A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications

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Abstract

The paper presents a CGE model for evaluating energy policy measures with emphasis on their employment impacts. It specifies a dual labor market with respect to qualification, two different mechanism for skill specific unemployment, and a technological description of electricity generation. The model is applied for assessing an exemplary technology oriented green house gas emission reduction strategy.

Content

1. Introduction

The relationship between environmental policy and employment has been theoretically discussed since the 1970s and numerically assessed subsequently.[1] Persistently high unemployment rates in Europe as well as upcoming decisions on future energy systems create a current need for research on the employment impacts of alternative environmental and energy policies.[2]

CGE modeling provides an established instrument for the quantification of the impacts of energy and environmental policy measures on the economy. The neoclassical principles of any CGE model imply flexible prices and market clearing for labor just as for any other good or factor of production. Consequently, standard CGE models do not take into account the non-clearing of the labor market as it occurs in reality and as it is of high importance for any economic assessment. The resulting research implication is the modeling of involuntary unemployment. With respect to energy economics, it has been discussed mainly in the context of the double dividend hypothesis by e.g. Böhringer et al. (2001), Koschel (2001), Böhringer et al. (1997), and Carraro et al. (1996).

Moreover, labor demand and unemployment differ between qualification, i.e. skill type of labor. For instance, as Reinberg and Hummel (2003) show for Germany throughout the last two decades the unemployment rate amongst unskilled labor was about three times higher than it was for skilled. Disaggregating labor input by skill level has recently been introduced to energy policy assessments, as e.g. in Faehn et al. (2004), Niez and Sue Wing (2004), Bosello and Carraro (2001), and Hill (1998).

Most energy policy instruments are technology oriented. The choice of technologies determines the economic and ecological outcome induced by a policy measure. As Fahl et al. (2005) point out this includes the energy system's employment impact.

Consequently, a CGE analysis of the economic implications of alternative energy systems needs to incorporate explicit labor market determinants based on labor economic theory as well as energy technology specifications. Chapter 2 formulates a CGE model that aims at meeting these requirements. It includes a dual labor market which allows not only for considering skill specific unemployment rates. As chapter 3 discusses a dual labor market also permits a distinct modeling of different causes for unemployment that each skill type is subject to. Here, involuntary unemployment of skilled workers is related to a wage curve. Unskilled labor's unemployment is due to a minimum wage formulation, i.e. downward rigid wages. In Chapter 4 the model is exemplarily applied for the assessment of GHG reduction policy measures in the context of energy related sustainability. Chapter 5 concludes and identifies research implications.

[1] For a recent overview see OECD (2004).

[2] These system decisions are determined by climate policy endeavours, market liberalization, and the strong necessity for replacement and extension of generation capacities in the national power plant system.

2. Model description

2.1 Origin and composition

The model applied in this paper is a multi regional, multi sectoral Arrow-Debreu general equilibrium model. It is formulated as a system of non-linear equations in the programming language GAMS/MPSGE by Brooke et al. (1996) and Rutherford and Paltsev (2000). The model itself is based on GTAP-EG by Rutherford and Paltsev (2000) and on Böhringer (1996). It has been further developed and applied by e.g. Küster et al. (2006) and Zürn et al. (2005). Underlying data for production and trade follows the economic input-output concept and is consistently provided by the GTAP6 database (cf. GTAP 2005).

The model accounts for ten regions. Regional aggregation is indicated in table 1. In each region 13 industries, of which five are energy sectors, produce output by applying four primary factors. Primary factors are capital, skilled labor, unskilled labor, and exhaustible energy resources. Natural resources other than primary energy carriers are not accounted for. In GATP6 these are forest and fish stock, which here are mapped to capital. Primary factors are regionally immobile but mobile between sectors. Households and government are represented by a single regional representative agent.

Table 1: Regional composition[3]

	Region	Definition	Countries within region (GTAP acronym)
1	DEU	Germany	DEU
2	OEU	Old EU15 w/out Germany	AUT, BEL, DNK, FIN, FRA, GBR, GRC, IRL, ITA, LUX, NLD, PRT, ESP, SWE
3	NEU	New EU members	CYP, CZE, HUN, MLT, POL, SVK, SVN, EST, LVA, LTU
4	EAB	All other European Annex B countries	ROM, BGR, CHE, XEF, HRV(*)
5	RUS	Annex-B country Russia	RUS
6	RAB	Rest of Annex-B	CAN, JPN, NZL
7	REJ	Annex B Rejecting Countries	USA, AUS
8	OPE	OPEC countries	IDN, VEN, XNF, XME
9	CHI	China and India	CHI, HKG, IND
10	ROW	Rest of World	All other 43 GTAP regions (**),(***)

[3] (*) Croatia (HRV) has not ratified Kyoto yet but it is assumed that in the course of EU accession ratification will soon be carried out.
(**) Rest of Sub-Saharan Africa (XSS) contains the OPEC country Nigeria. However, because there are numerous other countries incorporated in XSS, this group is mapped to ROW.
(***) Ukraine is part of Rest of former Soviet Union (XSU). Data for the single country Ukraine is not available in GTAP6. Hence, this Annex-B country cannot be accounted for as climate protection ally.

Table 2: Sectoral composition

Energy sectors		Non-energy sectors	
Coal	COL	Chemical, rubber, plastic products	CHM
Natural gas	GAS	Machinery and equipment	MAC
Crude oil	CRU	Buildings	BUIL
Petroleum	OIL	Transport	TRN
Electricity	ELE	Agriculture and forestry	AGR
		Paper products, publishing	PPP
		Iron and steel	I_S
		Rest of the economy, incl. services	Y

Table 3: Primary input factors

Primary input factors	
Skilled labor	SKL
Unskilled labor	USK
Capital (including land)	K
Exhaustible energy resources	R

Following Arrow and Debreu (1954), markets are assumed to be perfectly competitive so that for all economies equilibria are induced via flexible prices. As shown by Mathiesen (1985) the economic equilibrium can be determined by a system of nonlinear equations as a mixed complementarity problem. Three corresponding equilibrium conditions must be satisfied, namely (a) zero profit condition, (b) cleared market condition, and (c) income balance condition. (a) Any economic activity carried out must earn zero profit. Hence, firms maximize their profits subject to their production function by minimizing costs. (2) Any good produced by a firm has a positive prices that balances supply and demand. Goods in excess supply have a zero price. (3) Goods are acquired by agents under an income constriction.

2.2 The basic model

Any AGE model is characterized by a comprehensive perception of the circular flow economy. Figure 1 illustrates the major economic activities modeled.

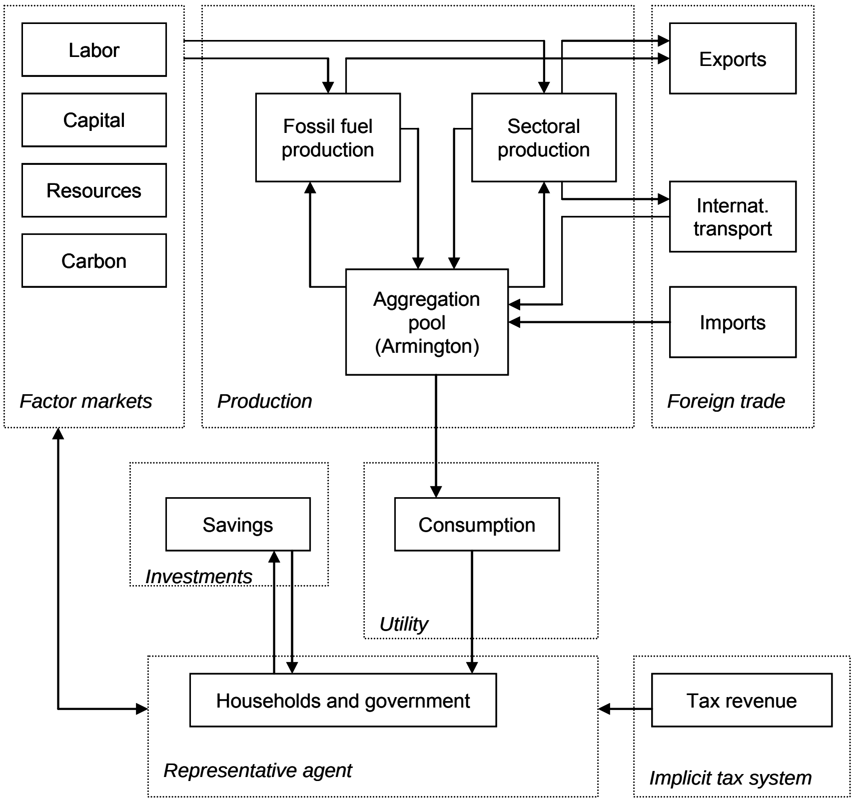

Figure 1: Model overview circular flow structure

Production is modeled by nested, linear homogeneous CES production functions which relate production factors according to elasticities of substitution.[4] Primary production factors are capital including land, exhaustible natural resources and labor. Following Arrow et. al (1961) production *Y* in a single economy *r* is realized by inputs of capital *K*, labor *L*, the intermediate product energy *E*, and non-energy intermediates i.e. material *M* (KLEM structure). For a simplified general model description one may abstract from specific nesting structures to show that an economy's output is given by

(1) $$Y_r = f\left(K_r, L_r, E_r, M_r\right) = (\theta_r^K \cdot K_r^{\rho_Y} + \theta_r^L \cdot L_r^{\rho_Y} + \theta_r^E \cdot E_r^{\rho_Y} + \theta_r^M \cdot M_r^{\rho_Y})^{\frac{1}{\rho_Y}}$$

Production factor inputs are weighted by a particular share parameter θ. The sum of share parameters equates to unity which reflects constant returns to scale. Factors are related to one another by constant factor substitution elasticities of $\sigma = 1/(1 - \rho_Y)$ where $(-\infty<\rho<1)$.

As indicated in figure 1 output may be exported or enter an Armington aggregate. As opposed to a Heckscher-Ohlin economy, Armington (1996) considers imported and domestic products to be imperfect substitutes. Hence, the Armington aggregate A_r composes of imports IM_r and of not exported domestic intermediate production (Y_r-EX_r). Imports and domestic absorption are linked to each other by an Armington elasticity parameter ρ_A.

[4] The general CES production function for a two factor economy is given by $Y = \left[\alpha K^{\rho} + (1-\alpha)L^{\rho}\right]^{\frac{1}{\rho}}$ with α as a share parameter and ρ being the substitution parameter.

(2) $$A_r = f(Y_r, EX_r, IM_r) = \left[\left(\theta_r^Y Y_r - \theta_r^{EX} EX_r \right)^{\rho_A} + \theta_r^{IM} IM_r^{\rho_A} \right]^{\frac{1}{\rho_A}}$$

International trade flows EX_r and IM_r are connected to a production function that reflects international transport services. Produced Armington goods may either be redirected as intermediates into the production process or consumed by the representative agent. Domestic consumption results as

(3) $C_r = f(A_r)$.

Utility is only generated through consumption. Investment is exogenous and does not enter the utility function. Leisure is not considered. Hence, utility of the representative agent in region *r* is given by

(4) $U_r = f(C_r)$.

The basic model is closed by limiting consumption through an income restriction for the representative household. Income *E* is generated on the perfectly competitive factor markets by selling endowments of production factors labor *L*, capital *K*, and exhaustible resources *R*, with their respective equilibrium prices *w, r,* and *π*.

(5) $E_r = w_r L_r + r_r K_r + \pi_r R_r + T_r - I_r + \gamma_r C_r$

Primary and intermediate factor inputs as well as output of any economic activity may be taxed. Factor taxes and commodity taxes are modeled as given in GTAP-EG (cf. Rutherford and Paltsev (2000)). Aggregate tax income *T* accrues to the representative agent and increases the budget. As part of the income is used for investment, budget to be allocated for consumption purposes is reduced by investment *I*. If emission trading schemes are included, CO_2 allowances *C* priced by *γ* come part of the factor endowment.

In addition to the stylized aggregate economy description, any multi-sector CGE model requires that each industry *i* is modeled by a specific nested CES production function. All industry production functions as a whole replace the aggregate output of equation (1). Before representing particular production functions in detail, their input factor labor is specified by skill type.

2.3 Heterogeneous labor

2.3.1 Categorization by occupation

The differentiation of labor by qualification can in principle be performed following a variety of categories and up to various details or levels of qualification. For instance, in a single country CGE model Lofgren (2001) distinguishes between four types of skill categories determined by educational level. In the paper at hand a dual differentiation between highly qualified (skilled) and less qualified (unskilled) labor input is carried out. It follows Liu et al. (1998) and applies the International Standard Classification of Occupations (ISCO-88) of the International Labor Organization (ILO) (cf. ILO 2006a). Consequently, differentiation is based upon occupational categories rather than education levels but as Liu et al. (1998) point out occupation and education tend to correlate with each other. Also, data availability is superior for occupational differentiation as the relevant input-output data is provided by GTAP6.

2.3.2 Replacing of homogenous labor in production functions

In the basic model of chapter 2.2 disaggregating labor *L* by skill implies to substitute homogenous supply *L* through skilled labor *SKL* and unskilled labor *USK*. The equilibrium price w_r is replaced by skill specific equilibrium wages. Regarding the sector specific production functions, heterogeneous labor inputs necessitate a modification of the usual nesting structures. Three major alternative implementations can be identified.

The *Single Primary Factor Nest* approach assumes that all four primary input factors can be introduced on a single nesting level under one prevailing substitution elasticity. This implies that all factors are direct substitutes. Applications can be find e.g. in Greenaway et al. (2002), and in Rutherford and Paltsev (2000).

The *Direct Labor Substitutability* approach suspends the direct composition assumption. Instead it aggregates skilled and unskilled labor on a distinctive nesting level. Value added is generated on a higher nesting level, where the thus created labor aggregate combines with capital and resource input. Consequently, substitution relations between the two types of labor can be taken into account discretely. This concept has been carried out e.g. by Niez and Sue Wing (2004), and Faehn et al. (2004).

On the other side, the *Capital-Skill Complementarity* theory, as developed by Griliches (1969), suggests that capital and skilled labor are complementary. Thus, they need to be modeled by a low elasticity of substitution or even by a Leontief nesting. On a higher nesting level, this capital-skill composition is integrated with other production factors. The capital-skill complementarity is applied e.g. in Böhringer et al. (2005).

The different nesting possibilities allow for taking into account inter industry differences in substitution possibilities and production structures. This is realized by differentiating the nesting structures according to the industry specific factor intensities. Following the GTAP6 data the factor intensities of the 13 sectors aggregated over all regions modeled is shown in Figure 2.

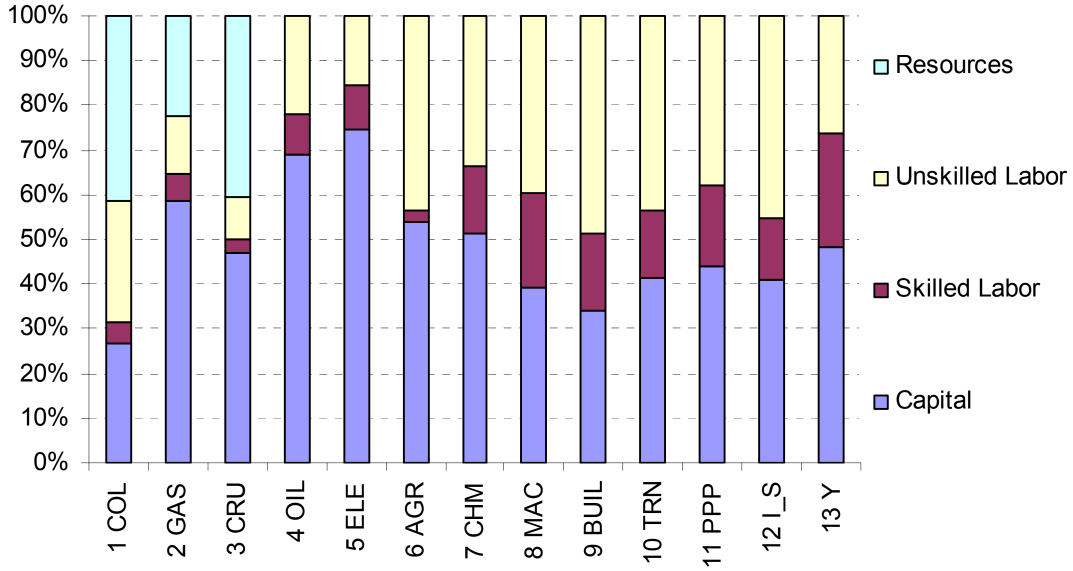

Figure 2: Sectoral primary factor intensities following GTAP6

The assumption is that in general industries can be described according to the concept denominated *single primary factor nest*. The exception is capital intensive industries which are characterized by *direct labor substitutability* and a value added nest that allows only modest substitution between the labor aggregate and capital. With the sectoral disaggregation applied here, these industries are the conversion industries, namely refinery and electricity production.[5] The idea behind this assumption is that in the conversion sector large part of the capital used is indispensable. Thus a rather limitational elasticity between labor and capital aims at avoiding unrealistic substation patterns.[6] In addition, the electricity sector as part of the conversion sector is treated in a more complex technology detailed way. The categorization of nesting structures yields four types of production functions as summarized in table 4.

Table 4: Categorization of nesting structures

	Sectors	Nesting concept
1	CHM, MAC, BUIL, TRN, AGR, PPP, I_S, Y	Single primary factor nest + other nests
2	COL, CRU, GAS	Single primary factor nest + exhaustible resources
3	OIL	Direct labor substitutability + other nests
4	ELE	Technology detailed

2.3.3 Production functions with heterogeneous labor

The first category includes all non energy sectors. Labor inputs are modeled in the style of the *single primary factor nesting* concept. Capital *K*, skilled labor *SKL*, and unskilled labor *USK* are linked through a Cobb Douglas function in the valued added nest with their respective

[5] The threshold for capital intensity is set at a capital share of 60 % in primary input.
[6] The principle possibility of unrealistic substitutions is also mentioned in Smajgl (2001).

shares θ_K, θ_{SKL}, θ_{USK} and $\theta_K + \theta_{SKL} + \theta_{USK} = 1$.[7] The substitution elasticity σ is given via the parameter ρ as $\sigma = 1/(1 - \rho)$, with $(-\infty<\rho<1)$. Value added is collocated on the next level with the energy aggregate. The energy aggregate itself is a composite of electricity, coal, gas, oil and if applicable CO_2 allowances. The final KLEM aggregate is formed on the upper level by a Leontief function, i.e. $\sigma^{KLEM}=0$ ($\rho^{KLEM}=-\infty$). Here, the production function for all sectors other than conversion or exhaustible resource production can be formulated as ion equation (6). Figure 3 illustrates the corresponding nesting structure.

(6)

$$Y_i = \left[\begin{array}{c} \left(\sum_j \theta_{j,i}^M M_{j,i}^{\rho_i^{KLEM}} \right) + \left(1 - \sum_j \theta_{j,i}^M \right) \\ \left[\theta_i^E E_i^{\rho_i^{KLE}} + \left(1 - \theta_i^E\right) \left(K_i^{\delta_i^K} SKL_i^{\delta_i^{SKL}} USK_i^{\delta_i^{USK}} \right)^{\rho_i^{KLE}} \right]^{\frac{\rho_i^{KLEM}}{\rho_i^{KLE}}} \end{array} \right]^{\frac{1}{\rho_i^{KLEM}}},$$

$$i \notin xe, ele, oil$$

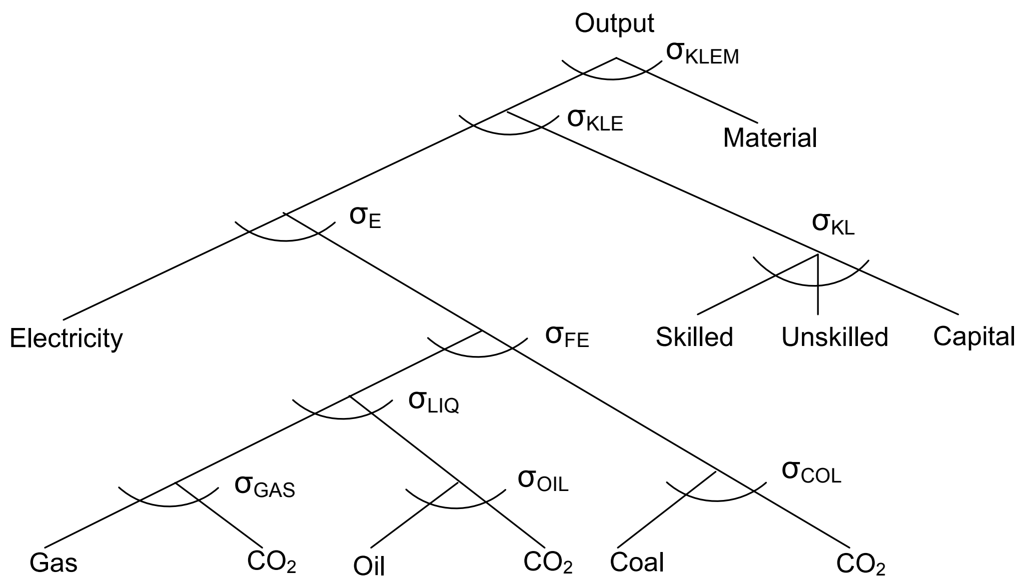

Figure 3: Nesting structure for all non-energy sectors

For the production of exhaustible energy resources in the sectors crude, gas, and coal production (*xe*) the elasticity between energy resources *R* and value added depends on the value share of resource inputs, following Rutherford and Paltsev (2000). Further inputs within the KLEM nest are linked as a Leontief composite because the sectors are considered as fixed technology descriptions. The production function with ρ as $\sigma^{KLEM}=0$ ($\rho^{KLEM}=-\infty$) and nesting structure result as follows.

[7] Under perfect competition in a Cobb Douglas function $Y=L^{\alpha}K^{\beta}$, α and β can be shown to be L's and K's share of output, above denominated θ. See e.g. Paltsev (2000).

(7)

$$Y_i = \left[\theta_i^R R_i^{\rho_i^S} \left(1-\theta_i^R\right) \left[\theta_i^K K_i^{\rho_i^{KLEM}} + \theta_i^{SKL} SKL_i^{\rho_i^{KLEM}} + \theta_i^{USK} USK_i^{\rho_i^{KLEM}} + \left(\sum_j \theta_{j,i}^M M_{j,i}^{\rho_i^{KLEM}} \right) \right]^{\frac{\rho_i^S}{\rho_i^{KLEM}}} \right]$$

$i \neq j,$
$i \in xe$

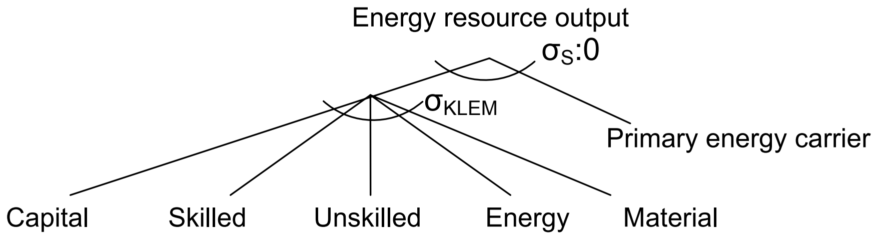

Figure 4: Nesting structure of production function for exhaustible resource production

For the capital intensive oil sector the concept of the *direct labor substitutability* yields following production function:[8]

(8)

$$Y_i = \left[\left(\sum_j \theta_{j,i}^M M_{j,i}^{\rho_i^{KLEM}}\right) + \left(1-\sum_j \theta_{j,i}^M\right) \left[\theta_i^E E^{\rho_i^{KLE}} + \left(1-\theta_i^E\right) \left[\theta_i^K K_i^{\rho_i^{KL}} + \left(1-\theta_i^K\right) \left[\left[\theta_i^{SKL} SKL_i^{\rho_i^L} + \left(1-\theta_i^{SKL}\right) USK_i^{\rho_i^L} \right]^{\frac{\rho_i^{KL}}{\rho_i^L}} \right]^{\frac{\rho_i^{KLE}}{\rho_i^{KL}}} \right]^{\frac{\rho_i^{KLEM}}{\rho_i^{KLE}}} \right] \right]^{\frac{1}{\rho_i^{KLE}}}$$

$i \neq j,$
$i \in oil$

Factor specific value shares of produced output are given by θ. Skilled labor *SKL* and unskilled labor *USK* form a nest with a relative low elasticity of substitution. The labor aggregate is combined with capital *K* to generate the value added on the KL-nest. On the next level, the energy aggregate is added. The upper level combines the resulting KLE-nest with non energy intermediate inputs to a KLEM aggregate. The corresponding nesting structure for the oil sector is displayed in Figure 5.

[8] For simplicity production functions are not defined over r in this representation.

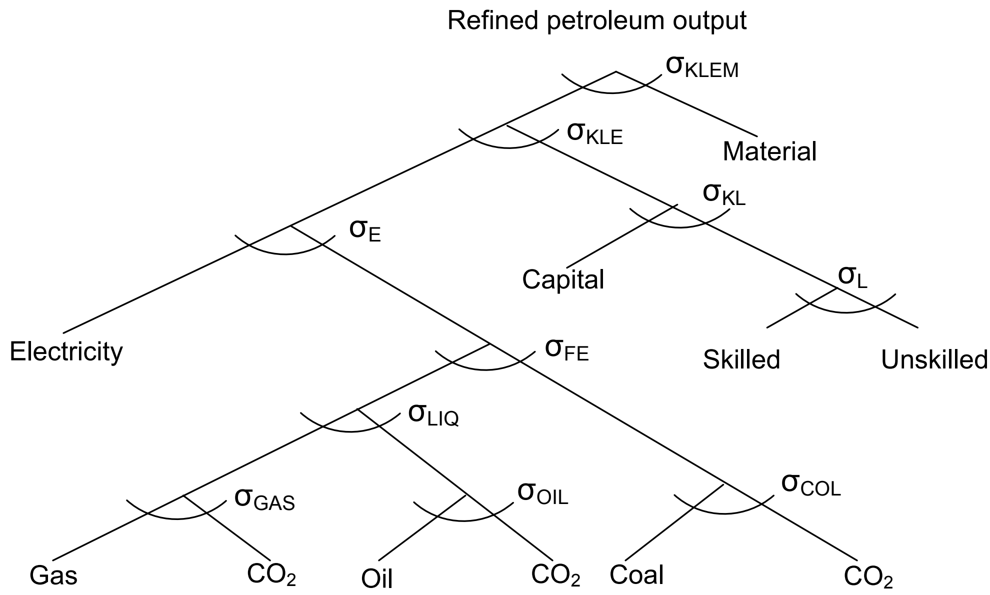

Figure 5: Nesting structure for refined petroleum production.

2.4 Modeling electricity generation

Fahl et. al (2005) show that employment impacts are dependent on the choice of technology in production. This is why the electricity generation is considered in detail in this paper. Different to most existing CGE models, electricity production is not modeled as a standard aggregated production function but in technological detail. Following Zürn et al. (2006) and Zürn et Al. (2005) ten distinct generation technologies are modeled. The technologies are captured in a bottom-down framework and characterized by a strict Leontief nesting, for the two types of labor just as for any other input. In the case of fossil fired generation technologies the input of energy is connected with CO_2 allowance input. Single technology outputs are aggregated in a production function which represents the power plant system. Aggregation is structured by differentiating between base, middle, and peak load technology application, as well as between constant and stochastic production technologies. The resulting electricity portfolio which consists of 16 generation options is where substitution patterns may take place. Hence, substitutions in the electricity sector are not directly occurring with respect to primary factors in the technology production function but rather by collocation of the electricity mix. The production function for a single generation technology *gen* is given by equation (9) where $\sigma=0$, hence $\rho=-\infty$.

(9)
$$Y_{gen} = \left[\begin{array}{l} \theta_{gen}^{K} K_{gen}^{\rho_{gen}^{KLEM}} + \theta_{gen}^{SKL} SKL_{gen}^{\rho_{gen}^{KLEM}} + \theta_{gen}^{USK} USK_{gen}^{\rho_{gen}^{KLEM}} + \theta_{gen}^{E} E_{gen}^{\rho_{gen}^{KLEM}} \\ + \left(\sum_{j} \theta_{j,gen}^{M} M_{j,gen} \right)^{\rho_{gen}^{KLEM}} \end{array} \right]^{\frac{1}{\rho_{gen}^{KLEM}}} ;$$
$$j \notin fe$$

Figure 6 illustrates the nesting structure for a generation technology. One has to bear in mind that the material bundle reflects intermediates. This is where electricity and own consumption as part of the generation technology inputs are accounted for. Moreover, there is no multifuel option. Each fossil fired generation technology relies on a single energy input, which is why there is no need to further separate the energy composite.

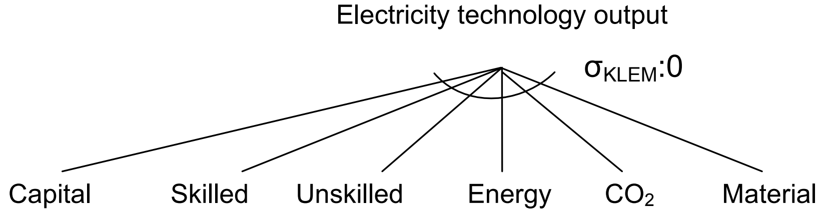

Figure 6: Nesting of Leontief production function for generation technologies

The electricity sector as a whole is displayed in Figure 7. Specific elasticities of substitutions are implemented in every nest and reflect different ease of substitution on inter- and intraload levels and for fluctuating and constant generation levels.

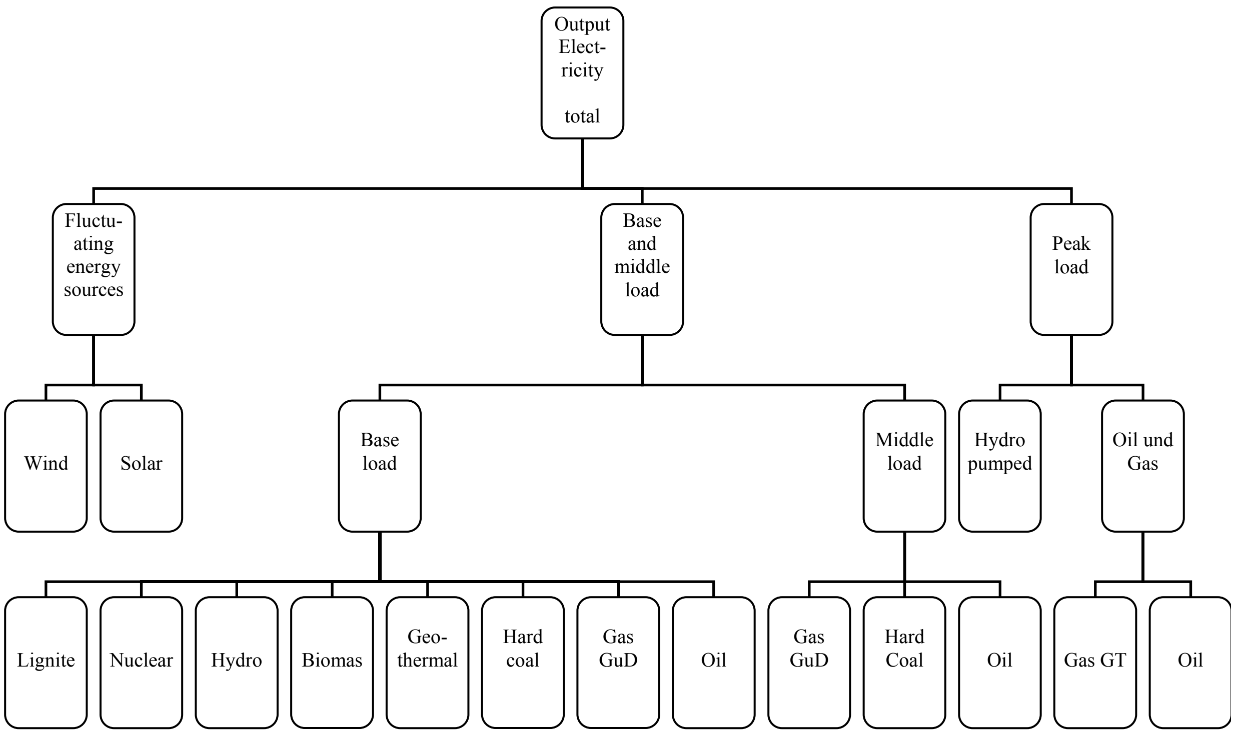

Figure 7: Nesting structure of the electricity sector[9]

[9] Following Zürn et al. (2005).

The detailed bottom up description of the electricity production sector requires that aggregate economic data of the GTAP6 database is expanded, as e.g. pointed out by Sue Wing (2004). Following Zürn et al. (2006), base year data for the country specific annual power generation for each technology is taken from IEA (2003a) and IEA (2003b). Since costs of electricity generation vary between regions, country specific costs of electricity generation for each technology are computed according to the information in IEA (2005) and IEA (1998). Because several electricity generation technologies can be used in different load segments, the cost of power generation is calculated for each load segment that a technology is applied in. In order to adjust the IEA data to the ten regions of the model, data is weighted by generation and average weighted costs and cost share are computed. Because data on technology related skill specific labor input is not available, the proportion of skilled to unskilled in the sector electricity as provided by GTAP6 is set constant for all generation technologies. Resulting cost data and cost shares which specify the Leontief production functions given by equation (9) are summarized in table 5 for Germany. Data for all ten regions is given in the appendix.

Table 5: Cost data for generation technologies in Germany

Load segment	Generation technology	Cost of power generation [€2000 per MWh]	Cost shares [%]		
			Capital	Labor	Intermediate/ energy
Fluctuating	Solar (PV)	442.9	83.95%	0.00%	16.05%
	Wind	65.4	96.95%	0.00%	3.05%
Peak	Pump storage hydro	215.4	76.23%	13.59%	10.18%
	Gas GT	118.5	38.74%	13.97%	47.29%
	Oil GT	202.7	39.59%	0.68%	59.73%
Middle	Oil	124.6	-	-	-
	Gas CC	61.7	16.55%	5.97%	77.48%
	Hard coal	57.4	42.36%	6.05%	51.58%
Base	Geothermal	49.5	83.89%	2.87%	13.23%
	Hydro	36.3	75.47%	13.46%	11.07%
	Biomass	81.5	46.56%	2.85%	50.59%
	Oil	119.0	-	-	-
	Gas CC	57.6	13.29%	4.79%	81.92%
	Hard coal	43.8	33.37%	4.77%	61.87%
	Soft coal	40.4	36.13%	3.87%	59.99%
	Nuclear	37.0	49.08%	4.13%	46.79%

Technology cost data is then calibrated to the input-output (I-O) data. For this purpose a single technology's value share of the sum of all generation costs is computed. This share is related to the GTAP parameter that represents value of output at input costs of the electricity sector. This yields GTAP coherent cost data, which is scaled by the computed cost shares as given in table 5.

2.5 Model dynamics

Dynamics can in principle be incorporated by two different means which differ in the way that economic agents handle decision problems. In an intertemporal dynamic CGE model economic agents have perfect foresight and rational expectations with respect to the entire time horizon. Their behavior is subject to an intertemporal optimization problem. Consequently, intertemporal substitution possibilities are accounted for. In a recursive dynamic CGE model agents are myopic. There is no intertemporal dimension of decision variables. Decision making is static and a sequence of static equilibria is solved. Equilibria are connected with one another by augmentation of primary factor endowments. Capital investment may either be exogenous or endogenous. Exogenous investment is determined by a given savings rate. In the endogenous case investment decisions are based upon return to capital and cost of capital (cf. Springer 1999).

For this paper, the model is solved recursive dynamically with exogenously determined investments. Equilibria are solved in five year steps starting with the benchmark year 2001 up to 2030. Dynamics are based upon the neoclassical Solow-Swan model. However, instead of a balanced growth path, growth rates for factor variables differ. This is done in order to calibrate economic development to projected growth as provided by the models POLES (cf. European Commission (2003)) and PRIMES (cf. European Commission (2004)).

There is no explicit investment function. In its place neoclassical theory states that on a competitive capital market the price of capital equilibrates savings and investments. Investment in period t equals savings s in period t and savings are given through a constraint that sets the savings rate constant. Taking into account depreciation of capital, this leads to a capital stock formation of

(10) $$Kst_{r,t+1} = (1-\delta)Kst_{r,t} + Inv_{r,t+1}.$$

Investments *Inv* undertaken in the current period t augment the capital stock *Kst* in period $t+1$. As in the GTAP database, the depreciation rate δ is assumed to be constant at 4 % for any region.

Equation (10) describes the augmentation of a capital stock through investments. However, input-output (I-O) data does not account for capital stock but for capital earnings, which are considered capital input. For a CGE model built upon I-O data the same holds true. If investments were to raise capital earnings in full scope, then capital input into the I-O system and hence into production would grow excessively. Consequently, growth in capital stock needs to be translated into growth in capital earnings. In the model at hand, this stock to flow conversion is done by computing the share of capital earnings to capital stock in the benchmark and using this share for scaling investments in equation (10). Then, with capital earnings determined by the return to capital r capital endowment K is given by

(11) $$K_{r,t+1} = (1-\delta)Kst_{r,t} + \frac{r_{r,t}K_{r,t}}{Kst_{r,t}} Inv_{r,t}.$$

The formulation of capital augmentation is strongly dependent on capital mobility. Here, all capital is modelled regionally immobile because the stock represents physical capital. In a more complex model, capital may be described as imperfectly mobile. In such a putty-clay model one can take into account that investment decisions are in fact regionally mobile but installed capital is vintage and hence immobile. This would better describe investment decision under prevailing actual capital markets, as pointed out by Springer (2002).

Fossil fuel resource endowment in region *r* is assumed constant over time and given by

(12) $R_{r,t+1} = R_{r,t} = R_{r,o}$.

Regional labor supply growth is exogenous at rate *g*. This growth parameter incorporates population changes, human capital formation, and increases in labor productivity. In principle, the skill and unskilled decomposition requires a differentiation into skill specific labor supply augmentation. However, due to data restrictions the model at hand applies identical growth parameters for skilled labor supply *SKL* and unskilled labor supply *USK*.

(13) $SKLS_{r,t+1} = g_{SKLS_{r,t}} SKLS_{r,t}$

(14) $USKS_{r,t+1} = g_{USKS_{r,t}} USKS_{r,t}$

This thoroughly describes a dynamic perfectly competitive model wit dual labor and generation technology specifications. In the following, the assumption of perfect competitiveness is relaxed for the labor market.

3. Labor market and unemployment

3.1 Unemployment rates

Labor markets are not cleared. They are imperfect. The neoclassical axiom of flexible wages that is inherent to any standard CGE model has to be suspended. The basic model described in chapter 2 is enriched by imperfect labor market and resulting unemployment.

Data on unemployment cannot be provided by GTAP6 due to its input-output framework. Hence, skill and region specific unemployment rates for the benchmark year 2001 are computed drawing on the ILO database which provides amounts of employed and unemployed persons by occupation (cf. ILO (2006b)). Because data for 2001 is partly missing for some GTAP6 countries data from the year 2000 as well as from OECD (2003) are consulted, too. Figure 8 visualizes the resulting unemployment rates *URUN* for unskilled and *URSK* for skilled labor. Taking unemployment into account labor supply in the model results as:

(15) $USK_r = (1 + URUN_r)USK_r$

(16) $SKL_r = (1 + URSK_r)SKL_r$

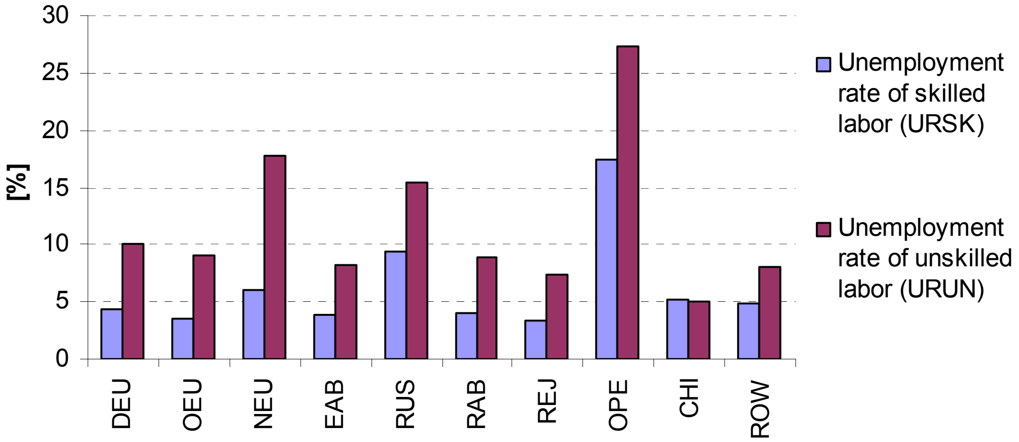

Figure 8: Unemployment rates by qualification for regions modeled in benchmark year 2001

The labor categorization by skill type allows to specify unemployment for skilled labor to be determined by different mechanisms than that for unskilled. Unemployment amongst the unskilled is considered to be classical unemployment due to sticky wages. Unemployment of skilled labor is modeled by a wage curve.

3.2 Minimum wages and classical unemployment for the unskilled

Rigid wages have been implemented numerously as a way to capture involuntary unemployment in MPSGE models, e.g. Böhringer (1996). In a classical labor market, marginal productivity of labor has to be equal to the real wage due to firms' profit maximizing behavior. If this rule is distorted by a wage rigidity, for instance due to a minimum wage, the labor market cannot clear and classical, involuntary unemployment occurs. In this case the wage rate is rigid downward. For a situation where supply is perfectly price elastic, figure 9 illustrates classical unemployment induced by wage rigidity following a reduction of labor's marginal productivity. Reductions in productivity may be caused for instance by imposing a green tax (e.g. Böhringer et al. (1997)). With decreasing productivity the market clearing real wage falls from w^0 to w^1. However, with the lower wage bound w^{min} prohibiting the wage from adjusting to marginal productivity involuntary unemployment occurs in the extent of ΔL which is the difference of labor supplied and labor demanded at w^{min}.[10]

[10] The effect of rigid wages strongly depends on the wage elasticity of labor demand. If factor demand is relatively price inelastic there will be a strong reaction of the labor applied, i.e. more severe unemployment.

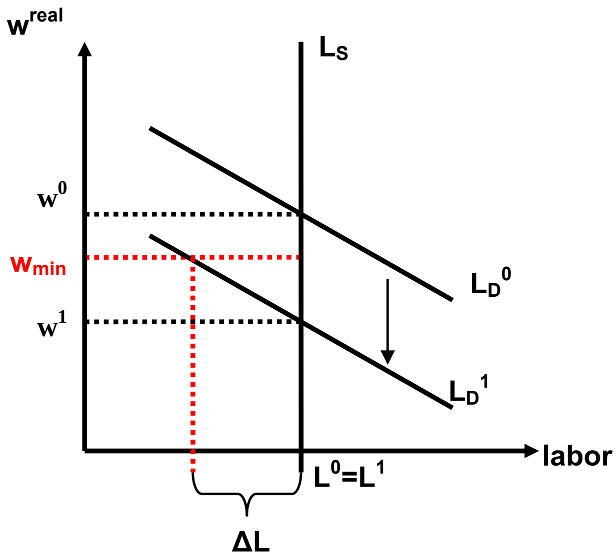

Figure 9: Classical unemployment trough minimum wages

In the model, the flexible market price for labor is substituted through a wage equation that sets the real wage constant so that employed workers keep their real consumption standard. The regional minimum wage w_r^{min} is defined by the utility price index P_r, where P_r is a Laspeyre price index reflecting a consumption bundle of consumption goods.

$$(17) \quad \frac{w_r}{P_r} \geq w_r^{\min}$$

Minimum wages are designed to reduce wage pressure on the low wage workforce. Assuming that earnings are positively correlated to qualification, unskilled employees rather earn a low pay. As a consequence, the model considers the minimum wage concept as relevant for unskilled labor.

3.3 Labor supply specification by wage curve for the skilled

In addition to wage rigidities involuntary unemployment may also be integrated by specifying a wage curve. The wage curve has been formulated and empirically tested by Blanchflower and Oswald (2005), and Blanchflower and Oswald (1995). First steps of integrating it into CGE modeling have been carried out by e.g. Böhringer et al. (2001), and Niez and Sue Wing (2004). Implementation in MPSGE format is scarce and can only be found in Rutherford and Light (2001) in an application for Columbia.

A wage curve captures the relationship between the level of unemployment and the level of real wages and describes how the price of labor is affected by the unemployment rate.[11] The wage curve hypothesis states that wages are negatively correlated with local unemployment rates, i.e. high (low) unemployment leads to lower (higher) wages. Such a negative correlation

[11] Note: In contrast to the wage curve, the Philipps Curve describes the relation between the wage *growth rate* and unemployment. See Franz (1999).

has at least two microeconomic rationales that both take into account the idea of noncompetitive labor markets. First, the correlation can be explained by the efficiency wage theory. Efficiency wage models are based on Solow (1979) and state that firms may set wages above market level, assuming that real wage levels affect productivity. When unemployment is high, firms do not have an incentive to pay an efficiency wage premium since strong job competition and the associated fear of losing employment function as an incentive not to shirk but work efficient. Thus, high unemployment may allow firms to offer lower wages. Second, drawing on wage bargaining theory based on McDonald and Solow (1981), unions generally bargain for wages above market level. High unemployment can hamper the ability of unions to claim high wages. The level of unemployment may also affect the union's preferences in wage bargaining. If a union's objective function includes both employed members as well as unemployed (members or nonmembers) it may alter its objective: The union bargains less for high wages for its employed members than for employment opportunities in favor of the unemployed members or nonmembers at the cost of somewhat lower wages.[12]

In contrast to the wage curve hypothesis the Harris-Todaro model suggests a reverse relationship, namely that high wage regions are likely to become regions with high unemployment as well. The Harris-Todaro model does not draw upon neoclassical unemployment where unemployment is caused by high wages above marginal productivity. Instead the idea is that high interregional wage differentials attract workers to move towards regions with higher wages. Transfer of labor increases supply and leads to a non clearing of the regional labor market. Reflecting on the Harris-Todaro hypothesis, it can be argued that the wage curve implies that labor is not perfectly mobile between regions. With labor modeled regionally immobile the MPSGE model at hand abstracts from the Harris-Todaro theory. Hence the wage curve theorem suits the model settings.

Just as in the case of wage rigidity through a lower real wage bound, a wage curve modeling implies substituting the flexible wage by a wage equation, only that price of labor is not linked to a minimum level, such as a consumption price index, but to the level of unemployment. With (w_r/P_r) being the real wage based on a consumer goods price index P_r, and ur_r being the unemployment rate, the real wage in region r is given by

(18) $$\frac{w_r}{P_r} = f(ur_r).$$

Figure 10 illustrated a labor market with a typical wage curve specification, plotting quantity of labor on the horizontal axis and real wage on the vertical axis. In a perfectly competitive labor market full employment is realized by the market clearing real wage. However, with the wage curve defining the real wage, the wage curve replaces the labor supply curve L^S on the labor market. The intersection of the labor demand curve L^D and the wage curve sets a real wage that is above the market clearing level. As a result unemployment occurs, illustrated in figure 10 as the difference between labor supply L^{S1} and labor demand L^1.

[12] To some extent labor contract models may also support the wage curve hypothesis.

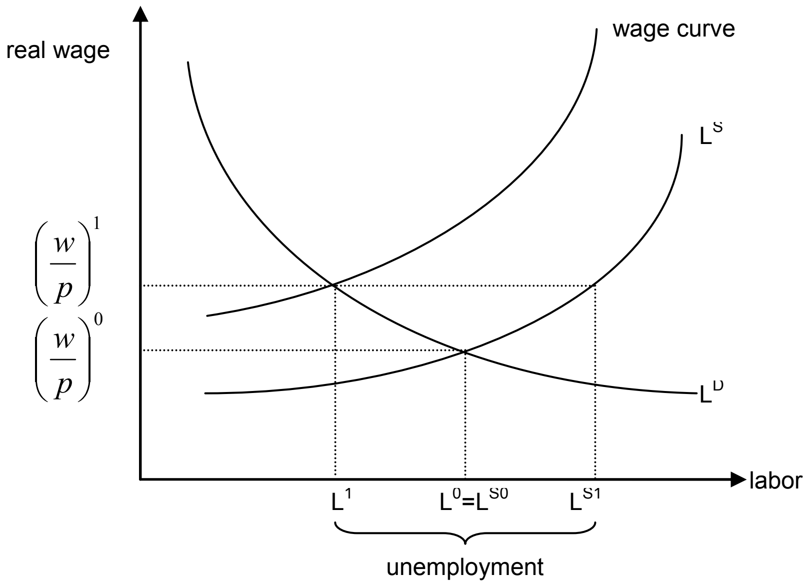

Figure 10: Wage curve[13]

Blanchflower and Oswald (1995) identify a typical wage curve by $\ln w^{real} = \beta \ln ur + z$, where w^{real} denotes the real wage, ur is the unemployment rate, and z stands for other terms affecting the correlation. These residual terms can be e.g. education, age, and gender as well as regional specific dummy variables. The parameter β is always negative and reflects the unemployment elasticity of the wage. It describes the marginal change in the level of real wages following a change in the unemployment rate. A main result of Blanchflower and Oswald (1995) is that the elasticity parameter β is approximately -0.1 for any region or country. An increase of unemployment by one percent is associated with a decrease of wages by 0.1 percent. In other words, a doubling of the unemployment rate is associated with a reduction of real wages by ten percent in that region.

In order to obtain the wage equation relevant for implementing a wage curve and its associated involuntary unemployment into the MPSGE model the residual term z is neglected, so that

(19) $\ln w^{real} = \ln(ur^{\beta})$.

Taking the antilog yields

(20) $w^{real} = ur^{\beta}$.

Applying the nomenclature as above, equation (20) can be rewritten as

(21) $\frac{w_r}{P_r} = ur^{\beta}$

For an implementation into MPSGE the wage equation needs further adjustment because the benchmark equilibrium with relative prices for labor and for the consumption bundle being equal to one is not reproduced by equation (21). This can be easily seen when replacing the left hand side of the wage equation by the actual values of the benchmark prices. In order to

[13] Following Rutherford and Miles (2001).

have benchmark consistency initial unemployment rates have to be taken into account, as well as benchmark prices for labor and consumption indices, which both have to be unity. A scaling parameter is added to equation (21), which calibrates the wage restriction to the benchmark equilibrium *BMK*.

(22) $$\frac{w_r}{P_r} = \frac{\dfrac{w_r^{BMK}}{P_r^{BMK}}}{{ur_r^{BMK}}^{\beta}} ur^{\beta}$$

The parameter ur^{BMK} is the initial unemployment rate whereas *ur* is the unemployment rate endogenously computed by the wage equation. In the benchmark *BMK* w^{BMK} equates to *w* which is unity and P^{BMK} is equal to *P* which is unity, too. The endogenously computed unemployment rate *ur* has to correspond to the exogenously specified initial unemployment rate ur^{BMK}, so that $ur^{BMK}=ur$. This yields $w=P$, which is compulsory for the benchmark equilibrium.

As e.g. Franz (1999) points out, efficiency wage theory suggests that the more damage an employee can do to the firm's productivity the higher the incentive for the hiring firm to pay a wage premium. These workers are the ones in leading positions which are presumably rather skilled workers. Bearing in mind that the mostly cited theoretical backing of the empirical wage curve is efficiency wage theory, the model considers the wage curve relation as relevant for skilled labor.

4. Applying the model

4.1 Scenario description

The model described above is applied to assess the efficiency of climate protection policies in the context of labor market impacts and under criterions of sustainability. The differentiation of electricity technologies permits the analysis of technology oriented policies which are increasingly discussed in the climate change discourse. At the same time, it allows for assessing technology dependent labor effects. The paper at hand analyzes the effects of an investment subsidy on CO_2 free (clean) electricity generation technologies (Tech) in contrast to upper emission limits (Kyoto). A policy that solitarily relies on GHG emission limits implies that climate protection endeavours are kept constant at a level of the current Kyoto agreement. Incorporating technology subsides can be understood as implementing a second pillar as for instance recommended by the 11th Conference of the Parties (cf. UNFCCC (2005)) and by the Commission of the Commission of the European Communities (2005) in the strategy paper *Wining the Battle against Global Climate Change.* Relying only on promoting clean technology but not setting any GHG emission limits can be considered a policy suggested by the *Vision Statement of the Asia-Pacific Partnership on Clean Development and Climate* (cf. Australian Government (2006)).

Two scenarios are calculated, namely the reference case BAU and the counterfactual case SCEN. For both scenarios a climate protection regime according to the Kyoto targets and the EU burden sharing is implemented. Due to the lack of a concrete formulation for emission limits following the first Kyoto period, it is assumed that after 2012 national Kyoto targets as well as Burden Sharing agreements are held constant until 2030. Limits are binding for all Annex-B countries that have ratified the protocol so far.[14] A broadening of the climate protection alliance is not considered. A further assumption is that of an emission trading scheme in effective operation between all active Annex-B countries. The counterfactual introduces a technology oriented policy in the Annex-B countries and in the USA and Australia as partners of the *Asia-Pacific Partnership on Clean Development and Climate*. In these regions investment subsidies decrease the capital input necessary for GHG free generation options. Pump storage hydro power and nuclear power generation are exempted from subsidies. All other regions are considered to not carry out specific policies.

Table 6: Scenario summary

	BAU	SCEN
Annex-B	Kyoto	Kyoto + Tech
REJ	-	Tech
Others	-	-

Next to the Kyoto regime, the reference case BAU as well as the counterfactual SCEN both are subject to some basic elements of the existing energy policy and energy technology framework. For both cases the agreements on nuclear phase out in Germany have been implemented. Figure 11 illustrates the applied phase out path for Germany based on data from IER (2006).

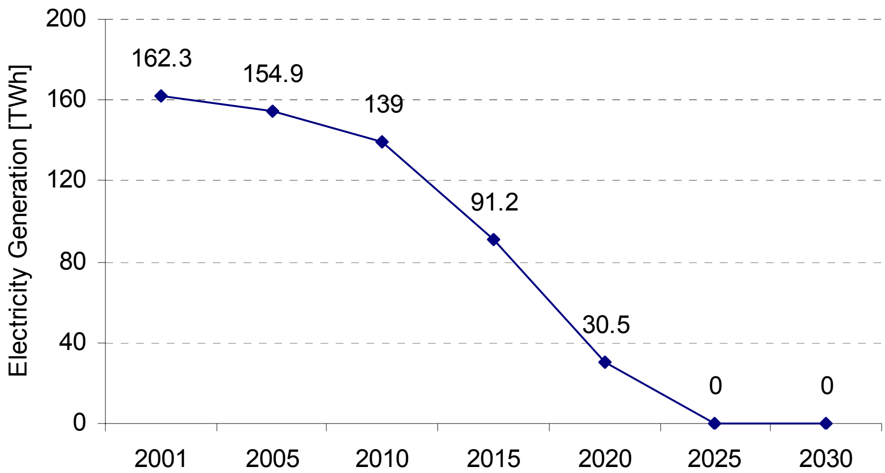

Figure 11: Electricity generation from nuclear power in Germany

[14] As mentioned in chapter 2 the climate protection alliance includes Croatia but excludes Ukraine.

Electricity generation from renewable energy sources is implemented in the model according to the observed production in the base year. Although the reported production is highly in consequence of feed-in tariffs and other supporting measures, the model does not explicitly consider any of these. Generation from biomass and hydro is limited in order to account for prevailing technical potentials. Regional potentials are calculated from capacity projections (cf. IER (2006)). Figure 12 and figure 13 illustrate the resulting upper bound on generation for the year 2030. Starting from the benchmark the limit is gradually increased until 2030.

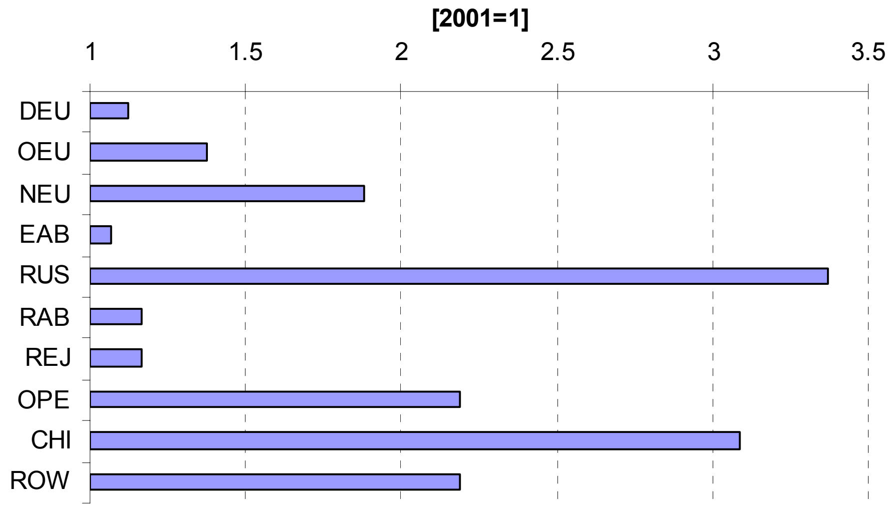

Figure 12: Hydropower potential in 2030 compared to 2001

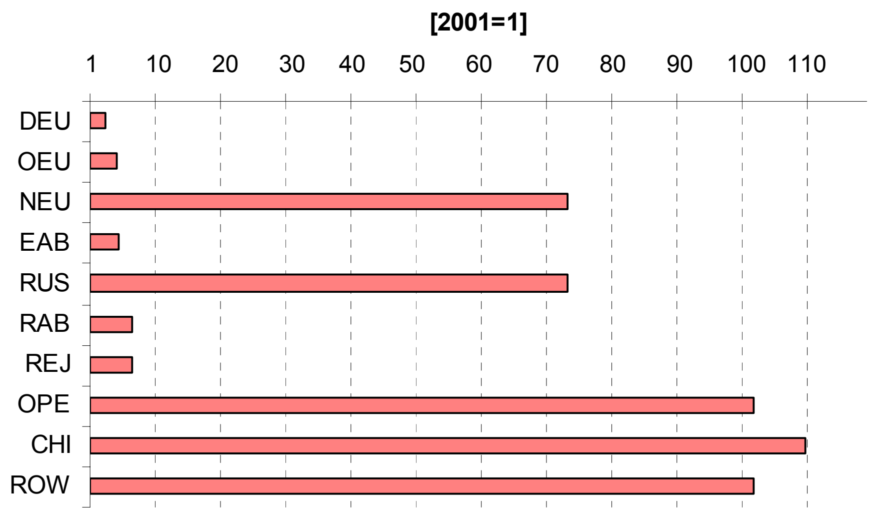

Figure 13: Biomass potential in 2030 compared to 2001

Similar restrictions are faced by strip mining of soft coal. Simplifying, the production of lignite as a fuel input into soft coal generation technology is limited to benchmark values. These restrictions hold for BAU as well as for the counterfactual scenario SCEN.

4.2 Preliminary selected reference development

Without any additional climate protection measure, the model yields projected economic development in a business as usual setting (BAU). Growth in the BAU development is calibrated towards projected regional growth rates that result from the models POLES and PRIMES. Figure 14 shows the regional diversity in real GDP development following preliminary results of the BAU.

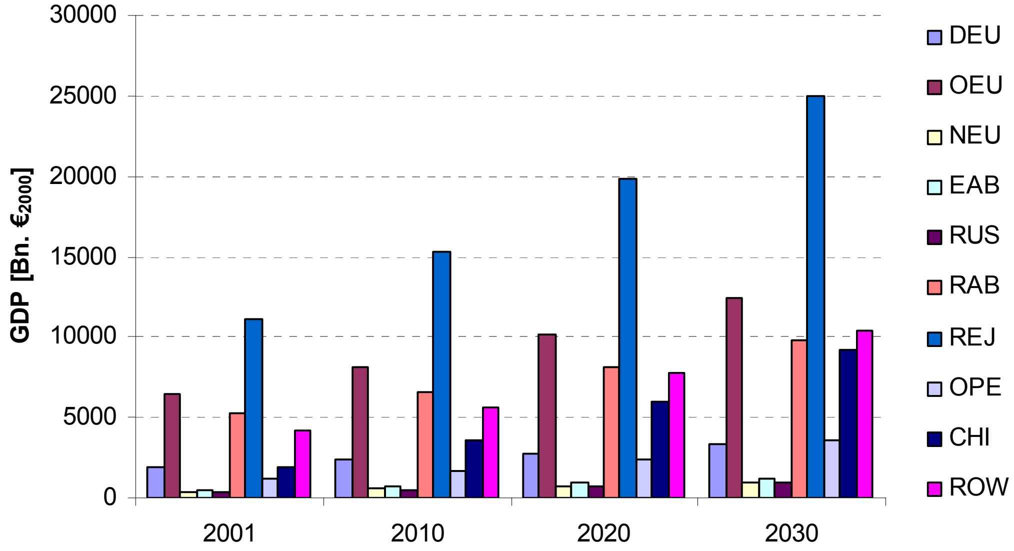

Figure 14: GDP development BAU

A major driving force behind economic growth is the parameter determining labor supply augmentation. This parameter also strongly affects the development of unemployment over time. Figure 15 shows unemployment for the old European Union members except Germany. As the economy grows, the real price of labor also rises and hence unemployment amongst skilled labor decreases. For unskilled labor the growth effect compensates any possible substitution effect that could result from the increasing supply of skilled labor.

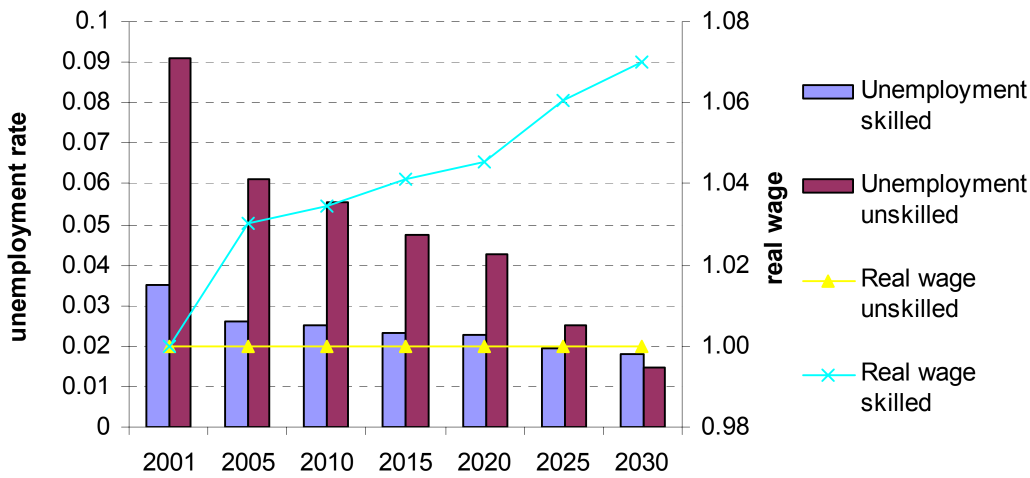

Figure 15: Unemployment and price development for OEU

However, in contrast to such an interpretation and also to what is observed e.g. by Niez and Sue Wing (2004), for other regions the development is not as straight forward. Although nominal prices increase, the real price for labor may decrease in growing economies which yields increasing unemployment rates under wage curve settings. Here, this is for instance the case for Germany as can be seen in figure 16. For unskilled labor the wage restriction becomes more distorting in the face of rising prices, so unemployment increases. The rather not straight forward development of unemployment rates for both types of labor in the BAU indicates the importance of growth in labor supply and price development for the labor market.

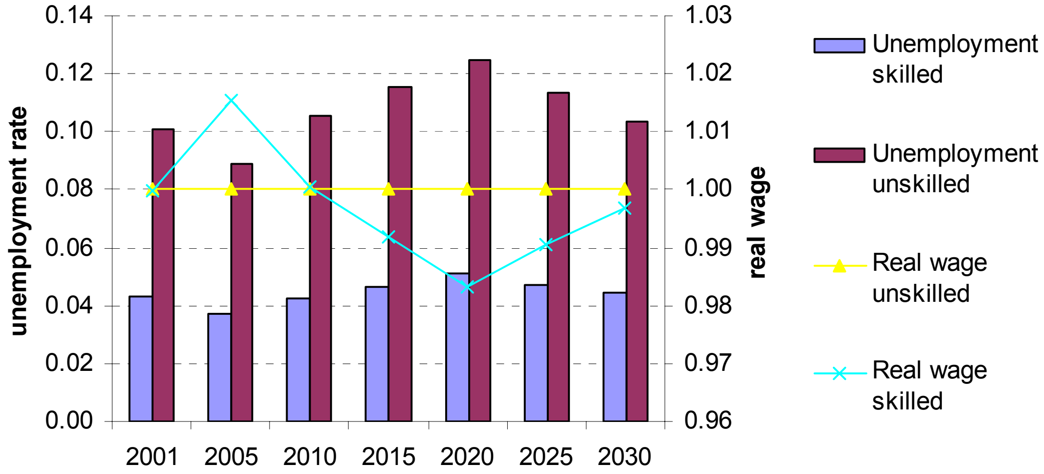

Figure 16: Unemployment and price development for Germany

Figure 17 indicates the trend of future CO_2 emissions as computed in the BAU scenario. It is obvious that emissions in China and India more than double until 2030. Emissions in the Annex-B regions are capped. Total emission in all Annex-B countries remain constant after 2012, whereas national emission may change due to allowance trade.

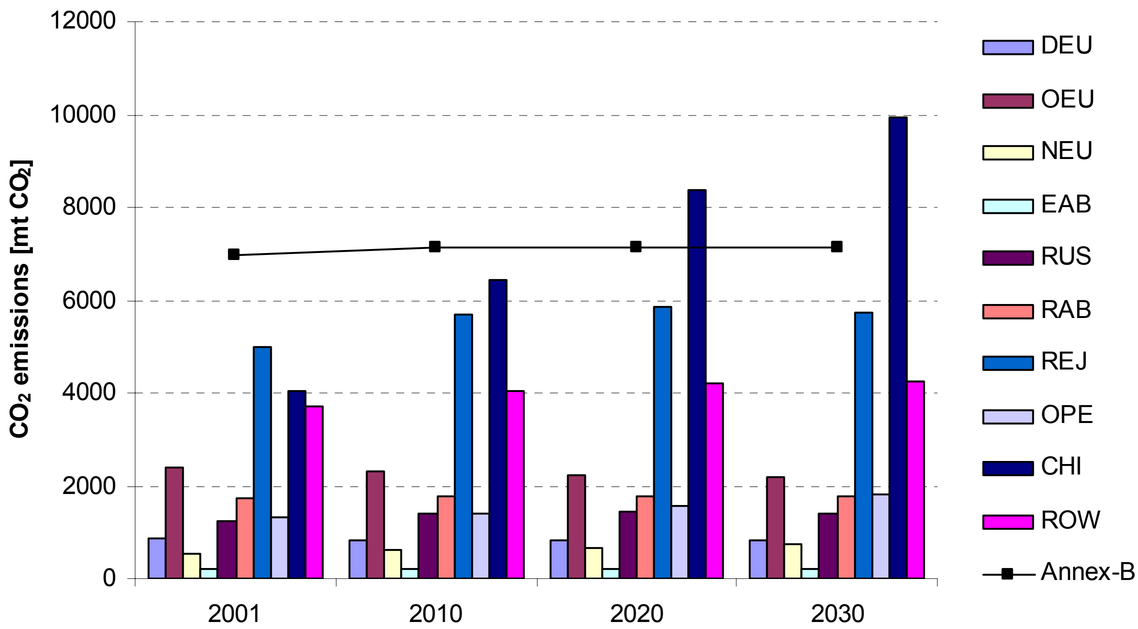

Figure 17: Development of CO_2 emissions

4.3 Preliminary comparison of counterfactual to reference case

The subsidy value is chosen adhoc. Still, in this very preliminary survey it serves the purpose of showing that technology subsidies induce effects on GDP, labor market, and emissions. Figure 18 shows that subsidies on specific generation technologies tend to yield negative effects on the economic development measured as GDP. The deviation reflects the negative income effect of a subsidy. Even those countries not engaged in technology promotion experience negative consequences on growth via international feed backs.

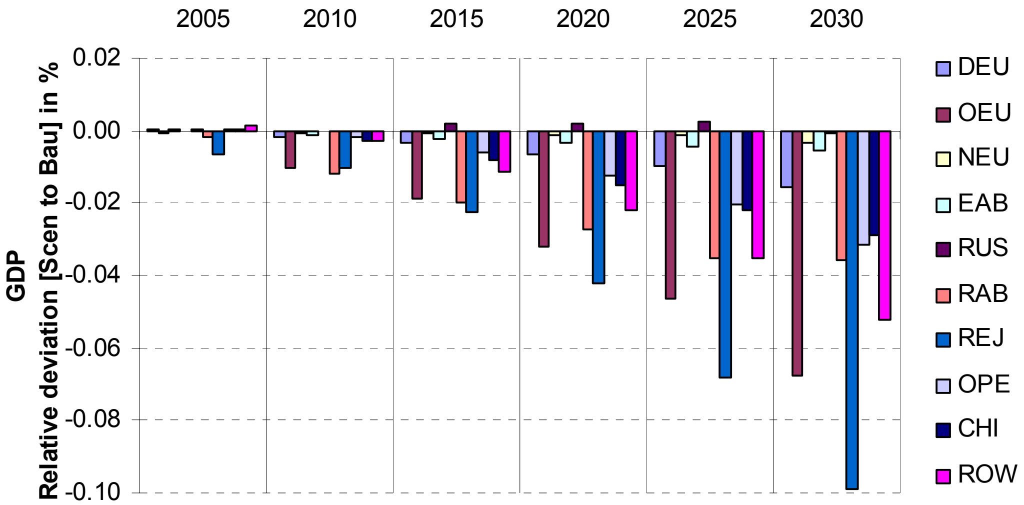

Figure 18: Deviation in GDP

Unlike the persistently negative effect on GDP in all regions modeled (except Russia), impacts on the regional labor markets are more diverse. Figure 19 shows that unemployment amongst the unskilled is reduced in Russia and in the new European members. The impact on unemployment amongst skilled is analogous, as can be seen in figure 20. Hence, in the model subsidies on CO_2 free generation technologies do not tend to create any skill premium.

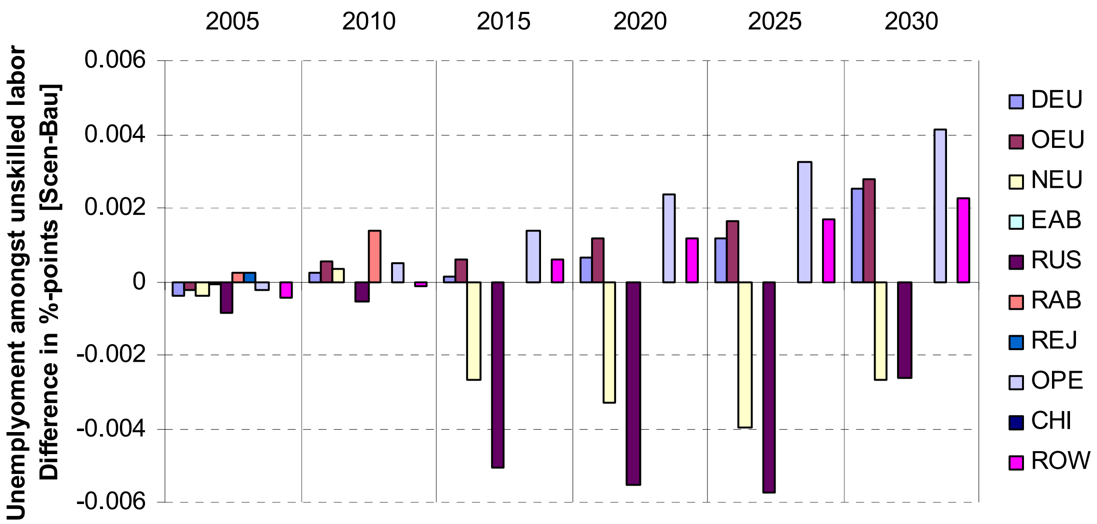

Figure 19: Deviation in unemployment rates unskilled labor

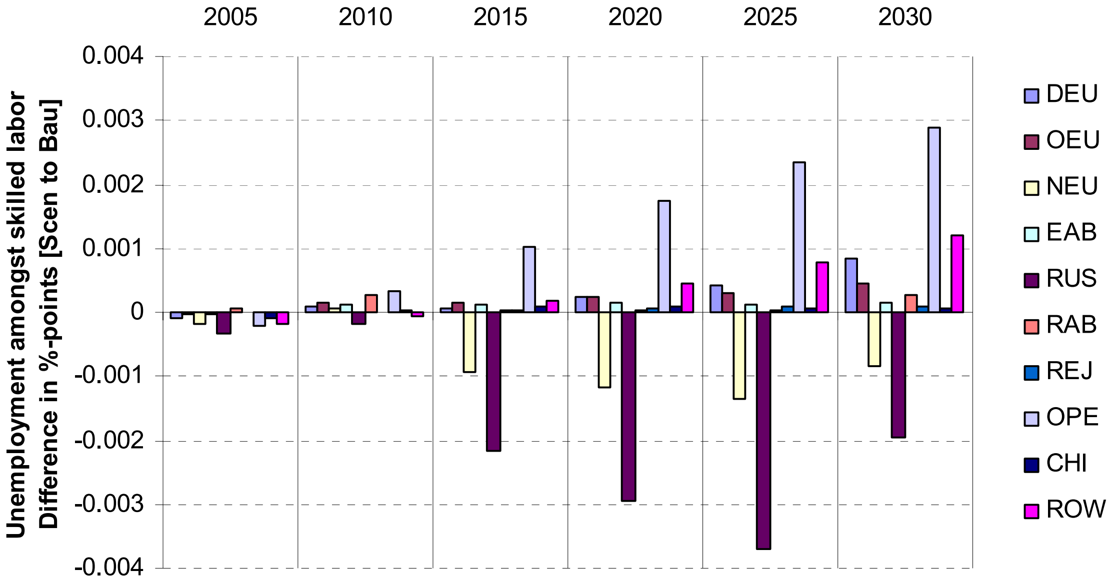

Figure 20: Deviation in unemployment rates skilled labor

The evaluation of results with respect to unemployment rates is complemented by comparing emissions in the two scenarios, since the primary purpose of energy technology subsides is to reduce GHG emissions.

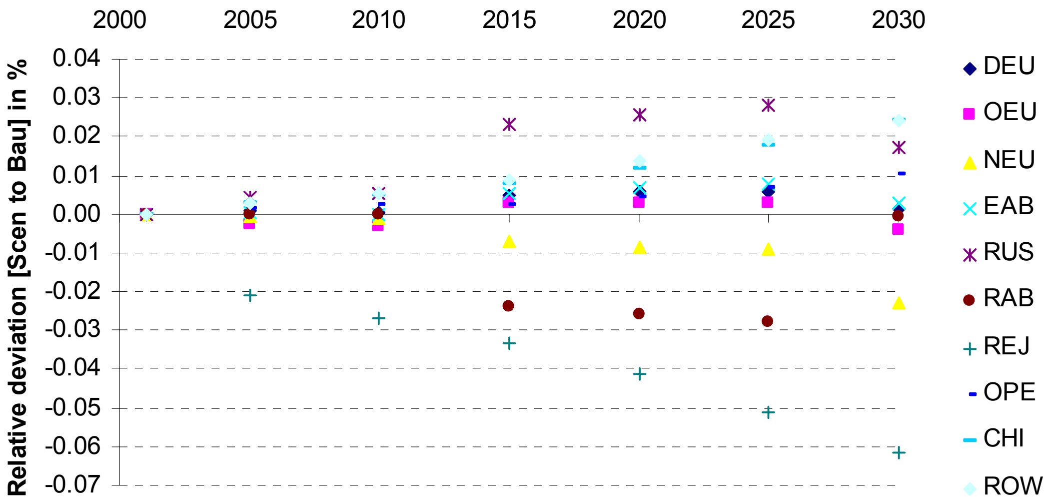

Figure 21: Differences in CO_2 emissions in the scenarios

As figure 21 reveals, preliminary model results indicate that technology subsidies do not automatically lead to a reduction of GHG. Due to positive feedback effects that induce growth in the conversion sectors, emissions are only slightly decreased. Especially for those countries under emission caps, subsidies in the electricity sector can yield negative effects on CO_2 emissions. This is also reflected in the composition of the electricity power plant system. Although the share of renewable energy sources applied in the electricity mix is significantly increased through the technology subsidy, total generation increases due to subsidies. For instance in Germany the reference electricity production as a whole increases by approx. 41 % whereas under the technology scenario increase is 43 %. It has to be considered that the subsidy is chosen arbitrarily and that its impacts on CO_2 emissions as well as on macro indicators are rather small.

4.4 Preliminary results in the context of sustainability

As shown by the CGE model's result, climate policy not only induces effects on GHG emission. By changing relative prices on all markets and via input output linkages it always has impacts on the entire economy. The relating trade-offs are consistently and comprehensively captured by the CGE model applied in chapter 4. As Böhringer and Löschel (2004) point out, quantitative scenario results can be assessed in the context of sustainability. There are numerous sustainable development indices. Some selective indices are used for evaluating the climate policy measures presented in table 6. First, the economic dimension of sustainability is represented by GDP development. Second, development of GHG emissions can be interpreted as the ecology pillar. Third, changes in unemployment and in the functional distribution of income represent the social facet of sustainability. Restricting the complex sustainability concept on a few indicators yields a very limited and primary assessment. Nonetheless table 7 can provide a sustainability related overview on the evaluation of measures analyzed.

Table 7: Evaluating quantitative results via sustainability indices

Sustainability pillar	Indicator	None	Kyoto+Tech	Tech
Economy	GDP growth	-	-	-
Ecology	CO_2 emissions	-	+/-	-
Social	Unemployment	+	+/-	-

It is interesting to see that those countries not taking any actions against climate change still experience negative growth effects. Although results are quite ambiguous and subject to a very limited significance, the preliminary model outcome shows that a combination of emissions caps and technology subsidies could provide the most effective and most sustainable way to achieve climate protection goals.

5. Conclusion

This paper establishes a CGE/MPSGE model with several specifications. First, the primary input factor labor is disaggregated into skilled and unskilled labor, thus establishing a dual labor market. Second, the assumption of perfect labor markets is suspended. Instead, unemployment is modeled through minimum wage restrictions for unskilled labor and through a wage curve in the case of skilled labor. Third, technology specifications for electricity generation technologies are introduced.

The technology specifications permits an analysis of technology oriented energy and climate policies. By integrating economic dimensions (e.g. GDP growth), ecologic dimensions (e.g. GHG emissions) and social facets (e.g. unemployment) the model can test such a policy in the form of quantitative analyses in the context of sustainability assessments. Preliminary model results show that different climate policies, namely technology subsides and emission caps have diverse effects on sustainable development. Quantitative results highlight that subsidies on CO_2 free generation technologies do not automatically lead to a more sustainable development.

Further research implications are the dynamic calibration of unemployment development in a reference scenario. This includes the more precise determination of skill specific growth rates in labor force, labor productivity and human capital. Although the wage curve has its evident microeconomic explanation, a formulation of a more complex wage equation that captures actual labor market behavior with explicit micro foundation should be considered. This could include efficiency wages or union behavior.

Acknowledgement: I am gratefully indebted to Ingo Ellersdorfer and especially Marcel Zürn for modeling assistance. Financial support is granted by *Stiftung Energieforschung Baden-Württemberg.*

Appendix

Appendix 1: Regional cost data for electricity generation technologies

Table 8: Cost data in €$_{2000}$ per MWh

		OEU	NEU	EAB	RUS	RAB	REJ	OPE	CHI	ROW
Fluctuating	Solar (PV)	442.9	442.9	442.9	442.9	442.9	442.9	442.9	442.9	442.9
	Wind	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9	62.9
Peak	Pump strg. hydro	254.3	245.2	249.1	252.8	251.3	249.4	252.8	252.8	252.7
	Gas GT	121.8	106.0	106.8	115.5	106.3	116.9	125.3	116.1	115.5
	Oil GT	227.8	227.0	226.8	227.7	227.5	227.4	227.7	226.8	227.7
Middle	Oil	125.9	125.8	125.7	125.9	125.9	125.8	125.9	125.7	125.9
	Gas CC	61.3	61.0	61.0	57.9	81.9	58.3	66.1	61.5	59.2
	Hard coal	58.0	57.0	56.5	57.9	74.9	54.0	58.1	46.0	57.0
Base	Geothermal	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5	49.5
	Hydro	42.9	41.3	42.4	42.5	41.8	42.0	42.5	41.1	42.5
	Biomass	76.6	75.6	76.3	76.4	76.1	76.0	76.4	75.8	76.4
	Oil	118.7	118.6	118.5	118.6	118.6	118.6	118.6	118.5	118.6
	Gas CC	77.3	80.3	96.3	84.5	101.9	79.1	85.2	75.4	85.0
	Hard coal	58.0	57.0	56.5	57.9	74.9	54.0	58.1	46.0	57.0
	Soft coal	37.0	40.7	41.0	43.4	36.8	37.0	43.4	37.1	41.5
	Nuclear	39.0	31.1	36.4	36.6	46.6	37.4	35.3	36.5	36.3

Appendix 2: MPSGE labor market

Appendix 2 represents the function declarations relevant for labor market specifications as implemented in MPSGE.

```
$commodities:
       pskl(r)                          ! Wage rate skilled labor
       pusk(r)                          ! Wage rate unskilled labor

$AUXILIARY:
       URUN(r)$URUN0(r)                 !Unemployment Rate (Rationing Multiplier) for Unskilled Labor
$AUXILIARY:
       URSK(r)$URSK0(r)                 !Unemployment Rate (Rationing Multiplier) for Skilled Labor

$demand:ra(r)
        d:pc(r)          q:ct0(r)
        e:pskl(r)        q: (EVOA("SKL",r)/(1-URSK0(r)))
        e:pskl(r)        q: (-EVOA("SKL",r)/(1-URSK0(r)))       R:URSK(r)$URSK0(r)
        e:pusk(r)        q: (EVOA("USK",r)/(1-URUN0(r)))
        e:pusk(r)        q: (-EVOA("USK",r)/(1-URUN0(r)))       R:URUN(r)$URUN0(r)

* wage curve with Blanchflower elasticity of annual labor earnings to ur of -0.1
$Constraint: URSK(r)$URSK0(r)
             PSKL(r)/PC(r)=E=((1/(URSK0(r)**(-0.1)))*(URSK(r)**(-0.1)));

* minimum real wage
$CONSTRAINT:URUN(r)$URUN0(r)
             PUSK(r)=G=PC(r);
```

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