R&D INVESTMENTS AND KNOWLEDGE INPUT IN A TECHNOLOGY ORIENTED CGE MODEL

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Abstract

Innovations and technological progress are one of the main drivers for economic development. R&D investments induce a more efficient use of natural and environmental resources. We use the GCE model NEWAGE-W for the quantitative analysis of the implications of R&D induced technological change. We explicitly implement endogenous technological change by modeling R&D investments and knowledge as a primary factor input within the production process. Thus the basic input-output tables have been modified. In the enhanced CGE model, knowledge endowment is determined by the endogenous calculated investments in R&D. To analyse the economic and ecological impacts of R&D investments and knowledge input two scenarios have been analysed. We calculate a scenario with direct subsidies on knowledge inputs and another scenario with subsidies on R&D investments. We show that knowledge accumulation has a much stronger impact on economic development than changes in knowledge allocation.

1 Overview

Innovations and technological progress are one of the main drivers for economic development. The gross domestic product (GDP) in the big industrial nations has grown rapidly in the last decades as a result of technological change. Through high expenditures in R&D, knowledge could build up which are used in the production process. But in the last three decades the problems related with economic growth became obvious. First the finiteness of fossil energy carriers gets important. Then increasing environmental pollution and finally climate change caused by the emissions of green house gases (GHG) are on top of the agenda.

For the solution of these problems technological progress and knowledge will be of great importance. Knowledge can substitute other physical production inputs as well as fossil fuels. Less use of fossil fuels through more knowledge inputs in the production process leads to less GHG emissions. It can be seen e.g. in the strategy of the Commission of the

European Communities „Wining the Battle against Global Climate Change “ (European Union, 2005), the COP 11 (UNFCCC, 2005) and the Vision Statement of the Asia-Pacific Partnership on Clean Development and Climate (Australian Government, 2006) that technological change plays a mayor role in mitigating GHG emissions.

Already since Schumpeter (1942) it is well known that investments into research and development (R&D) are a necessary condition for the generation of technological change. Innovations and technological progress result mostly not from a creative process but are a result of systematic work in research departments and laboratories. With investments in R&D, knowledge is generated which is a necessary condition for innovation.

Figure 1 shows that in the EU-25 approximately 1.9% of total GDP is spend for research and development activities. The percentage gross domestic expenditures on R&D (GERD) have been nearly constant in the EU-25 for the last 10 years. There are significant differences between the several European member states.

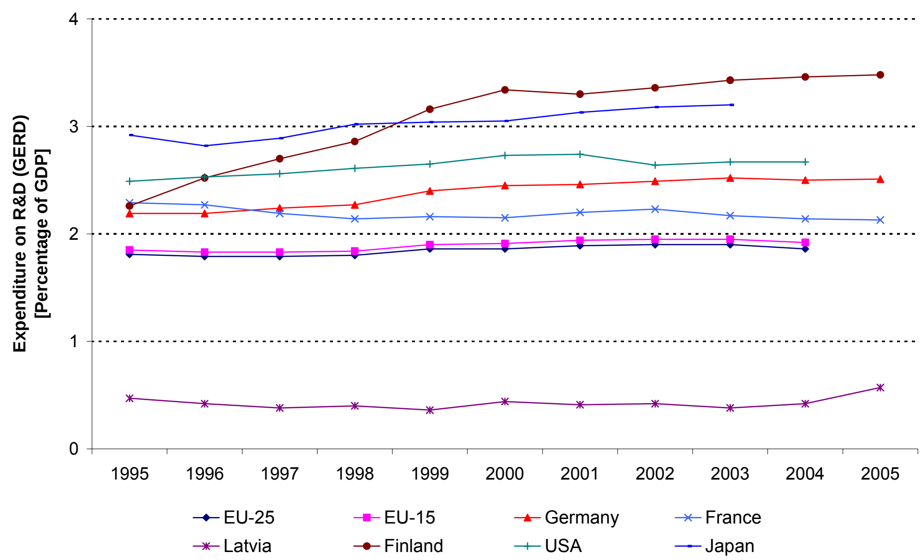

Figure 1: Expenditure for R&D (GERD) in percent of total GDP [Sourc: Eurostat (2006)]

While e.g. in Latvia only 0.6 % of total GDP were spent for R&D in 2005, the expenditures in Finland amounts to 3.5 % in the same year. The high percentage increase of more than one percentage point in 10 years in Finland can be primarily traced back on the R&D expenditures by the huge mobil phone companies. Germany is also above the European average with 2.5% GERD in 2005. The percentage expenditures for R&D are also much higher in the USA with 2.7% and in Japan with 3.2% compared to the average in the European Union.

Most of the R&D expenditures are spent in private enterprises. Mainly in countries with a high GERD share on total GDP the most investments are carried out by privately owned companies (cf. figure 2). In Germany 66%, in the United States 62%, in Japan 75% and in Finland 70% of overall GERD are spent by private enterprises. In the European Union about one third of the R&D investments is financed by the government. Approximately one half stems from firms and nearly 10% are from foreign countries.

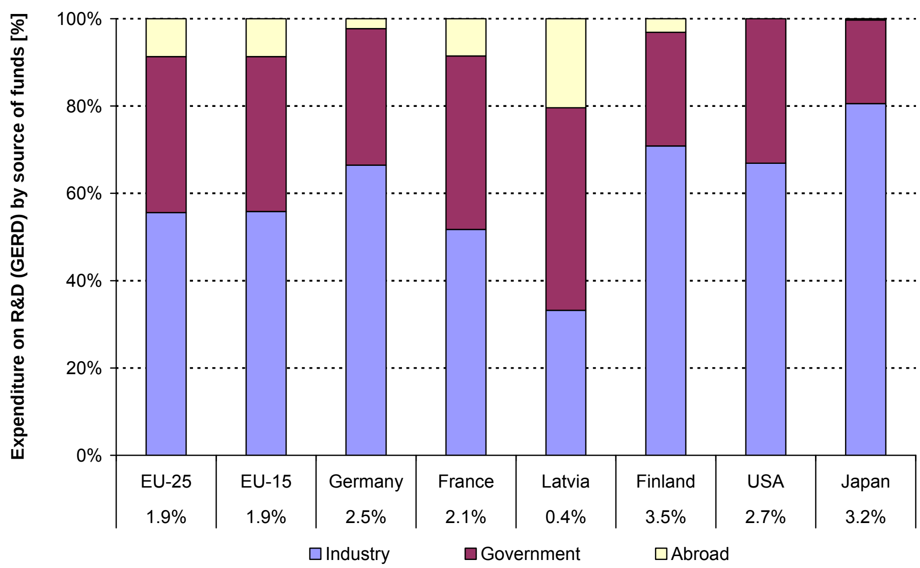

Figure 2: Gross expentitures on R&D (GERD) in 2004 [Source: Eurostat (2006)]

For the analysis of innovations and technological change the sectoral, regional and chronological dimension is important. Innovations are not restricted on certain industries or certain areas of the economy but include the whole economy. For this reason the instrument for the analysis should contain the whole economy. Hence a partial model which analysis only one sector or part of the economy is inappropriate in this context. Concerning the regional dimension innovations spill over national borders. Therefore the analysis should not be limited on a certain country or region and should account for all world regions. With respect to the chronological dimension a medium-term or long-term perspective is appropriate because adjustment reactions due to technological change need time.

A Computable General Equilibrium (CGE) model is suitable to fulfil the described requirements on the instrument of the analysis regarding the sectoral, regional and chronological dimension. Therefore the aim of this paper is to describe the implementation of investments in R&D and the endowment of knowledge in a technology oriented General Equilibrium model. Due to the total analytic approach, CGE models are best suited for the quantitative analysis of the implications of technological change. Especially for the analysis concerning future developments the description of technological change in CGE models is of special interest. On the one hand model results are significantly affected by the assumptions made about the implementation of technological change in those models. This means that through a more precise implementation of technological change results can be better classified and explained. On the other hand the contribution of technological change for lowering the conflict of goals between economic growth and the ecologic consequences, i.e. the emissions of GHG, can be quantified more appropriate.

Technological change affects the efficient use of energy and has an impact on GHG emissions. For questions concerning energy use, GHG emissions and technological change the electricity conversion sector plays a mayor role. About one third of the energy related CO_2 emissions stem from the combustion in fossil fuel fired power plants in the European Union. Until 2030 approximately 75% of the today installed capacity have to be replaced which gives the opportunity to invest in new efficient power plants.

The paper is organized as follows. Section 2 gives a general overview of the used CGE model. Section 3 deals with the question how technological change is usually implemented with an autonomous energy efficiency improvement (AEEI) and what are the disadvantages of this exogenous modeling approach. To avoid the disadvantages of exogenous technological change we model technological progress endogenously in representing investments in R&D explicitly. These investments determine an endowment of knowledge which can be used in the production process as another primary factor input. In section 4 we calculate exemplary scenarios in which we analyse the effects of direct knowledge promotion in the production process as well as an indirect promotion of knowledge through a subsidy on R&D. In both scenarios we focus on energy intensive industries.

2 Model description

For the quantitative analysis the global Computable General Equilibrium model NEWAGE-W (National European Worldwide Applied General Equilibrium Modelling System) is used. NEWAGE-W is a dynamic, multi-region and multi-sector model of the world economy. Through the total analytic framework of the model all regional and sectoral feedback effects of production, investment and consumption decisions are included endogenously. Economic activities are modelled by production functions with constant elasticities of substitution (CES). Factor inputs are capital, labor, energy and other intermediates. The input of fossil fuels are linked to CO_2 emissions. NEWAGE-W is formulated as a system of nonlinear inequations in the programming language GAMS/MPSGE (Brooke et al. (1996), Rutherford & Paltsev (2000), Böhringer (1996)).

The current version of the model contains ten countries or regions respectively as shown in Table 1. The regional settings allows a distinction between ratifying Annex-B countries, not ratifying Annex-B countries and Non-Annex-B countries.

Table 1. NEWAGE-W regions

1	Germany	DEU
2	EU-15 without Germany	OEU
3	New European Union member states (without Bulgaria and Romania)	NEU
4	Other European Annex-B countries	EAB
5	Russia	RUS
6	Rest of Annex-B	RAB
7	Rejecting countries	REJ
8	OPEC countries	OPE
9	China und India	CHI
10	Rest of World	ROW

Furthermore the economies consist of 13 separate sectors of which five are energy sectors and eight are non-energy sectors (cf. Table 2). The underlying data for production and trade is oriented on economic input-output systematics and uses the GTAP (Global Trade Analysis Project) database Version 6 from 2005 (GTAP 2005). The GTAP database is a consistent framework of national accounts of 87 countries or regions and 56 economic sectors.

Table 2. NEWAGE-W sectors

Energy sectors		**Non-energy sectors**	
Coal	COL	Chemical, plastic products	CHM
Petroleum	OIL	Machinery and equipment	MAC
Crude oil	CRU	Buildings	BUIL
Natural gas	GAS	Transport	TRN
Electricity	ELE	Agriculture and forestry	AGR
		Paper products, publishing	PPP
		Iron and steel	I_S
		Other Goods & Manufactures	Y

The base year of the GTAP 6 data is 2001. The dynamics of the model are characterised by a recursive dynamic framework and calculates in five year time steps until the year 2030. Economic growth is mainly induced by capital and labor endowment. Capital endowment grows by endogenously calculated investments and decline by an exogenously given depreciation rate of 4%. The labor endowment is driven by exogenously given population and labor productivity growth. A system of flexible prices assures market clearing on each factor and commodity market. The economic equilibrium is determined by a system of nonlinear equations as a mixed complementarity problem (MCP) where three types of inequalities must be satisfied. These are the zero profit condition, market clearance condition and income balance condition (Arrow and Debreu (1954), Paltsev (2004)).

To analyse questions concerning climate policies, the implementation of the electricity generation sector in the CGE model is of central interest. For this reason we enhance the top-down structure of the CGE model through a technology oriented approach of the region specific power plant system (Zürn et al. (2005, 2006), Ellersdorfer and Fahl (2005)). The extension is not restricted on the generation side of the conversion sector but contains also the investments in new capacities. The decommissioning of existing capacities is implemented through decommissioning curves for all generation technologies in every region.

3 Implementation of technological change in a CGE framework

3.1 Autonomous energy efficiency improvement

Technological change in CGE models is mainly represented with an autonomous energy efficiency improvement (AEEI). The basic idea behind the concept of the AEEI is the possibility to produce a given output with less energy input over time or to produce more output with the same energy input respectively, i.e. the energy productivity rises. The AEEI contains all non price driven changes of the energy intensity in an economy. Hence the AEEI covers structural changes in the economy as well as technological progress in terms of efficiency gains.

A disadvantage of the AEEI concept is the exogenous representation of technological change. This implies that the intensity of technological progress is independent of current model results. Another critical point of the exogenous formulation of technological change is the costless availability of efficiency gains. Neither the industrial sectors nor the consumption side have to finance efficiency improvements induced by the AEEI. Despite the simplifying representation of technological change the AEEI has great influence on the model results.

3.2 Investments in research and development – a survey

To avoid the problems related with exogenous modeling of technological change there are mainly three possibilities to implement endogenous technological change in CGE models. One possibility is to replace the exogenous given AEEI through a price induced energy efficiency improvement (PIEEI). In this approach the intensity of technological change is dependent on the endogenously calculated energy prices. The PIEEI approach is mostly used in economic models (see Dowlatabadi (1998), Dowlatabadi & Oravetz

(1997), Popp (2002)). Price induced technological change is also implemented in another version of NEWAGE-W (Zürn et al. (2005)).

Another possibility of modelling endogenous technological change are the learning by doing approach. The main idea behind learning by doing is that a technology gets cheaper with growing cumulated installed capacity or cumulated production output. This approach is mainly implemented in energy models (Barreto and Kypreos (1999), Grübler (1998), Kouvaritakes et al. (2000), Barreto and Kypreos (2004)). Beside energy system models, the learning by doing approach is also used in general equilibrium models (Welsch (1996), van der Zwaan et al. (2002), Rasmussen (2000)).

We implement endogenous technological change by modeling investments in research and development (R&D) as well as knowledge as a primary factor input into production. The investments into R&D are an endogenous decision and part of the utility maximation problem of the representative agent. This approach is mainly used in economic models (Lucas (1988), Romer (1990), Grossman and Helpman (1994), Goulder and Schneider (1999), Sue-Wing (2001)).

Goulder and Schneider (1999) use a dynamic CGE model in which every sector is modelled with the inputs labor, capital, knowledge, fossil fuels, non fossil fuels, energy intensive and non energy intensive goods. Investments in physical goods enlarge the capital endowment and investments in R&D enlarge the knowledge endowment. To determine the quantity of R&D investments and the knowledge endowment in the base year Goulder and Schneider (1999) identify two high technology sectors „legal, engineering, accounting and related services“ and „other business and professional services except medical“. In the approach of Goulder and Schneider (1999), the columns of the intermediate matrix of the input-output framework[1] from these two high technology sectors represent investments in R&D. Furthermore they ad-hoc assume that the primary factor input knowledge is 20% of the value of physical capital for every sector.

In contrast, Sue-Wing (2001) assesses that in the standard economic accounts knowledge is not part of the value added matrix. Rather it is treated as an intermediate input in production (Bureau of Economic Analysis of the US Department of Commerce (1994,

[1] For an explanation and a schematic overview of an input-output table see also chapter 3.3

2006)). Basically research investments can be carried out by private enterprises, by the government and by non-profit institutions. Government R&D spending is part of the final government demand of the final demand matrix (II. quadrant) in the input-output framework. Investments from non-profit institutions appear also in the second quadrant as private demand. Different to that R&D, investments from private companies are part of the intermediate matrix (I. quadrant) and are not part of final demand. This implies that one part of the intermediate transaction matrix represents physical goods while the other part must be considered as implicit knowledge inputs.

Consequently R&D investments have to be extracted from the intermediate transaction matrix. There are mainly two associated difficulties to solve. On the one hand information is needed how much knowledge is implicitly included in the intermediate transaction matrix. On the other hand the whole input-output framework will not be balanced after the knowledge adjustment. This means that row and column sums of the input output table are no longer equal. For this reason the whole input-output table (IOT) has to be adjusted so that the market clearing condition holds.

One possibility to extract the implicit knowledge in the interindustry transaction matrix is presented by Terleckyj (1974). The basic idea of Terleckyj's approach is that sectoral R&D expenditures spill over to other sectors in proportion of the product sales in the intermediate transaction matrix. The quantities of the sales of one industry to another industry is already known from the intermediate quadrant. For this reason the sectoral R&D spendings can be multiplied with the entries of the interindustry transaction matrix to receive the share of R&D investment for every entry in the matrix. This approach is also used by Sue-Wing (2001) for a sectoral highly disaggregated CGE model for the USA.

In following we adopt Terleckyj's approach to extract the relevant information from the transaction matrix for all model regions. Therefore we describe in detail how the economic data base look like and how we extract the knowledge share from the physical goods and services.

3.3 Investments in research and development in NEWAGE-W

The basic input-output table consist of three quadrants, namely the intermediate transaction matrix (I. quadrant), the final demand matrix (II. quadrant) and the value added matrix (III. quadrant). The intermediate transaction matrix gives information about the delivery of intermediate inputs between industries. The final demand matrix consists of private demand, governmental demand, physical investments and exports. The value added matrix subsumes the primary factor inputs capital, labour, natural resources and the imports of foreign goods and services. Figure 3 gives an overview of a standard input-output table.

	Coal	Gas	Oil	…	Machinery	Agriculture	Iron and Steel	Private Consumption	Gov. Consumption	Investments	Exports	Sum
Coal Gas Oil … Machinery Agriculture Iron and Steel			**I. quadrant intermediate transaction matrix**						**II. quadrant final demand matrix**			
Labour Capital Resources Imports			**III. quadrant value added matrix**									
Sum												

Figure 3. Standard input-output table

As indicated in section 3.2 R&D investments from private companies are part of the intermediate transaction matrix (I. quadrant). Therefore the relevant data must be extracted from the I. quadrant of the basic input output structure. As mentioned before we use the approach of Terleckyj (1974) to extract the R&D investments as well as knowledge from the basic input-output table. To obtain the knowledge share from the interindustry transaction matrix we need sectoral R&D data. For this we mainly use the OECD study „research and development expenditure in industry“ (OECD, 2005). The sectoral research expenditures provide information how much an industry spend for research and development in one year.

The quintessence of Terleckyj's approach is to extract the knowledge share from the intermediate transaction matrix with the sectoral R&D data $INV_{i,r}^{R\&D}$. For this we divide the entries of the interindustry transaction matrix $VL_{i,j,r}$ through the row sums of this matrix $\sum_j VL_{i,j,r}$. The resulting quotient is multiplied by the sectoral R&D expenditures $INV_{i,r}^{R\&D}$ (cf. equation 3).

$$(3) \quad W_{i,j,r} = \frac{VL_{i,j,r}}{\sum_j VL_{i,j,r}} INV_{i,r}^{R\&D}$$

The main idea is that the implicit included knowledge which is embodied in the intermediates of the first quadrant spills over to the receiving industries in proportion of the product sales. We obtain a new matrix with the knowledge entries $W_{i,j,r}$ of the primarily intermediate matrix $VL_{i,j,r}$. When subtracting the knowledge entries $W_{i,j,r}$ from the entries of the intermediate matrix $VL_{i,j,r}$ we obtain a modified intermediate transaction matrix $VL_{i,j,r}^{\text{mod}}$. The modified matrix is adjusted by the knowledge fractions and contains only physical intermediate inputs.

The primarily interindustry transaction matrix $VL_{i,j,r}$ is substituted through the modified matrix $VL_{i,j,r}^{\text{mod}}$ which contains only the physical intermediate inputs. The knowledge matrix $W_{i,j,r}$ in this form is not needed anymore, only the row and column sums of $W_{i,j,r}$ are necessary. The row sum $RDV_{i,r}$ have to be identical to the sectoral R&D investments $INV_{i,r}^{R\&D}$. The column vector $RDV_{i,r}$ is implemented in the final demand matrix (II. qudrant) of the input-output framework. The column sum $KNOW_{i,r}$ represents the endowment of knowledge. This row vector is implemented in the value added matrix (III. quadrant) as an additional primary factor input. For this reason knowledge can be used in the production function analogous to capital, labor and natural resources. Table 3 sumarizes the primary relations.

Table 3. Summarization of the primary relations

$VL_{i,j,r}$	intermediate transaction matrix in region r
$VL_{i,j,r}^{\mathrm{mod}}$	modified about knowledge intermediate transaction matrix
$W_{i,j,r}$	knowledge compononts of the intermediate transaction matrix
$INV_{i,r}^{R\&D}$	Sectoral R&D investments
$\sum_j W_{i,j,r} = RDV_{i,r}$	row sum of the interm. trans. matrix - sectoral investments in R&D
$\sum_j W_{j,i,r} = KNOW_{i,r}$	colum sum of the interm. trans. matrix - sectoral knowledge endowment

To make the idea of this approach clearer, figure 4 shows an example how R&D investments and knowledge is extracted from the intermediate transaction matrix. First we multiply the standard intermediate matrix $VL_{i,j,r}$ with the sectoral R&D investments $INV_{i,r}^{R\&D}$ which are written as a column vector. The marked entry $VL_{I\_S,MAC,DEU}$ in the intermediate transaction matrix gives information how much intermediates are delivered from the sector Iron and Steel (I_S) to the sector Machinery (MAC) in Germany. Multiplying this entry with the R&D investments made in the sector I_S show how much knowledge spills over from Iron and Steel (I_S) to Machinery (MAC). We do this with every input $VL_{i,j,r}$ and obtain the matrix $W_{i,j,r}$ with the knowledge components of the intermediate transaction matrix. The row sum of matrix $W_{i,j,r}$ is the column vector of R&D investments $RDV_{i,r}$ and have to be identical with the sectoral R&D expenditures $INV_{i,r}^{R\&D}$. The column sum $KNOW_{i,r}$ of the matrix $W_{i,j,r}$ represent the knowledge endowment in every industry. The column vector $RDV_{i,r}$ become part of the final demand matrix (II. quadrant) and the row vector $KNOW_{i,r}$ become part of the value added matrix (III. quadrant). In the last step the original intermediate transaction matrix $VL_{i,j,r}$ must be corrected by the knowledge in the matrix $W_{i,j,r}$. The outcome is the modified intermediate transaction matrix $VL_{i,j,r}^{\mathrm{mod}}$ which is used in the CGE model instead of the original transaction matrix $VL_{i,j,r}$.

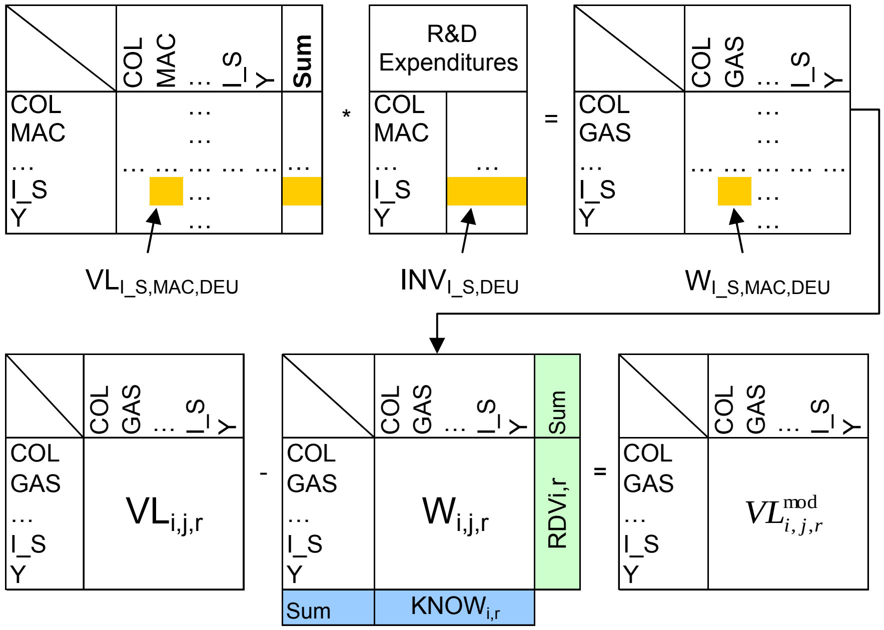

Figure 4. Extraction of R&D investments and knowledge from the original input-output table

Finally the input-output framework has to be re-balanced because the row and column sums are not identical and the conditions of a general equilibrium are violated. Figure 5 shows the new input-output table schematically with explicitly R&D investments and knowledge endowment.

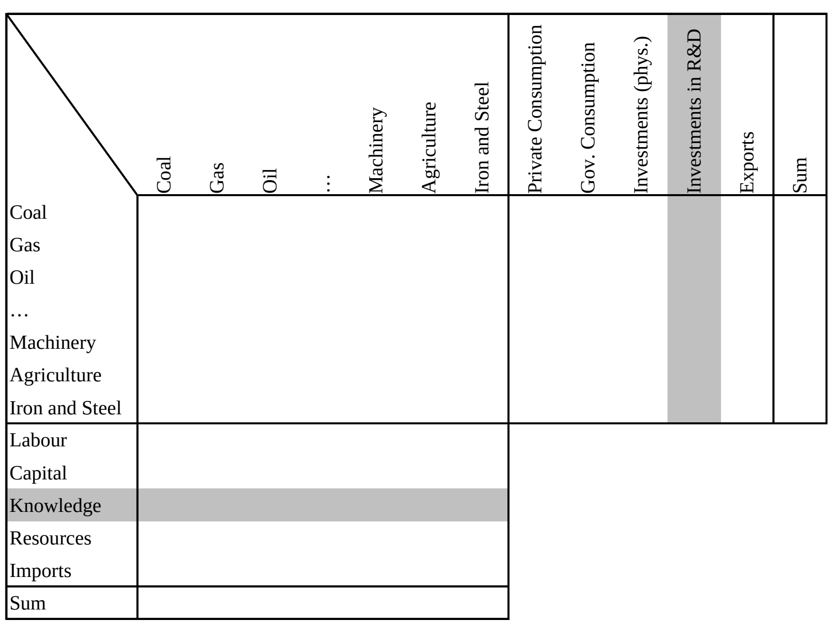

Figure 5. Input-output table with R&D investments and knowledge

In the last section we described in detail how R&D investments and knowledge are extracted from a standard input-output table and in which quadrants R&D and knowledge have to be arranged. Now we turn to the question how R&D investments and knowledge endowment will change over time in a recursive-dynamic model.

R&D investments and knowledge are treated in the same way as physical investments and capital endowment in the recursive dynamic model. In CGE models physical investments and capital endowments play a mayor role because investments in period t determine the capital endowment in period t+1.

$$(4) \quad CAP_{r,t+1} = CAP_{r,t}\left(1 - dep_r^{CAP}\right)INV_r$$

R&D investments play an adequate role for the composition of knowledge endowments:

$$(5) \quad KNOW_{r,i,t+1} = KNOW_{r,i,t}\left(1 - dep_r^{CAP}\right)INV_{i,r}^{R\&D}$$

In contrast to physical investment and capital we implement sectoral R&D investments and sectoral knowledge. At this point the question arises why it is possible to implement sectoral R&D investments and investments in physical goods only on a regional level. The overview of physical as well as R&D investments in table 4 clarifies this point.

Table 4. Physical investments and R&D investments in Germany

	Physical Investments		**R&D Investments**	
	bn EUR_{2001}	**%**	**bn EUR_{2001}**	**%**
COL	4.19E-06	0.00%	0.03	0.09%
GAS	5.75E-05	0.00%	0.02	0.05%
CRU	9.87E-07	0.00%	0.00	0.01%
OIL	1.97E-06	0.00%	0.05	0.16%
ELE	3.11E-05	0.00%	0.06	0.16%
AGR	0.44	0.12%	0.07	0.20%
CHM	1.02	0.28%	6.20	17.98%
MAC	158.37	43.24%	23.57	68.36%
BUIL	177.85	48.55%	0.05	0.15%
TRN	7.45	2.03%	0.78	2.26%
PPP	0.02	0.01%	0.12	0.34%
I_S	0.04	0.01%	0.58	1.68%
Y	21.12	5.76%	2.95	8.57%
	366.31	100.00%	34.48	100.00%

The physical investments are stem from the GTAP database and show how much was invested in Germany respectively in other countries or regions in the year 2001. The largest numbers are in the Machinery sector (MAC) and the Building sector (BUIL) with additional 336 bn EUR_{2001}. But the sectoral entries are misleading. E.g. when a new power plant is build by a company which belongs to the Electricity sector (ELE) the investments are not part of the investments of the electricity sector. Because the investments only say how much material stem from a sector and not that the investments are made in this sector. When a new power plant is build many materials are delivered by companies from the building and the machinery sector. The entry in the electricity sector give only information how much (physical) electricity is needed to build the power plant expressed in value terms. Therefore the entries in the input-output table are not sectoral investments taken by a several sector. For this reason we use only regional investments in NEWAGE-W.

The situation for investments in R&D is different. For example the entry for the chemical sector with an amount of 6.2 bn EUR_{2001} denote that companies which belong to the chemical sector invests this amount in R&D. Therefore the entries for the R&D expenditures are exactly the sectoral R&D investments and can be used in the CGE model. The sectoral R&D expenditures in period t determines the knowledge endowement in period t+1 as shown in equation 5. Knowledge is part of the value added matrix and is a further primary factor input in the production process like physical capital, labour and natural resources.

Figure 6 shows the nested CES production function for production of non-energy goods with the additional input factor knowledge. When knowledge endowment grows over time, less inputs on energy, material, capital and labour is needed in the production process. For this reason knowledge is applied in the top nest of the CES production function. Hence knowledge can substitute the whole capital, labour, energy, material (KLEM) nest.

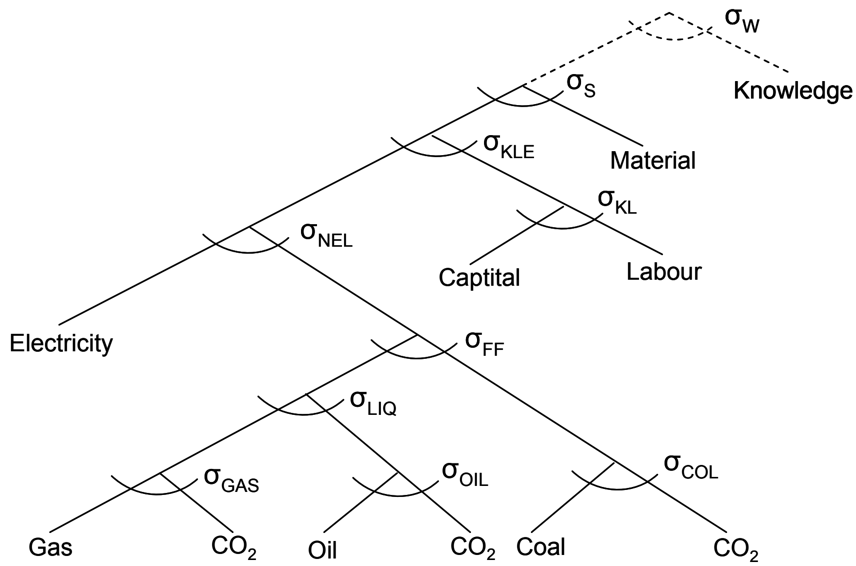

Figure 6. CES production function with an additional factor input knowledge

4 Scenario description

Knowledge is used in the production functions together with other primary factors capital, labour, natural resources and intermediates from other industries. The primary factor knowledge is able to substitute the other inputs in production. But the share of knowledge in the base year is very small. In the EU-25 only 0.8% of all total input value is knowledge. Therefore knowledge cannot substitute many other physical inputs.

In the following we analyse the impacts of direct as well as indirect knowledge promotion within three scenarios. In all scenarios investments in R&D and the primary factor knowledge are treated explicitly. The R&D investments determine the knowledge endowment in the knowledge accumulation equation (cf. equation 5). First we calculate a reference scenario (BAU) without any promotion of knowledge. In the first knowledge promotion scenario SCEN1 knowledge is promoted indirectly with a subsidy on sectoral R&D investments for the energy intensive industries electricity generation (ELE), chemical products (CHM) and transport (TRN). Through higher R&D investments knowledge accumulates faster which results in higher knowledge shares in the production process. In the second knowledge promotion scenario SCEN2 we implement a direct input subsidy on knowledge in the same energy intensive sectors ELE, CHM and TRN.

For all three scenarios a climate protection regime is defined according the Kyoto targets and the EU Burden Sharing agreement. Until now the responsible institutions (e.g. the COP 11) made no concrete suggestions how a climate protection regime after the first Kyoto period in 2012 will look like. Therefore we assume that after the first Kyoto period the now ratified Annex-B countries have to reduce their CO_2 emissions until 2030 about 16% compared to the emission level in 1990. It indicates that the not ratifying Annex-B countries as well as the non Annex-B countries will not accept concrete emission limits in the next years. Thus the assumption is made that there is no broadening, i.e. the only countries which have ratified the Kyoto Protocol by now will limit their emissions. Furthermore there is an emission trading scheme between all Annex-B countries ratifying the Kyoto Protocol.

Within scenario SCEN1, knowledge is promoted indirectly with an absolute subsidy on R&D investments in the energy intensive sectors electricity generation, chemicals and transport. Therefore we double the investments of the base year 2001. Table 5 gives an overview by region over the sectoral R&D investments in the three industries ELE, CHM and TRN in 2001. The subsidy is implemented from 2005 onwards as a fixed subsidy amount and remains constant over time. Through the promotion of the sectoral R&D investments knowledge grow faster due to higher R&D investments.

Table 5. R&D investments in the energy intensive industries in 2001

	DEU	OEU	NEU	EAB	RUS	RAB	REJ	OPE	CHI	ROW
	[bn EUR_{2001}]									
ELE	0.06	0.84	0.03	0.15	0.06	1.16	0.18	0.08	0.15	0.31
CHM	6.20	17.31	0.14	0.94	0.10	20.03	21.57	0.25	1.12	1.46
TRN	0.78	0.22	0.04	0.06	0.03	0.41	1.97	0.11	0.24	0.45
Sum	7.03	18.36	0.21	1.14	0.19	21.60	23.71	0.44	1.51	2.22

In the second scenario SCEN2 knowledge is promoted directly through a subsidy on knowledge also for the three energy intensive industries electricity generation (ELE), chemical products (CHM) and transport (TRN). For a better comparison of the two knowledge promotion scenario we implement the same absolute subsidy payment for SCEN2 as in SCEN1 also as a constant subsidiy payment.

For the BAU as well as for the two scenarios SCEN1 and SCEN2 the agreement on nuclear phase out in Germany has been implemented explicitly. Electricity generation from renewable energy sources are implemented in the model according to the observed generation in the base year 2001. But the subsidization of renewable energy and other instruments to promote the renewables have not modeled in this model version. The use of biomass and hydro power is bounded due to technical and geographical restrictions. For the use the other renewable energy sources no technical restrictions are made.

5 Results

5.1 Economic and ecologic effects

The GDP in the EU-25 grow about 75% in the reference scenario (BAU) between 2001 and 2030. The EU-15 contributes the greatest part on total GDP in the EU-25 with shares between 95% and 96% over the whole time period. Figure 7 shows the GDP growth rates for the three model regions EU-14 (OEU), Germany (DEU) and the new eastern European member countries (NEU). It is obvious that growth rates in the new European member states are higher compared to the EU-15. Nevertheless, the most GDP is still generated in the western European member countries.

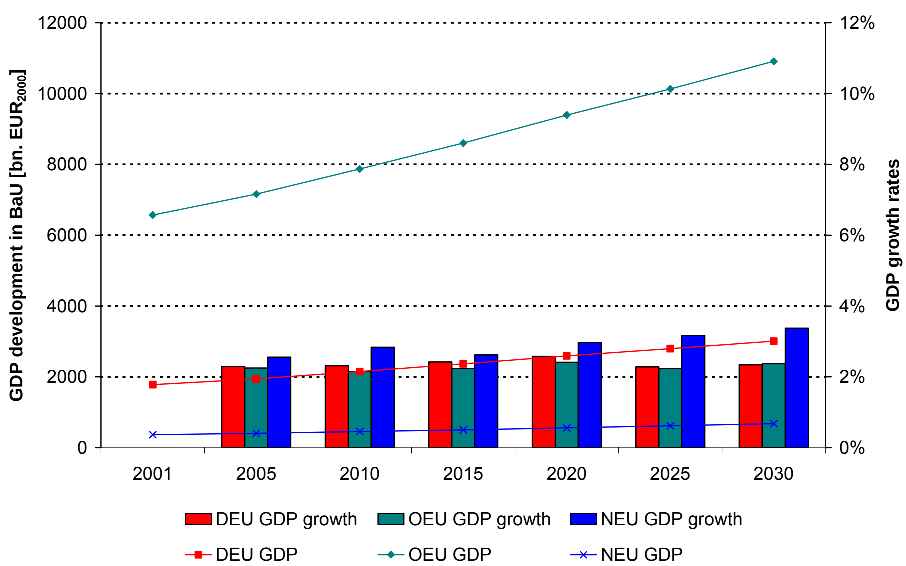

Figure 7. GDP development and GDP growth rates for the EU-25 in the BAU scenario

Figure 8 shows the GDP effects due to the R&D subsidies in SCEN1 as well as the GDP effect due to the knowledge subsidies in SCEN2. There are positive GDP effects as a result of the subsidies in both scenarios. It is obvious that promotion of knowledge accumulation (SCEN1) has a much bigger effect as knowledge allocation (SCEN2). The negative financing effect through the subsidies is smaller than the positive budget effects in both scenarios also in the first periods. There are only positive GDP effects over the whole time period as a result of the knowledge subsidy and the R&D subsidy respectively.

The main reason lays in positive effects from increased knowledge use in production. Through the promotion of R&D investments, knowledge accumulation is stimulated which results in 71% more knowledge use in the EU-25 in scenario SCEN1 compared to the baseline in 2030. More knowledge use leads to higher production in all industry sectors. In SCEN1 there is 2.4% more output in the electricity conversion sector, 7.2% more output in the chemical sector and 2.0% more output in transport services in the EU-25 in 2030. Higher production leads to significant higher GDP development. GDP in SCEN1 is 0.5% higher in 2010, 1.2% higher in 2020 and 1.8% higher in 2030 compared to the BAU scenario. In contrast, direct promotion of knowledge with a subsidy has a much lower effect. The main result is a reallocation of existing knowledge in the production process. Nevertheless there are also positive GDP effects in the EU-25 observable. In scenario SCEN2 GDP in the EU-25 is 0.2% higher compared to the reference case in the year 2030.

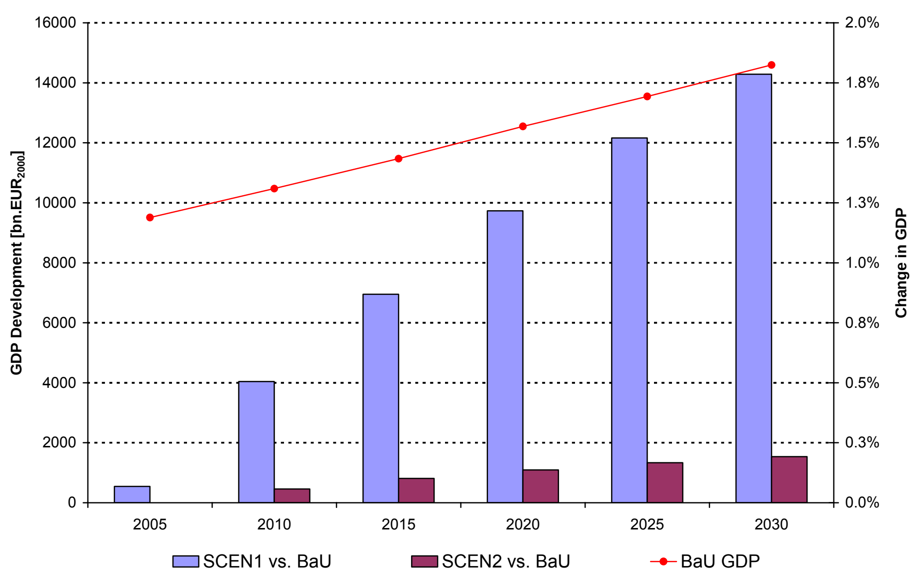

Figure 8. GDP development and differences in GDP for the EU-25

Another reason for the positive GDP effects is the formulation of the subsidy policies in the CGE model. The simplest approach is to implement a percentage subsidy rate on knowledge or on R&D investments. Through the percentual subsidy rate the net prices are lower and demand for the relevant input or product raises. But through the implementation of a subsidy rate there is no upper limit for absolute subsidy payment. This means that through the significant demand growth for the subsidized product the financing effect is much higher than the positive demand effect. In contrast we implement a fixed absolute subsidy payment. The absolute payment is endogenously calculated in an adequate subsidy rate in such a way that exactly the given absolute subsidy is paid. As a result we avoid a high negative financing effect and therefore negative economic effects.

Besides changes in GDP development, macroeconomic effects can be quantified by taking welfare measures into consideration. Therefore we determine the Hicksian Equivalent Variation (HEV) for all three scenarios. The HEV is a concept of the welfare theory and measures the amount of money a consumer must receive in a reference case in order to allow him to achieve the same utility level as in the counterfactional scenario. A positive HEV denotes utility growth and welfare gains. Figure 9 shows the welfare effects for all model regions for both scenarios compared to the reference case without any promotion instrument. In general there are the same results as for the GDP development. The positive welfare effects are much higher in scenario SCEN1 compared to scenario SCEN2. Welfare effects are highest in Germany (DEU) and the rest of the Annex-B countries (RAB) with approximately 1.6% in 2030. In the region China and India (CHI) welfare effects are lowest in scenario SCEN1. In scenario SCEN2 the results are also positive but on a much lower level compared to scenario SCEN1. Welfare is approximately 0.05% higher in the EU-25 compared to the business-as-usual scenario (BAU). In this case welfare effects are slightly higher in the non Annex-B countries compared to the Annex-B countries.

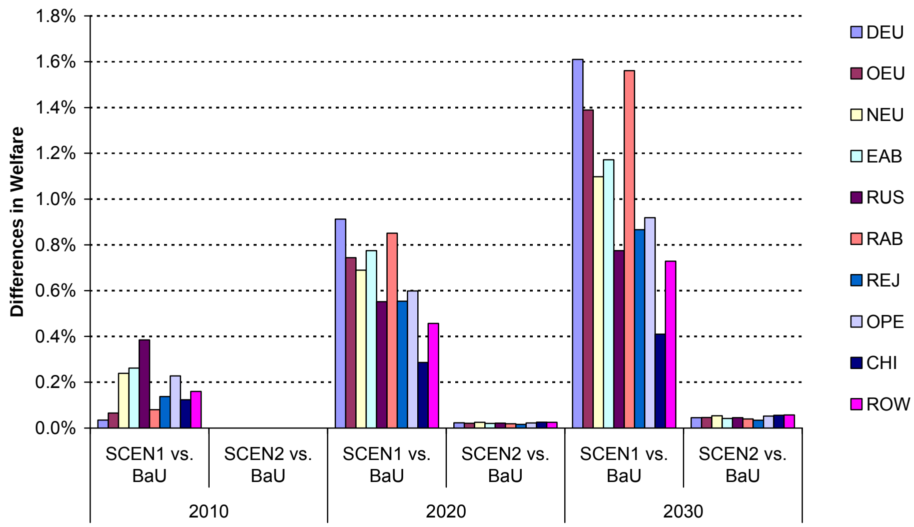

Figure 9. Differences in welfare in SCEN1 and SCEN2 scenario compared to the BAU scenario

As already described above the R&D subsidy in scenario SCEN1 leads to higher knowledge demand in the industry sectors. Figure 10 shows the differences in knowledge input for the three energy intensive industries electricity generation, chemicals and transport. In Germany (DEU), the highest effects are observable for the chemical sector followed by the transport sector. In 2030 knowledge inputs are 72% higher in the chemical sector and 65% higher in the transport sector. In the electricity conversion sector in Germany, knowledge inputs are 48% higher in SCEN1 compared to the BAU scenario in 2030. The effects look similar for the other western European member countries (OEU) but the results especially for the transport services look different. In the region OEU there is 15% more knowledge input in the transport sector in 2030. The effects in the eastern European member states (NEU) are lower compared to DEU and OEU. In the region NEU 20% more knowledge is used in the electricity conversion sector, 23% in the chemical sector and 15% in the transport sector in scenario SCEN1 compared to the reference scenario in the year 2030. The main reason is, that the share of knowledge in the production process in the new member countries is smaller in the base year 2001 compared to the EU-15. Therefore there are positive effects through the R&D subsidy but on a lower level compared to the other countries.

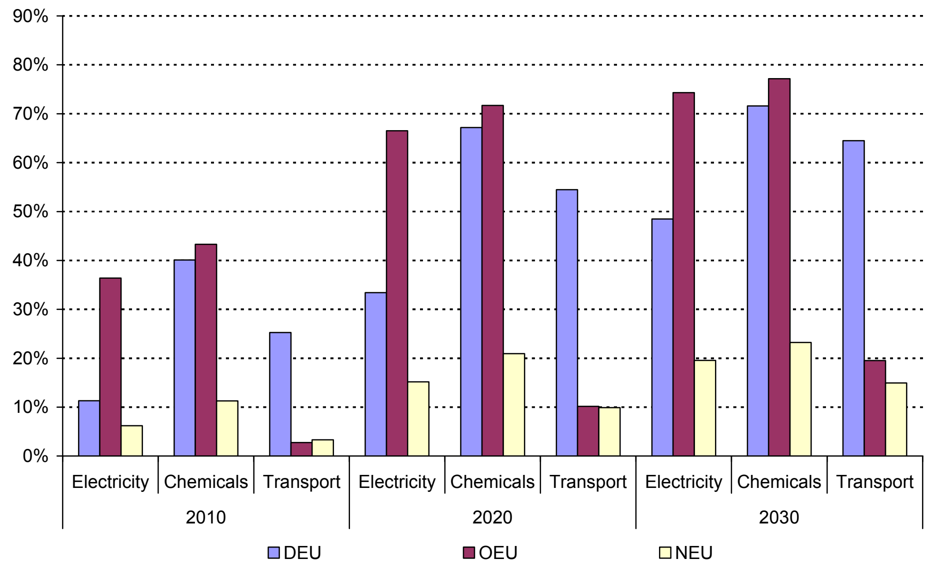

Figure 10. Difference of knowledge input SCEN1 vs. BAU in the EU-25 by region

Figure 11 gives an overview over the absolute development of knowledge inputs in the three industries electricity, chemicals and transport in the EU-25. Knowledge input growth is highest in the chemical industry. Already in the base year there is more knowledge in the chemical sector compared to the electricity conversion sector. The reason is that the sum of all inputs is also higher in the chemical sector compared to the electricity conversion sector.

Knowledge is a very important factor input in the production process of the chemical sector. Already in the baseline scenario knowledge grows from 24 bn € in 2001 to 77 bn € in 2030. In the scenario SCEN1 the knowledge grows by a factor of 6 from 24 bn € to 135 bn € in 2030. Also knowledge inputs in electricity generation sector grow more as a result of the R&D subsidy. In the reference case knowledge grows by the factor 2.1 and in the scenario SCEN1 there is a knowledge growth by a factor of 3.6 as a result of the subsidy. It is obvious that knowledge is more important in the chemical sector as in the electricity generation. Because there is less knowledge in the base year and the subsidy has a much stronger impact on the chemical sector. The results for the transport sector show that the knowledge input decline over time. In the base year 2001 there is 8.8 bn € knowledge used in the production function. In the year 2030 the absolute knowledge input decline to 6.1 bn €. Through the subsidy knowledge inputs are nearly constant over time.

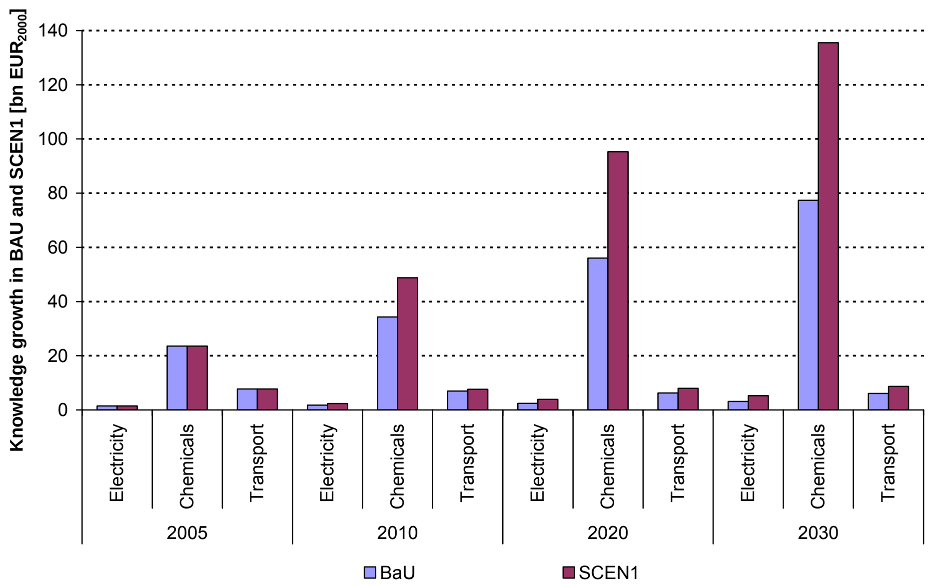

Figure 11. Knowledge growth in BAU and SCEN1 in the EU-25

We also analyse the effects on knowledge input and knowledge endowments in all three scenarios. Knowledge endowment is determined by an exogenously given depreciation rate and the endogenously calculated R&D investments. The endogenous R&D investments together with investments on physical goods and consumption of final goods are a result of the utility maximation problem of the representative agent for every region in the model.

There are also positive effects on knowledge inputs and therefore on knowledge endowments in the knowledge promotion scenario (SCEN2). The left axis of figure 12 shows the development of knowledge endowment in the reference scenario for Germany (DEU), the western European member countries (OEU) and the new eastern European member states (NEU). It is obvious that knowledge becomes more important in the future. The share of knowledge in production is 0.8% in all industries in the EU-25 in the base year 2001. This shares nearly doubles already in the reference scenario to 1.4% until 2030. That is equal to an absolute increase from 124 bn € to 423 bn € from 2001 to 2030.

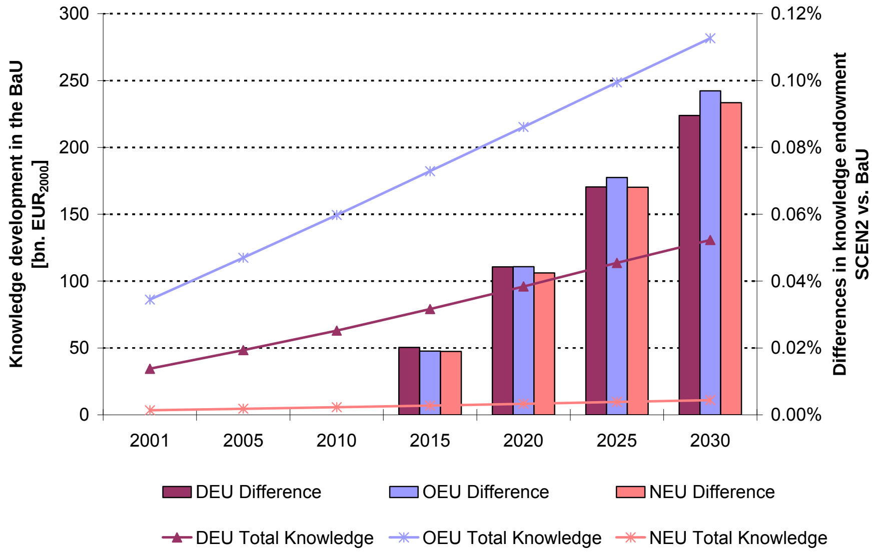

Figure 12. Development of knowledge and difference of knowledge SCEN2 vs. BAU in EU25

The right axis of figure 12 shows the differences in knowledge endowment between scenario SCEN2 and the reference case. As a result of the direct knowledge promotion in scenario SCEN2 and higher GDP growth, knowledge endowment is slightly higher compared to the baseline. This figure make it obvious that direct subsidization of knowledge for the energy intensive sectors change only the allocation of the knowledge input and fewer the accumulation of knowledge endowment.

R&D subsidies as well as knowledge subsidies have also an impact on CO_2 emissions and CO_2 allowance prices. There is a 16% reduction target of total CO_2 emissions in the ratifying Annex-B countries implemented. Between these countries trade of CO_2 emission certificates are possible. The left axis of figure 13 shows the absolute development of CO_2 emissions in all ratifying Annex-B countries. The greatest emission reduction is observed for the eastern European member countries of the EU (NEU) with 17% lower emissions in 2030 compared to the emissions in 2001. In the other European Non-EU countries (EAB) as well as in Russia (RUS) emissions are 13% lower in 2030. CO_2 emissions in Germany raises by 4% between 2001 und 2030.

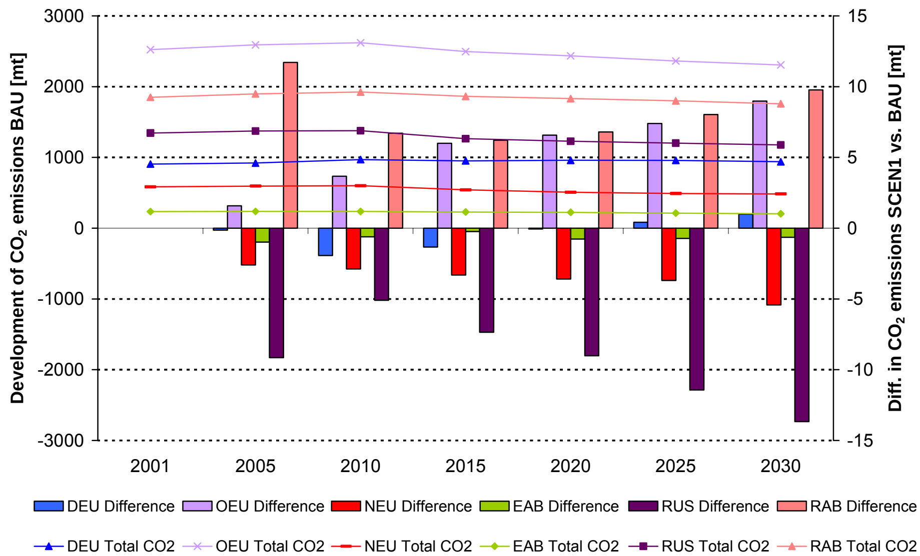

Figure 13. Development of CO_2 emis. and difference in CO_2 emis. in the rat. Annex-B countries

As a result of indirect knowledge promotion with a R&D subsidy, regional emissions changes. Total emissions in all Annex-B countries must be the same as in the baseline scenario. But regional emissions can change due to the emission trading scheme. Emissions in DEU and OEU increase slightly by 1 and 9 mt respectively. In the scenario SCEN1 CO_2 emissions are 14 mt lower in Russia, 5 mt lower in the region NEU and about 1 mt lower in the region EAB. In contrast emissions are higher in OEU (+9 mt), RAB (+10 mt) and Germany (+1 mt). It is evident, that changes in CO_2 emissions are very small compared to total emissions. The emissions in the other non-Annex-B countries and rejecting Annex-B countries are 40 mt lower in 2010, equal in 2020 and 33 mt higher in scenario SCEN1 compared to the baseline. Between scenario SCEN2 and the reference scenario there are only very slight differences for all countries observed.

As a result of changes in regional CO_2 emissions in SCEN1 there are also differences in CO_2 emissions allowance prices (cf. figure 14). In the baseline CO_2 prices are 5.1 €$_{2000}$/t CO_2 in 2010, 21.0 €$_{2000}$/t CO_2 in 2020 and 40.4 €$_{2000}$/t CO_2 in 2030. Higher GDP in SCEN1 indicates that the demand for CO_2 certificates raises but the supply is constant through the emission cap and these results in higher prices. The CO_2 price is 1.4 €$_{2000}$/t CO_2 higher in scenario SCEN1 compared to the baseline scenario in 2030. Similar to the differences in CO_2 emissions, the differences in carbon permission prices are also smaller in the SCEN2 scenario and amounts to 0.10 €$_{2000}$/t CO_2 in 2030.

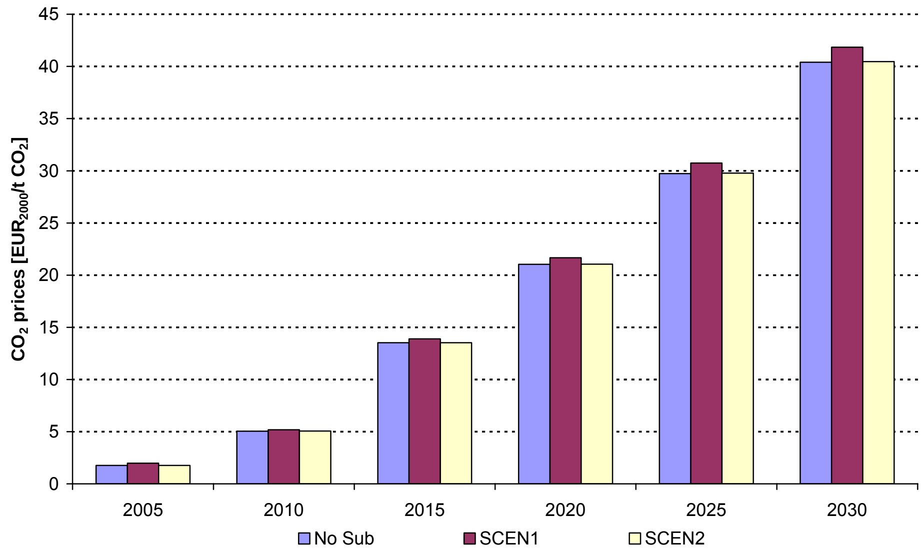

Figure 14. Development of CO_2 prices in all scenarios

5.2 Electricity generation

Electricity generation growth amounts to 47% in the EU-25 between the base year 2001 and 2030. The nuclear phase out is only implemented in Germany. For all other countries respectively regions there are no political restriction on the commission of new nuclear power plants. For this reason the share of generation from nuclear power plants raises significantly from 32% in 2001 to 46% in 2030. Due to the strict climate protection regime the share of electricity generated in fossil fired power plants declines from 52% in 2001 to 27% in 2030. Electricity generation from renewable energy sources account for 27% of total generation in 2030.

As a result of the subsidies in the scenarios SCEN1 and SCEN2 the electricity portfolios change slightly. Similar to the other presented results the effects in SCEN1 are much higher as the effects in SCEN2. In scenario SCEN2 generation for all technologies remains nearly constant. This shows that direct knowledge promotion has a much lower effect compared to indirect promotion with R&D investments.

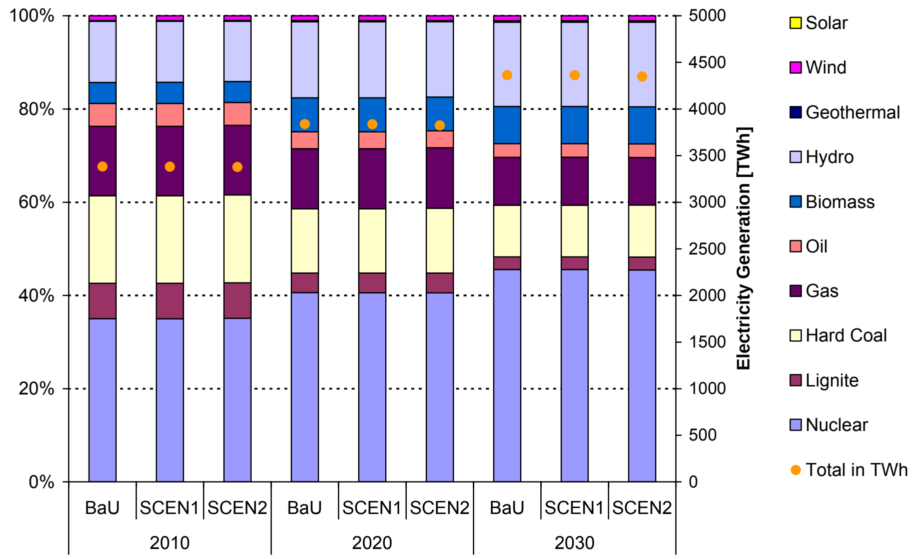

Figure 15. Electricity generation in all scenarios in the EU-25

Through the stimulation of knowledge endowment in scenario SCEN1 total electricity generation is 78 TWh higher in the EU-25 compared to the reference scenario in 2030. As a result of higher knowledge endowment and higher GDP, electricity demand raises for nearly all generation technologies in scenario SCEN1. There is only a decline for hard coal and lignite fired power plants observed. In 2030 electricity generation from hard coal decline by 0.3% and lignite by 0.7% in SCEN1 compared to the baseline scenario in the EU-25. The highest percentage changes are observed for nuclear power generation and for geothermal power plants. But we should bear in mind that production from geothermal is very small in the baseline. The largest absolute increase in electricity production is observed for nuclear power. Generation raises by 67 TWh in the EU-25 in 2030. There is no effect for hydro power. The reason is that there are geographical limitations for the commissioning of new mainly large hydro power. Therefore the potential is already complete used in the baseline and no further production increase is possible.

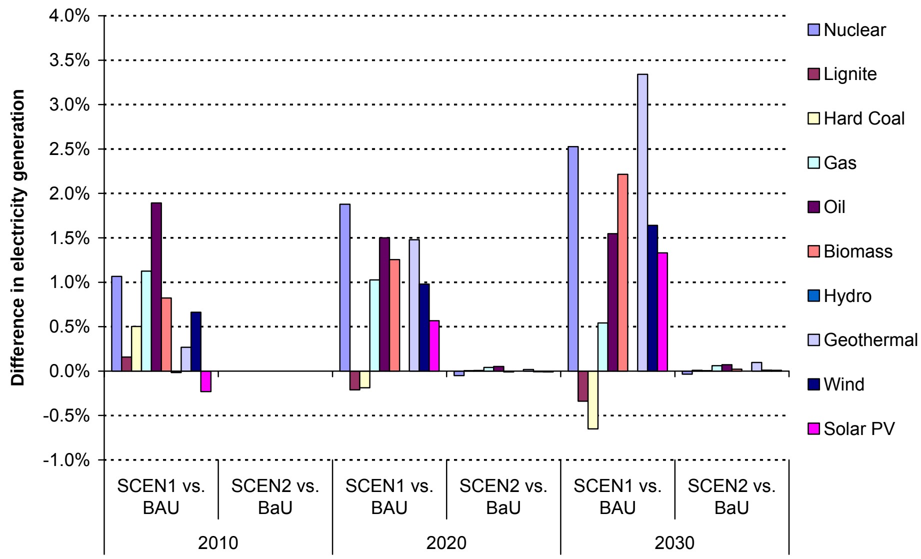

Figure 16. Change in electricity generation through knowledge promotion in the EU-25

6 Conclusion

Explicit representation of knowledge and R&D investments brings great advantages for the quantitative scenario analysis. Normally efficiency gains and structural changes are captured exogenously with the Autonomous Energy Efficiency Improvement (AEEI). The first problem related with the AEEI approach is the exogenous implementation. No matter what policy instrument is analysed, the intensity and height of the AEEI is not affected by the policy instrument. For instance, a strict climate protection regime does not lead to more efficiency efforts. The second problem is the costless availability of efficiency gains. The efficiency gains must not be financed by the production or consumption side. Nevertheless we still implement an AEEI component in the model because since the first oil price shock in the 1970s there is an empirical evidence for the decoupling of GDP growth rates and energy use growth rates.

But technological change is also implemented through the explicit treatment of knowledge in the production process and R&D investments because the problems related with the AEEI can be solved with the endogenous implementation of knowledge and investments in R&D. Only when the representative agent invests in R&D, knowledge endowment grows. When investments in R&D are made, financial resources can not be used for investments in physical goods or for consumption i.e. the financing aspect of technological change is represented in the model.

Implementing knowledge as an input into production and investments in R&D has an important impact on model results. In the base year 2001 0.9% of all inputs are knowledge in Germany. Due to investments in R&D knowledge endowment grows significantly in the reference case and accounts for 1.4% of all inputs in production in Germany in 2030. This implies that knowledge gets more important in the production process in the future. Therefore knowledge can substitute other physical material and energy inputs. This effect can be verified also for the other model regions. Knowledge inputs grow two to three times higher than other physical production inputs.

In the presented knowledge promotion scenarios there are different effects on GDP and other economic and ecologic variables. We showed that the effects through an indirect knowledge promotion with subsidies on R&D investments are much higher compared to direct knowledge subsidies. The reason is that investments in R&D are an endogenous decision of the representative agent. He decide how much of the financial resources are spend for investments in physical goods, for consumption or for R&D investments. A subsidy on R&D investments changes relative prices and R&D becomes cheaper compared to physical investments and consumption. As a result more money is spend for R&D investments because the only decision variable for the representative agent are relative prices. Knowledge endowment grows more rapidly because it is determined through higher R&D investments. This means that a subsidy on R&D investments lead to higher knowledge endowments and this augments more knowledge input in the production process. On the other side direct knowledge promotion has only an effect on knowledge allocation and not on knowledge accumulation. When knowledge is subsidized directly in the energy intensive industries, knowledge is shifted from other non-energy intensive sectors to energy intensive sectors. This leads to more knowledge inputs in the energy intensive sectors and therefore fewer inputs of other inputs are needed. Higher production in these industries compensates less production in the other sectors and this leads to a slight increase in GDP. Thus, the representative agent has more financial resources and is able to investment more in R&D investments which leads to a higher knowledge endowment. But this indirect accumulation effect is much lower compared to the subsidization of R&D investments.

Our analyses show that an absolute subsidy on R&D investments has a much higher effect as the same absolute subsidy on knowledge inputs. But it should be noted that the results are strongly depended on the recursive-dynamic framework. More R&D investments lead to more knowledge endowment in the next period and this leads to more knowledge input in the production process. But more knowledge demand in the production process cannot trigger knowledge supply i.e. knowledge endowment. Because knowledge supply is price inelastic and there is no direct relationship in the direction from knowledge input to knowledge endowment and R&D investments.

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