EC4MACS
Uncertainty Treatment

The GEM-E3 Macro-economic Model

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

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1. Uncertainties in the GEM-E3 model

1.1. Overview of GEM-E3 model

GEM-E3 is a general equilibrium model which includes many countries and sectors of economic activity. The model provides projections to the future, until 2050, of national accounts, prices, employment, trade, production, investment and use of production factors. A model projection depends on assumptions about future evolution of technical progress (productivity indices) associated to all production factors and for all sectors, changes in demography and public policy which is expressed in terms of public consumption and investment, taxation schemes and specific policies such as climate change mitigation objectives and related policy instruments, including ETS mechanisms.

The GEM-E3 model uses input data from Eurostat, OECD, UN, IEA and GTAP. The input data are rather robust and there is no possible alternative source; so testing about uncertainty in input data is not possible.

The GEM-E3 equation parameters are of two kinds: coefficients with values derived from econometric estimations and guess-estimates based on literature reviews; secondly, coefficients which are calibrated through a mathematical procedure which allows the model to reproduce past statistics when running for past years. Uncertainty regarding the values of the estimated coefficients has been explored in the past by doing sensitivity analysis simulations, as for example when running the model for the same policy scenario with varying values of certain elasticities (e.g. for the Armington foreign trade substitution elasticity parameters).

1.2. Exploring uncertainties related to numerical values of GEM-E3 parameters

The projections using GEM-E3 are not considered as a forecast but as a result of simulation; in this sense the projections depend on the assumptions about the future change of values of parameters that are exogenous to the model, which of course are uncertain. Because the model is very comprehensive and complex, it is not feasible, unless the model is simplified, to represent uncertainties endogenously in the system.

To explore uncertainties a scenario method is followed: the model is used to quantify alternative scenarios and sensitivity analysis cases, as a means for exploring uncertainties about the future; thus results allow assessing policies.

For example, within the EC4MACS project, scenarios are developed using GEM-E3 for exploring the uncertainties about future participation of world regions in climate change mitigation effort, regarding the scope of participation and the timeliness of actions. Another relevant example is the quantification of alternative European and world economic growth scenarios for the future, based on different assumptions which lead to contrasting levels of

GDP projections to the future. The GEM-E3 model results for a variety of future economic growth scenarios are used as inputs to PRIMES energy model which then feeds the suite of models represented in EC4MACS.

1.3. Example of uncertainty analysis regarding economic growth simulated with GEM-E3

The future growth of the European economy is among the major uncertainties which influence all model-based evaluations for energy, emissions, agriculture, etc. We remind that the economic activity scenarios quantified using the GEM-E3 model constitute the starting point of the linked model process.

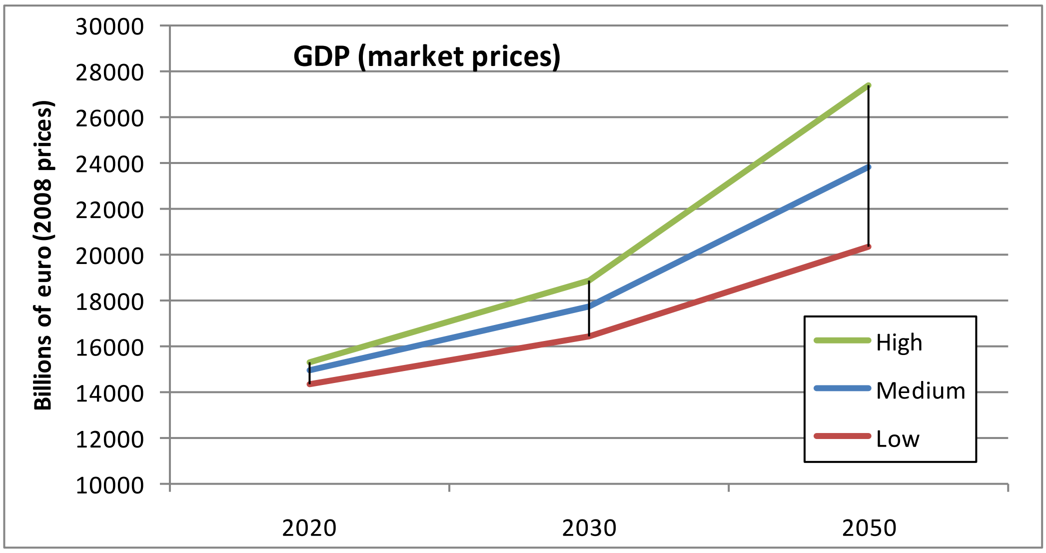
Exploring the uncertainties surrounding the economic activity projection is a difficult and complex task. For such exploration three scenarios were designed and quantified using GEM-E3, which describe three contrasted cases which correspond to low, medium and high growth. The medium case has been retained as the central case for model-based scenario development, whereas the other two cases serve to assess the sensitivity of projections around the central case. For all three economic activity projections, energy and emission scenarios have been quantified using the PRIMES model, which uses the economic scenario results as inputs.

Exploration of uncertainty about economic growth using GEM-E3

Billions of euro (2008 prices)	2020			2030			2050		
	Low	Me-dium	High	Low	Me-dium	High	Low	Me-dium	High
GDP (market prices)	14373	14963	15305	16403	17774	18898	20324	23833	27417
GDP per capita (EUR'08/person)	27971	29120	29786	31547	34184	36346	39442	46250	53206
Consumption Expenditure of Households	8367	8533	8688	9774	9955	10138	13214	13462	13713
Gross Value Added (basic prices)	12843	13369	13675	14675	15900	16905	18172	21306	24506
Agriculture	202	209	209	213	230	236	216	244	261
Construction	715	748	756	808	877	910	928	1085	1190
Services	9490	9888	10146	10945	11870	12702	13811	16215	18878
Market services	5002	5222	5389	5873	6383	6909	7661	9001	10662
Non market services	2942	3050	3090	3232	3481	3621	3718	4351	4825
Trade	1546	1616	1668	1840	2005	2172	2432	2863	3392
Industry & energy	2436	2525	2564	2710	2924	3056	3217	3762	4177
Energy Sector	341	350	351	354	379	393	363	418	456
Industry	2096	2176	2213	2356	2545	2663	2854	3344	3722
Energy Intensive Industry	330	341	345	354	380	394	387	442	484
Non Energy Intensive Industry	1766	1835	1868	2002	2165	2269	2467	2902	3238

The quantified scenarios include projection of activity by sector, which also vary between low growth and high growth, the medium scenario being the central case. The projection of activities by scenario is consistent with GDP, investment and employment projections.

The range of uncertainty explored can be shown graphically below:



1.4. Example of uncertainty analysis regarding economic growth simulated with PRIMES

The GEM-E3 scenarios mentioned in the previous section were used as inputs to the PRIMES model in order to explore the uncertainties related to future economic growth of the European economy. A summary of the results from PRIMES are shown below:

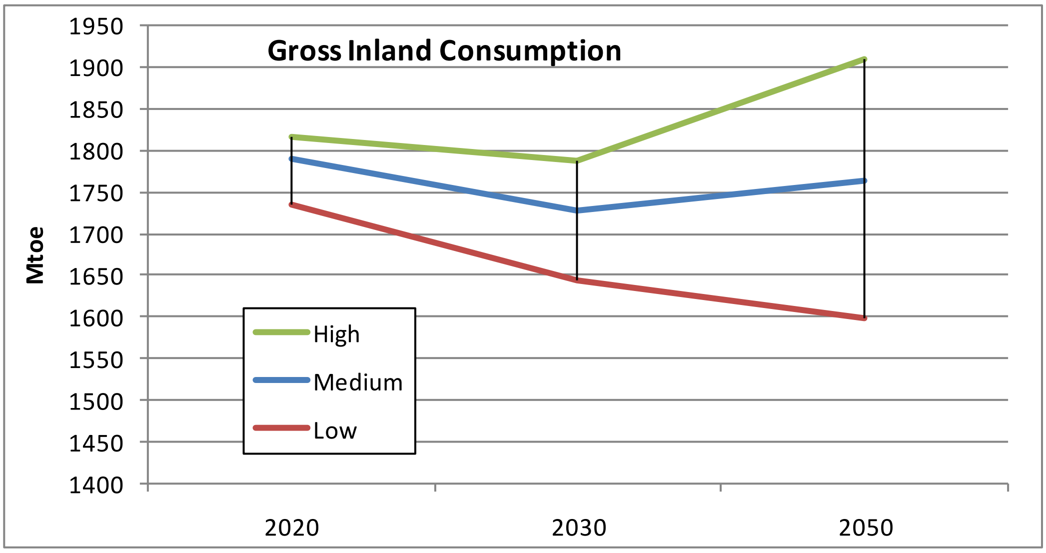
	2020			2030			2050		
	Low	Medium	High	Low	Medium	High	Low	Medium	High
Gross Inland Consumption (Mtoe)	**1734**	**1790**	**1817**	**1643**	**1729**	**1788**	**1599**	**1763**	**1911**
Solids	248	263	261	210	215	215	168	200	229
Oil	598	615	623	544	568	585	520	560	595
Gas	401	413	424	362	383	401	324	359	386
Nuclear	215	223	229	223	248	264	255	295	334
Renewables	274	278	281	306	318	326	334	352	369
Final energy demand (Mtoe)	**1193**	**1227**	**1246**	**1193**	**1227**	**1246**	**1193**	**1227**	**1246**
Industry	319	330	333	309	333	344	319	369	406
Households	311	318	323	294	299	305	283	288	294
Tertiary	174	181	185	160	174	185	155	181	208
Transport	388	398	404	369	382	392	361	383	404
Avg. electricity price (EUR'08/MWh)	150	149	149	157	158	160	154	154	154
GHG emissions (Mt CO2 equiv.)	4258	4396	4438	3815	3901	3937	3243	3337	3475

As expected, economic activity constitute a major driver of energy demand evolution which further drives energy supply changes. The range of uncertainty in future energy demand increases over time as the uncertainty about future economic activity also increases. Such a growing range is determined in detail by sector.

A similar range is quantified for GHG emissions, which also expands over time following uncertainty about future economic growth.

The range of uncertainty in estimating future costs and prices also depend on future economic growth but the estimation depends on two main factors which contradict each other: higher economic activity implying higher demand for energy requires larger energy resources in the supply side, hence higher costs to the extent at which the additional resources are scarce and more costly to develop; on the other side however, higher activity, hence higher demand, imply larger production scale which tend to allow for decreasing average production costs to the extent at which economies of scale are possible. This explains the model results about costs and prices: the table above shows that the resulting average electricity prices exhibit a small range of variation, compared to the range of variation of energy demand.

The following graphic illustrates the range of uncertainty regarding total primary energy requirements in relation to uncertainty in future economic growth of the EU economy.



1.5. Example of uncertainty analysis regarding carbon prices simulated with GEM-E3

Carbon prices act in a macroeconomic context as drivers of emission reduction restructuring which takes place through the readjustment of the production structure of firms and of the consumption mix of households. In addition, carbon prices induce restructuring in energy supply industry and generally imply higher energy prices which further propagate in the economy influencing decisions by firms and by households. Carbon prices generally induce less use of fossil fuels, which are mostly imported in the European Union. Consequently carbon prices imply more use of low or free carbon sources of energy which are produced with domestically produced equipments, and also imply higher investment aiming at increasing energy use efficiency. The substitution of fossil fuels is thus effected by increasing investment and generally spending in capital goods, which further induce higher domestic activity. The higher costs and prices, however, owing to the carbon prices and the higher cost of fossil fuel substitution also influence domestic activity, but unlike the investment, in a negative way, as foreign competitiveness of domestically produced goods is weakened. On the other hand, the additional investment and the carbon prices trigger more effort in innovation; the resulting technology progress increases productivities and may favour exports in case foreign trade partners do not engage in similar innovations.

The above reasoning illustrates that estimating the net macroeconomic effects of carbon prices is a complex task. It is of course expected that carbon prices do induce lower emissions, despite the possible increase of domestic production in some sectors; however the degree of responsiveness of the overall economic system to various levels of carbon prices is uncertain. Similarly, the impact of various levels of carbon prices on GDP and domestic production, as well as on investment and employment is also uncertain.

The model-based exercise, presented in this section, aim at exploring the uncertainty about the impacts of carbon prices at the level of the entire economic system. The exploration is based on a series of scenarios quantified using the full scale (with learning and productivity effects) global version of the GEM-E3 model.

<u>Uncertainty analysis regarding carbon prices simulated with GEM-E3</u>

	2030					2040					2050				
Carbon Tax (EUR'08/tCO2)	**0**	**20**	**36**	**78**	**143**	**0**	**29**	**36**	**116**	**143**	**0**	**36**	**43**	**143**	**171**
GHG emissions (Mt CO2 equiv.)	**5028**	**4199**	**3808**	**2366**	**1516**	**4604**	**3525**	**3371**	**1515**	**1297**	**4546**	**3205**	**3054**	**1117**	**1089**
Gross Domestic Product (bill. EUR'08)	15664	15613	15564	15424	15469	18183	18115	18087	17888	18038	21019	20916	20918	20855	20713
Investment (bill. EUR'08)	3190	3180	3171	3165	3219	3648	3633	3625	3604	3652	4222	4197	4201	4210	4162
Employment (in m. persons)	231	231	230	230	231	225	224	224	224	225	217	216	216	217	216
Welfare Equiv. Variation (bill. EUR'08)	23	-29	-71	-260	-393	1	-41	-62	-283	-348	-27	-45	-52	-273	-329
Domestic Production (bill. EUR'08)															
Agriculture	573	590	595	602	604	603	632	634	645	650	683	719	723	728	719
Fuels	258	223	204	139	107	232	191	184	98	88	221	180	174	75	72
Coal	12	11	10	5	2	10	9	9	4	3	10	9	9	3	2
Oil	258	220	199	135	106	233	189	182	93	85	222	178	171	71	68
Gas	23	23	23	17	13	21	19	19	14	12	20	19	18	11	11
Electricity Supply	337	327	323	307	293	349	340	339	334	332	359	349	349	352	358
Energy intensive	3398	3431	3457	3506	3616	3862	3927	3941	4083	4172	4399	4493	4519	4817	4827
Ferrous and non ferrous metals	1060	1076	1088	1108	1147	1119	1144	1150	1203	1231	1140	1172	1180	1275	1280
Chemical Products	1602	1624	1643	1677	1741	1893	1936	1946	2035	2084	2244	2303	2319	2493	2505
Other energy intensive	1208	1207	1206	1207	1229	1386	1392	1392	1410	1435	1626	1641	1646	1717	1712
Equipment goods	3282	3263	3249	3266	3320	3801	3775	3769	3806	3862	4200	4154	4155	4239	4172
Electric Goods	919	920	918	945	965	1099	1108	1109	1137	1150	1201	1208	1209	1230	1218
Transport equipment	1209	1199	1193	1178	1186	1430	1416	1413	1404	1426	1493	1475	1474	1490	1455
Other Equipment Goods	1610	1597	1589	1596	1630	1800	1775	1769	1793	1822	2089	2047	2048	2108	2077
Consumer Goods Industries	2906	2901	2892	2869	2865	3212	3200	3193	3145	3169	3762	3724	3722	3679	3634
Construction	1797	1799	1797	1820	1866	2029	2032	2029	2062	2093	2304	2306	2310	2390	2355
Services	16408	16336	16271	16142	16130	18838	18729	18691	18483	18580	21202	21056	21047	20982	20837

The results summarised in the above table (results for EU27) show that in most cases the effects of carbon prices on EU's GDP are negative (i.e. there is a reduction in volume trends from a reference scenario). They also show that the degree of loss of GDP is generally lower than the rate of increase of carbon prices. A significant part of potential losses is compensated by gains resulting from increased domestic activity and improved productivities enabled by induced technology progress. The latter is limited in the above shown cases, as it is assumed that carbon prices apply globally and thus induce technology progress also in other countries in the world.

The analysis shows that the effects of carbon prices on the activity of various sectors are very unequal. Industries which produce metals, building materials and chemicals profit from rising carbon prices as demand for the corresponding commodities increase as part of capital goods and constructions needed to substitute fossil fuels. Similar is the case of the equipment goods industry, as spending in equipment goods increases because of their use in building investment which enables lower emissions and also because of the additional cost needed to increase their energy efficiency. On the contrary, other sectors of the economy are negatively affected, as for example the consumer goods industry and at large extent the services sectors. As expected, activity related to fossil fuels and to distributed energy forms strongly decrease as a result of carbon prices.

The graphic below shows the relationship between the loss of welfare equivalent variation and the carbon prices. The change in welfare is negative in all carbon price cases and the magnitude of the loss is almost proportional to the level of the carbon prices. This result is consistent with a general equilibrium approach, which is implemented by the GEM-E3 model, since carbon prices constitute a counter-factual case relative to a baseline which also performs general equilibrium.