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

Project 213091

D10.3
Final plan for using and disseminating knowledge

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1. The objective of the study

The objective of the study was to develop and implement for Russia an integrated spatial-economic-ecological modelling approach, which represents the state-of-the-art in different areas of economic, transport, resource-use and environmental modelling, and which can be used to assist policy makers in their choice of medium and long-term sustainability policies.

The main goal of the SUST-RUS modelling project was to provide the Russian and international community with a sound scientific support for formulating sustainability policies, which is characterized by a balanced integration of social, economic and environmental policy objectives. The application of the SUST-RUS approach is able to 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 at regional and federal levels. The SUST-RUS modelling approach represents the state-of-the-art in many different areas of knowledge and, is hence superior to other models available for Russia.

During the project all partners actively participated in dissemination of the information about the project, its progress and results. The adopted dissemination strategy was twofold. Firstly, it aimed at dissemination of the knowledge developed, such as the methodological advancements and the results of the assessment of sustainability policy packages. Secondly, it disseminated and exploited the developed modeling tool for policy evaluations. Specific attention was given to the transparency of the method in order to enable third parties to understand when and how the developed tools can be applied.

A plan for using and disseminating knowledge obtained during the project was developed during the first stage of the project. The plan was aimed at raising public participation and awareness. Special attention was given to the following target groups:

- Russian policy makers in the area of sustainability, economic development and trade
- Relevant research institutes and companies
- World-wide research community
- General public

The adopted dissemination strategy ensured that policy makers, dealing with sustainability assessments of the Russian and international sustainability policies, were aware of the SUST-RUS project results and do know how they can obtain the modeling tool and work with it.

The dissemination strategy and actions were based on the rich experience of the consortium participants in dissemination of the and involvement of stakeholders ('target groups' with government and society). From the start on, the project launched the website (www.sust-rus.org) to provide easy and direct access to the project documentation and results for a wide public. The project website is a gateway for public to the proceedings and findings of the Consortium. The SUST-RUS web site is also a platform for discussion and collection of feedbacks on the project activities and deliverables. The information and reports about project activities and events are presented on website in full details. The website will remain available after the completion project and efforts will be made to keep it further up to data and alive.

In addition to passive distribution (website) more generic channels were actively exploited.

2. An exploitation strategy

To enable an optimal match between the products made by SUST-RUS and the needs of potential users an exploitation strategy was developed. Potential stakeholders were identified and interviews were made to outline their needs and to ensure that SUST-RUS activities match them as well as possible. Specific attention was given to the transparency of the methods in order to enable third parties to understand when and how the developed assessment tool can be applied. The end-user interviews and presentations in the first half of the project were used to fine-tune the needs of potential users.

2.1 Academic and research community

2.1.1 Dissemination of the database through the SUT-RUS website

Generation of the balances set of the regional social accounting matrices is a valuable output for Russian and international research community. The ruling principle of the disclosure of data of the SUST-RUS project dramatically increases interest of different research groups to the SUST-RUS activities. Multiple requests for presentation of the dataset were met by the consortium partners. Availability of the benchmark dataset on the project's site enables researchers from other institutions to use results of the SUST-RUS team in their work. Excellent reviews of developed database were done by researchers from CASE (Poland) which benefited from the use of the SUST-RUS data.

2.1.2 Dissemination of the model's code through the SUT-RUS website.

There is a substantial interest in the SUST-RUS code. The code will be available on the site as soon as all documentation on the project will be finalized by the Commission. There are multiple requests from different research groups for the SUST-RUS code.

2.1.3 The final project conference

On December 15, the final project conference Energy efficiency and sustainability policies in Russia took place in Moscow. This conference summed up the three-year project effort and presented the policy implications and availability of the SUST-RUS assessment tool. The concept of the conference was to bring together an impressive audience of leading experts on sustainability policies and energy related issues to discuss the project results, the SUST-RUS model and its policy and academic implications. The main topics of discussion were:

- Developing a sustainability model for Russia
- The Economic and Environmental Implications of Russian Sustainability Policy
- SUST-RUS model: Regional, industrial and social aspects of energy strategy
- Scenarios of CO2 emissions in Russia up to 2030 and potential for reduction based on best available technologies

The conference program featured presentations from all consortium members as well as invited experts in economic modeling from the Environmental Defense Fund (Washington, DC, USA).

The audience of the SUST-RUS final conference included:

- Representatives of the Russian government and non-government organizations responsible for environmental, sustainable development and energy policies of the Russian Federation
- Representatives of the embassies of European countries

- Academic scholars and modeling experts from Moscow high schools and universities
- Regional policy makers
- Journalists

The detailed report in two languages (English and Russian) and presentations from the conference are downloaded into project website and easily accessible to general public.

2.2 Teaching facilities

Dissemination of knowledge via master's level educational courses:

- Russian partners of the consortium developed an "Introduction to the Applied General Equilibrium Models" course. Upon the completion of the project, examples from the SUST-RUS dataset, code, scenarios' evaluation would be introduced in the teaching materials. The list of academic institutions, where the course is already taught, includes:
- National Research University - Higher School of Economics, a master level course
- Moscow Institute of Economics, Russian Academy of Science (Laboratory of the Macroeconomics, led by Academician V.M. Polterovich)
- The Russian Presidential Academy of National Economy and Public Administration (ANE), a master level course
- Urals Federal University, a master level course

2.3 Federal policymakers

President Medvedev's administration.

There were several interviews and consultations with Assistant to the President of the Russian Federation Arkadii Dvorkovich. Mr Dvorkovich being in charge of Russian delegations to various meetings and conferences on climate was interested in SUST-RUS modeling results concerning increase in the energy efficiency of the Russian economy, possible effects of more strict international obligations on Russia's CO_2 emissions, consequences of the natural gas price increase for the domestic consumers, consequences of the Russian WTO accession. The results of SUST-RUS experiments were communicated to the office of Mr Dvorkovich, Ministry of Economy of the RF, Department of natural monopolies and natural resources.

2.4 Regional policymakers

It was essential to involve regional stakeholders into discussion of project findings. There is a clear need for a well-documented policy analysis tool at the regional level. This can be used for both propagating goals of sustainable development at the regional level and for assessing regional policy scenarios that are relevant for particular regional stakeholders.

2.4.1 Far East Economic Forum 2009, 2010

The participation in the Far Eastern Economic Forums was a great opportunity to share project methodology and results with the policy makers and scientific community of the Far East Region. Presentations related to the SUST-RUS model always enjoyed the same success, mostly due to a very limited analytical capacity in the regions of the Russian Federation.

During the Forum in August 2010 the representatives of Consortium had a meeting with Vice Governor of Primorskii krai in charge of economic development and discussed among other issues the needs of regional governance which might be met by SUST-RUS modeling tool. The issues of energy efficiency increase were identified as the one of the major concerns of the economic governance in the region.

2.4.2 Yekaterinburg Economic Forum 2010

The Urals Economic Forum is famous for its high level of participants, among which are high ranking decision makers and prominent experts from the scientific community from all over Russia and a number of foreign countries. Open session devoted to SUST-RUS model and preliminary results were held in April 2010 an important feedback from forum participants both academic and policy making ones was obtained by project researchers.

During the VII International Conference "Sustainable Growth of the Russian Regions: Innovations, Institutions and New Technologies", which took place in Ekaterinburg (Ural Region of the Russian Federation) on April 23-24, 2010, the SUST-RUS consortium organized the public seminar – open session "Sustainable growth of the regions: world experience and models for Russia". Project partners gave an overview of the SUST-RUS project, FP7 framework as the source of the SUST-RUS funding; main objectives of the project, participants, project time-frame. The general framework of the SUST-RUS project was presented: types of relevant models, potential dimensions, etc.

The audience of the SUST-RUS open session included:

- students and researchers of the Urals region [Urals is one of the most industrialized regions of the Russian Federation, the major center of Russian iron and steel production];
- representatives of the Urals Energy Ministry and The Union of Industrialists and Entrepreneurs.

2.4.3 Roundtable with policymakers

Another roundtable was organized at the end of the project – a business breakfast aimed at the top-level decision makers and CEOs of major energy companies in Russia (December 2011, Moscow).

The business breakfast agenda was focused on policy implications and availability of the SUST-RUS tool for the assessment of industrial gas price rise, gas extraction tax increase, as well as shifts in energy-saving investments. The aim was to make the results of the project clear to the policy makers, to present the SUST-RUS model as a working tool/instrument for the assessment of the sustainable development policy measures. In order to achieve this, the calculations of a few economic development scenarios after the accession of Russia into WTO (a very hot topic at the moment, right on the day when WTO approved Russian accession). Some government officials had expressed their interest in the SUST-RUS modeling tool.

The presentations from the roundtable are available from the SUST-RUS website.

2.5 Commercial companies

BP Russia – consultations with chief economist.

The corporate sector in Russia does not often consult with the scientific community. However, BP corporation is always very interested in new research ideas, so this was the case with the SUST-RUS model. Representatives of economic office of BP always participated in dissemination activities of SUST-RUS project.

Ernst&Young Russia – consultations with researchers and partners.

Ernst&Young researchers and partners expressed their interest in general equilibrium assessment of the Russian WTO accession, which is one of the scopes of the SUST-RUS implementations. Ernst&Young representatives were especially interested in evaluation of region specific consequences of the WTO accession. The SUST-RUS model could generate sound estimates of different WTO accession scenarios, examining the scope and direction of possible regional changes.

Sberbank

Sberbank was appointed by Russian Government to be in charge of state wide CO2 reduction program. Experts of Sberbank expressed their interest in new research on effects of different climate policy options available for Russia for which SUST-RUS model is the best instrument.

2.6 Russian and world-wide research community

The International Conference on Economic Modeling (EcoMod) is a major international forum for researches and policy-makers in the field of economic modeling applied to today's most challenging issues. EcoMod-2011 brought together more than 100 selected participants from many countries and most continents. The papers presented at the conference covered all areas of applied modeling for economics, public and private finance and decision making in the government and business world. This was the best opportunity to share project results with the international community of economical modeling experts.

The SUST-RUS consortium participated in the EcoMod-2011 with the open session "Assessment of Sustainability Polices for Russia". This seminar provided an excellent opportunity to share an overall vision of the project, the innovative component of the SUST-RUS project (namely coherent work on different dimensions of sustainability) as well as technical details concerning its implementation. In particular the following issues were discussed.

In particular the following issues were discussed:

- SUST-RUS database: Regional social accounting matrix for Russia
- SUST-RUS model: a CGE model on regional level for sustainability policies in Russia
- the economic and environmental implications of Russian sustainability policy

2.7 Media

The results of the project – a unique spatial-economic-ecological model for the Russian Federation and its possible applications – were of great interest to Russian modeling experts and journalists, who were mostly interested in the analysis of the WTO-accession implications for Russia. The aim of the press-conference was to raise attention to the policy assessment tool SUST-RUS and it resulted in a number of publications in the prominent Russian news agencies – Interfax, Vedomosti, Gazeta.ru etc. The outcomes of the project were also mentioned in the articles published in the FREE Policy Briefs (an extensive network of leading academic experts on economic issues in Central and Eastern Europe and the former Soviet Union) internet project (http://freepolicybriefs.org/2011/12/22/russia-and-the-wto/). All these publications are also available at the SUST-RUS website.

3. Dissemination plans

3.1 Plan for using and disseminating the knowledge

The SUST-RUS project plan for using and disseminating the knowledge provides a complete picture of all activities undertaken during our three years project. *Table 1* below summarizes the milestones and deliverables of the project and *Table 2* provides information on our conference participation.

Table 1: Milestones and deliverables

Name and number	WP	Dates	Comments
D0.1 Project presentation	WP0	June 2009	Project presentation was aimed on dissemination of knowledge about SUST-RUS objectives and planned deliverables. The project presentation is published on the SUST-RUS website.
D1.1 Overview of the relevant literature	WP1	June 2009	Overview of the best practices of construction and use of spatial-economic-environmental models with the focus on Russian experience of construction and use of economic models that could be referred to the same class as SUST-RUS model.
D1.2 Description of the modelling methodology	WP1	September 2009	The methodology is outlined on the basis of the best international and Russian practices of development of a spatial-economic-environmental modelling tools for assessment of sustainable development policies. The methodology outlined takes into account special features and availability of Russian data.
D2.1 Description of the constructed database, data quality and data collection methods	WP2	March 2010	Detailed description of the constructed database, data quality and data collection methods.
D2.2 The spatial - economic-environmental database for the model	WP2	March 2010	A SUST-RUS model database on this stage consisted of seven regional social accounting matrices. Each region represented in the database corresponds to the federal district of the Russian Federation. Balanced set of regional social accounting matrices constitutes the core of the SUST-RUS model dataset.

ES1. An academic seminar *Yekaterinburg Economic Forum 2010*	WP10	April 2010	An academic seminar on development of the model structure: discussion of the modelling techniques implemented in the SUST-RUS, given the availability of data, discussion of WP3 and WP4 results
D3 Description of the general structure of the spatial-economic-ecological model for Russia	WP3	June 2010	This report documents the SUST-RUS methodology in concrete mathematical formulas, the model code, the database of model parameters, which cannot be calibrated from the SUST-RUS model database built in WP2.
D4 Description of a set of the sustainability indicators coupled with the constructed model	WP4	June 2010	This report documents the current European and international state of the art of economic, social and environmental indicators; the methodology for policy assessment is defined upon the set of social, economic and environmental indicators, developed in the WP4.
D5 Description of the environmental, international and social part of the model	WP5	April 2011	This report describes the WP5, WP6 and WP7 workouts: the development of the environmental, international and social parts of the spatial model of Russia.
ES2. An academic seminar on finalizing developments of international, social and environmental modules *EcoMod-2011 conference*	WP10	July 2011	This public seminar (an open session during the international EcoMod conference) was held in order to share findings and discuss strategies of linking international, social and environmental modules. This seminar provided an excellent opportunity to share an overall vision of the project as well as technical details concerning implementation of WP5, WP6 and WP7.
D8 Description of the links between the three dimensions of sustainability within the model	WP8	June 2011	This report contains a description of the links between the three dimensions of sustainability within SUST-RUS modelling framework.
D9.1 Assessment of the model reliability and sensitivity analysis	WP9	December 2011	This report focuses on assessment of the model reliability and sensitivity analysis. This report assesses systematic sensitivity analysis that evaluates the model outcomes by variations of the most important parameters (e.g. substitution elasticities).
ES3. Final conference with presentation of project results *Final SUST-RUS*	WP10	15 December 2011	The final conference was divided into two parts: a rather policy oriented business breakfast and an academic conference. The conference hosted a roundtable with Russian policymakers, representatives of energy companies, NGOs and general public on dissemination of project

conference in Moscow			results. A detailed report about the conference and all presentations are published on the SUST-RUS website in an open access.
D9.2. The spatial-economic-ecological model for Russia coupled with the consistent database	WP9	December 2011	The spatial-economic-ecological model for Russia coupled with the consistent database is the results of the SUST-RUS project. The integrated spatial-economic-ecological modelling approach, which represents the state-of-the-art in different areas of economic, transport, resource-use and environmental modelling, and can be used to assist policy makers in their choice of medium and long-term sustainability policies.
D10.1 SUST-RUS Website	WP10	start date – February 2009	Working from the first days of the project, the project website is a gateway for public to the proceedings and findings of the Consortium. The project web site is not only a means of informing public, but a stage for discussion and feedback on the project activities and deliverables.

Table 2: SUST-RUS participation in conferences

Date	Type	Title/Name	Type of audience	Countries addressed	Size of audience
17.09.09	VI International Expert Forum on Regional Development Strategies Vladivostok, Russia	Strategic Planning on interregional, regional and local levels	Scientific community; regional policy makers	Far East of the Russian Federation	50-70
23.04.10	VII International Conference on Growth and Regional Development Ekaterinburg, Russia	Sustainable Growth of the Russian Regions: Innovations, Institutes and New Technologies	Scientific community; regional policy makers	Regions of the Russian Federation	150-200
26.05.10	International WIOD (World Input-Output Database) Conference Vienna, Austira	Industry-Level Analysis of Globalization and its Consequences	Academic scholars, participants of the WIOD project, international experts in the field of input-output analysis	IO data is collected for the EU countries, BRIC countries, Korea and others	30-50
28.06-02.07.10	International Forum Voronezh, Russia	Days of European science in Central Russia	Experts and representatives from European countries and Central Russia	European countries and Central Region of the Russian Federation	50-70
02.11.10	The scientific seminar at the Nansen International Environmental and	Environmental and economic challenges in a changing climate	Scientific community; regional policy makers	Russian Federation and its regions	20-30

	Remote Sensing Center Saint Petersburg, Russia				
29.06.11-01.07.11	International Conference on applied modeling in economics Azores, Portugal	EcoMod-2011	Economists conducting quantitative analysis for policy and decision-making in the public and private sector	Many countries of the world	20-30
30.08.11-03.09.11	ERSA conference 2011 Barcelona, Spain	ERSA	Scientific community	Mainly European countries	20-30
26.09.11-01.10.11	International Scientific Workshop named after academician Stanislav Shatalin Svetlogorsk, Kaliningrad region, Russia	The system simulation of socio-economic processes	Scientific community: experts, economic scholars	Russian Federation and its regions	50-70
12.10.11	The final conference of the EXIOPOL project Luxembourg	A new environmental accounting framework using externality data and input-output tools for policy analysis	Scientific community: experts, economic scholars	Mainly European participants and international scholars	20-30
15.12.11	Business Breakfast (roundtable) with the policy makers of the Russian Federation Moscow, Russia	Energy efficiency and sustainability policies in Russia	This business breakfast was aimed at the top-level decision makers and CEOs of major energy companies in Russia	Russian Federation and its regions	20
15.12.11	The final project conference for NGOs and general public Moscow, Russia	Energy efficiency and sustainability policies in Russia	scientific community; regional policy makers	Russian Federation and its regions	40-50
20.01.2012	Workshop in the Russian Presidential Academy of National Economy and Public Administration Moscow, Russia	The Structure of the economical module of the SUST-RUS model; regional social accounting matrix.	scientific community: experts, economic scholars	Russian Federation and its regions	15-20

3.2 Future plans

Furthermore, the partners actively promote the use of the tools in further studies. As all of them have a track record in successful transfer of the tools from the research stage to the use phase, they continue to use their capacities and skills to valorize the SUST-RUS. These new initiatives would be accompanied by applying for suitable support.

Papers are also submitted to the International Energy Workshop (IEW) at the University of Cape Town, South Africa (June 19–21, 2012), 19th Annual Conference of the European Association of Environmental and Resource Economics in Prague, Czech Republic (June 27-30, 2012) and 2012 Berlin Conference on Evidence for Sustainable Development in Berlin (October 5-6, 2012).

3.2.1 Follow-up research projects, using results of the SUST-RUS

The SUST-RUS team will continue to improve the model and to work on spin-off activities. There are at least two projects that have already started and many more to come:

- Refinement of the system of social accounting matrices – a joint project between CEFIR and SOPS, supported by HSE's laboratory of spatial economics (SPB). The SUST-RUS experts from CEFIR will participate in newly founded Spatial Economics laboratory situated in Saint-Petersburg. The essence of the proposed project is to investigate peculiar features of the Russian interregional trade that were discussed in the D2.1 Description on the SUST-RUS database.
- Development of soft link between RU-TIMES and SUST-RUS – a joint project between CEFIR and the Russian Presidential Academy of National Economy and Public Administration (ANE). The ANE team is working on the regionalization of the TIMES model. They successfully implemented the RU-TIMES model for several major Russian industries. Since the RU-TIMES model is a partial equilibrium model, soft link between SUST-RUS and RU-TIMES will enrich our knowledge on producers' behavioral response to CO2 restriction in Russia. The connection between these two models would be very important in terms of meeting the demand from policy makers. An increase in energy efficiency under various policy scenarios will be studied carefully with the "soft link" between these two models.

4. Model manual

4.1 Setting up the model for simulations

The integrated model was developed to handle a large variety of policy issues for sustainability impact analysis and can be set up according to the best fitting assumptions. From the start of the model development it was decided to give the modeler a large freedom in adapting the model to his or her needs. Also the SUST-RUS model allows running the model several times, with different assumptions on closure, capital accumulation and government behavior.

This is shown in Table 1, which resumes the main closure options of the model. The modeler has to make a choice in each column to obtain a functioning model for a specific analysis. Each assumption has its advantages and disadvantages and should be chosen in accordance with theoretical considerations.

Table 3: Overview of model closures[1]

International closure	Government	Households/labor market	Investment/Capital market
Current Account balance	**Budget balance**	**Labour supply**	**Investment balance**
Flexible exchange rate	Flexible savings	Fixed labor supply in each region	Fixed investment demand
Flexible foreign savings	Flexible consumption	Fixed price of labor	Fixed capital
Exchange rate as numeraire	Flexible foreign debt	Unemployment according to wage curve	Simulation with capital accumulation
	Redistribution via transfers/lump-sum taxes		
	Tax incentives		

The basic set-up of the model as underlined in the *Table3* is the following:

- **International closure:** Flexible foreign savings
- **Government:** Flexible public savings
- **Households/Labor market:** Unemployment modeling via wage curve
- **Investment/Capital market:** Capital accumulation

Besides the choice of closures, the modeler can (de)activate a set of extra modules. This can be done to avoid overloading the model with elements that are not specific for the type of simulation performed.

Some of the elements in *Table 4* are activated by default in the SUST-RUS model. These are: the extended Armington functions (International module), the abatement curves for pollutants (Environmental module), trade and transport margins on interregional trade (Economic module), Impact of emissions on health and expenditures (Social module).

Table 4: Overview of extra modules

International module	Environmental module	Social module	Economic module
Extended Armington-function for imports and exports to EU & ROW countries	Emissions trading	Impact of emissions on health and expenditures on health services	Monopolistic competition module
Extension of monopolistic competition to foreign firms	Abatement curves for NOx, SOx and PM	Migration between regions / International migration[2]	Trade and transport margins on interregional trade

[1] Underlined items are referring to the default set-up of the model.

[2] A preliminary model code to handle migration (both interregional and international) is introduced in the recursive framework, but have been only applied in a few test cases. Optimally, they would be based on econometric research.

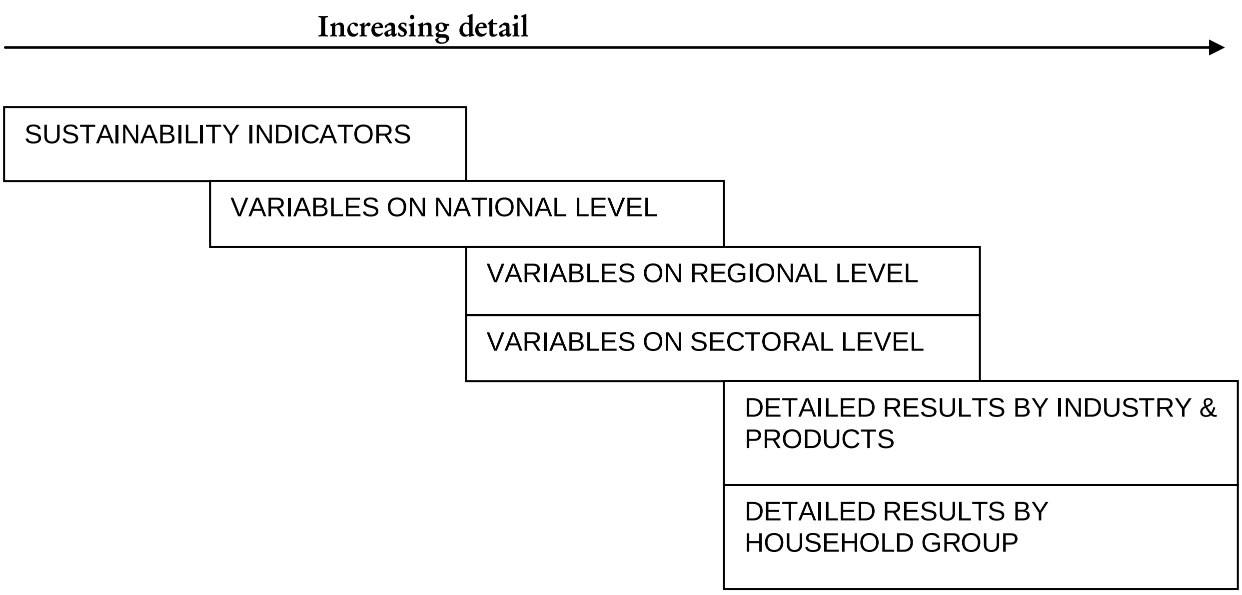
4.2 Running the model

Introducing a new scenario

When doing a new simulation one should perform the following steps:

1) **Obtain information:** on the type of simulation, the background and goal of the policy. In the case of fiscal policy/taxation one should try to get information on the height of the tax, compensating mechanisms and revenue recycling.
2) **Check the model:** Which parameters/variables does the policy affect? Is it necessary to introduce new features? Which type of model set-up is necessary for this type of analysis? Do we need to use the optional modules? Is a static model run enough or do we need a dynamic-recursive run? Is the data detail sufficient for the intended analysis?
3) **Implement the policy:** Create a new scenario file, which contains all the necessary parameter changes and calculations to be performed within the model run.
4) **Run the model:** ...and if it doesn't work, check what is wrong (reiterate step2)
5) **Check the model results:** Use the scheme developed in *Figure 1*. First check the sustainability indicators, then aggregated results at regional and national levels. Then proceed to relevance check how individual sectors and households react to the policy change in each region. If the results are in line with theoretical considerations (expectations), then go to step 6. Otherwise go back to step 2.
6) **Do sensitivity analysis:** Are the model results robust? What happens if we make changes to the model structure or if we change something to the exogenous parameters? Or make changes to the set-up of the policy? Repeat step 5 and in the worst case, go back to step 2.
7) **Report results:** consistent with the model results and the analysis performed.

Figure 1: Analyzing SUST-RUS results



5. Attachment: Technical Description of the SUST-RUS model

5.1 Overview of model parameters

Table 5: SUST-RUS 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 6: 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 7: 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 8: 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
$EEU_{ii,i,r}$	exports to EU
$EROW_{ii,i,r}$	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 derivates 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 goverment
$SUBSG_{gov}$	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 9: 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 subsitutiton 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 subsitutiton 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 subsitutiton 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 subsitutiton 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
$\gamma A4_{i,r}$	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

5.2 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), Bchir 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 10: 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 11: Proposed Armington elastticities 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

5.3 Model formulation

5.3.1 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).

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

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:

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

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.

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

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)

$$U_{th,r} = \prod_i \left(C_{th,i} - \mu_{th,i}\right)^{\alpha} \qquad (4)$$

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.

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

(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 ($\alpha_{i,r}$)

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

5.3.2 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.

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

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 (σis here the elasticity of substitution between land and the capital-labour bundle and αis a scaling parameter).

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

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 (σhere is the elasticity of substitution between capital and labour).

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

(11)

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

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

(12)

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

5.3.3 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.

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

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 three 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.

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

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

5.3.4 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.

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

5.3.5 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:

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

Where $elas\mathrm{Re}\,g_{i,r}$ 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:

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

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

$$AUXV_{i,r} = (NF_{i,r})^{\frac{1}{1-elas\mathrm{Re}\,g_{i,r}}} \qquad (24)$$

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.

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

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.

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

5.3.6 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.

$$TAXRG_{gov} = \sum_r \begin{bmatrix} PL_r \cdot L_{i,r} \cdot (tl_i \cdot tl\_gov_{r,gov}) + tk_i \cdot tk\_gov_{r,gov} \cdot K_{i,r} \cdot RK + txd_i \cdot txd\_gov_{r,gov} \cdot XD_{i,r} \cdot TFP \cdot PD_{i,r} \\ \left(+ \sum_i (tc_i \cdot tc\_gov_{r,gov}) P_{i,r} \cdot (\sum_{th} C_{th,i,r} + I_{i,r} + CG_{i,r}) \right) \\ + Y_{th,r} \cdot ty_{th} \cdot ty\_gov_{r,gov} \end{bmatrix} \tag{27}$$

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 exogeneously fixed parameters trep (wage replacement rate).

$$UNEMPB_{r,gov} = \left(UNEMP_r \cdot trep_r \cdot PW_r\right) indic\_UNEMPB_{gov} \tag{28}$$

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.

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

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

$$TRFGG_{gov,govv} = aTRFGE_{gov,govv} \cdot TRFGE_{gov} \tag{30}$$

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

$$TRFGY_{govv} = \sum_{gov} TRFGG_{gov,govv} \tag{31}$$

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).

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

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.

$$CGR_{r,gov} = \alpha G_{r,gov} \cdot CBUD\_GOV_{gov} \tag{33}$$

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):

$$P_{i,r} \cdot (1+tcg_i) \cdot CGG_{i,r,gov} = aG_{i,r,gov} \cdot CGR_{r,gov} \tag{34}$$

5.3.7 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.

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

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

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:

$$PMROW_i = PWMROW_i^0 \cdot ER \tag{37}$$

$$PMEU25_i = PWMEU25_i^0 \cdot ER \tag{38}$$

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)

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

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

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

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

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.

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

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

$$XDDE_{i,rr,r} = XDD_{i,r} \cdot \left(\frac{\gamma A4_{i,r}}{PDD_{i,rr} + PTM \cdot trmV_{rr,r,i}} \right)^{\sigma A1_{i,r}} \cdot PDDT_{i,r}^{\ \sigma A1_{i,r}} \cdot aA1_{i,r}^{\ \sigma A1_{i,r}-1} \tag{43}$$

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.

$$PTM = \sum_{i}\sum_{r}\left(atm_{i,r} \cdot P_{i,r}\right) \tag{44}$$

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.

$$XXD_{i,r} = XD_{i,r} \cdot \left(\frac{\gamma T3_{i,r}}{PDD_{i,r}}\right) \cdot \left(PD_{i,r}\right)^{\partial A_{i,r}} \cdot \left(T_{i,r}\right)^{\partial A_{i,r}-1} \tag{45}$$

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.

$$XXD_{i,r} = \sum_{rr} XDDE_{i,r,rr} \tag{46}$$

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.

$$TMX_{i,r} = \mathrm{atm}_{i,r} \sum_{i,rr,rrr} trm_{i,rr,rrr} \cdot XDDE_{i,rr,rrr} \tag{47}$$

5.3.8 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:

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

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:

$$IT = S + IEU + IROW - SEU \cdot ER - SROW \cdot ER - \sum_{i}\sum_{r}\left(SV_{i,r} \cdot P_{i,r}\right) \tag{49}$$

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:

$$I_{i,r} \cdot P_{i,r} \cdot \left(1 + ti_{i,r}\right) = \left(\alpha_{i,r}\right) IT \tag{50}$$

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

$$RGD_{r} = \frac{\sum_{i}\left(RK_{i,r} \cdot K_{i,r}\right)}{\sum_{i} K_{i,r}} \tag{51}$$

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:

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

5.3.9 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.

$$\sum_i L_i = LS_r - UNEMP_r \tag{53}$$

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.

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

5.3.10 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.

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

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

$$\begin{aligned} P_{i,r} \cdot X_{i,r} &= PDDT_{i,r} \cdot XDD_{i,r} + PMEU25_i \cdot (1 + tm_{i,r}) \cdot MEU25 \\ &+ PMROW_i \cdot (1 + tm_{i,r}) \cdot MROW_{i,r} \end{aligned} \tag{56}$$

5.3.11 Calculation of GDP and the Walras law

Regional real GDP (*GDPR*) 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:

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

(57)

Regional nominal GDP (*GDPCR*) 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:

$$GDPR_r = \sum_i (XD_{ir} \cdot PD_{i,r}) - \sum_{ii,i} (IO_{ii,i,r} \cdot P_{ii,r})$$
$$- \sum_i (ENER_{i,r} \cdot \sum_{ii} P_{ii,r}) + \sum_i (tc_{i,c} - sc_{i,c}) \cdot P_{i,r} \cdot C_{th,i,r}$$
$$+ \sum_i t_{i,r} \cdot I_{i,r} P_{i,r} + \sum_i tcg_{i,r} \cdot CG_{i,r} P_{i,r} + \sum_i tcg_{i,r} \cdot CGR_{i,r} P_{i,r}$$

(58)

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

$$GDP_c = \sum_r GDPR_r$$

(59)

$$GDPC_c = \sum_r GDPCR_r$$

(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.

$$GDPDEF = \frac{\sum_c GDPC_c}{\sum_c GDP_c}$$

(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:

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

(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.

5.3.12 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 εuse determines the share energetic use (combustion activity) of the energy input by sector, $\varepsilon conv$ translates monetary inputs to (Giga)Joules and $\varepsilon coeff$ 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.

$$EMSECF_{emis,ii,i,r} = IOE_{ii,i,r} \cdot \varepsilon use_{ii,i,r} \cdot \varepsilon conv_{ii,i,r} \cdot \varepsilon coeff_{ii,i,r} \tag{63}$$

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.

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

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).

$$\sum_{r} DEMANDETS_{r} = \sum_{r} SUPPLYETS_{r} \ \text{ if } r \in ETS \tag{65}$$

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

$$DEMANDETS_{r} = \sum_{i \in ETS} EMSEC_{i,r} \tag{66}$$

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

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

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:

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

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.

$$TAXENV_{emis,i,r} = PPSEC_{emis,i,r} + emisTax_{emis,i,r} = MACC_{emis,i,r} \tag{69}$$

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

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

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.).

$$IOABAT_{ii,i,r} \cdot P_{ii,r} \cdot (1 + txc_{ii,i,r}) = \sum_{emis} COSTABAT_{emis,i,r} \cdot coeffabatcost_{emis,ii} \qquad (71)$$

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.

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

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

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

5.4 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 constrains. 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

5.5 Recursive dynamics

The recursive dynamics of the SUST-RUS 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 hearth 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 SUST-RUS, 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 SUST-RUS with the dynamic structure offered by a full DCGE model. In the SUST-RUS 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 equilibriums 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*).

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

$$FDI_{i,r,t} = IROWT_t \cdot \eta \mathrm{Re}\, gF_r \cdot \eta SecF_{r,i} \quad (4)$$

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:

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

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

Investment shares on sector and regional level are calculated as:

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

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

The dynamic structure of SUST-RUS 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