for econometric analysis. The theoretical background in long term econometric analysis has dramatically changed by the work of Granger and Newbold (1974) on spurious regressions and by Engle and Granger on coïntegrating and error correction modeling (Engle and Granger 1987). Whereas in older studies the focus in standard econometric analysis was on describing the correlation properties, new insights in the nature of times series have generated a shift towards analyzing coïntegration properties. The coïntegration approach is standard technology in recently developed econometric models like NEMESIS (Fougeyrollas et all.2002,) and E3ME (Pollit 2010). We found a number of studies focusing on residential electricity demand and using the coïntegration approach which have some relevance for our study. Dergiades and Tsoulfidis (2008) used the Autoregressive Distributed Lag approach to coïntegration to analyze residential electricity demand in the US and found a long term income elasticity of -0.27 and a long term price elasticity of -1. Hondroyiannis (2004) also used a coïntegration framework to analyze the residential electricity demand in Greece. His findings are a long term income elasticity of 1.56 and a price elasticity of -0.41. Narayan et al.(2007) used a panel coïntegration analysis for residential electricity demand elasticities in G7 countries. They found a long term income elasticity of 0.31 and a price elasticity of -1.45.

There exist an extensive amount of literature on unit root statistics and coïntegration analysis. Maddala and Shaowen (1999) provide a comparative study of unit root tests with panel data and Breitung and Pesaran (2005) provide a review of the literature on unit roots and coïntegration in panels. The tests used for this paper are discussed in the following sections.

4.2 Methodology

Model specification

The objective is to derive long term income and price elasticities based on the following panel model specification:

$$Q_{i,t} = \alpha_i + \beta_i Y_{i,t} + \gamma_i P_{i,t} + \theta_i hdd_{\,i,t} + \varepsilon_{i,t} \qquad (3)$$

Q represents the log per capita residential fuel consumption, Y the log per capita real income of households, P the log of price of fuels deflated by the consumer price, hdd the log of degree days, ε the error term, and i an t respectively the index for the country (1..N)and time dimension(1..Ti) . In the first instance the intercepts and the slope coefficients are permitted to vary between countries. We allow for unbalanced panel data, i.e. the time dimension is permitted to vary between countries.

The variables income and price are standard in this type of econometric analysis. Temperature fluctuations are represented by heating degree days[15]. In the EU, average observations for the period 1980-2009 are between 560 (Malta) and 5970 (Finland). It is easy to see that the value of θ should be in the range [0-1] and depends on the thermal characteristics of the houses as well as on the habits of the residents. Other authors often include some derived composite index. Dergiades and Tsoufildis (2008) and Narayan and Smyth (2005) use one composite index representing heating and cooling degree days. Nayaran et all (2007) do not include any temperature related variable. Silk and Joutz (1997) use weighted cooling degree days and weighted heating degree days. The weights are indices for cooling and heating appliances stock. Hondroyiannis (2004) uses the weighted average temperature which represents electricity for heating as the sign is negative.

The dataset

Historical for EU members states data have been compiled from EUROSTAT. Availability has been a major criterion in defining the panel. Data have been compiled for residential fuel consumption expressed in TJ and the related price (€/GJ), disposable income in current prices, the consumer price index, population and heating degree-days. Data for DK, FR, DE, IT, NL,

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[15] These are calculated as the integral in time of the price difference between an assumed inside temperature of 18°C and the observed outside temperature, given that this difference is positive. For example, a day with an average temperature of 8° C counts for 10 degree days

ES, UK cover the period 1991-2008, for SI -1992-2008, FI, HU, IE, and PT 1995-2008 and AT 1996-2008 except for heating degree days which we have data from 1980 to 2009.

Unit root properties of the data

Our analysis is based on Levin et al. (2004) panel unit root tests and the ADF-t- tests for the individual time series. The null hypothesis is that the series are I(1). The Levin et all test starts from calculating individual ADF statistics. Both tests are parametric and require some expert judgement to decide on the parameters and the underlying model choice. Model-1 ADF test does not include a constant or time trend in the data generating process, model -2 ADF test includes a constant and model-3 ADF test additionally include a time trend. All tests are based on model -2 specification. Including a time trend seems inappropriate given the short lengths of the time series. The ADF test also requires a choice on the number of lags to be included. Here we have run various experiments and observed that the results are very sensitive to this parameter. Our approach is inspired by the suggestion of Levin et al. (2002) to follow the method recommended by Campbell and Perron: the maximum lag is fixed at 2 and if the t-statistic of the last lag < 1 then it is decided to use a lower smaller lag. The Levin-Lin panel data test requires an estimate of the long-run variance of the time series which involves the choice of a lag truncation parameter and a kernel. We used the Bartlett kernel as suggested by Levin et al. (2002) and the truncation parameter has been arbitrarily fixed at five.

Unit root statistics are presented in table 3. The Levin-et all statistic is below the 1 % significance level and rejects the null hypothesis of I(1) for heating degree days (hdd). This is confirmed by the individual ADF-t- statistics which, with the one exception of DK, all reach 10 % significance levels or better. For the fuel price P the opposite conclusion can be drawn. Based on the Levin-Lin statistic we cannot reject the null hypothesis of I(1) and this is also confirmed by the individual ADF-t statistics as none of them reaches the 10 % significance level. For real per capita income Y, the Panel Levin Lin test reaches the 10 % significance level. However there is some inherent uncertainty in the panel statistic. Indeed, as Levin et al. (2002) only report mean and standard deviation adjustments for 25 observations the statistic might be somewhat biased when used for 18 observations and given that the individual ADF statistics suggest that the series are I(1) we will not reject the null of I(1).

The result for fuel consumption (Q) is somewhat surprising. Indeed, per capita fuel consumption is closely related to the characteristics of the houses and we would expect some permanent effect. For instance, if the insulation of houses is improved, then this has a permanent effect. Improving energy efficiency of the boilers also has a permanent effect, i.e. it will never be reversed in the opposite direction. Construction and demolition activities also result in a permanent effect. From all these activities we would expect the series to be I(1) but based on the panel unit root test and the ADF statistics we would reject the null of I(1). To continue we have constructed the series Q* in which we have removed the noise from fluctuations in degree days, this based on the regression of equations (4) and subsequent calculation of Q* by (5)

$$\Delta Q_{i,t} = \gamma_i + \theta_i^* \Delta\, hdd_{i,t} + \varepsilon_{i,t} \qquad (4)$$

$$Q_{i,t}^* = Q_{i,t} - \theta_i^*\; hdd_{i,t} - hdd_{\,i} \qquad (5)$$

The values for θ* and the unit root statistics for Q* are reported in the last columns in table 5. The panel unit root and the ADF statistics now suggest that Q* has a unit root. This analysis suggest that it might be appropriate analysing the properties of (6) against (3), offering the advantage that all variables are I(1).

$$Q_{i,t}^* = \alpha_i + \beta_i Y_{i,t} + \gamma_i P_{i,t} + \varepsilon_{i,t} \qquad (6)$$

	Q		Y		P		Hdd		θ*	Q*	
DK	-2.747	(0)	-0.561	(0)	-1.628	(1)	-2.316	(0)	0.567	-1.685	(0)
FR	-2.693	(0)	-0.088	(0)	0.124	(0)	-4.208	(0)	0.474	-2.008	(2)
DE	-3.770	(0)	-1.790	(0)	0.422	(0)	-3.027	(0)	0.597	-2.339	(0)
IT	-1.822	(0)	-1.615	(0)	-2.141	(0)	-2.670	(2)	0.613	-1.261	(0)
NL	-1.397	(0)	-1.335	(0)	0.787	(0)	-2.944	(0)	0.745	0.515	(0)
ES	-1.450	(2)	-0.661	(1)	-0.851	(0)	-3.542	(0)	0.126	-0.793	(0)

UK	-2.492	(0)	-1.610	(0)	-0.192	(2)	-2.844	(0)	0.734	-1.861	(2)
Panel Levin-Lin	-1.922		-1.300		3.533		-4.514			1.221	
N observations	117		118		116		117			115	
Critical values:	ADF -t- test 10 % -2.64, 5% -2.99, 1% -3.75 for 25 observations Panel Levin-Lin test: 10 % -1.282, 5% -1.645, 1% -2.326										

table 19: Results of the unit root tests for the countries with 18 observations. Figures between brackets indicate the number of lags included in the ADF statistic

Coïntegration analysis

The analysis of the coïntegration properties are based on the panel coïntegration tests presented in Pedroni (1999) and slightly modified in Pedroni (2004). The Pedroni tests allow for homogeneous or country specific fixed effects and slope coefficients. The particular strength of panel analysis is to demonstrate the existence of homogeneous slope coefficient against the heterogeneous variant. In table 4 the slope coefficients for the income and price effects have been reported. They have been derived by OLS and DOLS. Although the model specification involves important autocorrelation in the error terms, OLS still provides unbiased slope coefficients but it is not efficient. DOLS takes this autocorrelation more explicitly into account by including lagged and leaded RHS variables in the regression. The drawback is that DOLS requires considerable longer times series for estimation. Therefore OLS has been used for all countries in the dataset (N=13) and DOLS only when allowed by the length of the time series (N=7). Whenever negative income effects or positive price effects have encountered, the variable has been omitted and the other parameters have been re-estimated. One remarkable observation is that income elasticities are consequently higher when DOLS is applied. For price elasticities no such analogues conclusion can be drawn. Another difference is that DOLS required less interventions as only one parameter (DK price) has been fixed, whereas in the corresponding sample in OLS two additional parameters (DE price and NL income) have been fixed.

	OLS		DOLS	
	Income	Price	Income	Price
AT	0.32	-0.20		
DK	0.09	0.00	0.17	0.00
FI	0.00	-0.14		
FR	0.04	-0.07	0.64	-0.51
DE	0.57	0.00	0.96	-0.07
HU	0.43	-0.14		
IE	0.22	-0.01		
IT	1.59	-0.34	2.70	-0.02
NL	0.00	-0.30	0.05	-0.30
PT	0.28	-0.06		
SI	0.10	-0.08		
ES	0.59	0.00	0.96	-0.35
UK	0.08	-0.18	0.36	-0.02
Homogenous N=7	0.31	-0.10	0.56	-0.10
Homogenous N=13	0.25	-0.11	0.46	-0.10

table 20: Heterogeneous and homogeneous income and price panel elasticities. Values in red have been fixed at zero.

The Pedroni tests reported in table 5 are standard normal distributed based on the correction parameters reported by Pedroni (1999). The panel v test converges to a positive figure and the other testconverge to negative values. The null hypothesis of no-coïntegration is rejected by big positive values for the panel v test and big negative values for the other tests.

A first observation is the significant difference for heterogeneous slope and homogeneous slope coefficients. For heterogeneous slope coefficients both the OLS and DOLS case, the Panel t, the parametric panel t, the group t test and the parametric group t test all reject the null hypothesis of no- coïntegration at the 5 % significance levels. From the panel v test, the panel ρ test and the group ρ test we cannot drawn conclusions as they do not reject the null hypothesis of no-coïntegration but they also do not allow to reject the null of coïntegration. For DOLS we observe higher significance levels for the panel t and the parametric panel t test compared to OLS. This is not confirmed in the group t test and the panel group t test, but the shift in the two panel tests is more outspoken. This again can be interpreted as an indication that DOLS is superior to OLS, even for relative small time series.

For homogeneous slope coefficients the conclusions are different. None of the tests allow rejecting the null of no-coïntegration. In fact none of the test sorts the write sign. Consequently we accept the null of no-coïntegration both for the OLS and DOLS results.

	heterogeneous-slope (N=7)		homogeneous-slope (N=7)		Full sample (N=13)
	OLS	DOLS	OLS	DOLS	OLS
Panel v	0.202	-1.508	-1.795	-2.280	0.129
Panel ρ	-0.154	-0.258	1.496	1.352	-0.661
Panel *t*	-1.959**	-2.885***	1.364	0.906	-4.138 ***
Panel *t* parametric	-2.238**	-3.023***	1.510	1.225	-4.368 ***
Group ρ	0.223	0.625	2.832	2.523	0.345
Group *t*	-6.562***	-4.311***	2.844	2.441	-8.738***
Group *t parametric*	-3.845***	-2.898***	2.482	1.694	-5.095***
Critical values	Panel v	Other			
10%	1.282	-1.282	*		
5%	1.645	-1.645	**		
1%	2.326	-2.326	***		

table 21: Pedroni coïntegration tests

The coïntegration tests for homogeneous slope coefficients demonstrate that Europe cannot be considered as a homogeneous area. With heterogeneous slope coefficients, the coïntegration statistics indicate that the regressions are not spurious, both for OLS and DOLS. In general the DOLS estimates are somewhat higher, both for the income and price coefficients. Economic consistency and the coïntegration tests suggest some preference for the DOLS results. We therefore conclude that price elasticities are in the range [0 -0.51] with an average value of -.18[16]. Values above -0.3 are not exceptional.

5. CONCLUSIONS

The objective of this study was to provide some guidance in quantifying the energy service price elasticity by comparing energy demand price elasticities in the optimisation model with econometric results. To this end we have first established a relationship between the energy demand elasticity and the energy service elasticity (equation 2). This relationship involves two parameters: the budget share of energy in the cost of the energy service and the substitution elasticity. We have also provided a means for quantifying these parameters on different aggregation levels. Basically the budget share determines how much the energy demand elasticity is determined by the energy service elasticity.

Quantifying price elasticities in optimisation models could be implemented as a matter of good practise as it allows for comparison with econometric estimates or literature review although this remains an intellectual exercise due to fundamental differences between optimisation models and econometric models pointed out in table 1. For instance, it might be useful to exclude new breakthrough technologies before measuring the price elasticity.

In this particular case we have found that the optimisation model was more elastic than what was observed econometrically, even when ESE = 0. From this comparison in a simplistic way we conclude that in this particular case the "best guess" for the energy service elasticity is 0. However, in general non-zero energy service elasticities might be useful, representing human behaviour in the short run as well as unknown technologic development.

---

[16] The homogenous panel estimates are lower but they have been rejected

Assuming the energy demand elasticity is "known", either from econometric analysis, literature review or any other source, the following procedure can be used to quantify energy service elasticities. The first step is the determination of budget share and the substitution elasticity. This requires a reference scenario and two additional model runs.

In the first additional run the energy demand elasticity (EDE1) for the optimisation model is determined when using zero energy service price elasticity. Then, using some arbitrary variable for the energy service elasticity (ESE2), the energy demand elasticity is determined again (EDE2). Then the budget share δ is calculated as $(EDE1-EDE2)/ESE_2$ and the substitution elasticity σ is as $EDE_1/(\delta-1)$. Then using these values, the energy service elasticity is given by equation (2′) where EDE represents the "known" energy demand elasticity.

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Addendum: Energy demand elasticity expressed as a function of the energy service elasticity (Vanregemorter's law)

For a CES production function

$$ES\ \ K,ED\ \ = [\delta_k\ K^{\frac{\rho-1}{\sigma}} + \delta_e\ ED^{\frac{\rho-1}{\sigma}}\ ]^{\frac{\sigma}{\sigma-1}} \qquad (1)$$

the associate unit cost function has the form

$$PES\ \ PK,PED\ \ = [\delta_k{}^{\sigma}\,PK^{\ 1-\sigma} + \delta_e{}^{\sigma}\,PED^{\ 1-\sigma}\ ]^{\frac{1}{1-\sigma}} \qquad (2)$$

and factor demand is expressed as

$$ED = \ \frac{PES}{PED}^{\ \sigma} ES\,\delta_e \qquad (3)$$

From (2)

$$\frac{\partial PES}{\partial PED} = \frac{1}{(1-\sigma)}\ \delta_k{}^{\sigma}\,PK^{\ 1-\sigma} + \delta_e{}^{\sigma}\,PED^{\ 1-\sigma\ \ \frac{1}{1-\sigma}-1}\ .\,\delta_e\ \ 1-\sigma\ \ PED^{-\sigma}$$

$$\frac{\partial PES}{\partial PED} = \delta_e{}^{\sigma}\ \frac{PES}{PES^{1-\sigma}}\ PED^{\ -\sigma} = \ \delta_e{}^{\sigma}\ \ \frac{PES}{PED}^{\ \sigma}$$

and using (3)

$$\frac{\partial PES}{\partial PED} = \frac{ED}{ES}$$

From (3)

$$\frac{\partial ED}{\partial PED} = \delta_e{}^{\sigma}\sigma\ \ \frac{PES}{PED}^{\ \sigma-1}\ \ \frac{\partial PES}{\partial PED}\,.\frac{1}{PED} - PES\,\frac{1}{PED^2}\ \ .\,ES + \delta_e{}^{\sigma}\ \ \frac{PES}{PED}^{\ \sigma}\ \frac{\partial ES}{\partial PES}\,\frac{\partial PES}{\partial PED}$$

Re-arranging and using (4) we get

$$\frac{\partial ED}{\partial PED} = \delta_e{}^{\sigma}\sigma\ \ \frac{PES}{PED}^{\ \sigma-1}\ \frac{1}{PED}\ \frac{\partial PES}{\partial PED}\ .-PES\,\frac{1}{PED}\ \ .\,ES + \delta_e{}^{\sigma}\ \ \frac{PES}{PED}^{\ \sigma}\ \frac{\partial ES}{\partial PES}\,\frac{ED}{ES}$$

Multiplying both sides by *PED/ED* and the definition of *EDE*

$$EDE = \delta_e{}^{\sigma}\sigma\ \ \frac{PES}{PED}^{\ \sigma-1}\ \frac{1}{PED}\ \frac{\partial PES}{\partial PED}\ \ - PES\,\frac{1}{PED}\ \ ES\,\frac{PED}{ED} + \delta_e{}^{\sigma}\ \ \frac{PES}{PED}^{\ \sigma}\ \frac{\partial ES}{\partial PES}\,\frac{ED}{ES}\,\frac{PED}{ED}$$

Using (4) and definition of ESE

$$EDE = \sigma \; \frac{ED}{ES}\frac{PED}{PES}\frac{1}{PED} \; \frac{ED}{ES} \; - \frac{PES}{PED} \; ES\frac{PED}{ED} + \frac{ED}{ES}ESE \; \frac{PED}{PES}$$

and because

$$\delta = \frac{ED\,.PED}{ES.PES}$$

We get

$$EDE = \sigma\,\delta\frac{ED}{ES} \; 1 \; - \frac{PES}{PED}\,\frac{ES}{ED} \; ES\frac{1}{ED} + \delta\,ESE \; = \sigma\,\delta \; 1 \; - \frac{1}{\delta} \; + \delta\,ESE \quad = \sigma \;\; \delta - 1 \; + \delta\,ESE$$

ANNEX 3: MINUTES OF THE FOLLOW-UP COMMITTEE MEETING on 18 december 2009

1. Aanwezig en *verontschuldigd*

Camps	Guido	CREG	Directeur Controle Prijzen en Rekeningen
Cornelis	Natalie	CREG	Hoofdadviseur Controle Prijzen en Rekeningen
Courcelle	Christophe	CREG	Hoofdadviseur Controle Prijzen en Rekeningen
Dandenne	Salomé	SPF	Mobilité et Transports
Devogelaer	Danielle	Federaal Plan Bureau	Afdeling Energie en transport
Duerinck	Jan	VITO	Transitie Energie en Milieu
Fierens	Anne	Federaal Wetenschapsbeleid	Responsible Officer TUMATIM
Grobben	Patricia	Vlaamse Overheid	Departement Leefmilieu, Natuur en Energie
Maes	Fre	FOD Volksgezondheid,…	DG Leefmilieu - Dienst Klimaatverandering
Michiels	Hanne	Hogeschool Universiteit Brussel	Thesis prijsgevoeligheid verplaatsingsgedrag
Nijs	Wouter	VITO	Transitie Energie en Milieu
Novak	*Marie*	*FGOV*	*DG Energie*
Ochelen	Sara	Vlaamse Overheid	Cel Milieueconomie
Piessens	Kris	RBINS	Geological Survey of Belgium
Valentiny	David	Cabinet du Ministre Jean-Claude Marcourt	Economie, des PME, du Commerce extérieur, des Technologies nouvelles et de l'Enseignement supérieur
Van Nuffel	Luc	GDF Suez	Strategy and sustainable development
Van Regemorter	Denise	KULeuven	Centrum Economische Studieën
Van Steenberghe	*Vincent*	*FOD VVVL*	*Dienst klimaatverandering*
Verheyden	Sophie	Federaal Wetenschapsbeleid	Responsible Officer PSS CCS II

2. Dagorde

09:45	Coffee and welcome	Wouter Nijs
	General update on the models	
10:15	Uncertainty and the impact on electricity investments	Denise Van Regemorter
10:45	Discussion and feedback	All
11:05	Electricity and fuel consumption: residential and transportation demand elasticities	Jan Duerinck; Wouter Nijs
11:35	Discussion and feedback	All
11:55	Discussion on the issues to be considered in the scenario work for 2010 (see down)	All
12:15	LUNCH	All

3. Lijst van de uitgedeelde documenten (deze documenten worden aan het huidig PV toegevoegd)
   De presentaties worden samen met het verslag verpsreid in één pdf.

4. Synthese van de discussies, advies en aanbevelingen

Goal of the meeting

To inform on the work progress and to discuss some results. Participants of the meeting also can participate in defining 5 new energy scenarios. More information on TUMATIM can be found on http://www.belspo.be/belspo/ssd/science/projects/TUMATIM_en.pdf

Previous scenarios

In the first year of TUMATIM, 8 scenario's have been performed, concentrating on the renewable target for Belgium. The results were presented at a workshop of the International Energy Agency:

http://www.etsap.org/Workshop/Paris_07_2008/3Wouter-IEW2008.pdf

Presentation on Uncertainty, Denise Van Regemorter

Remarks and advice:

- What about uncertainty at the level of final energy demand ? Impact on 13% renewable target ?
- Difference between "permanent" uncertainty and uncertainty that one day will be solved > hedging.
- What about uncertainty on investment costs ? And on external costs ?
- Give a technology mix a place in the portfolio graph
- Make fuel prices endogenous ? No, only useful in European model, example is biomass.
- Big uncertainty = price of CO_2
- Portfolio at the level of the company and not only society, drivers of this portfolio are the load factors, diversification (more than at state level) and availability for example of CCS. This raises the question whether Markal is only useful for plan economy. It is clearly not because Markal assumes competing markets where both producers and consumers are price takers (which might not be the case in reality).

Suggested literature:

Newbarry, tunnel for CO_2 price

http://www.rwea.ro/sorenkrohn.pdf

http://www.ewea.org/fileadmin/ewea_documents/documents/00_POLICY_document/Economics_of_Wind_Energy__March_2009_.pdf

Presentation on Price elasticities, Jan Duerinck and Wouter Nijs

Remarks and advice:

- Look at numbers of FOD Economy
- Take Cooling Degree Days into account for calculations
- Is there time to do exercise of residential sector on transport ?
- Is there impact of the policy of a country and can it be a variable in the analysis ? Example is major switch to heat pumps
- Policy impact also at level of demand itself, example: make people willing to take the bike.
- Thesis on residential energy services could estimate the disconto of private households
- Is the level of price elasticity independent of the price level ? Isn't the absolute price level also important ? Idea could be to create 2 subsets for the analysis.

New scenario work in 2010

Some suggestions on scenario work in 2010:

One group of three scenarios can tackle climate issues. For the EU dimension of the impact on the energy system, the Pan European TIMES (PET) model can be used. PET is a EU-wide Markal/TIMES model.

1. Focus on Belgium in a European scenario with greenhouse gas reduction in line with Copenhagen, low flexibility on renewable trading.
2. Focus on Belgium in a European scenario with greenhouse gas reduction in line with Copenhagen, high flexibility on renewable trading.
3. Compare results of LEAP and TIMES. Belgian "assimilated" scenario that shows great resemblance to a SEPIA scenario (more information on http://www.ua.ac.be/main.aspx?c=.SEPIA&n=64439). This is probably a scenario with high level of technology forcing.

A group op 2 scenarios focusing on uncertainty and price elasticities.

1. Sensitivity analysis with a focus on dealing with uncertainty. It can be analysed how sensitive the optimal technology choices are to fuel prices.
2. Sensitivity analysis. It can be analysed how sensitive the evolution of the energy system is to different assumptions on price elasticities.

Suggestions, advise:

- Final demand as important parameter for scenario runs
- Try to allocate the resulted reduction of emissions: is it a price effect, energy efficiency effect,... ?

Suggested literature:

EPRI, EEI, Eurelectric joint study

Eurelectric, Power Choices (used Primes)

McKinsey; 2050 new study

5. Datum van de volgende vergadering en varia

De volgende stuurgroep moet nog worden vastgelegd.

ANNEX 4: Orthogonal design (Price sensitivity of residential energy services)

Profile	A01	A02	A03	A04	A05	A06	A01	A02	A03	A04	A05	A06
1	0	0	0	0	0	0	1	1	1	1	1	1
2	0	1	1	1	1	1	1	2	2	2	2	0
3	0	2	2	2	2	0	1	3	3	3	3	1
4	0	3	3	3	3	1	1	0	0	0	0	0
5	1	0	1	2	3	0	2	1	2	3	0	1
6	1	1	0	3	2	1	2	2	1	0	3	0
7	1	2	3	0	1	0	2	3	0	1	2	1
8	1	3	2	1	0	1	2	0	3	2	1	0
9	2	0	2	3	1	0	3	1	3	0	2	1
10	2	1	3	2	0	1	3	2	0	3	1	0
11	2	2	0	1	3	0	3	3	1	2	0	1
12	2	3	1	0	2	1	3	0	2	1	3	0
13	3	0	3	1	2	0	0	1	0	2	3	1
14	3	1	2	0	3	1	0	2	3	1	0	0
15	3	2	1	3	0	0	0	3	2	0	1	1
16	3	3	0	2	1	1	0	0	1	3	2	0

ANNEX 5: Questionnaire (Price sensitivity of residential energy services)

This questionnaire has been developed for a thesis study. The questionnaire examines how you deal with energy in your home.

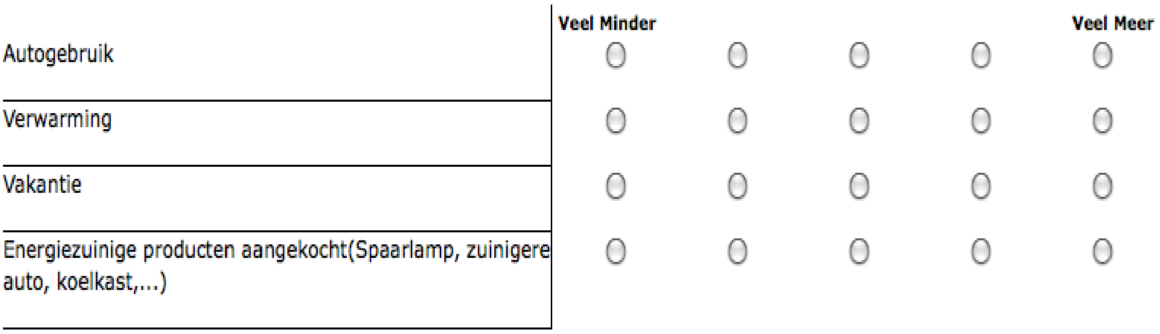
The results of the questionnaire will be treated anonymously and data will not be distributed further.

The questionnaire will consist of 6 parts and will take 15 minutes to complete.

Thank you for your cooperation!

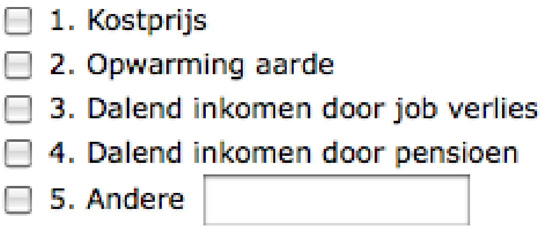
1. Section 1:

a. Have you performed more or less of the following activities during the past year?



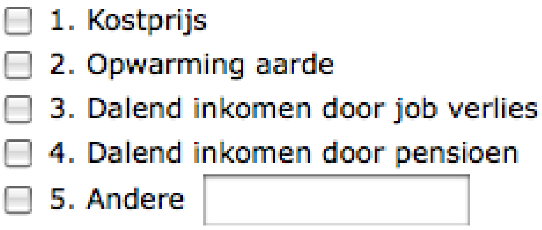
	Veel Minder				Veel Meer
Autogebruik	○	○	○	○	○
Verwarming	○	○	○	○	○
Vakantie	○	○	○	○	○
Energiezuinige producten aangekocht(Spaarlamp, zuinigere auto, koelkast,...)	○	○	○	○	○

b. Reason for changing car usage. (if there is no change in usage, continue to the next question)



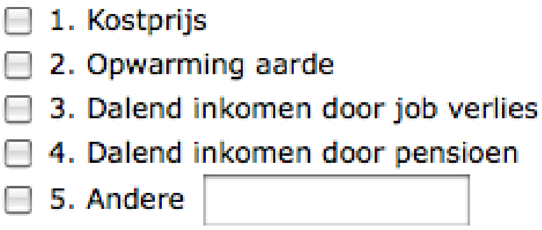
☐ 1. Kostprijs
☐ 2. Opwarming aarde
☐ 3. Dalend inkomen door job verlies
☐ 4. Dalend inkomen door pensioen
☐ 5. Andere ☐

c. Reason for changing heating usage (if there is no change is usage, continue to the next question)



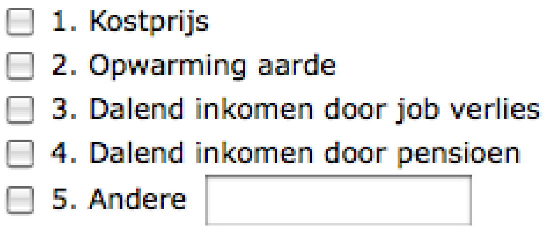
☐ 1. Kostprijs
☐ 2. Opwarming aarde
☐ 3. Dalend inkomen door job verlies
☐ 4. Dalend inkomen door pensioen
☐ 5. Andere ☐

d. Reason for changing holiday behaviour (if there is no change is usage, continue to the next question)



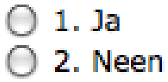
☐ 1. Kostprijs
☐ 2. Opwarming aarde
☐ 3. Dalend inkomen door job verlies
☐ 4. Dalend inkomen door pensioen
☐ 5. Andere ☐

e. Reason for changing purchasing behaviour for energy-efficient products. (if there is no change in usage, continue to the next question)


☐ 1. Kostprijs
☐ 2. Opwarming aarde
☐ 3. Dalend inkomen door job verlies
☐ 4. Dalend inkomen door pensioen
☐ 5. Andere

2. Section 2:

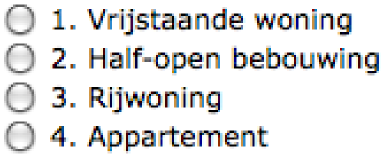
a. Do you own the house?


○ 1. Ja
○ 2. Neen

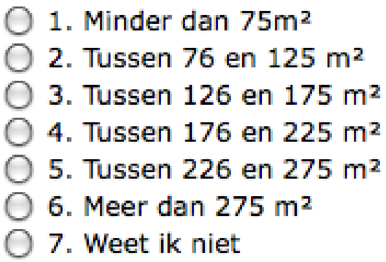
b. In which year was the house built or in which year was the last thorough renovation?

_ _ _ _

c. In which type of house do you live?


○ 1. Vrijstaande woning
○ 2. Half-open bebouwing
○ 3. Rijwoning
○ 4. Appartement

d. How much usable living space is there in your home in m²? (Usable living space refers to all spaces that can be used for living purposes). If the cellar and loft have been designed as living spaces, they will be included in the usable living space. Corridors between rooms are not included.)

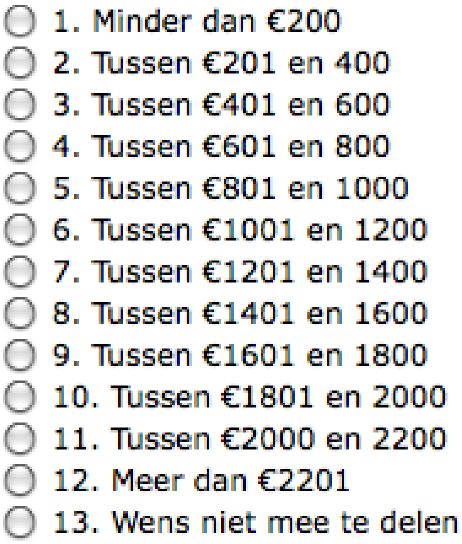

○ 1. Minder dan 75m²
○ 2. Tussen 76 en 125 m²
○ 3. Tussen 126 en 175 m²
○ 4. Tussen 176 en 225 m²
○ 5. Tussen 226 en 275 m²
○ 6. Meer dan 275 m²
○ 7. Weet ik niet

3. Section 3:

a. How do you currently heat your home? (multiple choices possible)

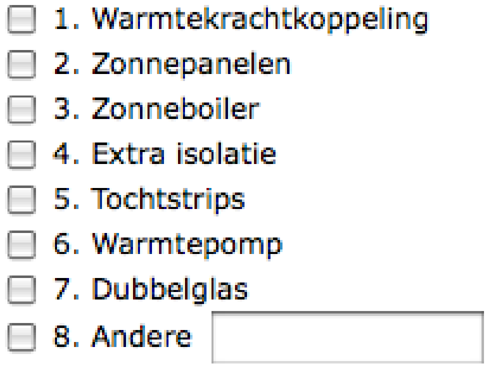
☐ 1. Elektriciteit
☐ 2. Aardgas
☐ 3. Mazout
☐ 4. Warmtepomp
☐ 5. Zonneenergie
☐ 6. Warmtekrachtkoppeling
☐ 7. Houtpellets
☐ 8. Hout
☐ 9. Andere

b. What was your energy bill for your home in the year 2008? (If you heat electrically, please indicate the amount on the electricity bill) (amount calculated on an annual basis) (If you are unsure, please estimate this amount; it is very important for the study – the results will be treated **ANONYMOUSLY**!)



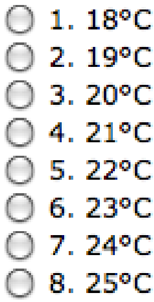
○ 1. Minder dan €200
○ 2. Tussen €201 en 400
○ 3. Tussen €401 en 600
○ 4. Tussen €601 en 800
○ 5. Tussen €801 en 1000
○ 6. Tussen €1001 en 1200
○ 7. Tussen €1201 en 1400
○ 8. Tussen €1401 en 1600
○ 9. Tussen €1601 en 1800
○ 10. Tussen €1801 en 2000
○ 11. Tussen €2000 en 2200
○ 12. Meer dan €2201
○ 13. Wens niet mee te delen

c. In the past 5 years, have you invested in one of these (fossil) energy saving measures? (If none of the options below are applicable to you, you may skip this question)



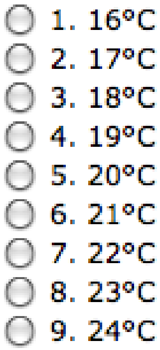
☐ 1. Warmtekrachtkoppeling
☐ 2. Zonnepanelen
☐ 3. Zonneboiler
☐ 4. Extra isolatie
☐ 5. Tochtstrips
☐ 6. Warmtepomp
☐ 7. Dubbelglas
☐ 8. Andere

d. On average, up to which temperature do you currently heat your main rooms? Main rooms refers to living areas where a lot of time is spent and where heating is essential. (Living room, Bathroom, study/play room, Kitchen)



○ 1. 18°C
○ 2. 19°C
○ 3. 20°C
○ 4. 21°C
○ 5. 22°C
○ 6. 23°C
○ 7. 24°C
○ 8. 25°C

e. Up to which temperature do you currently heat your other rooms? Other rooms refers to living areas where little time is spent and where heating is not essential. Bedrooms and other rooms (toilet, ironing room, cellar and loft if they are used)



○ 1. 16°C
○ 2. 17°C
○ 3. 18°C
○ 4. 19°C
○ 5. 20°C
○ 6. 21°C
○ 7. 22°C
○ 8. 23°C
○ 9. 24°C

4. Section 4:

In this study, we are looking at the things you consider when renovating your home. This is done using choice questions. One a few occasions later in this questionnaire, you will be presented a choice between two options. These two options differ in e.g. cost price, CO_2 emissions and temperature. You will be asked to indicate which of the two options you prefer. If you are not convinced by either of the two options, you can select option 3 'NO CHOICE'. This means that your house will be renovated but will not be made more energy-efficient – thus, the situation remains as it is.

Scenario
You are the owner of a house built prior to 1995. Now imagine that you are about to renovate your home.. Because you are going to renovate, you have the opportunity to invest in measures that will reduce your annual energy bill. The characteristics you are about to see only relate to making the home more energy efficient and energy-friendly, and not to the renovation itself.
It is important for you to realise that your house is about to be renovated: we would like to know the personal choices you would make in this fictional situation.

Every option you are presented is fictional, which means it is not or is only coincidentally related to your current living situation, and consists of six characteristics. We will first explain these characteristics. In order to make the right choices, it is important for you to carefully read the explanation below!

1. Temperature main rooms

Main rooms refers to living areas where a lot of time is spent and where heating is essential. (Living room, Bathroom, study/play room, Kitchen)

This characteristic consists of 4 levels, +0°C, +1°C,+3°C and +4°C measured from your current level.

2. Temperature other rooms

Other rooms refers to living areas where little time is spent and where heating is not essential. Bedrooms and other rooms (toilet, ironing room, cellar and loft if they are used)

This characteristic consists of 4 levels, +0°C, +1°C,+3°C and +4°C measured from your current level.

3. Investment costs

The investment costs are extra costs in addition to the renovation costs for your home. These are the extra costs that must be paid to make your home more energy efficient. Possible subsidies have already been deducted. These costs are a one-off payment.

This characteristic consists of 4 levels, €5000, €10,000, €15,000 and €20,000.

4. Running costs

The annual running costs is the amount that must be paid to heat your home. Considering that energy efficiency increases, energy costs will decline. The annual running costs include the distribution costs. The annual running costs are shown as a drop in percentage of the current running costs.

This characteristic consists of 4 levels, 0%, -10%, -20% and -30% measured from your current running costs.

5. CO_2 emissions

CO_2 emissions is a parameter that indicates the impact of your heating system on the environment. This characteristic consists of 4 levels, 0%, -10%, -20% and -30% measured from your current CO_2

emissions.

6. Creation extra room

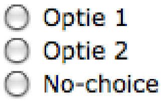
Depending on the renovation of your house, an extension could be built or an empty and unfinished room could be transformed into a finished room. You can choose to insulate this empty renovated space, heat it and equip it with energy-saving features.
This characteristic consists of 2 levels, Yes and No.

We will now proceed to the section of this questionnaire where we will, on various occasions, present you with a choice between situations that differ in terms of the six dimensions discussed in the explanation. This page contains an example of such a choice.
Three options are presented below; Option 1, Option 2 and No Choice. You will eventually be asked to state which of the three options you prefer, and to select this option by marking the little circle at the bottom. The choice below is only an example; thus, the choice you make on this page will not be included in the study.

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. **The no choice option means the dwelling will not be made more energy efficient during the renovation.**

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+3°C	+0°C	
Temp andere kamers	+3°C	+0°C	
Investeringskosten	€ 5000	€ 10000	
Gebruikskosten	-20 %	-30 %	
Co_2-uitstoot	-10 %	-20 %	
Extra kamer	Nee	Ja	

Which option do you prefer?

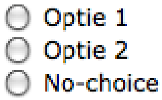

○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum

investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+0°C	+1°C	
Temp andere kamers	+0°C	+1°C	
Investeringskosten	€ 5000	€ 10000	
Gebruikskosten	0 %	-10 %	
Co_2-uitstoot	0 %	-10 %	
Extra kamer	Ja	Nee	

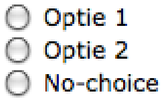
1. Which option do you prefer?


○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+1°C	+2°C	
Temp andere kamers	+0°C	+1°C	
Investeringskosten	€ 10000	€ 15000	
Gebruikskosten	-20 %	-30 %	
Co_2-uitstoot	-30 %	0 %	
Extra kamer	Ja	Nee	

2. Which option do you prefer?


○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+1°C	+2°C	
Temp andere kamers	+1°C	+2°C	
Investeringskosten	€ 5000	€ 10000	
Gebruikskosten	-30 %	0 %	
Co$_2$-uitstoot	-20 %	-30 %	
Extra kamer	Nee	Ja	

3.

Which option do you prefer?

○ Optie 1
○ Optie 2
○ No-choice

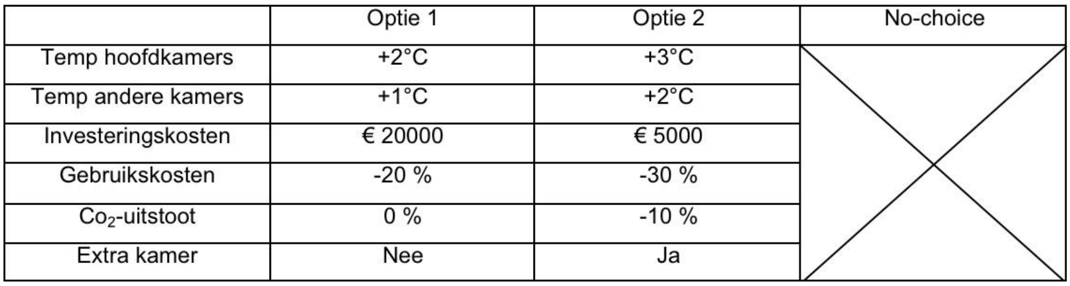
Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+2°C	+3°C	
Temp andere kamers	+0°C	+1°C	
Investeringskosten	€ 15000	€ 20000	
Gebruikskosten	-30 %	0 %	
Co$_2$-uitstoot	-10 %	-20 %	
Extra kamer	Ja	Nee	

4. Which option do you prefer?

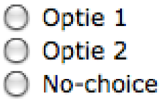
○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)



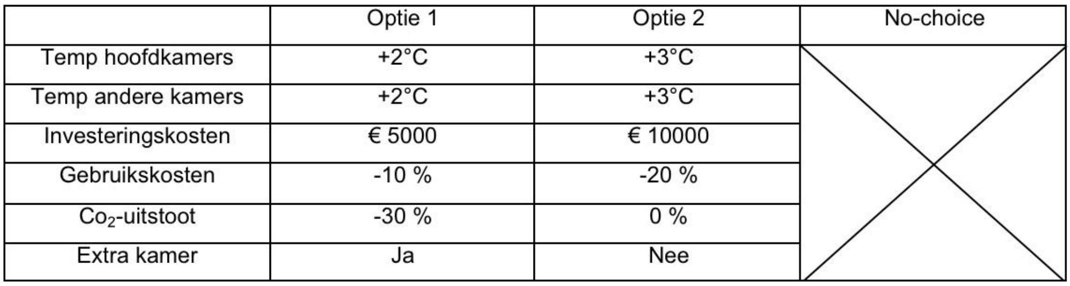
	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+2°C	+3°C	☒
Temp andere kamers	+1°C	+2°C	
Investeringskosten	€ 20000	€ 5000	
Gebruikskosten	-20 %	-30 %	
Co_2-uitstoot	0 %	-10 %	
Extra kamer	Nee	Ja	

5. Which option do you prefer?



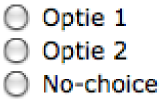
○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)



	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+2°C	+3°C	☒
Temp andere kamers	+2°C	+3°C	
Investeringskosten	€ 5000	€ 10000	
Gebruikskosten	-10 %	-20 %	
Co_2-uitstoot	-30 %	0 %	
Extra kamer	Ja	Nee	

6. Which option do you prefer?

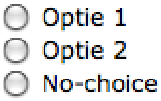


○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+3°C	+0°C	
Temp andere kamers	+0°C	+1°C	
Investeringskosten	€ 20000	€ 5000	
Gebruikskosten	-10 %	-20 %	
Co_2-uitstoot	-20 %	-30 %	
Extra kamer	Ja	Nee	

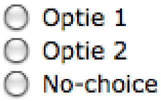
7. Which option do you prefer?


○ Optie 1
○ Optie 2
○ No-choice

Three options are presented below; Option 1, Option 2 and the No Choice option. Decide which of the two options you prefer and select this option by highlighting the little circle. The no choice option means the dwelling will not be made more energy efficient during the renovation. The no choice option means that a minimum investment cost of €5000 must be paid. The other attributes remain the same (Running costs, CO_2 emissions, temperature,..)

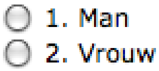
	Optie 1	Optie 2	No-choice
Temp hoofdkamers	+3°C	+0°C	
Temp andere kamers	+2°C	+3°C	
Investeringskosten	€ 10000	€ 15000	
Gebruikskosten	-30 %	0 %	
Co_2-uitstoot	0 %	-10 %	
Extra kamer	Ja	Nee	

8. Which option do you prefer?


○ Optie 1
○ Optie 2
○ No-choice

5. Section 5:

a. What is your sex?


○ 1. Man
○ 2. Vrouw

a. What is your date of birth?

19

c. Number of family members including yourself.

_ _

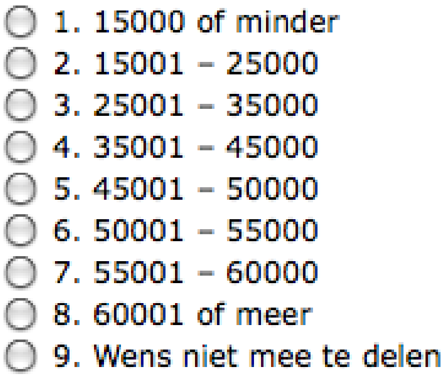
d. Number of family member young than 12 years of age

_

e. Number of family members older than 65, including yourself.

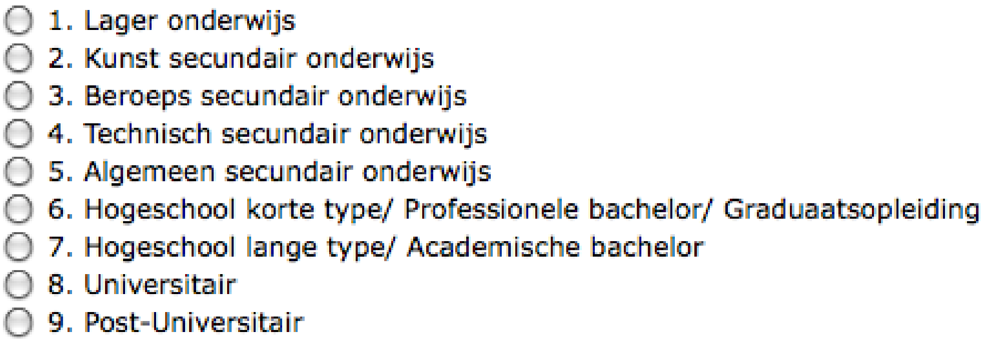
_

f. Which category best describes your family’s pre-tax income (gross) in 2008. (Family income includes all income generated by the family: Income from work, property-related incomes, maintenance monies, financial incomes, ...)



○ 1. 15000 of minder
○ 2. 15001 - 25000
○ 3. 25001 - 35000
○ 4. 35001 - 45000
○ 5. 45001 - 50000
○ 6. 50001 - 55000
○ 7. 55001 - 60000
○ 8. 60001 of meer
○ 9. Wens niet mee te delen

g. What is your highest level of education?

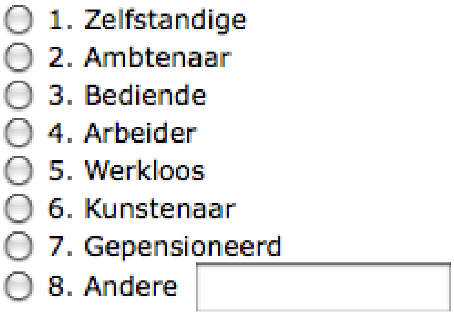


○ 1. Lager onderwijs
○ 2. Kunst secundair onderwijs
○ 3. Beroeps secundair onderwijs
○ 4. Technisch secundair onderwijs
○ 5. Algemeen secundair onderwijs
○ 6. Hogeschool korte type/ Professionele bachelor/ Graduaatsopleiding
○ 7. Hogeschool lange type/ Academische bachelor
○ 8. Universitair
○ 9. Post-Universitair

h. What is the post code of your main place of residence?

_ _ _ _

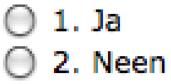
i. What is your current profession?



○ 1. Zelfstandige
○ 2. Ambtenaar
○ 3. Bediende
○ 4. Arbeider
○ 5. Werkloos
○ 6. Kunstenaar
○ 7. Gepensioneerd
○ 8. Andere ☐

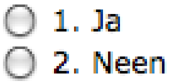
6. Section 6:

a. Are you a member of a nature society?



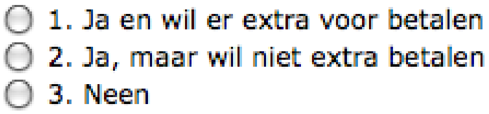
○ 1. Ja
○ 2. Neen

b. Do you believe that the earth is heating up due to the actions of humans?



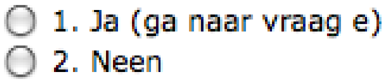
○ 1. Ja
○ 2. Neen

c. Are you prepared to live in a more environment-friendly manner, in order to improve the quality of life and the quality of air?



○ 1. Ja en wil er extra voor betalen
○ 2. Ja, maar wil niet extra betalen
○ 3. Neen

d. Are you already taking action to live in a more environment friendly manner?



○ 1. Ja (ga naar vraag e)
○ 2. Neen

e. Which steps have you already taken to live in a more environment friendly manner?

Thank you very much for completing my questionnaire.

Davy Vercammen

ANNEX 6: Biomass fuel prices

An important driver for biomass utilization levels are the expected biomass price levels. As biomass prices are influenced by the present and future expected situation on the biomass market as well as on substitute markets, it is difficult to numerically assess uncertainty with regard to them. An approximation of biomass price uncertainty could be based on biomass full-chain production cost uncertainty. The step up to biomass price uncertainty would entail factoring expected profit levels on each supply chain step.

Literature on biomass future prices, price uncertainty and full-chain production cost is scarce. Work package 3 final report of the Refuel project gives information on feedstock production cost. (de Wit M.P., 2008) The extension to full-chain production cost is made for biofuels in work package 4 final report of the Refuel project. (Londo H.M. et al., 2008) Uncertainty on feedstock cost and full-chain cost will be discussed. The step up to uncertainty on biomass prices is not made and hence not included for modelling purposes.

BIOMASS FEEDSTOCK PRODUCTION COST

Biomass feedstock potential and associated cost within the EU-27, Switzerland, Norway and Ukraine have been estimated based on available land, specific bio energy crop yield and supply potential of the available land. (de Wit M.P., 2008) The biomass feedstock crops under consideration are wood, grass, oil, starch and sugar. Forestry residues and agricultural residues are further added to these crop potentials. Cost functions are based on requested EJ of biomass feedstock within the EU. Cost drivers for biomass feedstock crops are land costs, fertilizer costs, labour costs, capital costs and miscellaneous costs. Learning in biomass feedstock crop production systems is accounted for.

Uncertainty on biomass feedstock crop costs are mainly situated in the land availability and bio energy crop yield. The level of uncertainty increases with increasing total supply level of biomass feedstock crops. Close to the maximum supply level the uncertainty is rising very sharply.

In the table below costs in €/GJ for different biomass crops, agricultural residues and forestry residues are listed. Costs are dependent on the EJ/year of the different feedstock that is requested on a EU level.

€/GJ in 2020		**EJ/year**									
Type of biomass crop		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Wood crops	**minimum**	1,60	1,70	1,75	1,90	2,00	2,30	2,80	3,50		
	baseline	1,60	1,75	1,90	2,00	2,45	2,95	4,30			
	maximum	1,90	2,00	2,10	2,60	2,80	3,10	5,90			
Grass crops	**minimum**	2,45	2,60	2,85	2,90	3,00	3,20	3,45	3,90	4,40	5,00
	baseline	2,50	2,80	2,90	3,10	3,20	3,60	4,20	4,85	6,00	
	maximum	2,90	3,10	3,20	3,50	3,75	4,00	4,50	5,10	7,00	
Starch crops	**minimum**	5,00	5,50	6,20	8,00						
	baseline	5,00	5,90	7,00							
	maximum	5,60	6,80	8,60							
Oil crops	**minimum**	4,90	7,80	10,10							
	baseline	5,20	8,50								
	maximum	5,90	9,30								
Sugar crops	**minimum**	4,10	4,40	5,20	5,90	6,70					
	baseline	4,10	4,90	5,80	6,60						
	maximum	4,50	5,40	6,00	6,80						
Agricultural residues		1,50	2,10	4,00							
Forestry residues (2005)		2,25	4,00								

Tabel 1: Biomass feedstock crop cost in 2020

In the table below a percentage cost difference is listed between the base case and the minimum (base-min), between the base case and the maximum (base-max) and finally between minimum and maximum (min-max). Note that the percentage cost difference is rated for 2020 and will be different for 2030. More precisely in 2030 there will be a lower cost uncertainty for the same amount of biomass feedstock crop supplied. Costs are based on *Figure 8, Cost-supply curves fort the five assessed crop groups,...* in (de Wit M.P., 2008).

Difference % in 2020		**EJ/year**									
Type of biomass crop		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Wood crops	**base-min**	0%	3%	8%	5%	18%	22%	35%			
	min-max	19%	17%	18%	35%	33%	27%	72%			
	base-max	19%	14%	11%	30%	14%	5%	37%			
Grass crops	**base-min**	2%	7%	2%	6%	6%	11%	18%	20%	27%	
	min-max	18%	18%	12%	19%	23%	22%	25%	25%	43%	
	base-max	16%	11%	10%	13%	17%	11%	7%	5%	17%	
Starch crops	**base-min**	0%	7%	11%							
	min-max	12%	22%	34%							
	base-max	12%	15%	23%							
Oil crops	**base-min**	6%	8%								
	min-max	19%	18%								
	base-max	13%	9%								
Sugar crops	**base-min**	0%	10%	10%	11%						
	min-max	10%	20%	14%	14%						
	base-max	10%	10%	3%	3%						

Tabel 2: Percentage difference in biomass feedstock crop cost in 2020

BIOFUELS FULL-CHAIN PRODUCTION COSTS

In work package 4 final report of the Refuel project the full-chain production cost for a mix of biofuels is determined. (Londo H.M. et al., 2008) Cost differences over time are caused by changing processing and feedstock costs. Other cost types like distribution and transport largely remain constant. The differences in processing and feedstock costs are themselves attributable to a changing mix of first generation and second generation biofuels. For first generation biofuels the feedstock costs are more important than processing costs while for second generation biofuels the processing costs become more important than the feedstock costs. The overall average full-chain production cost remains approximately stable over time which means that it will also remain stable with a changing biofuel mix as one cost type compensates the difference in another cost type. It is important to note though that this constant average full-chain production cost does assume learning effects to take place. This means that, in a quickly changing market, cost spikes might be possible.

The observed cost price effect in terms of feedstock cost and processing cost has an impact on future biofuel price uncertainty in two ways. Firstly, uncertainty on feedstock production costs cannot be extended to uncertainty on full-chain production cost without making assumptions about composition of the biofuel mix. The relative amount of first and second generation biofuels determines sensitivity to changes in feedstock cost. If the feedstock cost component is large then uncertainty on this cost component will have a more severe impact on full-chain production cost uncertainty. Secondly, the implementation path itself affects the learning effect. Hence uncertainty on the future situation cannot be assessed without knowledge of the implementation path towards the future.

In the table below, biofuel full-chain production costs are listed based on information from figure 3, *average biofuel costs over time for the high case* in Londo H.M. et al. (2008).

	€/GJ biofuel		**% of total cost**		**Difference**
Cost component	**2010**	**2020**	**2010**	**2020**	**2020-2010**
Additional end use	0.10	0.10	1%	1%	0%
Distribution	3.43	3.43	23%	23%	0%
Transport	0.57	0.57	4%	4%	0%
Processing	2.14	5.43	14%	37%	22%
Residuals and waste	0.29	1.14	2%	8%	6%
Crop	8.29	4.14	56%	28%	-28%
Total	14.81	14.81	100%	100%	0%

Tabel 3: Biofuel full-chain production cost and breakdown in cost components

BIOMASS PRICES

Taking into account the information available there cannot be a decisive conclusion on uncertainty with regard to future biofuel full-chain production costs. By extension quantification of uncertainty on future biomass prices remains intractable. As a consequence no uncertainty information on future biomass prices will be included in the TIMES model.

ANNEX 7: Sensitivity analyses on TIMES scenario results

During the analyses of TIMES scenario results it is important to assess the robustness as well as the plausibility of the optimal solution. To this end the solution algorithm possesses some unique qualities that allow for sensitivity analyses. These qualities are based on the linear programming trait that for each problem formulation (primal problem) there is matching problem formulation (dual problem) which shares the same optimal solution. While trait is theoretically well established, it is not completely implemented in the commercially available GUI for TIMES models (VEDA). In Remme et al. (2009) a theoretical overview of the dual problem solution and its interpretation for a TIMES model is presented. In addition to the theoretical overview a matrix tool is presented which applie duality theory to a TIMES model.

In the TUMATIM project the matrix tool was applied to the TIMES model and further developed. Though the development of the matrix tool falls outside the scope of the TUMATIM research goals, the acquired knowledge and findings are reported here as an important side-effect of the goal oriented research. The proficiency to quickly and accurately assess model results with regard to robustness and plausibility will have a positive effect on future study work with TIMES based models.

THEORETICAL BASIS – DUALITY THEORY

Duality theory is based on the relation between the primal and dual problem. (Hillier and Lieberman, 1995) The nature of the primal problem is a minimization of an objective function given a set of linear constraints which can be rephrased to a set of equations of the *larger or equal to* form. All variables are zero or positive. The dual problem is the maximization of an adjusted objective function with an adjusted set of constraints.

Primal problem

$$Minimize\ Z = \sum_{j=1}^{n} c_j x_j$$

$$subject\ to$$

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \quad for\ i = 1,2,\dots,m$$

$$and$$

$$x_j \geq 0 \qquad for\ j = 1,2,\dots,n$$

Dual problem

$$Maximize\ \ y_0 = \sum_{i=1}^{m} b_i y_i$$

$$subject\ to$$

$$\sum_{i=1}^{m} a_{ij} y_i \leq c_j \quad for\ j = 1,2,\ldots,n$$
$$and$$
$$x_i \geq 0 \qquad for\ i = 1,2,\ldots,m$$

In the above formulation the interpretation of coefficients and variables is as follows:

- Z = objective function value
- c = cost coefficients of decision variables
- x = decision variables related to technologies (example: activity, investment decision)
- a = non-cost coefficient representing properties of technologies (example: materials used and produced during operation)
- b = value of the upper bound (example: all material balances must be greater or equal to zero, you cannot use what you did not produce or import)

So the objective of the primal problem can be interpreted as cost minimization with regard to technology choices and the dual objective usefulness maximisation of material utilization.

It is in the interpretation of the dual problem constraints that the theoretical basis for the matrix tool can be found. For the sake of clarity it will be assumed that variable x (primal problem) represents the activity of a process and variable y (dual problem) reflects material usage value. In the TIMES model other variable representations are used and the theory presented is also applicable to them, albeit with another interpretation. For each variable in the primal problem there exists a constraint equation in the dual problem. This constraint equation states that the value created by consumption of a material minus the cost of production of a material should be greater then or equal to the operational cost of using it in a process. It can be shown that when a technology operates at a strictly positive level (the primal variable x is strictly positive) the related dual constraint inequality becomes an equality. If the process does not operate at a strictly positive level, the related dual constraint inequality remains an inequality and the value difference between the left and the right hand side shows the value loss incurred when the process would be forced to operate at a strictly positive level.

Mathematically this results in:

$$\sum_{i=1}^{m} a_{ij} y_i \leq c_j \quad for\ j = 1,2,\ldots,n$$

becomes

$$\sum_{i=1}^{m} a_{ij} y_i = c_j \quad for\ j = 1,2,\ldots,n$$

for all x_j

operating at a strictly positive level.

It is the value loss discussed above that provide the necessary insights in model dynamics. Possible questions to be answered are: Does the operational cost have to come down and by how much? Does the conversion efficiency has to rise and by how much? In what sequence would non-profitable technologies become profitable when a certain parameter is changed?

SENSITIVITY ANALYSES IN PRACTICE – BLAST FURNACE ALTERNATIVES

The matrix tool will be applied to blast furnace alternatives to illustrate the theoretical concept explored in previous section. Blast furnaces are part of the iron and steel industry and are used to produce raw iron. There are several options available to blast furnaces in order to accommodate other efficiencies and emission. In the table below a value analyses of a marginal activity unit per blast furnace variant is presented. A marginal activity value represents the generated cost/benefits attributable to one extra unit of activity ceteris paribus. So if the current activity is zero, the marginal value would be the cost/benefits attributable to an increase in activity from zero to one. The values listed are expressed as euro per ton iron output from the process alternatives for the year 2020.

	€/ton iron						
Process	Capacity utilization	Variable operating cost	Energy in/out	Materials in/out	Limit	Iron out	Value deficit
Blast furnace	0,00	-16,47	21,65	-199,83	34,09	160,56	
Blast furnace + CCS[17]	-531,01	-24,45	50,28	-161,80	34,09	160,56	472,33
Blast Furnace + DCI[18]	-22,98	-17,64	23,86	-177,90	34,09	160,56	
Blast Furnace + TGR[19]	-30,57	-13,55	20,78	-171,31	34,09	160,56	0,00
Blast Furnace + TGR + CCS	-453,26	-15,68	21,22	-134,67	34,09	160,56	387,74

Tabel 4: Value analyses of 1 marginal ton iron production for blast furnace alternatives in 2020 in a reference scenario

Column *Iron out* shows that the marginal value of one ton iron equals 160,56 €.

Active (profitable) processes are traditional blast furnace and blast furnace with direct coal injection since they have no value deficit in column *Value deficit*.

Blast furnace with top gas recirculation has a very small value deficit and is almost tied with the active blast furnace types. As a relatively lower value of materials in/out is observed for the blast furnace with top gas recirculation, a moderate cost increase of these materials might force a switch from the two active types to the top gas recirculation type.

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[17] CCS: Carbon Capture and Storage

[18] DCI: Direct Coal Injection

[19] TGR: Top Gas Recirculation

The alternatives with carbon capture and storage have a very high value deficit. This deficit originates from the high value in column *Capacity utilization*. Capacity utilization is an allocation of the cost of new capacity combined with fixed operating costs. The relative difference between capacity utilization value for CCS and non-CCS variants cannot be attributed to the level of the lump sum investment cost since it does not differ that much between the blast furnace types. The reason for the relative difference can be found in the allocation of the lump sum investment cost to the model periods for the different blast furnace types. Since there is no CO_2 limitation in the TIMES reference scenario, CCS technology does not add value in the long run and a large part of the lump sum investment cost is allocated to the current year. This allocation effect is further reinforced by the operational economies of CCS technologies which are such that even though an investment in CCS technology would take place, it would not be used in the future. Hence CCS variant lump sum investment costs is allocated to the current year instead of a spread over multiple years like for the non-CCS alternatives.

Column *Variable operating cost* presents non-energy, non-material related costs that are proportional to the activity level of an installation.

Column *Energy in/out* has a positive value because of produced side products like blast furnace gas which can be used as a fuel.

Column *Materials in/out* presents the value balance of consumed materials and valuable residues. The positive effect of CO_2 emission reductions is include here for the CCS variants. Due to the lack of stringent CO_2 caps the positive contribution only has a minor impact on the total material balance value.

Column *Limit* is model specific and represents a boundary on activity for all blast furnace types which has been defined by the modeller. Since a boundary has to be adhered to, there is an intrinsic value in each activity which adds to conformity with the boundary. It can be interpreted as the opportunity cost of not using the process in which case another process needs to fill the gap.

ADDITIONS TO THE MATRIX TOOL AND RELEVANCE OF SENSITIVITY ANALYSES

The short analyses above can be performed fairly quickly and so it becomes feasible for a large set of modelled technologies. As a result of this, the research team uncovered several possibilities for further model optimization in the TUMATIM project which would otherwise go un-noted. Examples are but not limited to:

- Identification of prohibitively expensive materials because of lacking capacity options
- Identification of unrealistic modelled solution boundaries
- Cost coefficient adjustments to better represent reality
- Identification of unrealistic modelled solution boundaries

While the model optimization itself is relevant for the TUMATIM scenario results, the matrix tool can add even more to future modelling exercises with TIMES. The TUMATIM research partners will present their findings to the ETSAP[20] community for further discussion.

The drawback of the existing matrix tool, prior to utilisation by the TUMATIM research team, is that it requires a thorough knowledge of the mathematical properties of linear programming, a proficiency in the use of GAMS[21] and it does not present the results in a generally accepted front-end[22]. The TUMATIM research team expanded the existing matrix tool by further automating the processing in GAMS and by establishing an automatic link and formatting of results in Microsoft Excel. By means of the automated formatting and import in Excel the team also hopes to make the output of the matrix tool accessible to non-experts whom might contribute to model structure and data without being proficient in the modelling activity itself.

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[20] ETSAP: Energy Technology Systems Analysis Program

[21] GAMS: General Algebraic Modelling system

[22] It is presented in VEDA-BE, a front-end tool used by energy modellers, that is not accessible to other users.

ANNEX 8 : TUMATIM visibility in Energy News and the annual report of VITO

In line with the findings of TUMATIM, the relation between energy efficiency and energy use is not straightforward. An interview on the macro-level was taken in 2009 with Wouter Nijs.

ENERGIE-EFFICIËNTIE: een prioriteit in crisistijden?

1| De socio-economische context

De economische crisis houdt de energieprijzen laag en dreigt een rem te zetten op veel energiebesparingsprojecten. Toch is de stap terug geen optie, vindt Didier Goetghebuer (ICEDD – Institut de Conseil et d'Etudes en Développement Durable). Hij pleit zelfs voor een verregaande omslag naar een groene economie. Hoe dan ook moeten bedrijven blijven investeren in energie-efficiëntie, al was het maar uit eigenbelang, vindt Wouter Nijs (VITO – Vlaamse Instelling voor Technologisch Onderzoek).

2| Politieke keuzes voor energie-efficiëntie

België is op het gebied van energie-efficiëntie een slechte leerling in Europa. Maar mits de juiste politieke keuzes kan ons primair energieverbruik tegen 2030 nog met 29 % dalen onder het niveau dat nu wordt voorspeld, zo concludeert een McKinsey-studie. De industrie kan ongeveer een derde van die bijkomende energiebesparing voor haar rekening nemen.

3| Optimaliseren om sterker te staan

In het huidige crisisklimaat is de industrie vooral op zoek naar energiebesparingsmaatregelen met een snelle return. Toch zullen bedrijven steeds beter voelen dat energie-efficiëntie een duidelijk competitief voordeel is in de internationale economie. Daarom moeten de bedrijven nu optimaliseren om na de crisis sterker te staan, zegt Randy Stiens van Laborelec, het technisch onderzoeks- en competentiecentrum van Electrabel.

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WOUTER NIJS (VITO) ZIET KANSEN IN TIJDEN VAN CRISIS MAAR WAARSCHUWT VOOR NEVENEFFECTEN

In de huidige economische crisis zijn bedrijven niet spontaan geneigd om veel te investeren in energiebesparende maatregelen. Toch zouden ze dat beter wel doen, vindt Wouter Nijs van de Vlaamse Instelling voor Technologisch Onderzoek (VITO). "De energieprijzen gaan straks immers weer stijgen", zegt hij, "niet alleen door de stijgende vraag, maar ook omdat de externe kosten onder meer via emissiecertificaten steeds meer zullen worden doorgerekend. Daardoor wordt energie-efficiëntie bijna onvermijdelijk". Toch waarschuwt hij voor onbedoelde neveneffecten.

1 | Economische instrumenten moeten energie-efficiëntie onvermijdelijk maken

Voor de meeste bedrijven is de eerste prioriteit vandaag om de facturen te kunnen betalen. Voor nieuwe investeringen lijkt het klimaat ongunstig. Maar u relativeert dat?

Inderdaad. Er zijn nog heel wat bedrijven die vandaag sterk staan. Zij kunnen profiteren van de lage risicovrije kapitaalkost. Projecten die een jaar geleden nog werden afgevoerd omdat ze niet snel genoeg werden terugverdiend, worden nu weer interessant dankzij de lage rentevoet. Anderzijds zijn de banken terughoudender geworden om kapitaal te verschaffen. Afhankelijk van het bedrijf of het soort investering rekenen ze soms veel grotere risicopremies aan.

Toch kiezen bedrijven vandaag niet snel om te investeren in energie-efficiëntie?

Bedrijven zouden investeringen in energie-efficiëntie moeten beschouwen als normale bedrijfsprojecten. Het zou een deel van hun core business moeten worden, al moet ik eerst toch waarschuwen voor overdreven verwachtingen. We gaan de crisis niet oplossen door alles te zetten op energiebesparing. Dat gaat niet, want energieprojecten werken op middellange termijn, terwijl crisisbeheersing altijd tijdelijke kortetermijnoplossingen vereist. Daarvoor is energiebesparing op zich niet geschikt.

Maar het is bedrijfseconomisch nonsens om geen energiebesparende maatregelen te nemen. Dat staat gelijk met geld weggooien. Er zijn zelfs directe winsten mee te boeken. Denk bijvoorbeeld aan de emissiehandel.

Is die emissiehandel nog altijd een doeltreffend instrument om tot energiebesparing aan te sporen? Ook in tijden van crisis?

De emissiehandel is een goed economisch instrument. Het is een doeltreffend mechanisme om de toenemende uitstoot van broeikasgassen tengevolge van energieverbruik uiteindelijk door te rekenen naar de verbruiker door het spel van vraag en aanbod. In de economie heet dat het internaliseren van een externe kost. Bijvoorbeeld: we zijn ons allemaal bewust van het schadelijk effect van een verdere toename van de CO_2-concentratie, maar tot voor kort draaide niemand daar financieel voor op. De emissiehandel verplicht de bedrijven nu wel om ervoor te betalen. In de toekomst zullen er nog meer schadelijke effecten worden doorgerekend in de kostprijs. Daardoor alleen al gaan de energieprijzen weer stijgen, nog los van de te verwachten stijging van de energievraag.

Waarom zijn economische instrumenten zoals de emissiehandel doeltreffender dan het vastleggen van uitstootnormen?

Europa legt vast dat we 20 % minder broeikasgassen gaan uitstoten tegen 2020. Met een systeem zoals de emissiehandel kan de overheid de doelstelling betonneren en de markt daarop laten inspelen. De handel in emissierechten zorgt er immers voor dat er maximaal in energie-efficiëntie geïnvesteerd wordt waar de grootste return zit. Bedrijven die met beperkte investeringen grote uitstootverminderingen kunnen realiseren, worden gestimuleerd om beter te doen dan een norm, omdat ze het saldo aan emissierechten kunnen doorverkopen. Dat is pure winst, zowel voor het bedrijf als voor de maatschappij.

Bovendien is het goedkoop omdat de energiebesparingen automatisch worden gerealiseerd op de meest efficiënte wijze. En als het systeem van de emissiehandel correct wordt uitgevoerd, zijn we zeker dat we de doelstelling gaan halen. Zoiets is moeilijker met het heffen van een taks.

> *"Investeringsprojecten in energie-efficiëntie moeten beschouwd worden als normale bedrijfsprojecten. Er zijn zelfs directe winsten mee te boeken".*

INVESTEREN IN BETROUWBARE KOSTENMODELLEN VOOR HET ENERGIE- EN KLIMAATBELEID

VITO stelt technisch-economische energiemodellen op punt

Klimaatverandering, bevoorradingszekerheid en duurzame ontwikkeling staan hoog op de agenda van de beleidsmakers. Dat belang wordt nog aangescherpt door de recente oliecrisis. VITO levert reeds enkele jaren wetenschappelijke ondersteuning aan het Vlaamse en Belgische energie- en klimaatbeleid. Zij maakt hiervoor gebruik van technisch-economische computermodellen zoals MARKAL-Times. Aan de hand van een integrale beschrijving van het energiesysteem - potentieel van energiebronnen, huidige energie-uitrusting, nieuwe technologieën, beleidskeuzes zoals het groenestroombeleid … - berekent dit model de goedkoopste combinatie van energiediensten om aan de energievraag van een land te kunnen voldoen.

VITO zet nu samen met het Centrum voor Economische Studiën van de KULeuven in op een verdere ontwikkeling en verfijning van het MARKAL-Times-model. Het energiebeleid wordt gekenmerkt door bepaalde onzekerheden, zoals de evolutie van de energieprijzen, de ontwikkeling van technologieën, de impact van het klimaatbeleid … Het doel is om de MARKAL-Times-software beter te laten omgaan met deze onzekerheden. De VITO-onderzoekers ontwikkelden een methodologie om de impact van deze onzekerheden te kwantificeren, en rustten vervolgens de bestaande software hiermee uit. Deze verbeterde versie van MARKAL-Times levert robuustere energiestrategieën op, die rekening houden met de risico's op verschillende niveaus. Een specifieke onzekerheid die het onderzoek in rekening bracht, is de prijselasticiteit van energiediensten - dit is de mate waarin burgers hun gedrag wijzigen als een energiedienst duurder of goedkoper wordt. Het spreekt voor zich dat prijselasticiteiten cruciaal zijn voor het welslagen van het duurzame-energiebeleid. Het is dus belangrijk ze correct te kunnen inschatten.

VITO verankert haar klimaatonderzoek ook in internationale programma's. Ze maakt deel uit van het internationale ETSAP-netwerk (Energy Technology Systems Analysis Programme van het Internationale Energieagentschap), dat verantwoordelijk is voor het onderhoud van de MARKAL-software en regelmatig bijeenkomt om de ervaring met beleidsstudies van een twintigtal landen te vergelijken. In ETSAP-verband werkt VITO onder andere mee aan een Europese referentiedatabank voor de energiesector.