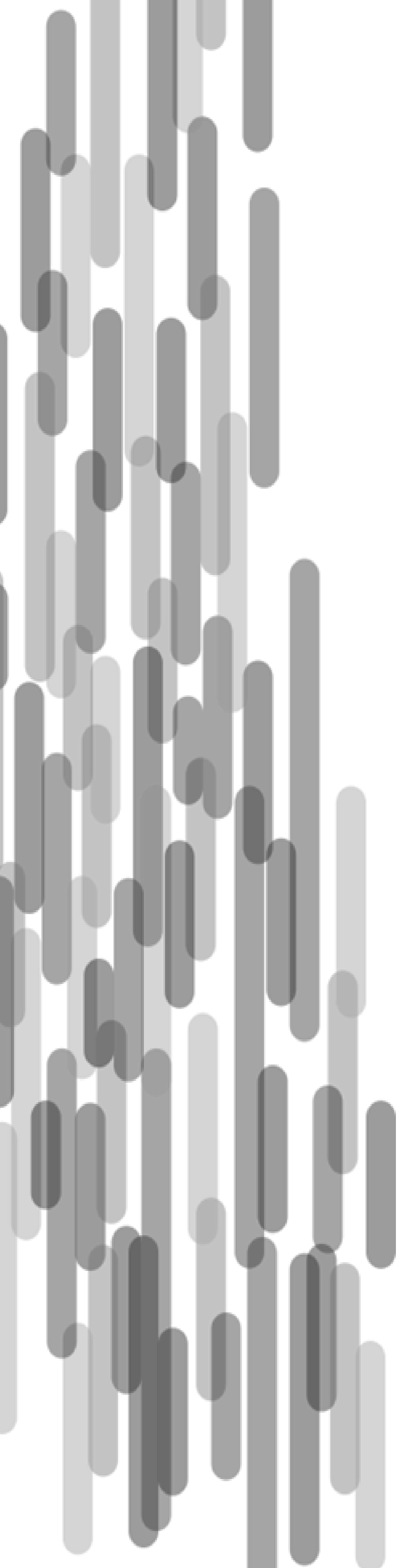

EC4MACS

Uncertainty Treatment

The PRIMES Energy Model

European Consortium for Modelling of Air
Pollution and Climate Strategies - EC4MACS

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1.1. Short overview of the PRIMES model

1.1.1. How PRIMES is structured as a simulation tool

The PRIMES model is a modelling system that simulates a market equilibrium solution for energy supply and demand, combining economic and engineering representation of energy related decisions of agents such as consumers and producers of different energy commodities. The model determines the equilibrium by finding the prices of each energy commodity such that the quantity producers find best to supply matches the quantity consumers wish to use. The simulation of agents' behaviours of market equilibrium follows a time-forward path, under dynamic relationships.

The model is organized in sub-models (modules), each one representing the behaviour of a specific (or representative) agent, a demander and/or a supplier of energy.

The agent's behaviour is modelled according to microeconomic foundation: the agent is represented to perform maximisation of benefit (profit, utility, etc) from energy demand and/or supply (for industry also from use of non energy production factors), under constraints that refer to activity, comfort, equipment, technology, environment or fuel availability. Microeconomic foundation is a distinguishing feature of the PRIMES model and applies to all sectors. Although the decision is assumed to be economic, many of the constraints and possibilities reflect engineering feasibility and restrictions. The model thus combines economics with engineering, in order to ensure consistency. PRIMES is clearly more aggregated than engineering models and far more disaggregated than econometric (or reduced form) models. So, the modelling of agents' behaviours is based on simulation founded on microeconomics and not on econometric relationships.

1.1.2. Calibration of model's coefficients not statistically estimated

All coefficients and parameters used in the mathematical formulation of agents' behaviours and in the market equilibrium relations are exogenously determined either based on expert estimates or calibrated (calculated) so as to allow the model reproducing the statistically observed energy balances and emission data when simulation runs for a past year.

This is a common approach for market equilibrium and models founded on microeconomics, which contrasts models with reduced-form equations that derive coefficient values from statistical estimations.

The market equilibrium models with calibrated coefficients are useful for detailed and long term simulations, whereas the reduced-form models with statistically estimated coefficients are useful for short term forecasting exercises.

1.1.3. Use of the model for scenario quantification

The model incorporates alternative policy instruments that are meant to influence energy demand, supply and prices, such as: taxes and subsidies, tradable certificates, tradable emission allowances, emission limitation standards, energy efficiency performance standards, obligations (e.g. for renewables, CHP, etc.) and technology push mechanisms (e.g. promotion of energy savings, etc.).

As with most detailed simulation models, PRIMES is used for policy analysis by applying the method of scenarios. Given that the number of exogenous parameters is very large, scenario design consists in giving values to the exogenous parameters in a consistent manner to reflect the context of a scenario, which can be expressed also as a storyline. Then the model is used to quantify the endogenous variables, in other words to perform the simulation. The values of exogenous and endogenous variables, all together, constitute a quantification of the scenario. By comparing scenarios, one can draw policy-relevant conclusions and perform analysis.

The quantitative analysis using the PRIMES model starts from the definition and development of a reference case (the "Baseline" scenario) which reflects the effects of current trends and policies in place. The Baseline scenario does not consist by any means a forecast and does not necessarily correspond to the most probable future. Its' quantification involves extensive consultation and exchange of ideas with Commission officials, industry stakeholders and Member States experts in an attempt to best capture the effects of current trends and policies on the evolution of the energy system per EU Member State and for the EU as a whole.

Inputs for the development of the reference scenario include:

- GDP and economic growth per sector (disaggregated at the level of sectors as represented in PRIMES)
- World energy supply outlook – world prices of fossil fuels
- Tax and subsidy policies
- Interest rates, risk premiums, etc.
- Environmental policies and constraints
- Technical and economic characteristics of future energy technologies
- Energy consumption habits, parameters about comfort, rational use of energy and savings, energy efficiency potential
- parameters of supply curves for primary energy, potential of sites for new plants especially regarding power generation sites, renewables potential per source type, etc.

Outputs include projection of detailed energy balances, emissions, investment, costs and prices.

1.2. Typology of uncertainties in the PRIMES model and its database

The very detailed representation of the energy system in the PRIMES model and its nature as a simulation tool for scenario quantification implies that the uncertainties surrounding the numerical values of parameters can be categorised as follows:

1. uncertainties related to historical statistical data
2. uncertainties related to engineering data
3. uncertainties related to parameters entering the modelling of agents' behaviours
4. uncertainties related to assumed policy drivers in scenario construction
5. uncertainties related to assumed future evolution of technologies in scenario construction
6. uncertainties related to the context outside the boundaries of the system simulated by PRIMES (e.g. world energy system, macroeconomics, etc.) in scenario construction.

The first three categories above concern the model database inputs, whereas the last three categories concern the exogenous assumptions when quantifying a scenario using the PRIMES model.

1.2.1. Historical statistical data

The main statistical source used in PRIMES is the EUROSTAT database, complemented by other sources such as the IEA database for energy prices, the PLATTS and ESAP database for power plants capacities, the EEA and UNFCCC for environmental statistics, various private databases for renewable potentials, data from professional associations about industry and infrastructure, and others.

The update of the model database is carried out periodically, usually every two or three years and in the context of "baseline" scenario construction supervised by DG Energy. Several updates were carried out since mid 90's and the most recent is dated back to end 2009, when the latest statistical data available referred to 2007.

Uncertainties related to historical data arise from the quality of available statistics, especially for the most recent statistical years, and the degree of matching of the statistical data with the level of disaggregation used in PRIMES. It is considered that the Eurostat databases are rather robust and so there is no uncertainty analysis for these data which comprise the energy balance sheets, the prices, the emissions and the import-export flows.

However, often Eurostat revises the statistics in a retrospective way. In that case it is possible that in a certain point of time, between two database revisions the PRIMES, data for the past are different from the latest Eurostat statistics. This discrepancy is remedied when the PRIMES database is updated. Another source of uncertainty occurs when Eurostat undertake revisions in the methodology of data definitions and their attribution to the different energy consuming agents. Examples are the CHP statistics and the biomass data.

The data from other sources, especially from the industry, professional associations, TSOs, private sources for RES, etc. are more uncertain regarding their accuracy and their coverage. Usually, before using them in the PRIMES database, a consistency analysis is performed consisting in checking aggregates from these data against Eurostat data. Adjustments are then made to render these data consistent with the energy balances.

As the model is fully calibrated to past statistics (parameter values are derived so as to allow the model simulate the past with accuracy), the derived numerical values of exogenous parameters influence the simulation of future evolution of the energy system. So statistical revisions and updates have an impact on the projections. This type of uncertainties is difficult to be foreseen and dealt with beforehand. Dealing with them occurs only after the publication of new statistics and involves the revision of the model database and the re-calibration of the model in order to reflect the revised characteristics of the energy system as recorded for the past.

Because of the large size of the model and the very high level of detail of the database, we do not perform sensitivity analysis regarding the historical database. Only small econometric models could afford doing this. So only when database revisions and updates are performed (every two or three years) we can report on the impacts on projections from the revision of the historical database. One can get an idea of such impacts when comparing the different versions of the Energy Trends publication of DG Energy which is based on PRIMES; the Energy Trends to 2030 publication has published three consecutive versions with different updates, namely updates in 2005, 2007 and 2009.

1.2.2. Engineering data

The engineering data in the PRIMES database concern the technical and economic parameters which characterise the energy efficiency and the cost of the energy technologies, both in demand and in supply sectors, which are represented in the model.

The sources for these data are diverse, including VGB database (a specialised German company in providing data derived from power plant construction projects), IEA, European Technology Platforms, and databases produced by EU research projects, such as the TECHPOL database.

Because the engineering data are uncertain and often different depending on the source, the PRIMES team often presents comparisons of engineering data used with data published by other sources; these presentations have been frequently discussed in workshops organised by the European Commission.

The engineering data have a form of time series and so part of the data correspond to the past and part constitute projections to the future. The engineering data for the past are not subject to uncertainty analysis, because they have rather small influence on the model calibration. On the contrary, the engineering data as projected to the future play an important role in the quantification of scenarios. Uncertainty analysis regarding these projections is discussed below.

1.2.3. Parameters entering the modelling of agents' behaviours

The numerical values of parameters entering the mathematical formulation of agents' behaviours are assumed by the PRIMES modellers, based on various sources, literature review and experience. As the model performs microeconomic simulation, these parameters cannot be estimated with econometric techniques in a direct way. However, the values assumed are decided after extensively reviewing econometric estimations published.

Because of the size of the model, we perform uncertainty analysis through sensitivity analysis model runs only for few behavioural parameters in the model, such as some activity and price elasticities and also with respect to the parameters reflecting perception of technology costs by consumers and the discount rates. Such sensitivity analysis are carried out by quantifying scenario variants in which the values of these parameters vary.

1.3. Exploring uncertainties through scenario construction

Uncertainties related to scenario assumptions span the whole range of model inputs such as:

- macro and global assumptions (macro-economic developments, demographic projections and international fuel prices assumptions),
- policy assumptions (possible policy failures, under-estimation or overestimation of the effectiveness of policies in place, introduction of new policy incentives etc),
- technological assumptions (possible technology failures, faster penetration of new technologies than that foreseen in a scenario, availability of new technological options etc.) and others.

The model outcomes are of course sensitive to changes of the above data which are exogenous to the model and which constitute scenario assumptions for the model-based projections to the future.

Analysis for this type of uncertainties is carried out by defining alternative scenarios reflecting contrasted evolution of the exogenous assumptions projected to the future. Because of model size and complexity, the only way to explore these uncertainties is by quantifying alternative scenario. This is a common practice for all models with similar size and nature as PRIMES.

It is more practical to combine changes of many of the above mentioned exogenous assumptions rather than changing a single exogenous parameter. So an important issue is to define which set of assumptions to change so as to ensure that the alternative scenarios to quantify are relatively few and are also relevant for the type of sensitivity analysis required.

This is the usual approach retained in the context of the quantitative analysis performed for the various European Commission studies which use the PRIMES model.

This approach, that is a scenario based exploration of uncertainties, was also retained in the context of the EC4MACS project. Starting from a Reference scenario, the PRIMES team developed five (5) energy scenarios for all EU Member – States for the time period until 2050. The scenarios were designed so as the EU reduces GHG emissions by 75-80% in 2050 compared to 1990 levels and by 40% in 2030. The five energy scenarios explore different pathways, different policy and macro contexts and different assumptions about future technology change while aiming at reaching the same emission reductions. The scenarios are useful for analyzing the uncertainties surrounding the projections of the energy system to the future. An example of scenario assumptions can be summarized as follows:

S1) Low carbon scenario assuming successful development of technologies in power generation, in energy efficiency and in mobility electrification. The EU emission reduction effort is assumed to take place at a world scale inducing lower world fossil fuel prices, compared to baseline.

S2) Low carbon scenario assuming successful development of technologies as in S1 but postulating that the emission reduction effort is not undertaken worldwide and so world fossil fuel prices remain at their baseline scenario level.

S3) Low carbon scenario, similar to S2, which assumes that the emission reduction effort is delayed until 2035 and starts more intensively after 2035.

S4) Low carbon scenario, similar to S1, which assumes that the electrification in road transportation is delayed and develops mainly after 2035-2040.

S5) Low carbon scenario, similar to S2, which assumes a world oil price shock which would take place around 2035 and will lead to increased energy prices until 2050.

Comparing S2 to S1 analyses the impact on the EU of a feedback on world energy prices resulting from global climate change mitigation effort. Comparing S3 to S2 analyses the impact on the EU of a delay in undertaking the climate change mitigation effort. Comparing S4 to S1 analyses the impact on the EU of failures in electrifying mobility in the medium term. Comparing S5 to S2 analyses the impact on the EU of an oil price shock in the context of a strong emission reduction effort. It is evident that the above scenario cases were selected in order to explore key uncertainties surrounding the pathways towards a low carbon energy system of the EU to the horizon of 2050.

1.4. Indicative results of uncertainty exploration through scenarios

1.4.1. Uncertainty about future import prices of fossil fuels

An important uncertain issue for European climate policy is whether or not the rest of the world will follow a similar emission reduction path in the future. If climate action is global, then it should be expected that world fossil fuel prices will tend to decrease from current levels as worldwide demand for fossil fuel will decrease in the future because of the deployment of low carbon emitting technologies. On the contrary, if the European climate action is not followed worldwide, it is possible that global demand for fossil fuel remains at a rather growing pathway inducing higher fossil fuels prices in the future, resulting from pressures in the supply of these fuels.

This uncertainty has important consequences on the domestic costs and prices in the EU: low world fossil fuel prices will moderate the trend towards higher energy costs owing to transition to a low carbon economy but in the same time the low prices will require more effort to incite consumers and suppliers to select low carbon emitting options. On the contrary, high world fossil fuel prices on one hand will contribute to using less fossil fuels but on the other hand the total compliance cost incurring for consumers will be high and will not be partly compensated by the dropping price levels.

This uncertainty has been explored using PRIMES by means of quantifying alternative scenarios. These scenarios deliver the same level of future carbon budget (that is cumulative emissions of greenhouse gases between 2010 and 2050). The scenarios deploy the decarbonisation actions in different contexts, one under high world energy prices and another under low prices. To reach the same carbon budget, the two scenarios require different levels of carbon prices, as energy prices are different, all other policies and measures being deployed similarly. The different levels of carbon prices induce different effects on energy demand and supply sectors, regarding energy efficiency improving actions and investment. They also affect the choices about fuel mix and the degree of development of low or zero carbon emitting technologies in the energy supply sectors, including electricity generation. So the consequences on the energy system are important and different; hence the cost implications are different.

The energy costs incurring by consumers change from reference projection levels through two mechanisms which contradict each other: decarbonisation both in demand and supply sectors tend to increase the cost of delivering the energy services and commodities, as the cost of capital increases by deploying energy savings, more efficient equipments, renewables, nuclear, CCS which are generally more costly in capital terms; the cost of fuel purchasing is lower because of lower consumption owing to decarbonisation, but in the case of low world energy prices this fuel cost tend to decrease furthermore from reference scenario levels; the drop of unit fuel costs partly compensates for the increasing capital cost of decarbonisation. This compensating effect is absent in the case of high world energy prices, but also the decarbonisation effort is slightly lower as part of rational use of energy is incited by high fossil fuel prices.

The above analysis can be illustrated and confirmed by the numerical simulations using PRIMES model, as it is shown in a table below which summarises results for EU27.

Uncertainty about future import prices of fossil fuels (EU27 results from PRIMES)

	2020		2030		2040		2050	
	Low prices	high prices	Low prices	high prices	Low prices	high prices	Low prices	high prices
Carbon price (EUR'08/tCO2)	25	25	60	51	78	64	190	147
Energy System Cost (bill. EUR'08)	**2156**	**2206**	**2753**	**2910**	**3185**	**3422**	**3768**	**4103**
Costs for industry (bill. EUR'08)	313	319	339	372	334	389	419	494
Costs for households (bill. EUR'08)	709	714	836	876	971	1045	1274	1350
Costs for tertiary (bill. EUR'08)	286	289	318	335	327	356	394	420
Costs for transport (bill. EUR'08)	848	884	1260	1328	1553	1632	1681	1839
Avg. electricity price (EUR'08/MWh)	151	151	157	159	153	159	155	167
GHG emissions (Mt CO2 equiv.)	4144	4114	3312	3277	2108	2160	1114	1113
Gross Inland Consumption (Mtoe)	**1737**	**1729**	**1674**	**1659**	**1519**	**1494**	**1358**	**1338**
Solids	225	225	130	137	107	112	112	113
Oil	597	584	525	504	348	326	179	165
Gas	406	409	385	371	321	291	244	219
Nuclear	239	240	301	307	329	343	337	347
Renewables	273	274	335	342	416	425	489	495

It is clarified that in the simulations shown in the table above, the carbon prices are an endogenous result of the PRIMES model and are determined at the level needed to obtain a constant carbon emission budget until 2050 in all scenarios.

The resulting levels of carbon prices are higher in all years under the assumption of low world energy prices, compared to the case of low world energy prices. The reason is that the fossil fuel prices partly induce lower energy consumption, hence lower emissions, and the additional price signal through carbon prices as needed to obtain the required carbon budget are consequently smaller in the case of high fossil fuel prices. The results on gross inland consumption (total primary energy requirements) as projected using the PRIMES model confirm the effects of world fossil fuel prices on energy consumption.

The above shown results, also confirm that part of the total decarbonisation costs (shown as energy system cost) is compensated by the decrease in fossil fuel prices; this effects is seen in the decomposition of costs by sector of final consumption. It is also confirmed when seeing the average electricity prices, which are lower in the cases of low world fossil fuel prices, as expected.

The line showing results for total GHG emissions correspond to annual emissions. The carbon budget is defined as a cumulative sum of emissions over the period 2010-2050 and is by scenario construction the same in both world energy price scenarios.

1.4.2. Uncertainty about climate policy and structural changes in transport

Although the European Union has clearly set emission targets for the time period until 2050, there remain uncertainty about the intensity of climate actions and policies during the time period until 2050. It could be the case that for various reasons the climate policies and actions are adopted with some delay, for example in the time period 2020-2030. In such case, the intensity of climate actions must by very intensive in the time period after 2030 in order to reach a given carbon budget (cumulative emissions). How such a delay case compares against adopting the climate actions and policy at the "optimal" pace and intensity in the intermediate time period?

A response to this uncertainty issue is approached using PRIMES model by quantifying alternative scenarios which do not differ in terms of carbon budget but they do differ in terms of climate action intensity during the intermediate period, essentially during the decade 2020-2030.

Another important policy uncertainty concerns the pace of introduction of electricity in road transport. Electrification in transportation is an important way of reducing emissions in a cost-effective way because as power generation decarbonises electricity increasingly becomes an energy carrier which can reduce emissions in the transport sector by substituting for oil. It is widely accepted that this is the most promising way for curbing emissions in an otherwise very inflexible sector, as the transport sector. Electrification of road mobility is a complex process: consumer decisions for buying electric cars depend on costs but also on availability of recharging infrastructure; investment to develop this infrastructure will develop once a certain critical mass of electric vehicles is already in operation and also if public policy, including regulated grid monopolies command for such investment. Also the electrification heavily depends on the pace of technology improvement in the domain of batteries and their density and costs.

All these uncertainties including the coordination between public policy (infrastructure, regulation) and private decisions (car choice and technology availability) may delay transport electrification. If despite this delay, climate strategy requires to keep a certain carbon budget unchanged, because of climate requirements, then an important issue to examine regards the cost and impacts of such a delay and generally the uncertainty surrounding the pace of transport electrification.

This uncertainty case was explored using PRIMES by quantifying alternative scenarios which assumed a delay in transport electrification and an increase in the intensity of deploying other decarbonisation options. The results of such delay scenarios compared to a scenario case without delay and with equal carbon budget provides information about the cost of the delay (in other words the cost of removing the uncertainty). Such an information is evidently very important for policy making and in particular for ensuring that the recharging infrastructure is in place in a timeliness manner within the context of a decarbonisation strategy.

The PRIMES model results for the above uncertainties (policy failures) are exemplified in the table below.

Uncertainty about climate policy and structural changes in transport

	Policy success case			Delayed climate policy			Delayed transport electrification		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Carbon price (EUR'08/tCO2)	60	78	190	36	170	340	57	92	245
Energy System Cost (bill. EUR'08)	**2753**	**3185**	**3768**	**2778**	**3402**	**4058**	**2745**	**3398**	**4430**
Costs for industry (bill. EUR'08)	339	334	419	334	339	420	340	340	423
Costs for households (bill. EUR'08)	836	971	1274	790	1012	1296	841	996	1307
Costs for tertiary (bill. EUR'08)	318	327	394	308	353	397	321	338	408
Costs for transport (bill. EUR'08)	1260	1553	1681	1346	1698	1944	1242	1724	2292
Avg. electricity price (EUR'08/MWh)	157	153	155	151	154	156	158	156	159
GHG emissions (Mt CO2 equiv.)	3312	2108	1114	3708	1627	918	3330	2087	1107
Gross Inland Consumption (Mtoe)	**1674**	**1519**	**1358**	**1731**	**1451**	**1302**	**1643**	**1475**	**1308**
Solids	130	107	112	142	107	116	114	78	74
Oil	525	348	179	547	313	155	549	384	199
Gas	385	321	244	427	288	219	368	294	229
Nuclear	301	329	337	302	323	327	278	279	278
Renewables	335	416	489	315	423	489	336	442	530

The above table shows PRIMES model results for EU27. The carbon prices are determined by the model in order to deliver the same carbon budgets under the different circumstances reflected in the alternative scenarios. The "policy success" case assumes no delays and no policy failures, so it corresponds to a best case from the perspective of cost-effectiveness of decarbonisation.

The results show that the uncertainty surrounding the implementation pace of policies, both for climate actions and for transport electrification, may have large impacts on energy system costs and on consumer costs. The cost impacts are less significant in the electricity sector contrasting the effects in the demand sectors, which may face significantly higher costs in case of policy delays.

The total cost of the uncertainty is estimated as a cumulative sum of costs per sector over the entire time period and has estimated to be of the order of trillion EUR. The policy message is then clear enough: planning for infrastructure and deploying the measure in a timeliness manner during the intermediate time period well before 2050 is of utmost importance for reaching affordable costs in case climate policy requirements require a certain carbon budget in terms of cumulative emissions over the same time period.

Such uncertainty exploration cases have been quantified using the PRIMES model also for other issues, as for example for technology development issues, for the development of CCS infrastructure and policies, and for others. The exploration was conducted by following the method of scenarios as illustrated above.

1.4.3. Uncertainty about technology deployment supporting policies

Uncertainty analysis about technology deployment supporting policies was carried out using PRIMES in a similar way as the case in the section before.

At present considerable uncertainty surrounds the future development of CCS (carbon capture and storage) and nuclear technologies. It is well known that these technologies are essential components in a cost-effective decarbonisation strategy, for various reasons including the impacts on costs of power generation and also because they ensure stable base-load supply of power at competitive costs, which constitute an essential requirement for the competitiveness of energy intensive industry.

However, their future deployment in uncertain mainly because of public acceptance issues, as fears exist regarding possible leakages from underground storage of carbon dioxide and regarding nuclear accidents.

The development of CCS does not depend only on public acceptance issues but also on the development of infrastructure for CO2 transportation and for storage, which are likely to develop according to a regulated monopoly regime at a large scale. The financial risk of such infrastructure development is very high, since CCS applications have not yet been implemented and public opposition may rise; thus it is unlikely that such infrastructure develops solely on the basis of private initiative. Thus CCS development will depend on the timeliness of public actions and investment by regulated monopolies. Certain analogies exist for nuclear industry, as future safe reactors and safe storage of nuclear waste also depend on public policy, at some extent; strong and successful policies in these two domain may curb public opposition in the future.

In summary, the possible delays of CCS deployment and of nuclear development in the future depend on public policy implementation and on technology; uncertainties surrounding their future development are thus very significant.

Exploring these uncertainties and estimating the impacts of possible failure in the future development of these technologies was studied using the PRIMES model. Alternative scenarios were quantified which assumed such failures or delays in the intermediate period before 2050 or for the entire period until 2050. The scenarios were designed to deliver a certain carbon budget, so the model determined carbon prices and a mix of decarbonisation options for this purpose, taking into account the delay of the low development of the CCS and nuclear options. The results were compared to a policy case, also simulated using PRIMES, which was assumed to deliver the same carbon budget but with possibility of developing the CCS and the nuclear options.

Examples of these PRIMES results are shown in the table below. The scenarios shown are an example among a larger set of scenarios which assumed several combinations of delays or failures for CCS and nuclear.

Uncertainty about technology deployment supporting policies

	Policy success			Delayed CCS			Low nuclear		
	2030	2040	2050	2030	2040	2050	2030	2040	2050
Carbon price (EUR'08/tCO2)	52	95	265	55	190	270	63	100	310
Energy System Cost (bill. EUR'08)	**2837**	**3235**	**3709**	**2849**	**3365**	**3673**	**2894**	**3277**	**3797**
Costs for industry (bill. EUR'08)	342	366	394	343	385	406	350	374	410
Costs for households (bill. EUR'08)	831	985	1318	833	1039	1333	846	1008	1345
Costs for tertiary (bill. EUR'08)	318	356	428	318	372	433	324	366	437
Costs for transport (bill. EUR'08)	1347	1527	1569	1355	1569	1500	1374	1529	1605
Avg. electricity price (EUR'08/MWh)	162	156	157	163	167	163	171	169	169
GHG emissions (Mt CO2 equiv.)	3259	2106	1111	3296	2070	1130	3277	2108	1088
Gross Inland Consumption (Mtoe)	**1534**	**1423**	**1217**	**1532**	**1365**	**1238**	**1489**	**1347**	**1137**
Solids	119	91	77	114	42	57	129	135	116
Oil	513	342	175	511	323	174	511	342	173
Gas	366	343	282	364	318	288	375	360	294
Nuclear	200	219	187	202	244	217	125	63	29
Renewables	337	430	499	341	439	504	349	448	526

The results in the table above show that the impacts from the uncertainty surrounding future development of CCS and nuclear are significant for costs, the energy mix in primary energy terms and for electricity prices.

The possible failures in CCS and nuclear technology developments induce higher costs for the energy system, when accounting for total cumulative costs of the entire time period (annual cost estimates are less relevant for comparing these scenarios). The underlying reason is that it was imposed that all scenarios deliver the same level of carbon budget. Thus, the scenario with success in developing all decarbonisation options (the first scenario shown in the table above) has the lowest cumulative cost since it avoids developing certain decarbonisation options at extreme levels which may entail incurrence of high non-linear costs. This is not avoided in the failure scenarios, such as the delayed CCS and the low nuclear cases, as shown in the table above.

The impacts on the energy mix are also important. For example the delay of CCS implies the lowest use of solid fuels among all scenarios, whereas the highest share of renewables among the scenarios quantified is obtained for the scenario which assume failure of future development of nuclear.

1.4.4. Uncertainty regarding the future level of the carbon prices

The carbon prices constitute important drivers in the various PRIMES energy scenarios and induce emission reduction both through the ETS mechanism in the sectors subject to ETS and though considering carbon prices as a price signal in the non ETS sectors.

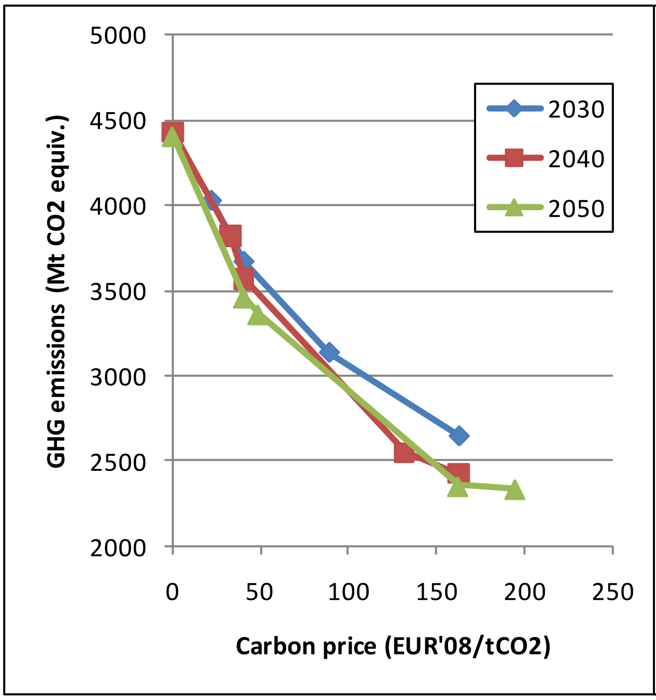
The carbon prices induce changes in the fuel mix in various sectors, including power generation, push investment towards more efficient and less carbon emitting technologies and facilitate actions and behaviour towards higher energy efficiency. The carbon prices affect the prices of energy commodities which further induce adaptation in the energy demand sectors.

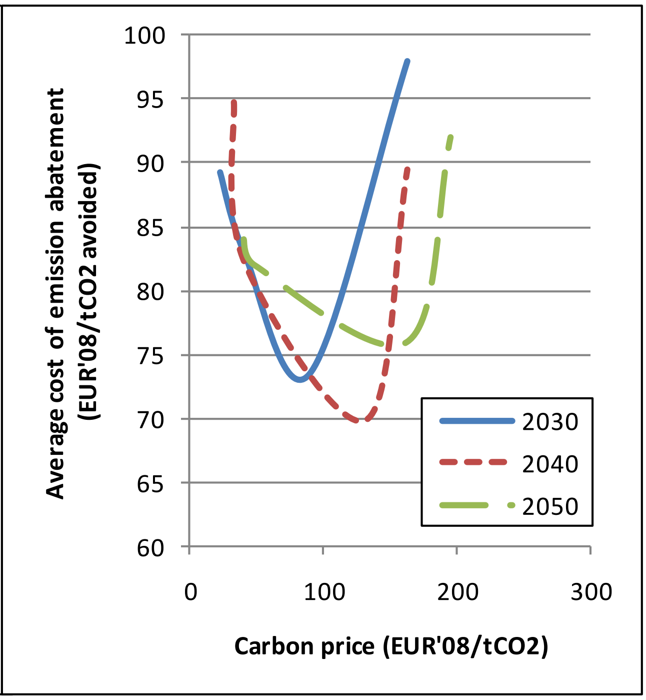
The degree of responsiveness of the energy system to carbon prices is considered as uncertain by analysts and policy makers. As several market barriers and market failures exist in reality, many argue that carbon prices may not be as effective as expected. Other argue that rising carbon prices may also induce removal of the barriers and so act in an effective way.

This uncertainty was studied by quantifying a series of scenario variants with PRIMES in which only the level of the carbon price was varying. A summary of these results can be shown in the table below:

Uncertainty with regard to system responsiveness to carbon prices

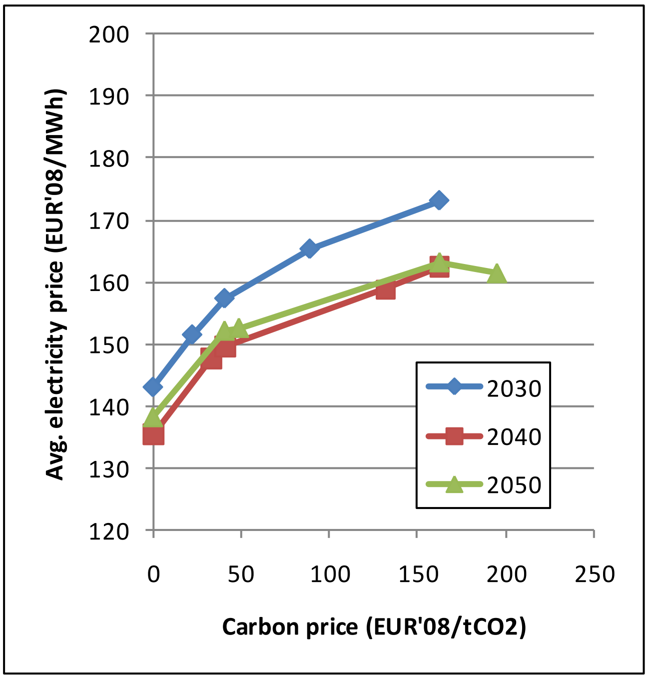
	2030					2040					2050				
Carbon price (EUR'08/tCO2)	**0**	**22**	**41**	**89**	**163**	**0**	**33**	**41**	**132**	**163**	**0**	**41**	**49**	**163**	**195**
Energy System Cost (bill. EUR'08)	**2729**	**2763**	**2791**	**2823**	**2902**	**3091**	**3149**	**3162**	**3223**	**3271**	**3472**	**3551**	**3552**	**3661**	**3642**
Costs for industry (bill. EUR'08)	361	372	377	384	392	409	427	430	442	444	478	498	498	514	516
Costs for households (bill. EUR'08)	822	837	852	876	910	901	926	933	967	987	1014	1051	1052	1105	1098
Costs for tertiary (bill. EUR'08)	320	328	334	345	357	352	364	366	381	386	390	406	408	426	424
Costs for transport (bill. EUR'08)	1226	1227	1228	1218	1243	1429	1431	1433	1434	1454	1590	1596	1594	1617	1604
Avg. electricity price (EUR'08/MWh)	143	152	157	165	173	135	148	150	159	162	138	152	153	163	161
GHG emissions (Mt CO2 equiv.)	4410	4025	3669	3139	2651	4433	3822	3568	2552	2427	4407	3461	3363	2356	2339
Gross Inland Consumption (Mtoe)	**1754**	**1727**	**1714**	**1705**	**1686**	**1772**	**1736**	**1736**	**1750**	**1723**	**1783**	**1747**	**1741**	**1732**	**1754**
Solids	288	239	215	206	205	295	217	211	210	202	291	203	192	198	207
Oil	566	561	558	552	538	559	554	552	542	532	559	553	554	532	535
Gas	396	390	380	360	344	376	372	369	345	338	369	361	361	330	328
Nuclear	205	231	247	262	262	231	265	272	299	294	245	286	288	302	309
Renewables	302	309	315	328	340	313	331	334	356	360	322	346	348	373	376





The left hand side graphic, shown above, demonstrates that the relationship between carbon prices and GHG emissions is non linear. As expected it has a negative slope but has a slope with rates of decrease of emissions being lower than the rates of increase of carbon prices. The relationship also seem to be steeper in years after 2030, as constraints from presently existing equipment vanish and technology possibilities expand.

The right hand side graphic, shown above, demonstrates that from the perspective of the average cost of emission reduction the effects of the carbon prices have a U shape, which means that the there exist an "optimum" level of carbon prices, in the sense of inducing the lowest possible average cost of emission reduction. For this consideration, costs are estimated as total system cost including investment, operation and disutility costs.



The effects of carbon prices in the supply side of energy are shown through the average electricity prices in the table above.

As expected, the results show (see graphic) a strong positive correlation between average electricity prices and carbon prices. The relationship is non linear and shows a trend towards decreasing rates of increase of electricity prices relative to the rate of increase of carbon prices. This is attributed to the decarbonisation progress in the power sector: as power generation lowers average emission factors owing to the increase of carbon prices, average electricity costs, hence prices, tend to be affected less for high levels of carbon prices.

A different relationship is found between total system costs and carbon prices. The correlation is strong and positive, but unlike the case of electricity prices, total costs tend to change at increasing rates relative to the rate of increase of carbon prices. Decarbonisation possibilities tend to imply increasing costs when carbon prices increase, at least beyond a certain level of carbon prices. Using the decarbonisation options at levels corresponding to non linear parts of cost-potential curves in order to adapt to increasing carbon prices explain the findings. A similar relationship to carbon prices is also found when looking at compliance costs by sector of final energy demand. This implies that carbon prices going beyond a certain high level may induce unnecessarily high costs.