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The SUSTRUS model: a CGE model on regional level for sustainability policies in Russia

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The SUSTRUS model: a CGE model on regional level for sustainability policies in Russia

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The present paper describes the construction and first empirical application of the SUSTRUS model (the name of the model refers to “Sustainable Russia”). This model will be the main result of the same-named EU funded project. The SUSTRUS model belongs to the group of regional CGE models, applied to analyze policies with a strong social, economic and environmental dimension. The SUSTRUS model can be used to assist policy makers in their choice of medium and long-term sustainability policies, for the implementation of the EU strategy for sustainable development in Russia as well as an efficient incorporation of the sustainability goals into the existing Russian policy tools on regional and federal levels.

The SUSTRUS model is constructed as a regional model on federal level, where regions are linked by interregional trade flows, a federal government level and migration. This paper will relate on the calibration of the database for the model and the addition of innovative elements in the model, necessary to model the link between the environmental, social, economic and international modules. The main data sources for the model are the public databases of Rosstat and the micro-level household data from the Russia Longitudinal Monitoring Survey (RLMS). Calibration of the model database was performed by a flexible cross-entropy minimization sub model and standard applied general equilibrium techniques.

The general structure of the model will be discussed, focusing on the innovative features of the model and the link between the environmental and economic modules. The application of the model will be shown by a simulation exercise and a presentation of the main results.

Keywords: Regional general equilibrium model, sustainable development, environmental economics

Spatial-economic-ecological model for the assessment of sustainability policies of the Russian Federation

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1. Introduction

With this research, we want to test and validate a modelling tool that enables ex-ante validation of policies aiming at orienting the economy to sustainable development. Sustainability means that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs. The EU sets the following key objectives concerning sustainability¹:

1. Environmental protection
2. Social equity and cohesion
3. Economic prosperity
4. Meeting international responsibilities

The primary aim of the spatial-economic model SUSTRUS, is to assess past, current and future policies and relate their success to these sustainability goals. The SUSTRUS model will assist the implementation of the EU strategy for sustainable development in Russia as well as an efficient incorporation of the sustainability goals into the existing Russian policy tools on regional and federal levels conditions.

The SUSTRUS modelling approach is based on the Spatial Computable General Equilibrium (SCGE) framework. The model is built around a detailed dataset of Russia on the Federal district level, containing economic data, social data and environmental data. The approach is characterized by a balanced integration between social, economic and environmental policy objectives. The model is formulated as a system of simultaneous nonlinear equations in GAMS, which represent the solutions to utility maximization and production costs minimization problems as well as the market equilibrium conditions.

SCGE models typically are comparative static equilibrium models of interregional trade and location based in microeconomics, using utility and production functions with substitution between inputs. The present SCGE models have a sophisticated theoretical foundation and rather complex, non-linear mathematics. The latter is precisely the reason why SCGE models are able to model (dis)economies of scale, external economies of spatial clusters of activity, continuous substitution between capital, labour, energy and material inputs in the case of firms, and between different consumption goods in the case of households.

During the past decade, several SCGE models have been developed for the analysis of policy related questions, especially when involving the regional interactions and/or transport or the analysis of regional disparity. Some examples of well known CGE models with disaggregation on the level of regions are: CGEurope (Bröker et al, 2001), the IFPRI model (Löfgren et al, 2001 ; Thurlow J, 2008), RELU (Anas A, et al, 2007), RAEM (Thissen et al., 2004, Ivanova et al, 2007), WorldScan (Lejour et al. 2006), GEM-E-3 (Capros et al, 1997), Burniaux and Troung (2002), Kemfert and Welsch (2000), Bchir et al. (2002), Kemfert (2002), Böhringer and Löschel (2004), Saito (2004), Paltsev et al. (2005), Van der Werf (2007), Nemeth et al. (2008), Okagawa and Ban (2008), Welsch (2008).

SUSTRUS fits within this general framework of models and implements many of the techniques used by applied general equilibrium modelling. The model is constructed in the same line as the GEM-E-3 model, but with more disaggregation on the level of trade and transport, as well as on the government sector.

The SUSTRUS model has a flexible nature and has been built keeping in mind that the model can be updated and extended, based on the specific need for different policy simulations or on specific research topics. The basic framework of the model is based on the RAEM model, but takes into account the specificities of the Russian economy. These are related to the very large territory modeled (Russia on Federation level), the inclusion of resource and export oriented sectors (the minerals, gas and oil mining industry), the Russian labour market (with a large share of unofficial unemployment) and the strong central government in Russia

¹ EU-SDS: EU sustainable development strategy

The major problem of sustainable development is the rational use of natural resources such as: minerals, water, land and ecosystem services. The use of most of these resources depends upon the allocation of production and consumption activities in space. By incorporating the representation of geographically distributed consumption and production patterns into the SUST-RUS modelling framework, we are able to account for the use of natural resources in the economy as well as to assess the effects of sustainability policies upon different Russian regions.

The present model represents Russia on the level of the Federal regions and includes the representation of the micro-economic behavior of three different household types (low skilled, medium skilled and high skilled) on each regional level and two levels of government (regional and federal level). Production sectors are distinguished by NACE 95 category and disaggregated in 32 sectors, a comprehensive list of these sectors is added to the appendix.

In conclusion the SUST-RUS model incorporates the following elements:

- region-specific factor endowments capital and labour
- regional production and consumption
- intermediate inputs of the sectors (total output is produced using not only capital and labour but also inputs of various services and goods)
- interregional trade
- representation of governmental finances (taxes, subsidies and transfers) and multi-level governance system
- emissions related to production and energy inputs of the sectors
- emissions negatively influence the households' welfare
- intertemporal investments decisions of households and firms
- representation of agglomeration mechanism in the modern sectors via Dixit-Stiglitz framework with monopolistic competition (optional)

The next paragraph gives an overview of the main structure of the model discussing its main components and the underlying theory. In the appendix a full description of all equations of the model with explanations of their economic meaning is added. Most of the model equations are the results of utility maximization or costs minimization problem.

2. Main assumptions and structure of the model

2.1 Basic economic framework of the SUSTRUS model

Model structure and numeraire

The model represents a real economy with no inflation or banking sector. There is no monetary authority in the model. All prices in the model are relative prices and calculated in terms of the numeraire. A GDP deflator is used as the numeraire in the model. Because there is no banking sector in the model the economic agents do not have the possibility to borrow money and the interest rate is fixed exogenously in the model.

The model utilizes the notion of the aggregate economic agent. They represent the behavior of the whole population group or of the whole industrial sector as the behavior of one single aggregate agent. It is further assumed that the behavior of each such aggregate agent is driven by certain optimization criteria such as maximization of utility or minimization of costs. The model is neo-classical and assumes average costs pricing and no excess profits. The excess profits are normally due to the existence of monopoly or oligopoly on the market. Normal profits of the firms are paid in the form of dividends (return to capital) to the households who own all capital goods in the economy.

Households

The behavior of the households is based on the utility-maximization principle. Household's utility is associated with the level and structure of its consumption, level of emissions and the amount of leisure. The household cannot influence the level of emission and takes this as exogenous variables. It is assumed that the utility of household is separable in consumption and leisure.

Each household spends its consumption budget on services and goods in order to maximize its satisfaction from the chosen consumption bundle. Households have substitution possibilities between different consumption commodities. In the model these substitution possibilities are captured by Stone-Geary utility function, which corresponds to the Linear Expenditure System (LES) of demands. According to the Stone-Geary utility function a household derives its utility only from the amount of consumption, which is higher than the minimum subsistence amount and the elasticity of substitution between commodities is equal to one. In case of all subsistence amounts being equal to zero, the Stone-Geary utility function reduces to the Cobb-Douglas utility function.

Utility of the household is maximized under the budget constraint, where the household's consumption spending is equal to its income minus income tax and the household's savings. Households in the model receive their income in the form of wages, capital, unemployment benefits and other transfers (pensions and other social transfers) from the federal government.

Capital rents are the returns to capital paid to the households by the firms. It is assumed that households own all the firms in the domestic economy. Capital rents are equal to the total capital rents of the economy. In reality each regional household receives its capital rents from a particular region and sector. The present data availability does not allow for the detailed formulation of such a model as there is no data about the flow of investments and corresponding capital rents between the regions of the country. Instead, the net flow of capital income between the regions was roughly estimated, by assuming that the savings rate in each region would be similar to the average national savings rate. In this way, an overestimation of the capital profits and underestimation of the savings is avoided.

The level of the unemployment benefits, received by the household, depends upon the level of unemployment of the individuals within the household. The unemployment is modelled according to a simplified wage curve, where households reduce or increase their participation on the labour market, depending on the real market wage.

The wage curve is chosen based on two important facts on the Russian labour market: 1) high participation rates of both sexes 2) a high wage flexibility. Adjustment through negative labour market shocks mostly goes through wages and not through increase in (the official) unemployment.

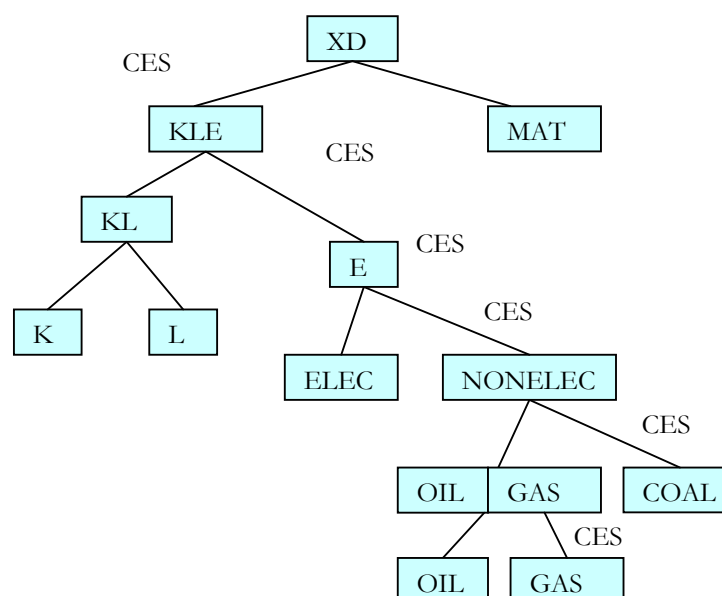
Firms

The behavior of the production sectors is based on the profit-maximization principle and is captured by the behavior of the representative firm. The dividends (return to capital) of the sectors are associated with the costs and structure of their intermediate inputs and factor inputs. Intermediate inputs of the firms include energy, various commodities and services. Factor inputs of the firms include physical capital and labour.

At each time period, the instantaneous behavior of the sectors is based on the minimization of the production costs for a given output level under the sector's technological constraint. The level of the sectors' output is equal to the aggregate demand for its production, which reflects of the market equilibrium condition. Production costs of each sector in the model include labor costs by type of labor, energy costs, capital costs and the costs of intermediate inputs. The sector's technological constraint describes the production technology of each sector. It provides information on how many of different units of labor, energy, capital and commodities, are necessary for the production of one unit of the sectoral output.

The production technology of the sector is represented by the nested Constant Elasticity of Substitution (CES) functions. Nested CES functions are quite flexible and allow for different assumptions about the degree of substitutability between the production inputs. Inputs which are easier to substitute with one another are put into the same nest. Inputs which are more difficult to substitute in the production process are put into different nests. The degree of substitutability is the lowest on top of the nested CES function and the highest at the bottom of it. All production inputs in the CES tree have a certain degree of substitutability between each other and it depends on their relative position in the tree. In accordance with their production technology, sectors have substitution possibilities between different intermediate inputs and production factors.

Figure 1: CES technology of the production sector



At the top level of the CES function sectors can substitute between intermediate inputs and the aggregate capital-labour-energy bundle. At the second nest they can substitute between capital-labour and energy. At the lowest nests they can substitute between the use of different energy types, capital and labour. The structure of the CES tree was based on the PACE model (Böhringer C., Löschel A., 2004).

Competition and market equilibrium

Production sectors will produce according to perfect competition rules. In this case the value of the output is equal to the marginal cost of production, which is in turn equal to the average cost of production. The assumption of perfect competition greatly simplifies modelling and allows an easy interpretation of the model results. Simulations according to perfect competition are also an important benchmark, if a modeler would wish to deviate from the assumption of perfect competition.

One such type of deviation from the perfect competition rule is implemented as an optional part of the model, through incorporation of the Dixit-Stiglitz framework. The base data for the modelling of monopolistic competition in each sector is based on Guriev S. et al (2004) and Goskomstat data on the number of firms and share of profits in each sector.

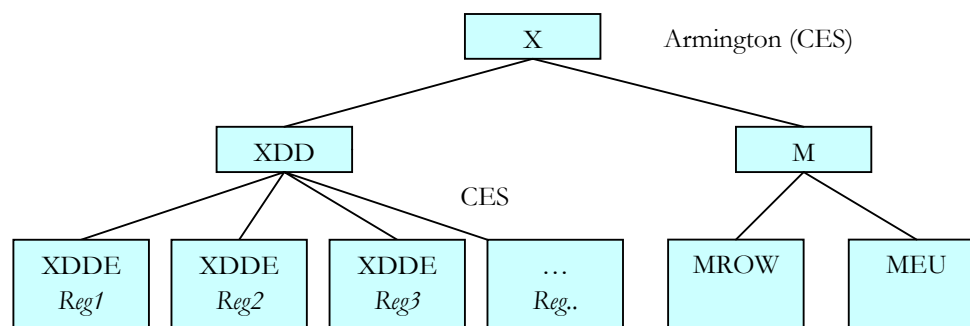
Under the monopolistic competition framework, it is assumed that each sector consists of a number of identical firms, each producing a unique specification of a particular commodity. The same type of the commodity, produced by an individual firm, is slightly different from the same type of commodity, produced by other firms inside the sector.

These differences in the commodity specification then give individual firms a certain monopolistic power over the consumers. Certain consumers prefer a certain specification of the commodity and, hence, they are prepared to pay a bit more for it. The monopolistic power of the individual firms results in the deviation from the marginal costs pricing rule of perfect competition. The producer prices are now equal to the sector's average production costs and depend upon the number of the individual firms, which operate on the market. The sectoral variable costs are equal to the marginal output costs multiplied by the sectoral output level. The sectoral fixed costs depend upon the number of the individual operating firms and are equal to the number of firms inside a sector multiplied by the fixed costs per firm.

Sales

Domestic regional sales of services are equal to the production of a service sector in the region. In the model we make an assumption that services are not traded between the regions and countries. This is a restrictive assumption, which is justified by the absence of the data on inter-regional trade in services at federal level.

Figure 2: Sales - Armington



Domestic regional sales of each type of commodities are composed of the commodities and services produced by the domestic sectors, those imported from other regions and those imported from the rest of the world. According to the Armington assumption, the same type of commodity produced by the domestic sectors, imported from the other regions or imported from the rest of the world has different specifications and, hence, cannot be treated as a homogenous good. Domestic consumers have different preferences for these specifications and can substitute between them in case the relative prices of the specifications change. The substitution possibilities between these commodities specifications are captured by a CES function that varies between the types of commodities. This means that the shares in which commodity are bought from the domestic producers, from other regions and from the rest of the world. are determined by the relative producer prices of the commodity, transport and trade costs.

The modelling of interregional trade flows is an essential part of the interregional linkage. However, the only data available is the data on the total origin-destination flow of commodities between the regions by type of commodity. There is no information about the trade between the regions in services, which lead us to assume that services are only tradable within the federal region.

All regional households and firms purchase the same geographical mix of commodities, which is produced by the commodity-specific wholesaler in each region. This mix consists first of commodities bought from different regions and further from commodities bought from different producers within the sector producing the commodity (this represents different varieties). The assumption that all economic agents in the region consume the same geographical mix of commodities does not reflect the reality. As mentioned before, this assumption is made because of the lack of the data about the trade flows between the regions.

The equilibrium prices of all commodities and services are defined by the market equilibrium conditions. Under the market equilibrium the sum of demands for a particular commodity and service is equal to the sum of its supply.

Savings and investment

The model incorporates the representation of investment and savings decisions of the economic agents. Savings in the economy are made by firms, households, government and the rest of the world. The total savings accumulated at each period of time are invested into accumulation of the sector-specific physical capital, which is not mobile between the sectors.

The total investment into the sector-specific capital stock is spent on buying different types of capital goods such as machinery, equipment and buildings. The concrete mixture of different capital goods used for physical investments is determined by the maximization of the utility of the investment agent. This is an artificial national economic agent responsible for buying capital goods for physical investments in all the domestic sectors.

The endogenous determination of investment behaviour of households and firms is essential for the dynamic part of the model. The SUSTRUS model applies a similar framework as described in Thurlow J. (2008) for the IFPRI model. Investments are savings-driven. Households and firms invest in the domestic economy or in foreign countries. In each time period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period. The assumption of fixed short-term capital in each region implies an endogenous calculation of the return to capital in each sector. Sectors with a high return to capital in the previous period, attract a higher share of investments in the next period. In long term, the return to capital equalizes over sectors and regions.

Population growth (or decline), productivity trends of different industries and energy efficiency is incorporated in the model dynamics by exogenous terms.

Governments

The model incorporates the representation of the federal and regional governments. The governmental sector collects taxes, pays subsidies and makes transfers to households, production sectors and to the rest of the world. Tax revenues are shared by the national and regional governments according to the certain rates determined from the base year data. The federal and regional governments consume a number of commodities and services, where the optimal governmental demand is determined according to the maximization of the governmental consumption utility function. We use a Cobb-Douglas utility function in the model. Its maximization results in the demand rules, which says that the expenditure share of different commodities and services purchases by the government stay constant over time. The model incorporates the governmental budget constraint. According to this constraint the total governmental tax revenues are spend on subsidies, transfers, governmental savings and consumption. There are transfers between the regional and national governments.

Finally, the model includes the trade balance constraint, according to which the value of the country's exports plus the governmental transfers to the rest of the world are equal to the value of the country's imports.

2.2 Environmental module

The environmental module of the SUSTRUS model models emissions dependent on the input and combustion of energy resources. Besides CO₂, and CO₂ equivalent emissions we distinguish several non-greenhouse gas pollutants such as PM₁₀, NMVOC, NO_x and SO_x. The amount and type of air pollutants emitted are specific for each sector.

An Emissions Trading System (ETS) is explicitly taken up in the model. Additional restrictions on trading of permits between regions and sectors can be integrated into the model, by introducing caps on trade in emissions or excluding sectors from the permit trading system. The total availability of permits is set exogenously. The income from the permits is attributed either to the sector holding a surplus of permits (grandfathering) or to the government sector. Without grandfathering, it is assumed that the permits are sold by the government sector, which is collecting all revenues from the permits (similar to a tax on emissions).

The permit price of the system is calculated from the market equilibrium of demand for permits and supply of permits. The demand for permits from each sector is dependent on the energy use, emission coefficient and production of each sector. Sectors which have no possibility to invest in abatement technologies can switch to other energy inputs, reduce overall consumption or buy permits, dependent on the sector-specific production technologies.

In the case of NO_x and SO_x emissions, sectors can invest in end-of-pipe abatement technologies. The sector will abate emissions up to the point where the marginal cost of abatement is equal to the implied price of an emission permit. The marginal cost of abatement curve is based on the GEM-E-3 model and has the same generic form.

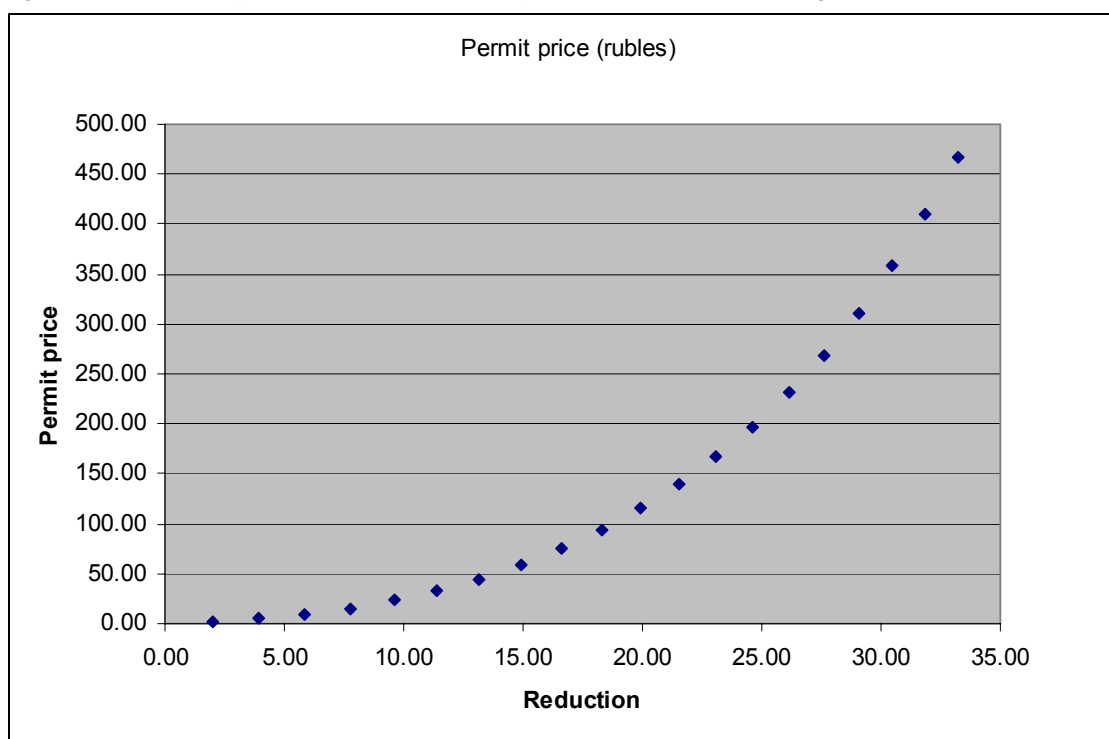
3. Test case: the effect of a cap on carbon emissions

As a preliminary test of the model, we introduce a cap on total CO₂ emissions for the entire Russian federation equal to the 2006 emissions level. Then we run the model dynamically for 20 periods. Each period represents 1 year, making the last year 2026. We assume that GDP grows at an average of 5% each year, up till 2026, carbon emissions are supposed to grow at a fixed rate of 2% each year. The simulation is purely hypothetical as we neglect the ‘hot air’ savings of Russia under the Kyoto protocol and assume that a fully functional ETS system is operational, incorporating all economic sectors. While an exogenous trend for energy efficiency is assumed, no additional abatement technologies become available for the economy.

From the CGE model, the ‘shadow price’ of carbon emissions can be calculated. A marginal abatement curve (MAC) plots the endogenously calculated tax on emissions (or ‘shadow price of emissions’) on the (relative) level of emission abatement. This same exercise is shown in Paltsev S. et al (2003), citing Ellerman and Decaux (1998). “A general equilibrium models is capable to produce ‘shadow prices’ for any constraint on carbon emissions for any region at a particular time t”.

Figure 3 is the result of the simulation, where each point represents the permit price in one year. The demand for energy inputs increases with economic growth, which also increases the demand for energy and subsequently for combustion related emission permits. The price of carbon related emissions rises in a typical convex way in function of the relative amount of emission reduction. Compared to Paltsev S. et al (2003), the permit price is substantially lower². Further research is necessary to check the origin of this difference.

Figure 3 Permit price (for 1 ton of CO₂ emissions), in relation to the percentage of abatement



² In Paltsev S. et al (2003), 200 Mtonnes of carbon emission abatement are priced at 100 dollars/tonne (1995). The same amount of emission reduction is priced at about 40 rubles/tonne of CO₂ emissions or +/- 1.5 dollars/tCO₂ in the SUSTRUS model.

Table 1 disaggregates the amount of emission reduction by energy source. Relative to the basecase, the emissions from coal are reduced the most (41 % in 2026), while the emissions from refined oil the least (15% in 2026). In absolute terms, the emissions from the gas sector take the biggest share of the reduction efforts. Natural gas remains the most popular energy source in Russia. More than half of the emission reduction is realized in the electricity sector (422 Mtonnes to a total of 766 Mtonnes in 2026).

Table 1 Emission abatement by energy source (coal, gas and refined oil) in MTonnes

	Unit	2007	2013	2018	2023	2026
Coal	<i>Mtonnes</i>	10.23	87.85	162.68	240.67	289.12
Gas	<i>Mtonnes</i>	20.68	132.90	227.50	334.57	405.15
Oil	<i>Mtonnes</i>	0.75	14.41	33.69	56.64	72.52
Total abatement	<i>Mtonnes</i>	31.67	235.17	423.87	631.88	766.78
Coal	<i>%Change</i>	-2.13	-16.27	-27.28	-36.56	-41.38
Gas	<i>%Change</i>	-2.62	-14.97	-23.21	-30.91	-35.28
Oil	<i>%Change</i>	-0.24	-4.05	-8.59	-13.07	-15.77
Relative abatement	<i>%</i>	-2.00	-13.19	-21.53	-29.07	-33.24
Permit price	<i>Rubles (2006) / ton</i>	2.06	44.82	139.67	311.24	466.10
Electricity	<i>Mtonnes</i>	4.66	82.35	197.61	333.86	422.71
	<i>%Total Reduction</i>	16.2	38.5	51.3	58.1	60.6

In Table 2 we survey some of the main country level economic indicators. The welfare loss (measured in equivalent variation) from the emissions tax is substantial (0.9% of national income in 2026), but should be put relative to the increase in tax revenues, as the government collects the income from the permit system (390 bill. Rubles). The SUSTRUS model does not assume lump-sum redistribution of the tax income to households. Instead, the government increases government consumption and investment domestically and abroad. A more redistributive scheme to households would largely decrease the welfare cost. In terms of GDP the impact is smaller, as government tax revenues are a part of the indicator. Compared to the basecase, the model predicts a 0.13% reduction in productive capacity in 2026. In absolute terms, exports are reduced more than imports.

Table 2: Main economic results

	Unit	2007	2013	2018	2023	2026
Welfare	<i>Bill. Rubles</i>	-1.99	-42.50	-128.73	-280.31	-416.16
	<i>%Income</i>	-0.01	-0.17	-0.40	-0.69	-0.89
Tax Revenues	<i>Bill. Rubles</i>	1.66	36.55	115.31	259.83	390.80
	<i>%Change</i>	0.02	0.27	0.67	1.18	1.53
GDP	<i>Bill. Rubles</i>	-0.87	-16.03	-39.77	-68.58	-89.06
	<i>%Change</i>	0.00	-0.05	-0.09	-0.12	-0.13
Total exports	<i>Bill. Rubles</i>	-0.44	-10.80	-34.63	-78.33	-118.55
	<i>%Change</i>	-0.01	-0.11	-0.27	-0.47	-0.62
Total imports	<i>Bill. Rubles</i>	-0.61	-11.48	-31.63	-63.20	-89.63
	<i>%Change</i>	-0.01	-0.16	-0.34	-0.53	-0.65

In Table 3 we show the four best and four worst off sectors in terms of production activity. Resource producing/transforming sectors (gas, coal, refined oil, electricity sector) show the largest decrease in economic activity (base price). Service sectors, especially those dependent on government funding (education, health, public service) and the financial sector are the biggest winners.

Table 3: Production by sector (best and worst off)

Sector	Production	2007	2013	2018	2023	2026
Education	%Change	0.02	0.32	0.78	1.38	1.80
Health	%Change	0.02	0.25	0.63	1.11	1.44
Public	%Change	0.01	0.18	0.51	1.01	1.38
Finance	%Change	0.00	0.07	0.20	0.38	0.52
...						
RefOil	%Change	-0.03	-0.44	-1.10	-1.98	-2.61
Gas	%Change	-0.05	-0.86	-2.16	-3.76	-4.81
Electricity	%Change	-0.05	-0.86	-2.13	-3.75	-4.85
Coal	%Change	-0.12	-1.92	-4.49	-7.43	-9.28

Table 4: Full sector output (relative change) in 2026

	Price%	Demand%	Production%	Export%	Import%
Agriculture, ea	-0.47	-0.03	0.03	0.74	-0.29
Fishing	-0.16	0.05	0.31	0.63	-0.04
Coal	-2.41	-10.70	-9.28	-4.55	-15.02
Gas	-7.51	-6.20	-4.81	4.35	-11.41
Oil	-1.24	-1.17	-0.17	0.61	-1.58
Mining (non-energy)	-0.57	-0.85	-0.58	0.04	-1.64
Food, beverage and tobacco	-0.07	-0.16	-0.14	0.03	-0.22
Textiles	0.04	-1.14	-1.29	-1.47	-1.10
Leather	0.01	-1.15	-1.28	-1.36	-1.13
Wood	0.09	-0.57	-0.64	-0.72	-0.46
Pulp&Paper	-0.15	-0.21	-0.05	0.23	-0.31
Refined oil	0.34	-2.35	-2.61	-2.91	-2.51
Chemicals	0.27	-0.78	-1.35	-1.98	-0.43
Rubber and plastics	0.44	-1.37	-1.84	-2.82	-0.84
Non-metallic products	1.29	-1.57	-1.83	-3.82	-0.54
Basic metals	0.36	-1.43	-1.76	-2.19	-1.00
Machinery	0.16	-0.40	-0.58	-0.90	-0.23
Electric and optics	0.18	-0.62	-0.85	-1.44	-0.42
Transport Eq.	0.08	-0.80	-0.90	-1.10	-0.68
Other manufacturing	3.77	-3.73	-4.04	-6.55	-1.36
Electricity, gas and water (distribution)	3.58	-1.98	-2.01	-5.14	0.46
Electricity	18.35	-4.65	-4.85	-26.30	-0.18
Construction	-0.13	-0.01	0.01	0.29	
Wholesale trade	-1.31	-0.56	-0.17	1.07	0.00
Hotels and restaurants	-0.03	-0.75	-0.74	-0.58	-0.64
Communication	-0.47	-0.67	-0.65	-0.03	-0.88
Transport	0.70	-1.53	-1.59	-2.05	-1.08
Financial intermediation	0.08	0.54	0.52	0.45	0.80
Government service and defence	0.46	1.38	1.38	0.14	
Real estate, renting and business activities	-0.09	-0.61	-0.59	-0.34	-0.70
Education	0.43	1.80	1.80	1.11	2.06
Health and social work	0.47	1.45	1.44	0.96	1.70

In Table 4 we show the full output on sector level for the whole of the Russian Federation in the final year (2026). As can be expected, the demand for energy inputs decreases quite a lot, with the demand for coal in particular (-9%), followed by gas (-4.8%) and refined oil (-2.35%). Interestingly, export of natural gas (+4.35%) and raw oil (+0.61%) increase, pointing at a leakage of carbon containing energy inputs. In terms of price, the electricity price raises the most (+18%) due to the higher cost of natural gas and coal inputs. In general those manufacturing sectors with larger dependencies on combustion of energy inputs (basic metals, refineries) experience a decrease in competitiveness towards light manufacturing (food, textiles) and service sectors (financial, real estate).

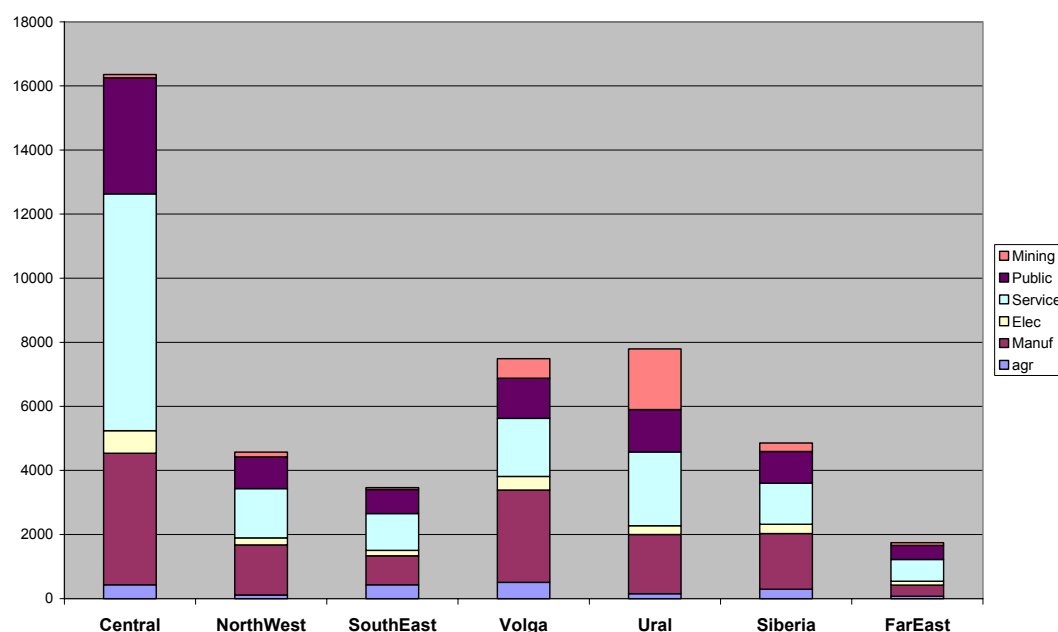
Table 5: Production factors used by economy (2026), base prices

	Absolute Values			Shares	
	BC	SIM	%Change	BC	SIM
Capital	101423.1	101752.5	0.32	0.5373	0.5406
Labour	25543.4	25489.3	-0.21	0.1353	0.1354
Materials	54567.9	54181.6	-0.71	0.2891	0.2878
Coal	607.7	527.8	-13.15	0.0032	0.0028
Gas	827.4	718.1	-13.21	0.0044	0.0038
Oil	2096.6	2045.1	-2.46	0.0111	0.0109
Electricity	3705.3	3524.1	-4.89	0.0196	0.0187

In Table 5 we show the change in the production factors demanded by all industries in the Russian economy. As was stated before, the overall energy efficiency is increased, both in terms of absolute numbers as in terms of shares. Coal and gas consumption decreases with 13%, refined oil with 2.46% and electricity with 4.89%. The capital intensity slightly increased, labour demand is stable.

Next, we show the effect of the cap on emissions on the regional level. All results of the SUSTRUS model can be disaggregated on the level of Russian Federations (7 regions), for 32 economic sectors. Below we show a small selection of these results, explaining the main mechanisms underlying the results above and illustrating the disparities on regional level.

Figure 4: Russian GDP (absolute terms), split up by main economic activity



In Figure 4 we show how the GDP of Russia (2007) is composed in 6 main economic activities (Mining, Public sector, Services, Electricity sector, Manufacturing and Agriculture).

From Figure 4, we can conclude that the Urals region is the most dependent on the mining sector, while the central region (containing the Moscow area) is the most service intensive. Volga and Siberia economy resemble the Urals economy, but are less resource intensive. This reflects in the results of Table 6. Regional GDP in the Urals decreases the most (0.9% in 2026), followed by the Volga (0.19%) and Siberian region (0.06%). In absolute terms, the Urals region loses about 100 billion euros, which represents 4% of the mining sector in the Urals region. In all other regions, a shift to more service intensive sectors takes place, leading to an overall increase in regional GDP.

Table 6: Relative change in regional GDP to baseline

		2007	2013	2018	2023	2026
Central	<i>%Change</i>	0.00	-0.01	0.00	0.04	0.07
North West	<i>%Change</i>	0.00	-0.02	0.00	0.05	0.10
South East	<i>%Change</i>	0.00	-0.01	0.03	0.14	0.23
Volga	<i>%Change</i>	0.00	-0.04	-0.09	-0.15	-0.19
Urals	<i>%Change</i>	-0.01	-0.16	-0.40	-0.69	-0.88
Siberia	<i>%Change</i>	0.00	-0.04	-0.07	-0.07	-0.06
Far East	<i>%Change</i>	0.00	-0.01	0.01	0.08	0.14
Russia	<i>%Change</i>	0.00	-0.05	-0.09	-0.12	-0.13

In Table 7 we show the effects in welfare in three income groups (low, middle and high income). In relative terms (compared to the income level of each income group), the low income group is losing slightly more. This is explained through higher prices for electricity and heating and a decrease in labour demand in the manufacturing sector. Capital income, which is mostly attributed to the higher income class, reduces less than labour income.

Table 7: Relative change in welfare (equivalent variation in % of income) in 2026

	Low income	Medium income	High income
Central	-1.00	-0.94	-0.88
NorthWest	-1.00	-0.83	-0.83
SouthEast	-0.64	-0.47	-0.50
Volga	-1.11	-1.09	-1.14
Urals	-1.10	-1.28	-1.12
Siberia	-0.76	-0.68	-0.47
FarEast	-0.77	-0.64	-0.50
Russia		-0.57	

4. Conclusion

This paper introduces a new spatial computable general equilibrium model (SCGE) on regional level for the Russian Federation, primarily targeted at sustainability analysis, which is being developed in the EC funded SUSTRUS project. The model, which stands for ‘Sustainable’ Russia, is a disaggregated regional model in the tradition of models as GEM-E-3 and can evaluate policies according to the so-called pillars of sustainability or ‘3-E’ (Economy, Equity, Ecology).

The main economic framework and many of the model mechanisms have been finished and are currently under review and testing. This paper shows the preliminary results of one such test-case, which is the introduction of a theoretical cap on carbon emissions and the result of such a policy on socio-economic indicators. The model results are evaluated in correspondence to the test case.

The shadow price of emissions calculated from the model is quite low (466 rubles/tCO₂). Overall, this leads to a quite low projected cost of the emission reduction for the Russian Federation, even at a relatively large reduction of emissions. The mining sector, manufacturing sector and the electricity sector in particular, lose in terms of production and economic activity when a cap on emissions is introduced. Most services sectors and light manufacturing sectors gain from the emissions cap. The Urals region faces the largest decrease in GDP, due to its dependence on mining and heavy manufacturing. However, the cost in terms of economic activity comes at a substantial gain in environmental benefits. Like the Urals, the Siberian and Volga federal region are losing in terms of competitiveness and gaining in terms of ecology, but to a smaller degree.

While the results of the test case follow economic intuition and provide a basis for further sensitivity and finally policy analysis, there is a notable case for further research. The emission permit price (or shadow price) calculated from the model is probably too low and should be further cross-checked with other models. The distributive scheme used by the model now is not redistributive to households, which leads to a substantially higher welfare effect and may have influence on the rest of the model results. Many of the ‘real policy’ circumstances of Russia are currently ignored. There are no ‘hot air savings’, there is no emission permit trading with other countries, there is no grandfathering of emissions, a full ETS permit system is implemented without any restrictions on the level of sectors or regions, the effect on other emissions is currently ignored, only combustion dependent CO₂ emissions are taken into account and no additional (end-of-pipe) abatement is possible for the sectors.

The current modelling framework of the SUSTRUS model is currently being checked and debugged and the model is prepared to handle more realistic simulations.

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6. Appendix: full model description

6.1 Overview of model parameters

Table 8: SUSTRUS sectors

All sectors	
Agriculture, ea	Machinery
Fishing	Electric and optics
Coal	Transport Eq.
Gas	Other manufacturing
Oil	Electricity, gas and water (distribution)
Mining (non-energy)	Electricity
Food, beverage and tobacco	Construction
Textiles	Wholesale trade
Leather	Hotels and restaurants
Wood	Communication
Pulp&Paper	Transport
Coke, refineries	Financial intermediation
Chemicals	Government service and defence
Rubber and plastics	Real estate, renting and business activities
Non-metallic products	Education
Basic metals	Health and social work

Table 9: Federal regions of Russian Federation

Region number	Federal Region of Russian Federation
Reg1	Central region
Reg2	North-West
Reg3	South
Reg4	Volga area
Reg5	Urals
Reg6	Siberia
Reg7	Far East

Table 10: Subscripts used in mathematical formulation

	Subscript
Sectors/products (each sector produces only one product)	i
Intermediate inputs (products ii , sectors i)	ii, i
Regions (Federal regions of Russia)	r
Rest of the world regions	RoW
Flows of goods, labour and capital (from region r to region rr)	r, rr
Superscript 0 is used to indicate the initial (previous period) level of variable	0

Types of households	th
Education / Skill levels	ed

Table 11: Overview of variables of SUST-RUS economic module

VARIABLE	DESCRIPTION
Prices	
$P_{i,r}$	domestic sales prices of commodities and price of leisure
$PD_{i,r}$	domestic producer prices of commodities
$PDDT_{i,r}$	composite domestic producer prices of domestic commodities
$PDD_{i,r}$	price level of domestic good, delivered to domestic market
ER	exchange rate
INDEX _r	consumer price index
PI	price of investments private
$PMEU_i$	import price of imports form EU in local currency
$PMROW_i$	import price of imports form ROW in local currency
PLROW	price of labour supplied to RoW (exogenous)
PL_r	domestic price of labour
$PKLEM_{i,r}$	price of capital-labour-energy-materials bundle
$PKLE_{i,r}$	price of composite capital-labour-energy bundle
$PMAT_{i,r}$	composite price of materials
$PKL_{i,r}$	price of composite labour-capital bundle
$PENER_{i,r}$	energy price
$PNONELEC_{i,r}$	non electricity price
$PELEC_{i,r}$	electricity price
$PGASOIL_{i,r}$	price of oil-gas bundle
$RK_{i,r}$	return to capital
RGD	nominal interest rate
Basic variables of production and inputs	
KS_r	capital endowment (exogenous)
LS_r	labor supply (exogenous)
$LROW_r$	labor supplied to RoW (exogenous)
$X_{i,r}$	domestic sales (domestic+foreign origin)
$XD_{i,r}$	gross domestic output
$XDDE_{i,r,rr}$	domestic production delivered to domestic market
$XDD_{i,r}$	gross domestic output bought from domestic market
$XXD_{i,r}$	gross domestic output delivered to domestic market
$TMX_{i,r}$	Commodity consumed for prod of transp and trade margins

$EEU_{ii,r}$	exports to EU
$EROW_{ii,r}$	exports to RoW
$MEU25_{i,r}$	imports from EU
$MROW_{i,r}$	imports from RoW
ET	total exports
MT	total imports
IT	total investments private
$K_{i,r}$	capital input
$L_{i,r}$	labor input
$KL_{i,r}$	capital-energy bundle
$ENER_{i,r}$	energy input
$ELEC_{i,r}$	electricity input
$NONELEC_{i,r}$	non-electricity input
$GASOIL_{i,r}$	Oil-gas inputs
$GAS_{i,r}$	Fuels (bottom-nest) oil, gas and coal
$COAL_{i,r}$	Coal and coal derivatives as input to the production process
$OIL_{i,r}$	Oil as input to the production process
$IOE_{i,ii,r}$	Intermediary energy inputs
Consumption of households and government	
$C_{th,i,r}$	demand for consumer goods and leisure
$CBUD_{th,r}$	consumer expenditure commodities
$Y_{th,r}$	household income
SH	household savings
SG_{gov}	Government savings
SEU25	savings of or from EU25 (exogenous)
SROW	savings of or from RoW (exogenous)
S	national savings
$I_{i,r}$	demand for investment goods private
$CG_{i,r}$	Intermediate public demand for goods
$CGR_{r,gov}$	public spendings on regional level
$CGG_{i,r,gov}$	Intermediate public demand regional governments
TAXR	tax revenues
SUBS	Total subsidies
$TAXRG_{gov}$	total tax revenue of regional government
$SUBSG_{gov}$	total subsidies of regional government
$TRF_{th,r}$	total transfers of government to households (exogenous)
$TRFF_{r,gov}$	total transfers of regional government to households

TREU25 _{gov}	total transfers to government from EU25 (exogenous)
GDP	Gross domestic product (real)
GDPC	Gross domestic product (nominal)
GDPDEF	GDP deflator (exogenous-numeraire)
GDPR _r	regional gross domestic product (real)
GDPRC _r	regional gross domestic product (nominal)
INDEXE	price index for exports
INDEXM	price index for imports
PTM	composite price of trade and transport margin
PEV _r	equivalent variation price index
EV _{th,r}	welfare change as a percentage of households income
U _{th,r}	regional utility level
Labour market	
UNEMP _{ed,r}	regional unemployment level
UNRATE _{ed,r}	regional unemployment rate
UNEMPB _{r,gov}	unemployment benefits
LMIG _{r,rr}	labor migration from reg to regg
trmV _{r,rr,i} ^c	freight transport costs
Environmental module	
DEMANDETS	Demand for permits on country level
SUPPLYETS	Supply of permits on country level
DEMANDETSREG _r	Demand of permits on regional level
SUPPLYETSREG _r	Supply of permits on regional level
PPETS	Price of permits
PPETSREG _r	Price of permits on regional level
PPSEC _{i,r}	Sectoral price of emission permits
TAXENV _{i,r}	Total taxes on emissions, as perceived by the sector
MACC _{i,r}	Marginal cost of abatement curve
COSTABAT _{i,r}	Total cost of abatement
IOABAT _{ii,i,r}	Intermediate good use for abatement
ABAT _{i,r}	Relative share of abatement of emissions
Regional governments	
TRFG	total intra-government transfers
TRFGE _{gov}	outgoing transfers from government
TRFGY _{gov,govv}	incoming transfers from government
TRFGG _{gov,govv}	Intra government transfers gov to govv
PB	total public budget
CBUD_GOV _{gov}	regional consumption budget of government
Monopolistic competition (optional)	

$PDC_{i,ii,r}$	Monopolistic competition price of domestic good
$NF_{i,r}$	equilibrium number of monopolistic firms
$AUXV_{i,r}$	auxiliary variable
$PROFITS_{i,r}$	profits of the sectors
$Kv_{i,r}$	variable capital input
$Lv_{i,r}$	variable labour input

Table 12: Parameters associated with the model

Parameters associated with taxation and government consumption	
$aTRFGOV_{gov,govv}$	coefficient for initial intra-government transfers
$shareTRFGE_{gov}$	share of the government income going to transfers
$aTRFGE_{gov,govv}$	division of transfers between subgovernments
$aG_{i,r,gov}$	Cobb-Douglas parameter for government spending on regional level
$\alpha G_{r,gov}$	Cobb-Douglas power in government utility function (goods
$sp_gov_{r,gov}$	share of subsidies on production subgovernment
$sc_gov_{r,gov}$	share subsidies on products subgovernment
$tc_gov_{r,gov}$	share of tax products subgovernment
$tk_gov_{r,gov}$	share of corporate tax rate subgovernment
$tl_gov_{r,gov}$	share of labour tax
$txd_gov_{r,gov}$	share of production tax subgovernment
$ty_gov_{r,govv}$	income tax
sp_i	subsidies rate on production
sc_i	subsidies rate on products
tc_i	tax rate on products
txc_i	tax rate on intermediates
tcg_i	tax rate on government consumption
ti_i	tax rate on investment goods
tk_i	corporate tax rate
tl_i	tax rate on labor
txd_i	tax rate on production
ty	tax rate on income
Parameters of the labour market	
$trep_r$	replacement rate of unemployed
Technical coefficients of production and input-output	
$trm_{r,rr,i}$	trade and transport margins
$io_{i,ii,reg}$	Technical coefficients intermediate inputs

$iop_{i,ii,reg}$	technical coefficients outputs
$iops_{i,ii,reg}$	technical coefficients outputs (production share in demand
$ioKLE_{i,r}$	Technical coefficients for BDLDKL bundle (land- labour capital -energy
$\sigma^{KLE}_{i,r}$	CES elasticity of substitution between land-buildings and capital-labor bundle
$\gamma^{KLE}_{i,r}$	CES share parameter for labor-capital bundle
$aKLE_{i,r}$	scaling parameter of the CES function
$\sigma^{KLE}_{i,r}$	CES elasticity of substitution between capital, labor and energy
$\gamma^{KL}_{i,r}$	CES share parameter for capital and labour bundle
$\gamma^E_{i,r}$	CES share parameter for energy inputs
$\gamma^{GASOIL}_{i,r}$	CES share parameter for gas-oil bundle
$\gamma^{COAL}_{i,r}$	CES share parameter for coal
$\gamma^{OIL}_{i,r}$	CES share parameter for oil
$\gamma^{GAS}_{i,r}$	CES share parameter for gas
$aKLE_{i,r}$	scaling parameter of the CES function
$aECNEC_{i,r}$	scaling parameter of CES function of energy
$aGASOIL_{i,r}$	scaling parameter of CES function of fuels
$\sigma^E_{i,r}$	CES elasticity of substitution between electricity and non-electricity
$\sigma^{NE}_{i,r}$	CES elasticity of substitution between fuels (non electricity)
$\sigma^{OIL}_{i,r}$	CES elasticity of substitution between oil and gas
$\gamma^K_{i,r}$	CES share parameter for capital and labour bundle
$\gamma^E_{i,r}$	CES share parameter for energy
$\gamma^{EC}_{i,r}$	CES share parameter for Electricity
$\gamma^{NEC}_{i,r}$	CES share parameter for non-electricity
$aKL_{i,r}$	scaling parameter of the CES function
$\sigma^{KE}_{i,r}$	CES elasticity of substitution between capital and labor
$\gamma^L_{i,r}$	CES share parameter for labor
$\delta_{i,r}$	Depreciation rate
Associated with international and interregional trade	
$\sigma^A_{i,r}$	Armington elasticity of substitution between domestic prod and imports
$\sigma^{A1}_{i,r}$	Armington elasticity of substitution between domestic prod from diff regions
$\gamma^{A1}_{i,r}$	CES share parameter of ARMINGTON function for imports from EU25
$\gamma^{A2}_{i,r}$	CES share parameter of ARMINGTON function for imports from ROW
$\gamma^{A3}_{i,r}$	CES share parameter of ARMINGTON function for domestic goods

$\gamma A_{i,r}$	CES share parameter of ARMINGTON function for XDDE _i sec
$aA_{i,r}$	scale parameter of ARMINGTON function of sector i
$aA1_{i,r}$	scale parameter of ARMINGTON function of sector i
Household consumption and investment	
mps_r	marginal propensity to save of households
αH_r	power in in nested-LES household utility on good i
$muH_{i,r}$	subsistence household consumption quantity of good i
$\alpha I_{i,r}$	Cobb-Douglas power in investment production function
$atm_{i,r}$	share of commodity for prod of transp and trade margins

6.2 Elasticities of substitution and other exogenous parameters

To construct the database of exogenous model parameters, we performed a review of applied general equilibrium models with respect to the non-calibrated parameters. These parameters can subsequently be introduced into the modelling framework. Hereafter, we in particular focus on the sector-specific elasticities of substitution between different input factors in production and the Armington elasticities. Our literature review encompassed three single-country CGE studies for Russia (Rutherford and Paltsev (1999), Alekseev et al. (2004), Lokhov and Welsch (2008)). However, we also review CGE and econometric studies with a multi-regional focus (Capros et al. (1998), Burniaux and Troung (2002), Kemfert and Welsch (2000), Behr et al. (2002), Kemfert (2002), Liu et al. (2003), Böhringer and Löschel (2004), Saito (2004), Paltsev et al. (2005), Van der Werf (2007), Nemeth et al. (2008), Okagawa and Ban (2008), Welsch (2008)).

For the specific determination of elasticities of substitution disaggregated into various sectors, it seems appropriate to rely on the econometric studies focussing on OECD countries, most notably the newest study by Okagawa and Ban (2008) as employed in the most recent version of the PACE model (Böhringer et al., forthcoming). As explained above, this furthermore opens the possibility for choosing between two different nesting structures. Regarding the more specific suggestions with respect to the values for substitution elasticities, it is suggested to use Okagawa and Ban's (2008) estimates in general but possibly to adjust them upwards for the substitution elasticity between Capital and Energy, as Lokhov and Welsch (2008) provide a higher figure based on the argument that Russia still has a much higher potential for energy saving. For the intra-energy elasticities of substitution (Coal-Oil and Gas; Oil and Gas), we can rely on Lokhov and Welsch's (2008) values.

Table 13: Proposed exogenous parameter of input substitution

Production Technologies	KLEM	M	KLE	KL	ELEC	COAL	OIL/GAS
Agriculture, ea	0.392	0	0.516	0.023	0.6	0.5	0.75
Fishing	0.392	0	0.516	0.023	0.6	0.5	0.75
Coal	0.729	0	0.553	0.139	0.6	0.5	0.75
Gas	0.729	0	0.553	0.139	0.6	0.5	0.75
Oil	0.729	0	0.553	0.139	0.6	0.5	0.75
Mining (non-energy)	0.729	0	0.553	0.139	0.6	0.5	0.75
Food, beverage and tobacco	0.729	0	0.553	0.139	0.6	0.5	0.75
Textiles	0.329	0	0.395	0.382	0.6	0.5	0.75
Leather	0.722	0	0.637	0.161	0.6	0.5	0.75
Wood	0.695	0	0.456	0.087	0.6	0.5	0.75
Pulp&Paper	0.187	0	0.211	0.381	0.6	0.5	0.75

Coke, refineries	0.848	0	0.529	0.334	0.6	0.5	0.75
Chemicals	0.848	0	0.529	0.334	0.6	0.5	0.75
Rubber and plastics	0.306	0	0.411	0.358	0.6	0.5	0.75
Non-metallic products	0.306	0	0.411	0.358	0.6	0.5	0.75
Basic metals	1.173	0	0.644	0.22	0.6	0.5	0.75
Machinery	0.13	0	0.292	0.295	0.6	0.5	0.75
Electric and optics	0.876	0	0.524	0.163	0.6	0.5	0.75
Transport Eq.	0.548	0	0.519	0.144	0.6	0.5	0.75
Other manufacturing	0.406	0	0.529	0.046	0.6	0.5	0.75
Electricity, gas and water (distribution)	0	0	0.256	0.46	0.6	0.5	0.75
Electricity	0	0	0.256	0.46	0.6	0.5	0.75
Construction	1.264	0	0.529	0.065	0.6	0.5	0.75
Wholesale trade	0.9	0	0.784	0.316	0.6	0.5	0.75
Hotels and restaurants	0.9	0	0.784	0.316	0.6	0.5	0.75
Communication	0.654	0	0.518	0.37	0.6	0.5	0.75
Transport	0.352	0	0.281	0.31	0.6	0.5	0.75
Financial intermediation	0.492	0	0.32	0.264	0.6	0.5	0.75
Government service and defence	0.9	0	0.784	0.316	0.6	0.5	0.75
Real estate, renting and business activities	0.492	0	0.32	0.264	0.6	0.5	0.75
Education	0.9	0	0.784	0.316	0.6	0.5	0.75
Health and social work	0.9	0	0.784	0.316	0.6	0.5	0.75

Second, the literature review of Armington elasticities encompasses the types NEST1 (substitutability between domestic and imported goods) and NEST2 (substitutability among imports from different regions), sectorally disaggregated, short and long-term as well as Russia-specific estimations. Alekseev et al. (2004) present a comprehensive database for Russia-specific NEST1 Armington elasticities for 15 sectors, based on the econometric analysis conducted by Zemnitsky (2002), with values ranging between 0.6 (amongst others: agriculture) and 0.94 (machinery equipment). As highlighted above, these values seem very low when compared to the common practice values of Armington elasticities as employed in global CGE models; they are, however, supported by most recent econometric analysis carried out by Welsch (2008). For NEST2 Armington values, we cannot draw on Russia-specific econometric estimates, only on econometric studies for the OECD (Saito, 2004) and the EU (Nemeth et al., 2008). The wide range given by Lokhov and Welsch (2008) might be used for the sensitivity analysis.

Table 14: Proposed Armington elasticities for SUST-RUS model

Production Technologies	Armington (Alekseev et al.)
Agriculture, ea	0.6
Fishing	0.6
Coal	0.75
Gas	0.75
Oil	0.75
Mining (non-energy)	0.75
Food, beverage and tobacco	0.6
Textiles	0.79
Leather	0.79
Wood	0.79
Pulp&Paper	0.79
Coke, refineries	0.83
Chemicals	0.83
Rubber and plastics	0.83
Non-metallic products	0.83
Basic metals	0.81
Machinery	0.94

Electric and optics	0.75
Transport Eq.	0.75
Other manufacturing	0.61
Electricity, gas and water (distribution)	0.75
Electricity	0.75
Construction	0.6
Wholesale trade	0.6
Hotels and restaurants	0.6
Communication	0.6
Transport	0.6
Financial intermediation	0.6
Government service and defence	0.6
Real estate, renting and business activities	0.6
Education	0.6
Health and social work	0.6

6.3 Model formulation

6.3.1 Households

The total income of each household is calculated as the sum of its regional labour income and capital income. Households' capital income includes income from capital investments in the production sectors that are owned by private firms (non-public sectors). The labour income includes the income from work in the home region and from work in the rest of the world (RoW) of different types of education levels. The total amount of wage and capital is attributed to each household type (low, middle and high earning) by an exogenous share (*shareWage* and *shareCap*).

$$Y_{th,r} = \left[(LS_{ed,r} - UNEMP_{ed,r}) \cdot PL_r - LROW_{th,ed,r} \cdot ER \right] \cdot shareWage_{th,ed,r} + \left[\sum_i K_{i,r} \cdot RK_{i,r} \cdot (1 - sharePublic_{i,r}) \right] \cdot shareCap_{th,ed,r} \quad (1)$$

The total consumption budget of the households' (*CBUD*) is calculated as the sum of after-tax income (net income) plus the social transfers of national and regional governments (*TRF* and *TRFR*) minus the households' savings (*SH*) plus the unemployment benefits received by the household (calculated as the unemployment level (*UNEMP*) times the price of labour times the replacement rate of unemployment (*trep*) minus the investments of households' into education:

$$CBUD_{th,r} = Y_{th,r} \cdot (1 - ty_{th,r}) + TRF_{th,r} \cdot GDPDEF + TRFR_{th,r} \cdot GDPDEF - SH_{th,r} + \sum_{ed} (UNEMP_{ed,r} \cdot PL_{ed,r} \cdot trep_{ed,r}) \cdot shareWage_{th,ed,r} \quad (2)$$

Where *ty* is the income tax rate and *GDPDEF* is the GDP deflator. Governmental transfers are indexed in the model with the GDP deflator. If the overall price level in the economy goes up so will the transfers.

The savings of the regional household are calculated as a fixed proportion of its total disposable income that consists of the household's net income plus the social transfers and unemployment benefits. This fixed proportion (marginal propensity to save (*mps*)) is different for each region and household.

$$SH_{th,r} = mps_{th,r} \cdot ((Y_{th,r} \cdot (1 - ty_{th,r}) + TRF_{th,r} \cdot GDPDEF + TRFR_{th,r} \cdot GDPDEF) + \sum_{ed} (UNEMP_{ed,r} \cdot PL_{ed,r} \cdot trep_{ed,r}) \cdot shareWage_{th,ed,r} \quad (3)$$

The amounts of the goods and services bought by the regional household types are determined according to a utility-maximization problem, where the household maximizes the following utility function. This is a utility function based on the LES or Stone-Geary function. The LES function is a variation on the Cobb-Douglas utility function, where we subtract a fix part of the consumption of goods which is defined as 'basic' or 'subsistence' consumption (μ_i) from the total consumption of a good (C)

$$U_{th,r} = \prod_i (C_{th,i} - \mu_{th,i})^{\alpha_i} \quad (4)$$

The welfare of an individual regional household is calculated as the change in equivalent variation of the aggregate regional household. The equivalent variation is defined as the change in monetized change in utility, based on the LES utility function.

$$EV = \frac{1}{scalU} [U^A - U^0] \cdot \frac{1}{PEV_r} \quad (5)$$

The calculation of the equivalent variation measure according to this formula is based on the price of equivalent variation and on the level of utility. The superscript '0' refers to the initial baseline values of the utility price and the budget. The price index of utility obtained by the household is derived according to the following equation. This price depends on the after-tax prices of goods and services as well as the utility shares ($\alpha_{i,r}$)

$$PEV_r = \prod_{i=products} \left(\frac{P_{i,r} \cdot (1 - sc_i + tc_i)}{\alpha_{i,r}} \right)^{\alpha_{i,r}} \quad (6)$$

6.3.2 Firms

The behavior of the firms is based on the minimization of the production costs for a given output level under the firm's technological constraint. Production costs of each sector in the model include labor costs by type of labor, energy costs, capital costs, land costs and the costs of intermediate inputs. By capital we mean physical capital of the sector, which includes machinery, equipment and buildings. The sector's technological constraint describes the production technology of each sector. It provides information on how many of different units of labor, energy, capital and commodities, are necessary for the production of one unit of the sectoral output.

Production sectors are assumed to operate under constant returns to scale and perfect competition. Their pricing are equal to marginal production costs, which are in turn equal to the average production costs.

The production technology of the firm is represented by the nested Constant Elasticity of Substitution (CES) functions. The nested CES function is quite flexible and allows for different assumptions about the degree of substitutability between the production inputs. Inputs which are easier to substitute with one another are put into the same nest. Inputs which are more difficult to substitute in the production process are put into different nests. The degree of substitutability is the lowest on top of the nested CES function and the highest at the bottom of it. All production inputs in the CES tree have a certain degree of substitutability between each other and it depends on their relative position in the tree. In accordance with

their production technology, sectors have substitution possibilities between different intermediate inputs and production factors.

The following equation derives the value of the top CES bundle (KLE) which is equal to the total domestic production (XD) multiplied by a Leontief coefficient.

$$KLE_{i,r} = ioKLE_{i,r} \cdot XD_{i,r}, \quad (7)$$

where KLE is the composite labour and capital bundle and io are technical coefficients. PD is the domestic producer price of commodities. The composite price of this bundle is equal to the weighted average of the prices of land (LD) and the capital-energy-labour bundle (KLE).

$$PKLE_{i,r} \cdot KLE_{i,r} = PKL_{i,r} \cdot KL_{i,r} + PENER_{i,r} \cdot ENER_{i,r} \quad (8)$$

The value of the capital-labour-energy bundle is calculated according to the CES demand function and depends upon the value of the top CES bundle (KLE), the composite price of the capital-labour-energy bundle ($PKLE$), the composite price of the top CES bundle ($PKLE$) and the CES technological coefficients (σ is here the elasticity of substitution between land and the capital-labour bundle and α is a scaling parameter).

$$KL_{i,r} = KLE_{i,r} \cdot \left(\frac{\gamma KLE_{i,r}}{PKL_{i,r}} \right)^{\sigma KLE_{i,r}} \cdot PKLE_{i,r}^{\sigma KLE_{i,r}} \cdot aKLE_{i,r}^{\sigma KLE_{i,r}-1} \quad (9)$$

Likewise, the composite price of this bundle is equal to the weighted average of the prices of energy ($ENER$) and capital-labour (KL) bundle.

$$PKLE_{i,r} \cdot KLE_{i,r} = PKL_{i,r} \cdot KL_{i,r} + ENER_{i,r} \cdot PENER_{i,r} \quad (10)$$

The value of the capital-labour bundle is calculated according to the CES demand function and depends upon the value of the top CES bundle (KLE), the composite price of the capital-labour bundle (PKL), the composite price of the top CES bundle ($PKLE$) and CES technological coefficients (σ here is the elasticity of substitution between capital and labour).

$$KL_{i,r} = KLE_{i,r} \cdot \left(\frac{\gamma KL_{i,r}}{PKL_{i,r}} \right)^{\sigma KLE_{i,r}} \cdot PKLE_{i,r}^{\sigma KLE_{i,r}} \cdot aKLE_{i,r}^{\sigma KLE_{i,r}-1} \quad (11)$$

The composite price of this bundle is equal to the weighted average of the prices of capital (K) and composite labour input (LT).

$$PKL_{i,r} \cdot KL_{i,r} = (RK_{i,r}(1 + tk_{i,r}) + \delta_{i,r} \cdot PI_c) \cdot K_{i,r} + PLT_{i,r} \cdot LT_{i,r} \quad (12)$$

Where tk is the corporate tax rate; δ the depreciation rate, PI the price of private investments and PLT the price of the composite labour bundle.

6.3.3 Energy inputs

Sust-Rus takes into account 4 aggregated energy inputs: electricity, gas, oil and coal. The demand for energy is derived from a standard nested-CES tree as used throughout the entire project.

Aggregated energy inputs (gas-oil, coal and electricity) are derived from the capital-labour-energy bundle by the following formula.

$$ENER_{i,r} = KLE_{i,r} \cdot \left(\frac{\gamma ENER_{i,r}}{PENER_{i,r}} \right)^{\sigma KLE_{i,r}} \cdot PENER_{i,r}^{\sigma KLE_{i,r}} \cdot aKLE_{i,r}^{\sigma KLE_{i,r}-1} \quad (13)$$

The price of the composite energy bundle PENER is equal to the weighted price of the electricity and non-electricity inputs. This is defined by the equation below.

$$PENER_{i,r} \cdot ENER_{i,r} = PNONELEC_{i,r} \cdot NONELEC_{i,r} + P_{ii=electricity,r} \cdot ELEC_{i,r} \quad (14)$$

The demand for electricity and non-electricity inputs are given by the following equations. These are essentially at a lower nest of the energy inputs.

$$NONELEC_{i,r} = ENER_{i,r} \cdot \left(\frac{\gamma NEC_{ii,i,reg}}{PNONELEC_{i,r}} \right)^{\sigma E_{i,r}} \cdot PENER_{i,r}^{\sigma E_{i,r}} \cdot aECNEC_{i,r}^{\sigma E_{i,r}-1} \quad (15)$$

$$ELEC_{i,r} = ENER_{i,r} \cdot \left(\frac{\gamma EC_{ii,i,reg}}{PELEC_{i,r}} \right)^{\sigma E_{i,r}} \cdot PENER_{i,r}^{\sigma E_{i,r}} \cdot aECNEC_{i,r}^{\sigma E_{i,r}-1} \quad (16)$$

The demand for each type of fossil fuel is again a subnest of the NONELEC bundle, given by the next equation. We distinguish 3 types of fuels: an oil, coal and gas bundle. Oil and gas act as a separate bundle, distinguished from coal.

$$GASOIL_{i,reg} = NONELEC_{i,r} \cdot \left(\frac{\gamma GASOIL_{ii,i,reg}}{PGASOIL_{ii,reg}} \right)^{\sigma NE_{i,r}} \cdot PNONELEC_{i,r}^{\sigma NE_{i,r}} \cdot aFUEL_{i,r}^{\sigma NE_{i,r}-1} \quad (17)$$

$$COAL_{i,reg} = NONELEC_{i,r} \cdot \left(\frac{\gamma COAL_{ii,i,reg}}{P_{ii=coal,reg}} \right)^{\sigma NE_{i,r}} \cdot PNONELEC_{i,r}^{\sigma NE_{i,r}} \cdot aFUEL_{i,r}^{\sigma NE_{i,r}-1} \quad (18)$$

The demand for gas and oil is derived at the bottom nest.

$$GAS_{i,reg} = GASOIL_{i,r} \cdot \left(\frac{\gamma GAS_{ii,i,reg}}{P_{ii=gas,reg}} \right)^{\sigma OIL_{i,r}} \cdot PGASOIL_{i,r}^{\sigma OIL_{i,r}} \cdot aOIL_{i,r}^{\sigma OIL_{i,r}-1} \quad (19)$$

$$OIL_{i,reg} = GASOIL_{i,r} \cdot \left(\frac{\gamma OIL_{ii,i,reg}}{P_{ii=oil,reg}} \right)^{\sigma OIL_{i,r}} \cdot PGASOIL_{i,r}^{\sigma OIL_{i,r}} \cdot aOIL_{i,r}^{\sigma OIL_{i,r}-1} \quad (20)$$

6.3.4 Capital stock

For cost minimizing (and profit maximizing) firms operating under constant returns to scale, expenditures on capital (K) are derived as a sub-nest from the capital-labour bundle, as a solution of the cost minimization problem.

$$K_{i,r} = KL_{i,r} \cdot \left(\frac{\gamma K_{i,r}}{(1 + tk_{i,c}) \cdot RK_{i,r} + \delta_{i,r} \cdot PI_c} \right)^{\sigma KL_{i,r}} \cdot PKL_{i,r}^{\sigma KL_{i,r}} \cdot aKL_{i,r}^{\sigma KL_{i,r}-1} \quad (21)$$

6.3.5 Dixit-Stiglitz varieties and monopolistic competition (optional)

This mathematical description of the model includes a set of equations that deviate from the assumption of perfect competition. We allow monopolistic competition as an option to the modeler. Under the monopolistic competition framework, it is assumed that each sector consists of a number of identical firms, each producing a unique specification of a particular commodity. The same type of the commodity, produced by an individual firm, is slightly different from the same type of commodity, produced by other firms inside the sector. These differences in the commodity specification give individual firms a certain monopolistic power over the consumers.

Each new production firm under monopolistic competition faces initial fixed costs of establishing itself in the market. The fixed production costs of an individual firm are related to its initial establishment in the industry and include both labour and capital costs. Each new firm produces one particular type of the product type/variety. The firms charge prices higher than their marginal costs in order to be able to cover their fixed costs. Since consumers have widely differentiated preferences with respect to the types/varieties of goods and services produced by the firms, they purchase output of all the firms in the sector. The functional form of the consumer utility function associated with consuming product of a certain sector is represented by the CES function, which positively depends on the number of firms (varieties) in a region. This setup is generally called the Dixit-Stiglitz form of monopolistic competition.

The sector variable costs are equal to the marginal output costs multiplied by the sectoral output level. The sector fixed costs depend upon the number of the individual operating firms and are equal to the number of firms inside a sector multiplied by the fixed costs per firm. Given that there are no statistical data that describe the production process of each firm in the industry, all firms are assumed to be homogenous and have the same production technology, the same output size and the same fixed production costs.

The strength of the monopolistic competition framework, is that it allows to model agglomeration and dispersion forces. Agglomeration forces in this set-up follow the following logic: when the number of the operating firms in the region increases, the variety of differentiated goods available in the region will increase. This means that the cost of obtaining a certain set of differentiated goods will decrease. For a given nominal wage, this decrease in the price index will increase the real wage of regional workers in relative terms. This leads to in-migration. The new migration reinforces the agglomeration because migrants expand the consumption market in the region, again increasing the offered variety, reducing the price index and increasing real wages in a cumulative process.

Given that the entry to all the industries is assumed to be free, the number of the monopolistic firms in each sector (NF) is determined by the condition that the total costs of the firms equal its total revenues (zero profit condition). Once the firms in the industry starts making profits, several new firms enter the market and drive total profits down to zero again. The fixed capital and labour costs for each firm are assumed to be constant, making the total number of the firms operating in a sector endogenous, defined by the zero profit condition for the sector as a whole:

$$NF_{i,r} \cdot elas Re g_{i,r} \cdot fcL_{i,r} + fcK_{i,r} \cdot INDEX_r = XD_{i,r} \cdot PD_{i,r} \quad (22)$$

Where $elas Re g_{i,r}$ is the demand elasticity for imperfectly competitive sectors in regions and $fcK_{i,r}$ the total labour fixed costs. Just as in equation (n2) of the standard NEG model the price of the goods or services produced by a monopolistically competitive sector (PDC) depend negatively on both the number of the operating firms and on the elasticity of substitution between the varieties of a good or a service produced by each firm. However, this is made operational by using a simple auxiliary variable. Under the assumption that the firms operating in a sector are identical, the price of a monopolistically competitive sector is derived according to the following formula:

$$PDC_{i,r} = PD_{i,r} \cdot AUXV_{i,r} \quad (23)$$

This price is higher than the marginal production costs. Which is the domestic production price (PD), multiplied by the auxiliary variable (AUXV)

$$AUXV_{i,r} = (NF_{i,r})^{\frac{1}{1-elasRe g_{i,r}}} \quad (24)$$

Firms charge prices higher than their marginal costs, which results in obtaining the profits. The profits made by the monopolistic firms are identical to the sum of their fixed labour and capital costs. This equality determines the total number of operating firms in each sector.

$$PROFITS_{i,r} = NF_{i,r} \cdot (fcL_{i,r} + fcK_{i,r}) \cdot INDEX_{i,r} \quad (25)$$

If a sector does not include spatially bound inputs agglomeration in a small set of regions is possible. If spatially bound inputs are needed, the price of this input will act as a spreading force, since the input cannot migrate. Agglomeration is still possible, but given the countervailing force, it will occur in a larger set of regions and is less likely to be catastrophic. Simulations will be needed to assess the sensitivity of results.

For the modern firms operating under increasing returns to scale, the variable expenditures on capital (Kv) is derived as a sub-nest from the capital-labour bundle, as a solution of the cost minimization problem. The total expenditures on capital are a sum of the variable capital inputs and the fixed capital costs. These are the fixed cost of capital per firm (fcK), multiplied by the amount of firms (NF) in the sector.

$$K_{i,r} = KL_{i,r} \cdot \left(\frac{\gamma K_{i,r}}{(1 + tk_{i,c}) \cdot RK_{i,r} + \delta_{i,r} \cdot PI_c} \right)^{\sigma KL_{i,r}} \quad i \in \text{monopolistic} \quad (26)$$

$$\cdot PKL_{i,r}^{\sigma KL_{i,r}} \cdot aKL_{i,r}^{\sigma KL_{i,r} - 1} + (NF_{i,r} \cdot fcK_{i,r})$$

6.3.6 Government

The Russian government is modeled at 2 levels, a regional and a country level government. The elements taken up in the SUST-RUS model, concerning the different levels of government, are related to the type and share of tax income and subsidy, monetary transfers between governments and government consumption.

The tax revenues within each region (TAXRG) are calculated as the sum of the labour taxes, profit taxes of the firms (tk), taxes on production (txd) and taxes on the total consumption (tc). The taxes on consumption are subdivided in: final tax on consumption of households, tax on investment, tax on government consumption and export taxes. They are all modelled as a fixed percentage of the value of a good. Regional governments get a different fixed share of the total tax revenues from each tax subtype. The total tax income for each government is equal to the sum of its tax revenues within each region.

$$TAXRG_{gov} = \sum_r \left[\begin{aligned} & PL_r \cdot L_{i,r} \cdot (tl_i \cdot tl_{gov_{r,gov}}) + tk_i \cdot tk_{gov_{r,gov}} \cdot K_{i,r} \cdot RK + txd_i \cdot txd_{gov_{r,gov}} \cdot XD_{i,r} \cdot TFP \cdot PD_{i,r} \\ & \left(+ \sum_i (tc_i \cdot tc_{gov_{r,gov}}) \cdot P_{i,r} \cdot \left(\sum_{th} C_{th,i,r} + I_{i,r} + CG_{i,r} \right) \right) \\ & + Y_{th,r} \cdot ty_{th} \cdot ty_{gov_{r,gov}} \end{aligned} \right] \quad (27)$$

The total subsidies of each government consist of subsidies on production and consumption. Subsidies are treated similarly as tax revenues. The national rates are fixed and equal for each province, but the share of the total subsidies paid by each government are different in each region.

The governments transfer income to the households and to the other governments. For the transfers to the households a distinction is made between unemployment benefits and ‘other transfers’. Transfers to the households are partially fixed; the ‘other transfers’ are assumed to be constant, but the unemployment benefits depend on the wage level and on unemployment within each region. Unemployment benefits only partially compensate the loss in real wage (PW); the degree of compensation depends on the exogenously fixed parameters $trep$ (wage replacement rate).

$$UNEMPB_{r,gov} = (UNEMP_r \cdot trep_r \cdot PW_r) \cdot indic_UNEMPB_{gov} \quad (28)$$

Transfers from government to government are endogenous and are calculated in the following way.

First, we assume that a fixed share of the total government income (tax revenues and income from transfers) is transferred.

$$TRFGE_{gov} = shareTRFGE_{gov} \cdot (TAXRG_{gov} + TRFGY_{gov}) \quad (29)$$

Next, we assume that each government gets a fixed share of the government transfer expenditures

$$TRFGG_{gov,govv} = aTRFGE_{gov,govv} \cdot TRFGE_{gov} \quad (30)$$

The income from transfers is assumed to be the sum of the total transfers from each government

$$TRFGY_{govv} = \sum_{gov} TRFGG_{gov,govv} \quad (31)$$

The consumption budget of each government (CBUD_GOV) consists of the total tax revenues (TAXRG) minus total subsidies (SUBSG), minus the unemployment benefits, minus the transfers to the households (TRFF), plus the income from intergovernmental transfers (TRFGY) minus the expenditures on intergovernmental transfers (TRFGE), and savings plus the transfers to the government from abroad (TREU25).

$$\begin{aligned} CBUD_GOV_{gov} = & (TAXRG_{gov} - SUBSG_{gov}) \\ & \sum_{th,r} \cdot TRFF_{th,r,gov} \cdot GDPDEF - \sum_{th,r} UNEMPB_{th,r,gov} + (TRFGY_{gov} - TRFGE_{gov}) \cdot GDPDEF \\ & + TREU25_{gov} \cdot ER - SG_{gov} \cdot GDPDEF \end{aligned} \quad (32)$$

There are several possible closures of the government budget, each with a distinct effect on model results. The first possibility is closure via government savings in this case, a change in the government revenues is added or subtracted from the public budget surplus or deficit, keeping government consumption constant. A second possibility is that extra revenues are redistributed via the government consumption and having a direct effect on the economy. (However, note that this can lead to rather large price and consumption effects on education, government services and health provision). Another possibility is that government tries to achieve budget balance, through an increase or decrease of lump sum transfers to households or by increasing taxation of other goods.

We included some basic equations to model the government expenditures on commodities based on a 2 stage approach. In the first stage we assume that each region gets a fixed part of the government spendings on commodities.

$$CGR_{r,gov} = \alpha G_{r,gov} \cdot CBUD_GOV_{gov} \quad (33)$$

In the next stage, we assume that the consumption budget within each regions is distributed on the basis of government's maximization of a Cobb-Douglas welfare utility function, which depends upon its consumption of goods and services under its budget constraint. This broadly corresponds to one of the theoretical models of governments, where the Government "knows best" while maximizing economic welfare (this model is referred to as the despotic benevolent model; Bailey, 1995, 1999). The result is the following demand function for regional goods (for the national Government):

$$P_{i,r} \cdot (1 + tcg_i) \cdot CGG_{i,r,gov} = \alpha G_{i,r,gov} \cdot CGR_{r,gov} \quad (34)$$

6.3.7 Interregional and international trade

The formulation of the trade part of the model is based on the theory for a small open economy. Domestic sales in each region are a composite commodity of domestically produced goods, imports from EU countries and imports from countries outside the EU (Rest Of World).

The equations below show the corresponding equations for imports from the EU and imports from the ROW.

$$MEU25_{i,r} = X_{i,r} \cdot \left(\frac{\gamma A1_{i,r}}{PMEU25_i} \right)^{\alpha_{i,r}} \cdot (P_{i,r})^{\alpha_{i,r}} \cdot (aA_{i,r})^{\alpha_{i,r}-1} \quad (35)$$

$$MROW_{i,r} = X_{i,r} \cdot \left(\frac{\gamma A2_{i,r}}{PMROW_i} \right)^{\alpha_{i,r}} \cdot (P_{i,r})^{\alpha_{i,r}} \cdot (aA_{i,r})^{\alpha_{i,r}-1} \quad (36)$$

The prices of the commodities imported to the country from EU countries and from the rest of the world in foreign currency are exogenously fixed in the model and their prices in the domestic currency are calculated according to the following formulas, where the subscript '0' refers to the commodity prices in foreign currency:

$$PMROW_i = PWMROW_i^0 \cdot ER \quad (37)$$

$$PMEU25_i = PWMEU25_i^0 \cdot ER \quad (38)$$

Domestic sectors have the possibility to export their production to the EU countries and to the rest of the world. Exports are determined through a similar function as the Armington CES function in the case of imports. This function is mathematically equivalent and is commonly referred to as the CET function or the constant elasticity of transformation. Note that in this case, X (sales) are replaced by XD (production) and P (sales price) is replaced by PD (producers price)

$$EEU_{i,r} = XD_{i,r} \cdot \left(\frac{\gamma T1_{i,r}}{PEEU25_i \cdot (1 - t \exp_i)} \right) \cdot (PD_{i,r})^{\sigma_{i,r}} \cdot (aT_{i,r})^{\sigma_{i,r}-1} \quad (39)$$

$$EROW_{i,r} = XD_{i,r} \cdot \left(\frac{\gamma T2_{i,r}}{PROW_i \cdot (1 - t \exp_i)} \right) \cdot (PD_{i,r})^{\sigma_{i,r}} \cdot (aT_{i,r})^{\sigma_{i,r}-1} \quad (40)$$

The demand for the composite domestic commodity is determined in the first CES nest

$$XDD_{i,r} = X_{i,r} \cdot \left(\frac{\gamma A3_{i,r}}{PDDT_{i,r}} \right) \cdot (P_{i,r})^{\alpha_{i,r}} \cdot (aA_{i,r})^{\alpha_{i,r}-1} \quad (41)$$

The price of the composite domestic goods and services is derived as the weighted average of the prices of the commodities bought from all domestic regions. This weighted price includes the price for domestically produced goods (PDD) in each region, plus the relative transport costs.

$$PDDT_{i,r} \cdot XDD_{i,r} = \sum_{rr} XDDE_{i,rr,r} \cdot (PDD_{i,r} + PTM \cdot trm_{rr,r,i}) \quad (42)$$

The demand for domestic commodities by region is given by the next equation

$$XDDE_{i,rr,r} = XDD_{i,r} \cdot \left(\frac{\gamma A_{i,r}}{PDD_{i,rr} + PTM \cdot trm_{rr,r,i}} \right)^{\sigma A_{i,r}} \cdot PDDT_{i,r}^{\sigma A_{i,r}} \cdot aA_{i,r}^{\sigma A_{i,r}-1} \quad (43)$$

The calculation of the transport costs of commodities deserves some additional explanation. Instead of using the commonly applied iceberg transportation costs, the model bases transport costs on the relative production and consumption of transport margins. The countrywide (!) price of trade margins (PTM) is a weighted sum of the **production cost** of transport margins **relative to the sales price of some sectors**. The sectors producing transport margins are the trade and retail sector and the transport sector. The shares (atm) are exogenously fixed.

$$PTM = \sum_i \sum_r (atm_{i,r} \cdot P_{i,r}) \quad (44)$$

Producers are selling at a price PDD on the domestic market, which is the so called 'mill price' of the good. A competitive transport agent is responsible for moving the good and demands a total value equal to the transport and trade margin.

$$XXD_{i,r} = XD_{i,r} \cdot \left(\frac{\gamma T_{i,r}}{PDD_{i,r}} \right) \cdot (PD_{i,r})^{\sigma A_{i,r}} \cdot (aT_{i,r})^{\sigma A_{i,r}-1} \quad (45)$$

The next equations close the interregional trade market. The first one is an obvious restriction, but probably one of the most important ones, when concerning interregional trade. This equation states that all the production of a region, delivered to the domestic market, has to be equal to the total demand of goods from that region.

$$XXD_{i,r} = \sum_{rr} XDDE_{i,r,rr} \quad (46)$$

The second and last equation is related to the **production** of transport and trade margins. The production of trade margins is made by the transport and trade sectors and is determined by a fixed share (comparable to the Leontief configuration). This equation relates to production of trade margins to the consumption of transport and trade.

$$TMX_{i,r} = atm_{i,r} \sum_{i,rr,rrr} trm_{i,rr,rrr} \cdot XDDE_{i,rr,rrr} \quad (47)$$

6.3.8 Savings

The total domestic savings consists of the savings made by all regional households, government and the regional sectors. The savings of the regional sectors are assumed to be equal to their depreciation costs. The total domestic savings are calculated according to the following formula:

$$S = \sum_{th,r} SH_{th,r} + \sum_{gov} SG_{gov} + \sum_{i,r} \partial_{i,r} \cdot K_{i,r} \cdot PI \quad (48)$$

The total investments in the economy consist of domestic savings, plus the investments received from the EU countries and from the rest of the world minus the amount of foreign savings (to EU or RoW), minus total changes in stocks:

$$IT = S + IEU + IROW - SEU \cdot ER - SROW \cdot ER - \sum_i \sum_r (SV_{i,r} \cdot P_{i,r}) \quad (49)$$

The total investments are spent on buying physical investments goods from various domestic regions, where the demand for them is determined according to the Cobb-Douglas demand function:

$$I_{i,r} \cdot P_{i,r} \cdot (1 + t_{i,r}) = (\alpha_{i,r}) \cdot IT \quad (50)$$

The nominal rate of return in the economy is calculated as the average return to capital of all domestic sectors:

$$RGD_r = \frac{\sum_i (RK_{i,r} \cdot K_{i,r})}{\sum_i K_{i,r}} \quad (51)$$

The price of additional unit of the composite physical investment good is calculated in accordance to the Cobb-Douglas demand function and has the following form:

$$PI = \prod_i \prod_r \left(\frac{P_{i,r} \cdot (1 + t_{i,r})}{\alpha_i} \right)^{\alpha_{i,r}} \quad (52)$$

6.3.9 Labour market

The labour market was chosen deliberately to be very simple. The reason of this specification can be found in the high labour participation rate in Russia, the weak position of labour unions and subsequently high bargaining power of firms, limited enforcement of labour regulations and relatively low labour mobility between regions.

The price of labour is determined from the labour market clearing condition indicated below. This basic equation will simply indicate that all labour will either be employed or unemployed. There is no leisure in the utility function of households and no involuntary unemployment. The labour supply of the region is fixed on a yearly basis.

$$\sum_i L_i = LS_r - UNEMP_r \quad (53)$$

Unemployment is determined from the so-called Philips curve. This curve provides a very basic link between real wage (PL/INDEX) and unemployment rate (UNRATE). In this set-up all unemployment is voluntary.

$$\left(\frac{PL}{PL^0} \cdot \frac{INDEX^0}{INDEX} - 1 \right) = philips \cdot \left(\frac{UNRATE}{UNRATE^0} - 1 \right) \quad (54)$$

6.3.10 Market equilibrium conditions

Markets for goods and services are in equilibrium in each region of the country. According to the market clearing condition the total supply of a certain commodity in each region is equal to the sum of the demand of the regional households, region-specific demands of the governments, region-specific demand for physical investment goods, changes in stocks, region-specific demand for commodities used for production of freight trade and transport margins, intermediate demands of the regional production sectors both of materials as energy inputs.

$$X_{i,r} = \sum_{th} C_{th,i,r} + CG_{i,r} + I_{i,r} + SV_{i,r} + TMX_{i,r} + \sum_{ii} io_{i,ii,r} \cdot IO_{ii,r} + \sum_{ii} IOE_{ii,i,r} \quad (55)$$

The corresponding sales price is determined from the internal and external market equilibrium from goods of the local market and imported goods.

$$P_{i,r} \cdot X_{i,r} = PDDT_{i,r} \cdot XDD_{i,r} + PMEU25_i \cdot (1 + tm_{i,r}) \cdot MEU25 + PMROW_i \cdot (1 + tm_{i,r}) \cdot MROW_{i,r} \quad (56)$$

6.3.11 Calculation of GDP and the Walras law

Regional real GDP (GDP_R) is calculated according to the value added approach and is equal to the sum of output values minus intermediates inputs, where the prices are fixed at their initial levels:

$$\begin{aligned} GDP_R &= \sum_i (XD_{ir} \cdot PD_{i,r}^0) - \sum_{ii,i} (IO_{ii,i,r} \cdot P_{ii,r}^0) \\ &- \sum_i (ENER_{i,r} \cdot \sum_{ii} P_{ii,r}^0) + \sum_i (tc_{i,c} - sc_{i,c}) \cdot P_{i,r}^0 \cdot C_{th,i,r} \\ &+ \sum_i t_{i,r} \cdot I_{i,r} \cdot P_{i,r}^0 + \sum_i tcg_{i,r} \cdot CG_{i,r} \cdot P_{i,r}^0 + \sum_i tcg_{i,r} \cdot CGR_{i,r} \cdot P_{i,r}^0 \end{aligned} \quad (57)$$

Regional nominal GDP (GDP_{CR}) is calculated according to the value added approach and is equal to the sum of output values minus intermediates inputs, all calculated in current prices:

$$\begin{aligned} GDP_{CR} &= \sum_i (XD_{ir} \cdot PD_{i,r}) - \sum_{ii,i} (IO_{ii,i,r} \cdot P_{ii,r}) \\ &- \sum_i (ENER_{i,r} \cdot \sum_{ii} P_{ii,r}) + \sum_i (tc_{i,c} - sc_{i,c}) \cdot P_{i,r} \cdot C_{th,i,r} \\ &+ \sum_i t_{i,r} \cdot I_{i,r} \cdot P_{i,r} + \sum_i tcg_{i,r} \cdot CG_{i,r} \cdot P_{i,r} + \sum_i tcg_{i,r} \cdot CGR_{i,r} \cdot P_{i,r} \end{aligned} \quad (58)$$

Country-level GDP (real and nominal) is calculated as the sum of the regional-level GDPs:

$$GDP_c = \sum_r GDP_R \quad (59)$$

$$GDP_{C_c} = \sum_r GDP_{CR} \quad (60)$$

EU-level GDP deflator is used as a numeraire of the model. All prices in the model are calculated relative (in terms of) to GDP deflator. GDP deflator is calculated as the ratio between nominal GDP of EU divided by the real GDP of EU.

$$GDPDEF = \frac{\sum_c GDP_{C_c}}{\sum_c GDP_c} \quad (61)$$

General equilibrium model represents a system of non-linear equations, where the number of variables is equal to the number of equations. Given that the functional forms of the production and utility functions are well-behaved (continuous and concave), this ensures that the model has a unique solution. All prices in the model are relative prices and calculated in terms of the numeraire, in our case it is the GDP deflator. Numeraire is exogenously fixed in the model. Once one has fixed one of the variables of the nonlinear system of equations (numeraire) it is necessary to remove one of the equations from the system in order to keep the equality between the number of equations and the number of variables. In case of our model the following trade balance equation has been dropped:

$$PMEU25_{i,r} \cdot MEU25_{i,r} \cdot ER + PMROW_{i,r} \cdot MROW_{i,r} \cdot ER + \sum_r LROW_r \cdot PLROW_{ed} \cdot ER = SEU25_r + SROW_r + TEU25_r \cdot ER + TROW_r \cdot ER \quad (62)$$

Since our system of equations represents a closed economic system where all monetary flows have origin and destination, the trade balance equation will be satisfied even if it is dropped from the system of nonlinear equations describing the model. This property is called Walras law which states that if N-1 market is in equilibrium than the Nth market will also be in equilibrium even if it is not a part of the general equilibrium problem. In the case of trade balance, it represents the market clearing condition for the exchange rate.

6.3.12 Environment and emissions

Emissions are attributed to the consumption of all energy resources combusted in production activities. The total amount of emissions by fuel source ($EMSECF$) depends on the total energy input used, multiplied by a set of parameters to convert monetary inputs (IOE) to implicit emissions. The parameter $euse$ determines the share energetic use (combustion activity) of the energy input by sector, $econv$ translates monetary inputs to (Giga)Joules and $ecoeff$ is the emission factor in terms of physical units by input of energy. In practice the three last parameters are reduced to one implicit emission factor for each energy input in each sector.

$$EMSECF_{emis,ii,i,r} = IOE_{ii,i,r} \cdot euse_{ii,i,r} \cdot econv_{ii,i,r} \cdot ecoeff_{ii,i,r} \quad (63)$$

For NOx and Sox emissions, the amount of relative abatement of emissions ($ABAT$) is determined for each sector. For other pollutants, abatement is fixed to nil. The total emissions by sector are a sum of all fuel-dependent emissions, multiplied with the relative abatement by sector. Abatement is not modelled on the level of fuels, only on sectoral (end-of-pipe) level.

$$EMSEC_{emis,i,r} = (1 - ABAT_{emis,i,r}) \cdot \sum_{ii} EMSECF_{emis,ii,i,r} \quad (64)$$

The price of permits depends directly on the demand and supply of emission permits. At each moment in time a certain amount of permits is distributed to each region. The permit price can differ by region if some constraints are built into the model (for example a cap on total trade in emissions).

$$\sum_r DEMANDETS_r = \sum_r SUPPLYETS_r \quad \text{if } r \in ETS \quad (65)$$

The demand for permits is directly dependent on the emissions of all sectors which take part in the ETS system.

$$DEMANDETS_r = \sum_{i \in ETS} EMSEC_{i,r} \quad (66)$$

The final permit price at the level of the sector (PPSEC) is determined from the permit price (PPETS) or regional permit price (PPETSREG).

$$PPSEC_{emis,i,r} = PPETS_{emis}(r \in ETS) + PPETSREG_{emis,r}(r \notin ETS) \quad (67)$$

The marginal abatement curve (MACC) follows the same general formula as described in the GEM-E-3 model and which is applied in many different CGE and non-CGE type models. The general formula is:

$$MACC_{emis,i,r} = \alpha_1 + \alpha_2 \cdot (1 - ABAT_{emis,i,r})^{\alpha_3} \quad (68)$$

The amount of abatement is determined directly from the equalization of the marginal abatement cost (MACC) curve and the total environmental tax (TAXENV). The environmental tax is equal to the price of permits on sector level and an exogenous emission tax.

$$TAXENV_{emis,i,r} = PPSEC_{emis,i,r} + emisTax_{emis,i,r} = MACC_{emis,i,r} \quad (69)$$

The total cost of abatement (COSTABAT) is the integral of the abatement curve

$$COSTABAT_{emis,i,r} = \alpha_0 + \alpha_1 \cdot ABAT_{emis,i,r} - \frac{\alpha_2}{\alpha_3 + 1} \cdot (1 - ABAT_{emis,i,r})^{\alpha_3 + 1} \quad (70)$$

The total abatement cost is converted to intermediate inputs for each sector by the following formula. The total intermediate use (IOABAT) is equal to the total cost of abatement, multiplied with an input factor (fixed share) of expenditures attributed to specific investment goods (machinery, building materials, etc.).

$$IOABAT_{ii,i,r} \cdot P_{ii,r} \cdot (1 + txc_{ii,i,r}) = \sum_{emis} COSTABAT_{emis,i,r} \cdot coeffabat_{cost}_{emis,ii} \quad (71)$$

Optionally a part of the permits per sector can be allocated free of charge (grandfathered) to a sector. Rents are dependent on the amount of exemption that is granted to the sector, compared to the lagged amount of emissions (previous time period). The parameter $\partial_{reduction}$ determines the external amount of emission reduction imposed, χ_{exempt} the amount of emissions that are grandfathered.

$$RENTS_{emis,i,r} = EMSECLAG_{emis,i,r} \cdot (1 - \partial_{reduction}) \cdot \chi_{exempt} \cdot PPSEC_{emis,i,r} \quad (72)$$

These RENTS are directly allocated to the output of the sector and reduce the income from the emission permit system for the government. The total income for the government (PEXPEND) is equal to

$$PEXPEND = \sum_{emis,i,r} PPSEC_{emis,i,r} - RENTS_{emis,i,r} \quad (73)$$

6.4 Closure and exogenously fixed variables

The formal introduction of the concept of closure rule can be traced back to Sen (1963). Sen (1963), showed that the necessary ex-post equality between savings and investment cannot be fulfilled when all the following conditions are satisfied: the factors are paid at their marginal productivity, household consumption is a function of real income, real investment is fixed and the factors are fully employed. The equilibrium is achieved only by relaxing one of these constraints. The choice of the constraint to be dropped, represents in fact the choice of the closure rule. In mathematical terms, the model should consist of an equal number of independent equations and endogenous variables. The closure rule reflects the choice of the model builder of which variables are exogenous and which variables are endogenous, so as to achieve ex-post equality. The following variables are exogenously fixed and define the closure:

- Sector-specific capital endowments in each region
- Governmental transfers to households and savings (optional)
- Transfers from abroad
- Price of labor in the rest of the world
- Labour supply in each region (migration can be modeled as a change in labour supply)
- Transport margins
- Public savings / Government consumption (one of these has to be fixed, government consumption is fixed by default)
- Exchange rate / foreign savings (exchange rate is fixed by default)
- Fixed numeraire

6.5 Recursive dynamics

The recursive dynamics of the SUSTRUS model are opposed to dynamic deterministic CGE models. Deterministic dynamic CGE models (or DCGE) require complex algorithms to calculate optimal paths of capital accumulation and investment over time. They are essentially derived from the basic Ramsey model, which at its heart contains an economic agent producing output from labour and capital, who must decide how to split production between consumption and investment. DCGE models take over this reasoning and apply it to an economy with multiple sectors and households, sometimes including a public sector (for applied examples see B. Heer & A. Maussner, 2005).

Recursive dynamic CGE's such as SUSTRUS, have in general a more detailed and complex production technology and economic structure. In practice it is hard to reconcile the scope of economic details offered by a model such as SUSTRUS with the dynamic structure offered by a full DCGE model. In the SUSTRUS model, we employ a practical approach, used by many well-known economic models (GEM-E-3, EPPA, GTAP, MIRAGE, IFPRI), where we assume that capital stocks cannot adjust instantaneously, but need to adjust slowly over time based on accumulation of investments.

The first equilibrium in the sequence is given by the benchmark year 2006. In each time period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period. The equilibria are connected to each other through capital accumulation. In the benchmark case, we assume that the economy is on a steady-state growth path, where all the quantity variables grow at the same rate and all relative prices remain unchanged. The simulation horizon of the model has been set up until 2020 but it can easily be extended. In between periods, some other variables like the transfers between firms, government and the rest of the world, and the balance of payments balance (foreign savings) are updated exogenously.

Demand for capital is derived from the production function and investment in new capital is fixed in each year. The first equilibrium in the sequence is given by the benchmark year. Each time period in the model

corresponds to a certain year in the future. In each time period, the model is solved for an equilibrium given the exogenous conditions assumed for that particular period, the (standard) growth rate and depreciation. The economy is initially assumed to be in a ‘steady state’, with constant rates of growth and depreciation.

The standard equations for capital accumulation are given below. These equations are also known as the capital motion equation. The savings and investment market on country level clear in each time period. This means that investments in capital in each region are assigned from the total investments. We distinguish two types of investments, those from foreign origin (FDI) and of domestic origin (INV). The total capital of a sector is an accumulation of both foreign (KF) and domestic capital (KD).

$$KD_{i,r,t} = (1 - \partial_i) \cdot KD_{i,r,t-1} + INV_{i,r,t} \quad (1)$$

$$KF_{i,r,t} = (1 - \partial_i) \cdot KF_{i,r,t-1} + FDI_{i,r,t} \quad (2)$$

The basic formulation of the model requires that the total domestic and total foreign investments are consistently attributed to capital goods in each period. We follow the following general approach, where total domestic investments (DOMINV) and total international investments are split up, based on 2 sets of parameters: 2 share parameters on regional level ($nuReg$, $nuRegF$) and 2 share parameters on sector and regional level ($nuSec$, $nuSecF$).

$$INV_{i,r,t} = DOMINV_t \cdot \eta Re g_r \cdot \eta Sec_{r,i} \quad (3)$$

$$FDI_{i,r,t} = IROWT_t \cdot \eta Re g_r^F \cdot \eta SecF_{r,i} \quad (4)$$

The basic problem is now reduced to calculating the investment shares. We choose to apply a similar formulation for the dynamic part of the model, as used within the IFPRI model (Thurlow J., 2008). This is a simplification of the exponential share module used (for example) within the GEM-E-3 model and the MIRAGE model.

Investment shares on regional level are calculated as:

$$\eta Re g = \frac{\sum_i KD_{i,r,t}}{\sum_{i,rr} KD_{i,rr,t}} \cdot \left[1 + \beta_r \cdot \left(\frac{RGD_r}{RGDT} - \frac{RGD^0}{RGDT^0} \right) \right] \quad (5)$$

$$\eta Re g^F = \frac{\sum_i KF_{i,r,t}}{\sum_{i,rr} KF_{i,rr,t}} \cdot \left[1 + \beta_r \cdot \left(\frac{RGD_r}{RGDT} - \frac{RGD^0}{RGDT^0} \right) \right] \quad (6)$$

Investment shares on sector and regional level are calculated as:

$$\eta Sec_{i,r} = \frac{KD_{i,r,t}}{\sum_{ii} KD_{ii,rr,t}} \cdot \left[1 + \mu_i \cdot \left(\frac{RK_r}{RGD_r} \right) \right] \quad (7)$$

$$\eta SecF_{i,r} = \frac{KF_{i,r,t}}{\sum_{ii} KF_{ii,rr,t}} \cdot \left[1 + \mu_i \cdot \left(\frac{RK_r}{RGD_r} \right) \right] \quad (8)$$

The dynamic structure of SUSTRUS represented here has the required properties

- 1) Rate of return is calculated in a way respecting the economic theory of investment
- 2) Total investments on country level are assigned to each region consistently