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

Project 213091

D5:
Description of the environmental, international and social parts of the SUST-RUS model

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Authors	Victoria Alexeeva-Talebi, ZEW Christophe Heyndrickx, TML Natalia Tourdyeva, CEFIR
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1. The SUST-RUS project

The objective of the SUST-RUS project is to develop and implement for Russia an integrated spatio-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.

The SUST-RUS model among others allows to tackle the following issues: rational use of available natural resources and land; differences in the economic development of Russian regions; efficient use of labour; environmental impacts of transportation, production and consumption activities distributed in space; analysis of inequality and poverty in the country; influence of international trade and delocalisation of economic activities of the EU upon the Russian economic development.

The present document describes the data, modelling choices and structure of the environmental, social and international modules of the SUST-RUS model. It connects our choices to the state-of-the-art in literature and explains how the model can be tested. The document ends with some exemplary simulations, focusing on the structure of the different modules.

2. The environmental module

The mathematical formulation of the environmental module of the SUST-RUS model follows the general methodology of the GEM-E-3 and PACE modelling framework. The environmental module of SUST-RUS concentrates on energy related emissions such as CO_2, NOx, SO_2, VOC and particulates, which are the main source of air pollution.

In principle, environmental module allows simulating two instruments for controlling pollution: taxation and tradable permits. The two instruments are based in the theory of Pigouvian taxes (Pigou 1920) where a charge per unit of emissions equal to the total value of the damage caused by an extra unit of emission is levied. Emitters are expected to pay the true social costs by the application of this charge.

In the system of marketable permits, the regulatory authority allocates permits which are tenable for a defined period and tradable. Permit price will be determined in the market resulting from permit supply and demand equilibrium. As in the case of emission tax, permit price represents damage costs and give emitters financial incentives to respond by reducing emissions.

2.1 Emissions

2.1.1 Data source for energy and emissions module

The data on emissions with the required level of specification for our model were largely missing. Therefore it was necessary to calculate the emissions from energy consumption data applying emission factors for each particular energy source and industry. The main data sources for the model are the 11TER energy database of ROSSTAT, as well as other ROSSTAT publications, data from National Reports for IPCC, and State Reports of the Ministry of Natural Resources of the RF. We also use the IEA/IIASA emissions database. Other data on emissions for the Russian Federation, such as those calculated by ROSSTAT, were used for comparison only.

In the beginning of the project it was attempted to use both the IIASA and ROSSTAT data on emissions, without the data on energy use. However, this idea was soon abandoned as the specifications of both databases are too different. Table 1 summarizes the attempt to match the 2 databases. It can be seen in

Table 1 that the total emissions for the particular pollutants still matches to some degree, but the sectoral disaggregation fails in all but a few cases.

The reason for this is that the databases on emissions from IIASA and ROSSTAT differ in 3 important aspects:

1. **Regional coverage**: IIASA only covers the European part of the Russian Federation, while ROSSTAT reports emissions on the level of Federal regions
2. **Industry coverage**: IIASA covers a different set of sectors than ROSSTAT, which cannot be easily matched
3. **Emissions coverage**: ROSSTAT data only covers static sources from non-CO2 sources, which means that transport is only partially accounted for

Table 1: Non-CO2 emissions from IIASA GAINS-Europe model and ROSSTAT matched to the SUST-RUS sectors for 2006[1]

	GAINS DATA					ROSSTAT DATA (European part)			
	SOx	**NOx**	**PM10**	**NMVOC**		**SOx**	**NOx**	**PM10**	**NMVOC**
Mining sectors	0	0	40	397.5		72.03	50.16	99.39	338.16
Basic metals	0	0	119.9			0	0		
Manufacturing No basic metals	576.4	240.9	49			846.63	240.55	339.37	353.07
Manufacturing Total				555					
Energy	897	649.2	284.5	0		445.24	433.76	301.50	15.94
Transport	457.20	2462.8	60	1269.4		140.30	1721.18	131.71	2067.07
Total	**1930.6**	**3352.9**	**553.4**	**2221.9**		**1504.2**	**2445.649**	**872**	**2774.2**

Therefore, it was extremely important for the progress in the model development, to gain access to data on energy consumption with a sufficient detail on the regional and sectoral level. In Russia, ROSSTAT is responsible for the collection of very detailed industry related data. The industry-level questionnaire, known as the 11TER form provides energy consumption at the four-digit ISIC level. This data was eventually coupled to the SUST-RUS model. The energy consumption in the raw data is in million tonnes of coal equivalent, so it was expressed in million tonnes of oil equivalent (Mtoe) for model use. Energy consumption data was used for CO2 emissions estimation on industry level.

In addition, we use data on total regional emissions by type of pollutant (Table 2) and data on total emissions of pollutants by industry and by type of pollutant from industrial stationary and mobile sources (Table 3) published in the State Report of the Ministry of Natural Resources of the Russian Federation in 2006. These data is essential for estimation of emissions of NOx, SO2, VOC and PM10 on industry and regional level.

[1] Emission data in this tables matches fuel use in the regional social accounting matrices, thus there are discrepancies from Russian official emission statistics reported by ROSSTAT. All data manipulations are documented in the model code.

Table 2. Regional Emissions by type of the Pollutant in 2006 (Source: State Report 2006, Ministry of Natural Resources, RF)

	units	Russian Federation	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
Total automobile emissions	tousand tons	15 154,9	4 027,9	1 423,8	2 291,6	3 094,6	1 423,8	2 182,3	710,8
Total emissions from stationary sources	tousand tons	20 580,1	1 570,3	2 301,9	886,7	3 067,1	6 320,9	5 582,8	850,4
PM10	tousand tons	2 842,8	232,7	290,4	90,4	229,5	878,5	811,7	309,8
liquid and gas emissions	tousand tons	17 737,3	1 337,6	2 011,5	796,3	2 837,7	5 442,4	4 771,2	540,6
of which:									
SO2	tousand tons	4 764,7	214,5	590,2	140,8	508,4	579,3	2 536,3	195,3
CO	tousand tons	6 338,3	583,0	685,0	265,5	885,3	2 653,9	1 051,4	214,2
NOx	tousand tons	1 703,1	267,9	170,5	122,1	289,2	413,8	339,8	99,8
CnHm	tousand tons	2 826,6	125,6	409,3	173,2	589,4	868,7	651,4	9,0
VOC	tousand tons	1 863,1	108,9	134,4	81,9	518,5	873,6	134,2	11,7
Captured and neutralized	%	74,8	76,4	72,9	74,1	65,0	70,9	79,6	83,7
Water used	mln m3	79 273,4	13 237,2	12 336,5	25 851,9	11 032,2	4 830,3	9 896,4	2 089,0
Fresh water used	mln m3	62 153,0	10 622,5	11 641,2	15 379,6	10 124,8	3 964,3	8 684,5	1 736,1
Volume of recycled water	mln m3	142 596,5	39 020,3	10 846,9	6 379,5	31 354,0	32 127,2	16 919,8	5 948,9
Fresh water conservation	%	79,2	86,2	51,8	60,4	81,6	93,5	72,4	84,2
Surface impoundment, total	mln m3	51 387,4	9 129,0	11 648,0	9 238,5	8 606,2	3 305,5	7 913,0	1 547,2
of which:									
polluted wastewater	mln m3	17 488,8	4 185,6	3 091,7	2 006,0	3 140,1	1 725,9	2 497,6	841,9
clean wastewater	mln m3	31 800,0	4 491,0	8 406,0	7 063,9	5 013,1	1 380,9	4 806,5	638,6
recovered wastewater	mln m3	2 098,7	452,5	150,4	168,6	453,0	198,7	608,9	66,7

Table 3. Total emissions of pollutants by industry and by type of pollutant from industrial stationary and mobile sources (thousand tonnes, State Report of the Ministry of Natural Resources of the RF)

NACE code	Name of the activity	Emissions, total	Total emissions colsists of:		Liquid and gas emissions consist of:				
			PM10	liquid and gas emissions	SO2	CO	Nox	CnHm	VOC
A	Agriculture, hunting and forestry	129,3	38,6	90,7	7,2	44,5	8,9	7,5	3,4
01	Agriculture, hunting and related service activities	103,2	29,9	73,3	6,2	29,4	8,0	7,4	3,2
02	Forestry, logging and related service activities	26,1	8,7	17,4	1,1	15,1	0,9	0,1	0,2
C	Mining and quarrying	6 027,1	470,1	5 557,0	207,6	2 761,0	128,6	1 389,5	1 055,5
10	Mining of coal and lignite; extraction of peat	904,0	60,6	843,4	13,5	39,2	12,5	776,2	1,0
11	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying	4 585,9	264,5	4 321,4	83,0	2 486,0	80,2	611,5	49,1
CB	Mining and quarrying, except of energy producing materials	517,8	138,1	379,7	101,6	235,0	34,0	1,9	5,2
13	Mining of metal ores	433,6	86,4	347,2	91,1	223,7	25,3	1,4	4,1
14	Other mining and quarrying	84,2	51,7	32,5	10,5	11,3	8,7	0,5	1,1
D	Manufacturing	7 167,9	804,3	6 363,6	2 997,3	2 277,6	376,3	92,6	500,9
DE	Manufacture of pulp, paper and paper products; publishing and printing	84,2	17,0	67,2	3,9	54,1	5,4	0,1	3,1
21	Manufacture of pulp, paper and paper products	161,4	46,5	114,8	47,0	39,1	22,8	0,3	4,2
DF	Manufacture of coke, refined petroleum products and nuclear fuel	764,4	15,7	748,7	117,6	135,8	30,7	65,4	328,4
DG	Manufacture of chemicals, chemical products and man-made fibres	368,9	40,4	328,5	44,1	124,7	40,5	16,0	76,7
DI	Manufacture of other non-metallic mineral products	497,6	215,8	281,8	20,3	144,6	82,2	1,4	8,7
27	Manufacture of basic metals	4 756,3	363,0	4 393,3	2 639,6	1 570,8	130,7	2,4	10,6
DK	Manufacture of machinery and equipment n.e.c.	102,6	22,8	79,8	10,5	41,6	14,8	0,6	9,9
E	Electricity, gas and water supply	4 352,9	1 273,2	3 079,7	1 426,7	580,5	962,7	30,7	7,9
40	Electricity, gas, steam and hot water supply	4 303,4	1 265,3	3 038,1	1 420,1	564,9	959,3	16,7	7,0
41	Collection, purification and distribution of water	49,5	7,9	41,6	6,6	15,7	3,4	14,0	0,8
I	Transport, storage and communication	2 334,2	222,4	2 111,8	86,7	439,2	183,1	1 258,3	123,0
60.1	Transport via railways	157,6	45,4	112,2	35,6	48,0	13,2	1,3	-
60.2	Other land transport	105,6	7,7	97,9	10,4	69,7	4,3	13,5	
60.30.1	Oil and oil products transportation via pipelines	108,1	0,3	107,8	1,8	2,7	0,9	2,0	100,3
60.30.2	Natural gas and gas products transportation via pipelines	1 741,4	1,1	1 740,3	0,5	309,3	159,0	1 241,5	22,7
	Auxilary activities of the road construction	221,5	167,9	53,6	38,4	9,5	5,7	0,0	-
K	Real estate, renting and business activities	*390,2*	-	-	-	-	-	-	-
O	Other community, social and personal service activities	59,1	7,0	52,1	3,4	9,7	1,6	33,1	3,4
90	Sewage and refuse disposal, sanitation and similar activities	55,0	5,8	49,2	2,8	8,0	1,4	33,1	3,3
	Total emissions from stationary sources	***20 460,7***	***2 815,6***	***17 254,9***	***4 728,9***	***6 112,5***	***1 661,2***	***2 811,7***	***1 694,1***
	Total emissions from mobile sources (Transport and communication)	***15 823,4***	***69,3***	***15 754,1***	***131,0***	***11 513,5***	***2 303,1***	***1 804,5***	***2,0***
	Emissions by diesel locomitives	210,6	8,4	202,2	-	40,0	143,2	19,0	-
	Emissions by cars	15 154,8	53,9	15 100,9	119,8	11 202,2	2 055,1	1 723,8	-
	Emissions by heavy road construciton machinery	458,0	7,0	451,0	11,2	271,4	104,8	61,7	2,0

To derive emissions at the regional level, we used a large set of emission factors. These are fixed coefficients which transform the combustion of energy to CO_2, NOx, SO_2, PM10 and VOC emissions.

Some industry specific emission factors could be found, however no information was available to derive emission factors at the regional (federal) level. Hence, we assume that emission factors are uniform across the regions, though they differ at the sector level for different types of fossil fuels. The main source of data for the emission factors was the IEA/GAINS database.

2.1.2 Emission factors

CO_2 emission coefficients

CO2 emissions are calculated according to IPCC methodology, described in IEA publication "CO2 Emissions From Fuel Combustion", 2007 edition. This methodology implies use of carbon emission factors (CEF). CEF values used are presented in Table 4below.

Table 4. Carbon Emission Factors used in CO2 emissions estimation

CARBON EMISSION FACTORS (CEF), Source: CO2 EMISSIONS FROM FUEL COMBUSTION: BEYOND 2020 DOCUMENTATION, 2007 edition			
Fuel	Carbon Emission	Fuel	Carbon Emission
LIQUID FOSSIL		**SOLID FOSSIL**	
Primary fuels		*Primary Fuels*	
Crude oil	20.0	Anthracite	26.8
Orimulsion	22.0	Coking Coal	25.8
Natural Gas Liquids	17.2	Other Bituminous Coal	25.8
Secondary fuels/products		Sub-Bituminous Coal	26.2
Gasoline	18.9	Lignite	27.6
Jet Kerosene	19.5	Oil Shale	29.1
Other Kerosene	19.6	Peat	28.9
Shale Oil	20.0	*Secondary Fuels/Products*	
Residual Fuel Oil	21.1	BKB & Patent Fuel	(25.8) (a)
LPG	17.2	Coke Oven / Gas Coke	29.5
Ethane	16.8	Coke Oven Gas	13.0 (b)
Naphtha	(20.0) (a)	Blast Furnace Gas	66.0 (b)
Bitumen	22.0	**GASEOUS FOSSIL**	
Lubricants	(20.0) (a)	Natural Gas (Dry)	15.3
Petroleum Coke	27.5	**BIOMASS c**	
Refinery Feedstocks	(20.0) (a)	Solid Biomass	29.9
Refinery Gas	18.2 (b)	Liquid Biomass	(20.0) (a)
Other Oil	(20.0) (a)	Gas Biomass	(30.6) (a)

Notes to Table 4

(a) This value is a default value until a fuel specific CEF is determined. For gas biomass, the CEF is based on the assumption that 50% of the carbon in the biomass is converted to methane and 50% is emitted as CO2. The CO2 emissions from biogas should not be included in national inventories. If biogas is released and not combusted 50% of the carbon content should be included as methane.

(b) For use in the sectoral calculations.

(c) Emissions from the use of biomass for fuel are not shown in this publication.

NOx, SO_2, PM10 and VOC emission coefficients

The distribution of emissions of SOx, NOx, PM10 and VOC by fuel type was made on the basis of coefficients derived from the GAINS Europe model (IIASA, 2012,http://gains.iiasa.ac.at/gains/EUR/index.login) which provides sector- and technology specific data for the European part of Russia. We rely on data specified for the scenario BL for GAINS MEC; Nov2008, for the year 2005. The *unabated* emission factors were reported in kt $SO_2/10^{15}$ Jules, kt $NOx/10^{15}$ Jules, kt $VOC/10^{15}$ Jules, t $PM10/10^{15}$ Jules, respectively.

We used a concordance table between the UNFCCC CRF and the NACE to assign sectors used in the GAINS Europe model to the sectoral coverage of the Sust-Rus model (Figure 1). Table 5 and Table 6 contain the emissions factors used in the SUST-RUS model for NOx, SO2, VOC and PM10.

Figure 1: Concordance table between the UNFCCC CRF and the NACE

Table 2: Concordance between the UNFCCC CRF and the NACE

CRF	Description	NACE	Description
1	Energy		
1A	Fuel combustion		
1A1	Energy industries		
1A1a	Public electricity and heat production	40-41	Fuel, power, water
1A1b	Petroleum refining	23,36-37	Other manufacturing
1A1c	Manufacture of solid fuels and other energy industries	23,36-37	Other manufacturing
1A2	Manufacturing industries and construction		
1A2a	Iron and steel	27	Metal production
1A2b	Non-ferrous metals	27	Metal production
1A2c	Chemicals	24	Chemical production
1A2d	Paper and print	21-22	Pulp, paper and print production
1A2e	Food processing, beverages and tobacco	15-16	Food, beverage, tobacco
1A2f	Other manufacturing	17-20,25-26,28-35	Emissions allocated on the basis of fuel use
1A3	Transport		
1A3a	Civil aviation	60-63	Transport
1A3b	Road transportation	60-63	Transport
1A3c	Railways	60-63	Transport
1A3d	Navigation	60-63	Transport
1A3e	Other transportation	60-63	Transport
1B	Fugitive emissions from fuels	10-14	Coal, peat, petroleum, metal ores, quarrying
	International bunkers		Not attributed
2	Industrial processes		
2A	Mineral products	26	Other non-metallic mineral products
2B	Chemical industry	24	Chemicals, chemical products and man-made fibres
2F	Consumption of halocarbons and SF_6	31	Electrical machinery and apparatus nec
3	Solvent and other product use	24	Chemicals, chemical products and man-made fibres
4	Agriculture	1,2,5	Agriculture, forestry, fishing
5	Land-use, land use change, and forestry		Not attributed
6	Waste	90	Sewage and refuse disposal services, sanitation and similar services

Source:http://unfccc.int/

Table 5: Unabated emission factors SO2 (kt SO2/1015 J) Source: IIASA GAINS-Europe model estimations, own calculations

Sectors		coal	gas	oil
sec1	Agriculture, hunting and forestry	0,000	0,000	0,000
sec2	Fishing	0,000	0,000	0,000
sec3	Coal	0,000	0,000	0,000
sec4	Gas	0,000	0,000	0,000
sec5	Oil	0,000	0,000	0,000
sec6	Mining and quarrying, except of energy producing materials	0,000	0,000	0,000
sec7	Manufacture of food products, beverages and tobacco	0,440	0,004	0,747
sec8	Manufacture of textiles and textile products	0,440	0,004	0,747
sec9	Manufacture of leather and leather products	0,440	0,004	0,747
sec10	Manufacture of wood and wood products	0,440	0,004	0,747
sec11	Manufacture of pulp, paper and paper products; publishing and print	0,440	0,004	0,747
sec12	Manufacture of coke, refined petroleum products and nuclear fuel	0,626	0,004	0,795
sec13	Manufacture of chemicals, chemical products and man-made fibres	0,000	0,000	0,000
sec14	Manufacture of rubber and plastic products	0,440	0,004	0,747
sec15	Manufacture of other non-metallic mineral products	0,440	0,004	0,747
sec16	Manufacture of basic metals and fabricated metal products	0,440	0,004	0,747
sec17	Manufacture of machinery and equipment n.e.c.	0,440	0,004	0,747
sec18	Manufacture of electrical and optical equipment	0,440	0,004	0,747
sec19	Manufacture of transport equipment	0,440	0,004	0,747
sec20	Manufacturing n.e.c.	0,000	0,000	0,000
sec21	Electricity, gas and water supply distribution	0,661	0,004	0,806
sec22	Electricity, gas and water supply generation	0,661	0,004	0,806
sec23	Construction	0,000	0,000	0,000
sec24	Wholesale and retail trade;	0,000	0,000	0,000
sec25	Hotels and restaurants	0,000	0,000	0,000
sec26	Transport and communication	0,000	0,000	0,000
sec27	Transport	0,000	0,013	0,130
sec28	Financial intermediation	0,000	0,000	0,000
sec29	Public administration and defense	0,000	0,000	0,000
sec30	Real estate, renting and business activities	0,000	0,000	0,000
sec31	Education	0,000	0,000	0,000
sec32	Health and social work	0,000	0,000	0,000

Table 6: Unabated emission factors NOx (kt NOx/10^{15} J) Source: IIASA GAINS-Europe model estimations, own calculations

Sectors		coal	gas	oil
sec1	Agriculture, hunting and forestry	0,000	0,000	0,000
sec2	Fishing	0,000	0,000	0,000
sec3	Coal	0,000	0,000	0,000
sec4	Gas	0,000	0,000	0,000
sec5	Oil	0,000	0,000	0,000
sec6	Mining and quarrying, except of energy producing materials	0,000	0,000	0,000
sec7	Manufacture of food products, beverages and tobacco	0,229	0,070	0,139
sec8	Manufacture of textiles and textile products	0,229	0,070	0,139
sec9	Manufacture of leather and leather products	0,229	0,070	0,139
sec10	Manufacture of wood and wood products	0,229	0,070	0,139
sec11	Manufacture of pulp, paper and paper products; publishing and print	0,229	0,070	0,139
sec12	Manufacture of coke, refined petroleum products and nuclear fuel	0,229	0,070	0,164
sec13	Manufacture of chemicals, chemical products and man-made fibres	0,000	0,000	0,000
sec14	Manufacture of rubber and plastic products	0,229	0,070	0,139
sec15	Manufacture of other non-metallic mineral products	0,229	0,070	0,139
sec16	Manufacture of basic metals and fabricated metal products	0,229	0,070	0,139
sec17	Manufacture of machinery and equipment n.e.c.	0,229	0,070	0,139
sec18	Manufacture of electrical and optical equipment	0,229	0,070	0,139
sec19	Manufacture of transport equipment	0,229	0,070	0,139
sec20	Manufacturing n.e.c.	0,000	0,000	0,000
sec21	Electricity, gas and water supply distribution	0,247	0,105	0,150
sec22	Electricity, gas and water supply generation	0,247	0,105	0,150
sec23	Construction	0,000	0,000	0,000
sec24	Wholesale and retail trade;	0,000	0,000	0,000
sec25	Hotels and restaurants	0,000	0,000	0,000
sec26	Transport and communication	0,000	0,000	0,000
sec27	Transport	0,000	0,868	0,291
sec28	Financial intermediation	0,000	0,000	0,000
sec29	Public administration and defense	0,000	0,000	0,000
sec30	Real estate, renting and business activities	0,000	0,000	0,000
sec31	Education	0,000	0,000	0,000
sec32	Health and social work	0,000	0,000	0,000

The level of sectoral disaggregation used in the GAINS-Europe model is relatively low in comparison to the SUST-RUS coverage. In particular with respect to NOx emissions, there exists a variation in factors between electricity generation and distribution on the one hand, and the rest of industrial production, if any, on the other hand. For the former (sec21 and sec22), emission factors reported are 0,247 kt NOx/10^{15} J for coal, 0,105 kt NOx/10^{15} J for gas and 0,150 kt NOx/10^{15} J for oil. For the remaining industrial branches, the NOx emission factors are slightly below these values. For most of non-energy intensive industries, however, the emissions factors are not reported in the GAINS-Europe model and are assumed to be zero in the SUST-RUS model (Table 6). For SO2, we observe a slightly higher variation of emission factors. In particular, emission factors (different than zero) are reported for (i) electricity generation and distribution, (ii) manufacturing of coke, (iii) transport sector and (iv) other industries (i.e. paper and pulp production).

Table 7: Unabated emission factors PM10 ($t/10^{15}$ J) Source: IIASA GAINS-Europe model estimations, own calculations

Sectors		coal	gas	oil
sec1	Agriculture, hunting and forestry	0,000	0,000	0,000
sec2	Fishing	0,000	0,000	0,000
sec3	Coal	0,000	0,000	0,000
sec4	Gas	0,000	0,000	0,000
sec5	Oil	0,000	0,000	0,000
sec6	Mining and quarrying, except of energy producing materials	0,000	0,000	0,000
sec7	Manufacture of food products, beverages and tobacco	898,206	0,100	10,279
sec8	Manufacture of textiles and textile products	898,206	0,100	10,279
sec9	Manufacture of leather and leather products	898,206	0,100	10,279
sec10	Manufacture of wood and wood products	898,206	0,100	10,279
sec11	Manufacture of pulp, paper and paper products; publishing and print	898,206	0,100	10,279
sec12	Manufacture of coke, refined petroleum products and nuclear fuel	1890,195	0,100	14,843
sec13	Manufacture of chemicals, chemical products and man-made fibres	0,000	0,000	0,000
sec14	Manufacture of rubber and plastic products	898,206	0,100	10,279
sec15	Manufacture of other non-metallic mineral products	898,206	0,100	10,279
sec16	Manufacture of basic metals and fabricated metal products	898,206	0,100	10,279
sec17	Manufacture of machinery and equipment n.e.c.	898,206	0,100	10,279
sec18	Manufacture of electrical and optical equipment	898,206	0,100	10,279
sec19	Manufacture of transport equipment	898,206	0,100	10,279
sec20	Manufacturing n.e.c.	0,000	0,000	0,000
sec21	Electricity, gas and water supply distribution	2665,095	0,100	12,512
sec22	Electricity, gas and water supply generation	2665,095	0,100	12,512
sec23	Construction	0,000	0,000	0,000
sec24	Wholesale and retail trade;	0,000	0,000	0,000
sec25	Hotels and restaurants	0,000	0,000	0,000
sec26	Transport and communication	0,000	0,000	0,000
sec27	Transport	0,000	30,377	65,409
sec28	Financial intermediation	0,000	0,000	0,000
sec29	Public administration and defense	0,000	0,000	0,000
sec30	Real estate, renting and business activities	0,000	0,000	0,000
sec31	Education	0,000	0,000	0,000
sec32	Health and social work	0,000	0,000	0,000

Unabated emission factors for PM10 reported in Table 7 (measured in $t/10^{15}$ J) measured to a considerable degree for different types of fossil fuel. The emissions of PM10 are mainly related to the electricity generation and refineries. They are the highest for coal consumption in electricity generation and distribution sector (2665,1 $t/10^{15}$ J). Again, the data provided for PM10 emissions are fragmentary as they cover only the energy-intensive part of an economy. Finally, Table 8 reports unabated emission factors VOC ($t/10^{15}$ J) at the sectoral level. As indicated previously, emission factors are assumed to be equal across federal districts.

Table 8: Unabated emission factors VOC (kt/10^{15} J) Source: IIASA GAINS-Europe model estimations, own calculations

Sectors		coal	gas	oil
sec1	Agriculture, hunting and forestry	0,000	0,000	0,000
sec2	Fishing	0,000	0,000	0,000
sec3	Coal	0,000	0,000	0,000
sec4	Gas	0,000	0,000	0,000
sec5	Oil	0,000	0,000	0,023
sec6	Mining and quarrying, except of energy producing materials	0,000	0,000	0,000
sec7	Manufacture of food products, beverages and tobacco	0,006	0,002	0,005
sec8	Manufacture of textiles and textile products	0,006	0,002	0,005
sec9	Manufacture of leather and leather products	0,006	0,002	0,005
sec10	Manufacture of wood and wood products	0,006	0,002	0,005
sec11	Manufacture of pulp, paper and paper products; publishing and print	0,006	0,002	0,005
sec12	Manufacture of coke, refined petroleum products and nuclear fuel	0,015	0,003	0,005
sec13	Manufacture of chemicals, chemical products and man-made fibres	0,000	0,000	0,000
sec14	Manufacture of rubber and plastic products	0,006	0,002	0,005
sec15	Manufacture of other non-metallic mineral products	0,006	0,002	0,005
sec16	Manufacture of basic metals and fabricated metal products	0,006	0,002	0,005
sec17	Manufacture of machinery and equipment n.e.c.	0,006	0,002	0,005
sec18	Manufacture of electrical and optical equipment	0,006	0,002	0,005
sec19	Manufacture of transport equipment	0,006	0,002	0,005
sec20	Manufacturing n.e.c.	0,000	0,000	0,000
sec21	Electricity, gas and water supply distribution	0,006	0,001	0,004
sec22	Electricity, gas and water supply generation	0,006	0,001	0,004
sec23	Construction	0,000	0,000	0,000
sec24	Wholesale and retail trade;	0,000	0,000	0,000
sec25	Hotels and restaurants	0,000	0,000	0,000
sec26	Transport and communication	0,000	0,000	0,000
sec27	Transport	0,000	0,679	0,514
sec28	Financial intermediation	0,000	0,000	0,000
sec29	Public administration and defense	0,000	0,000	0,000
sec30	Real estate, renting and business activities	0,000	0,000	0,000
sec31	Education	0,000	0,000	0,000
sec32	Health and social work	0,000	0,000	0,000

Given the lack of data for the Russian Federation, we do not account for pollutants' transportation across federal districts. NOx, SO2, VOC and PM10 emissions are transboundary in nature. In theory, the concentration and deposition of pollutants in a certain geographical area depends not only on emission levels in this area but also on meteorological conditions and some other factors. In a modelling environment this is approximated by transport/deposition coefficients which were, however, not available for Russia at the level of federal districts. Source-receptor calculations with the Unified (UN-ECE) EMEP model could not be applied due to the high level of regional disaggregation. Finally, in this version of the model, we do not account for the secondary pollutant tropospheric ozone.

2.1.3 Emissions by sector and by region

CO_2 emission by sector, by region and by fuel

We use WIOD methodology[2] for estimation of total fuel used for combustion purposes by industry. Applying IPCC methodology for estimation of CO2 emissions given fuel use, we get figures on total CO2 emissions by each industry in Russia. Total industry emissions are distributed by regions according to shares of regional production. SUST-RUS regional production data is presented in Table 9.

Regional CO2 emissions by fuel type and by industry are presented in Table 10 - Table 13 below.

[2] WIOD Deliverable D4.1 "Technical Report On the Conceptual Framework For The WIOD Environment Satellite Accounts", part 4.1 "Energy use and energy-related air emissions".

Table 9. Regional production in the SUST-RUS model's database, 2006 mln RUB

sust-rus sectors		Russia	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	1 817 038,16	391 041,93	102 417,18	390 598,10	463 020,00	139 297,05	265 355,83	65 308,05
sec2	B	184 923,64	39 790,53	10 421,48	39 745,37	47 114,67	14 174,19	27 001,32	6 676,07
sec3	CA_col	314 534,46	10 184,22	15 054,87	5 777,60	60 728,45	188 969,53	25 789,60	8 030,17
sec4	CA_gas	511 413,71	16 559,60	24 479,30	9 394,41	98 744,77	307 265,42	41 934,03	13 036,18
sec5	CA_oil	2 326 656,10	75 341,34	111 373,65	42 741,82	449 259,86	1 397 967,84	190 787,56	59 184,03
sec6	CB	511 797,54	93 513,64	67 957,05	8 432,32	39 438,58	57 805,98	70 308,81	174 341,16
sec7	DA	2 469 901,89	936 171,91	426 557,56	295 611,17	380 994,83	114 035,23	243 550,27	72 980,92
sec8	DB	278 136,84	156 059,67	26 146,47	25 132,81	48 039,27	8 640,22	11 496,94	2 621,47
sec9	DC	69 617,47	40 570,00	4 361,89	5 380,40	10 893,07	4 397,74	2 997,77	1 016,59
sec10	DD	199 113,73	53 298,60	60 573,88	5 024,14	27 654,71	15 955,26	31 099,53	5 507,62
sec11	DE	534 389,22	230 604,79	148 396,39	20 374,74	71 604,62	12 297,63	46 119,67	4 991,39
sec12	DF	1 485 604,09	505 835,28	65 865,82	91 257,43	377 107,81	242 822,52	191 821,52	10 893,72
sec13	DG	822 731,08	231 151,59	87 835,48	52 139,39	334 892,25	27 827,10	85 737,86	3 147,42
sec14	DH	343 350,66	128 717,14	21 133,10	20 010,95	119 485,52	19 346,63	31 474,50	3 182,82
sec15	DI	512 415,34	206 199,39	57 967,19	50 558,12	83 343,50	63 634,53	40 129,49	10 583,12
sec16	DJ	2 771 443,78	463 679,73	345 945,33	139 529,57	328 617,62	824 444,14	649 326,02	19 901,38
sec17	DK	2 016 053,22	686 452,24	89 384,31	123 842,43	511 760,48	329 526,37	260 314,61	14 772,79
sec18	DL	108 218,54	45 127,74	18 256,42	3 752,24	23 103,83	8 522,48	8 572,18	883,66
sec19	DM	836 177,00	166 835,84	91 078,54	40 644,84	432 093,35	47 859,33	43 381,68	14 283,40
sec20	DN	425 264,83	165 149,70	55 469,00	20 285,46	86 774,30	64 964,58	22 963,36	9 658,43
sec21	E_distr	633 063,32	200 699,20	61 597,86	49 161,19	122 751,91	80 236,41	83 105,38	35 511,37
sec22	E_ely	1 571 279,18	498 165,07	152 894,99	122 025,34	304 688,38	199 158,63	206 279,84	88 066,93
sec23	F	2 878 716,60	866 894,89	442 100,79	286 658,66	431 008,87	375 138,65	264 175,81	212 738,93
sec24	G	7 493 860,36	4 201 673,22	525 226,68	430 547,12	682 317,31	1 010 835,19	445 762,16	197 498,67
sec25	H	321 232,44	124 787,49	30 019,33	36 072,73	41 040,37	47 866,83	28 268,12	13 177,56
sec26	I_cmn	546 438,99	160 864,86	64 010,87	49 707,52	78 774,21	93 932,58	67 365,89	31 783,06
sec27	I_trn	3 677 699,51	1 082 766,67	430 851,33	334 576,76	530 222,02	632 251,60	453 433,67	213 597,46
sec28	J	1 242 872,90	955 645,68	43 991,71	16 473,84	49 023,49	143 912,50	23 220,45	10 605,24
sec29	LO	3 331 744,60	1 168 739,56	388 028,26	322 982,50	446 797,03	371 298,62	399 134,39	234 764,24
sec30	K	3 946 195,50	1 868 715,80	340 021,00	208 041,95	461 789,92	647 567,33	285 240,01	134 819,50
sec31	M	1 058 232,12	286 930,83	123 901,75	106 494,65	176 909,72	138 781,22	154 975,58	70 238,37
sec32	N	1 032 399,84	297 327,79	140 415,41	110 423,66	166 745,28	164 156,87	153 266,82	64,00

Table 10. Russian regional CO2 emissions from gas combustion (thousand tonnes)

sust-rus sectors		Total tonnes of CO2 from combustion GAS	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	8 374,41	1 802,24	472,02	1 800,20	2 133,98	642,00	1 222,98	300,99
sec2	B	25,02	5,38	1,41	5,38	6,37	1,92	3,65	0,90
sec3	CA_col	31,36	1,02	1,50	0,58	6,05	18,84	2,57	0,80
sec4	CA_gas	34 244,00	1 108,82	1 639,12	629,04	6 611,90	20 574,34	2 807,88	872,90
sec5	CA_oil	4 243,67	137,42	203,14	77,96	819,42	2 549,80	347,98	107,95
sec6	CB	15 320,97	2 799,39	2 034,34	252,43	1 180,62	1 730,46	2 104,74	5 219,01
sec7	DA	1 981,48	751,04	342,21	237,15	305,65	91,48	195,39	58,55
sec8	DB	183,89	103,18	17,29	16,62	31,76	5,71	7,60	1,73
sec9	DC	1 873,26	1 091,65	117,37	144,78	293,11	118,33	80,66	27,35
sec10	DD	8 575,95	2 295,60	2 608,96	216,39	1 191,11	687,20	1 339,48	237,22
sec11	DE	93,60	40,39	25,99	3,57	12,54	2,15	8,08	0,87
sec12	DF	6 666,93	2 270,03	295,59	409,54	1 692,34	1 089,71	860,84	48,89
sec13	DG	18 990,73	5 335,57	2 027,47	1 203,51	7 730,16	642,32	1 979,05	72,65
sec14	DH	1 407,87	527,79	86,65	82,05	489,94	79,33	129,06	13,05
sec15	DI	34 122,66	13 731,19	3 860,14	3 366,76	5 549,99	4 237,54	2 672,29	704,75
sec16	DJ	59 498,88	9 954,53	7 426,94	2 995,50	7 054,94	17 699,62	13 940,09	427,25
sec17	DK	5 833,25	1 986,18	258,62	358,33	1 480,73	953,45	753,20	42,74
sec18	DL	4 066,10	1 695,59	685,95	140,98	868,08	320,22	322,08	33,20
sec19	DM	6 299,18	1 256,83	686,12	306,19	3 255,09	360,54	326,81	107,60
sec20	DN	783,71	304,35	102,22	37,38	159,91	119,72	42,32	17,80
sec21	E_distr	1 380,35	437,61	134,31	107,19	267,65	174,95	181,20	77,43
sec22	E_ely	465 393,41	147 550,32	45 285,60	36 142,39	90 244,92	58 988,32	61 097,53	26 084,33
sec23	F	2 372,24	714,38	364,32	236,22	355,18	309,14	217,70	175,31
sec24	G	958,13	537,20	67,15	55,05	87,24	129,24	56,99	25,25
sec25	H	195,75	76,04	18,29	21,98	25,01	29,17	17,23	8,03
sec26	I_cmn	107 766,78	31 725,20	12 624,00	9 803,14	15 535,57	18 525,05	13 285,66	6 268,14
sec27	I_trn	136,97	40,32	16,05	12,46	19,75	23,55	16,89	7,95
sec31	M	617,92	475,12	21,87	8,19	24,37	71,55	11,54	5,27
sec32	N	1 126,45	395,15	131,19	109,20	151,06	125,53	134,95	79,37
sec29	LO	910,52	431,17	78,45	48,00	106,55	149,41	65,81	31,11
	other	15 158,18	4 110,01	1 774,78	1 525,44	2 534,06	1 987,91	2 219,88	1 006,10
	TOTAL	**808 633,60**	**233 690,72**	**83 409,06**	**60 353,59**	**150 225,08**	**132 438,51**	**106 452,13**	**42 064,52**

Table 11. Russian regional CO2 emissions from refined oil products combustion (thousand tonnes)

sust-rus sectors		Total tonnes of CO2 from refined oil products combustion	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	1 078,63	232,13	60,80	231,87	274,86	82,69	157,52	38,77
sec2	B	22,35	4,81	1,26	4,80	5,70	1,71	3,26	0,81
sec3	CA_col	174,46	5,65	8,35	3,20	33,68	104,81	14,30	4,45
sec4	CA_gas	1 434,94	46,46	68,68	26,36	277,06	862,14	117,66	36,58
sec5	CA_oil	2 184,86	70,75	104,59	40,14	421,88	1 312,77	179,16	55,58
sec6	CB	2 163,24	395,26	287,24	35,64	166,70	244,33	297,18	736,90
sec7	DA	139,21	52,76	24,04	16,66	21,47	6,43	13,73	4,11
sec8	DB	64,51	36,20	6,06	5,83	11,14	2,00	2,67	0,61
sec9	DC	2 345,88	1 367,08	146,98	181,30	367,06	148,19	101,02	34,26
sec10	DD	9 119,53	2 441,11	2 774,32	230,11	1 266,60	730,76	1 424,38	252,25
sec11	DE	2 500,50	1 079,04	694,37	95,34	335,05	57,54	215,80	23,36
sec12	DF	33 632,16	11 451,46	1 491,12	2 065,95	8 537,23	5 497,19	4 342,59	246,62
sec13	DG	7 249,74	2 036,86	773,99	459,44	2 951,00	245,21	755,50	27,73
sec14	DH	35,02	13,13	2,16	2,04	12,19	1,97	3,21	0,32
sec15	DI	923,17	371,49	104,43	91,09	150,15	114,64	72,30	19,07
sec16	DJ	34 085,82	5 702,77	4 254,76	1 716,07	4 041,65	10 139,79	7 986,02	244,77
sec17	DK	782,15	266,32	34,68	48,05	198,54	127,84	100,99	5,73
sec18	DL	348,16	145,19	58,73	12,07	74,33	27,42	27,58	2,84
sec19	DM	797,57	159,13	86,87	38,77	412,14	45,65	41,38	13,62
sec20	DN	206,75	80,29	26,97	9,86	42,19	31,58	11,16	4,70
sec21	E_distr	414,91	131,54	40,37	32,22	80,45	52,59	54,47	23,27
sec22	E_ely	27 647,53	8 765,49	2 690,27	2 147,10	5 361,16	3 504,31	3 629,61	1 549,59
sec23	F	668,85	201,42	102,72	66,60	100,14	87,16	61,38	49,43
sec24	G	575,36	322,60	40,33	33,06	52,39	77,61	34,22	15,16
sec25	H	62,54	24,30	5,84	7,02	7,99	9,32	5,50	2,57
sec26	I_cmn	4 483,90	1 320,01	525,25	407,88	646,40	770,78	552,78	260,80
sec27	I_trn	16,75	4,93	1,96	1,52	2,42	2,88	2,07	0,97
sec31	M	35,99	27,68	1,27	0,48	1,42	4,17	0,67	0,31
sec32	N	147,97	51,91	17,23	14,34	19,84	16,49	17,73	10,43
sec29	LO	88,64	41,97	7,64	4,67	10,37	14,55	6,41	3,03
	other	2 389,25	647,83	279,74	240,44	399,42	313,34	349,90	158,58
	TOTAL	**135 820,36**	**37 497,54**	**14 723,04**	**8 269,93**	**26 282,63**	**24 637,86**	**20 582,15**	**3 827,21**

Table 12. Russian regional CO2 emissions from oil combustion (thousand tonnes)

sust-rus sectors		Total tonnes of CO2 from oil combustion	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	39,69	8,54	2,24	8,53	10,11	3,04	5,80	1,43
sec2	B	1,29	0,28	0,07	0,28	0,33	0,10	0,19	0,05
sec3	CA_col	0,16	0,01	0,01	0,00	0,03	0,09	0,01	0,00
sec4	CA_gas	915,04	29,63	43,80	16,81	176,68	549,77	75,03	23,32
sec5	CA_oil	-	-	-	-	-	-	-	-
sec6	CB	21,49	3,93	2,85	0,35	1,66	2,43	2,95	7,32
sec7	DA	0,14	0,05	0,02	0,02	0,02	0,01	0,01	0,00
sec8	DB	-	-	-	-	-	-	-	-
sec9	DC	-	-	-	-	-	-	-	-
sec10	DD	-	-	-	-	-	-	-	-
sec11	DE	-	-	-	-	-	-	-	-
sec12	DF	28,96	9,86	1,28	1,78	7,35	4,73	3,74	0,21
sec13	DG	-	-	-	-	-	-	-	-
sec14	DH	-	-	-	-	-	-	-	-
sec15	DI	3,64	1,47	0,41	0,36	0,59	0,45	0,29	0,08
sec16	DJ	1,38	0,23	0,17	0,07	0,16	0,41	0,32	0,01
sec17	DK	8,60	2,93	0,38	0,53	2,18	1,41	1,11	0,06
sec18	DL	100,98	42,11	17,04	3,50	21,56	7,95	8,00	0,82
sec19	DM	3,47	0,69	0,38	0,17	1,79	0,20	0,18	0,06
sec20	DN	1,27	0,49	0,17	0,06	0,26	0,19	0,07	0,03
sec21	E_distr	9,29	2,95	0,90	0,72	1,80	1,18	1,22	0,52
sec22	E_ely	876,28	277,82	85,27	68,05	169,92	111,07	115,04	49,11
sec23	F	63,88	19,24	9,81	6,36	9,56	8,33	5,86	4,72
sec24	G	14,87	8,34	1,04	0,85	1,35	2,01	0,88	0,39
sec25	H	-	-	-	-	-	-	-	-
sec26	I_cmn	270,28	79,57	31,66	24,59	38,96	46,46	33,32	15,72
sec27	I_trn	-	-	-	-	-	-	-	-
sec31	M	7,80	5,99	0,28	0,10	0,31	0,90	0,15	0,07
sec32	N	0,28	0,10	0,03	0,03	0,04	0,03	0,03	0,02
sec29	LO	1,50	0,71	0,13	0,08	0,18	0,25	0,11	0,05
	other	268,86	72,90	31,48	27,06	44,95	35,26	39,37	17,85
	TOTAL	**2 639,15**	**567,82**	**229,43**	**160,30**	**489,80**	**776,27**	**293,69**	**121,85**

Table 13. Russian regional CO2 emissions from coal combustion (thousand tonnes)

sust-rus sectors		Total tonnes of CO2 from coal combustion	FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	4 368,58	940,16	246,23	939,09	1 113,21	334,90	637,98	157,02
sec2	B	85,60	18,42	4,82	18,40	21,81	6,56	12,50	3,09
sec3	CA_col	4 231,59	137,01	202,54	77,73	817,01	2 542,30	346,96	108,03
sec4	CA_gas	11,25	0,36	0,54	0,21	2,17	6,76	0,92	0,29
sec5	CA_oil	2 534,58	82,07	121,33	46,56	489,41	1 522,90	207,84	64,47
sec6	CB	2 405,26	439,48	319,37	39,63	185,35	271,67	330,43	819,34
sec7	DA	194,02	73,54	33,51	23,22	29,93	8,96	19,13	5,73
sec8	DB	38,00	21,32	3,57	3,43	6,56	1,18	1,57	0,36
sec9	DC	1 154,72	672,92	72,35	89,24	180,68	72,94	49,72	16,86
sec10	DD	3 276,49	877,05	996,77	82,67	455,07	262,55	511,75	90,63
sec11	DE	1,82	0,78	0,50	0,07	0,24	0,04	0,16	0,02
sec12	DF	0,75	0,25	0,03	0,05	0,19	0,12	0,10	0,01
sec13	DG	1 041,19	292,53	111,16	65,98	423,82	35,22	108,50	3,98
sec14	DH	17,24	6,46	1,06	1,00	6,00	0,97	1,58	0,16
sec15	DI	2 970,48	1 195,34	336,04	293,09	483,14	368,89	232,63	61,35
sec16	DJ	79 246,42	13 258,42	9 891,93	3 989,70	9 396,46	23 574,08	18 566,77	569,06
sec17	DK	1 741,19	592,86	77,20	106,96	441,99	284,60	224,82	12,76
sec18	DL	350,46	146,14	59,12	12,15	74,82	27,60	27,76	2,86
sec19	DM	615,96	122,90	67,09	29,94	318,30	35,26	31,96	10,52
sec20	DN	239,82	93,13	31,28	11,44	48,93	36,64	12,95	5,45
sec21	E_distr	921,05	292,00	89,62	71,53	178,59	116,74	120,91	51,67
sec22	E_ely	204 689,27	64 895,56	19 917,51	15 896,14	39 691,51	25 944,23	26 871,91	11 472,41
sec23	F	869,34	261,79	133,51	86,57	130,16	113,29	79,78	64,25
sec24	G	834,30	467,78	58,47	47,93	75,96	112,54	49,63	21,99
sec25	H	35,39	13,75	3,31	3,97	4,52	5,27	3,11	1,45
sec26	I_cmn	4 978,13	1 465,50	583,15	452,84	717,64	855,74	613,71	289,55
sec27	I_trn	259,38	76,36	30,39	23,60	37,39	44,59	31,98	15,06
sec31	M	671,01	515,94	23,75	8,89	26,47	77,70	12,54	5,73
sec32	N	988,72	346,83	115,15	95,85	132,59	110,19	118,45	69,67
sec29	LO	663,18	314,05	57,14	34,96	77,61	108,83	47,94	22,66
	other	10 216,33	2 770,07	1 196,17	1 028,11	1 707,91	1 339,81	1 496,16	678,09
	TOTAL	**329 651,54**	**90 390,81**	**34 784,61**	**23 580,96**	**57 275,46**	**58 223,06**	**50 772,14**	**14 624,50**

NOx, SO_2, PM10, VOC and CnHm emissions

Regional emissions of NOx, SO2, VOC and PM10 are estimated on the basis of the State Report of the Ministry of Natural Resources for 2006 (Table 3). This report contains data on emissions for the whole country by NACE industry and type of pollutant.

Distribution of emissions for each type of the pollutant in each region by industry type was made proportionally to regional production recorded in the SUST-RUS database (Table 9).

We use RAS procedure for distribution of emissions at regional level. The resulting regional emissions by type of the pollutant are presented below (see Table 14-Table 18).

Table 14. Regional emissions of PM10, thousand tonnes

sust-rus sectors		FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	1,93	2,69	4,67	12,15	8,57	6,37	2,22
sec2	B	-	-	-	-	-	-	-
sec3	CA_col	0,89	7,52	1,18	0,07	2,39	47,08	1,47
sec4	CA_gas	-	0,18	0,24	0,42	26,36	0,09	0,01
sec5	CA_oil	-	15,32	2,52	23,91	199,26	2,75	0,33
sec6	CB	4,74	24,35	1,55	1,17	11,91	74,98	19,39
sec7	DA	5,27	5,05	2,10	2,90	1,47	7,80	1,31
sec8	DB	1,22	0,42	0,25	0,53	0,18	0,53	0,06
sec9	DC	0,55	0,11	0,11	0,14	0,14	0,31	0,04
sec10	DD	1,99	4,67	0,25	1,40	1,41	6,63	0,66
sec11	DE	10,97	14,93	1,22	4,57	1,38	12,78	0,75
sec12	DF	4,84	0,84	1,15	5,54	5,76	8,78	0,29
sec13	DG	6,27	4,96	1,79	12,20	1,73	13,18	0,27
sec14	DH	0,28	0,10	0,05	0,36	0,09	0,39	0,02
sec15	DI	48,66	28,60	15,00	26,71	34,21	54,72	7,90
sec16	DJ	23,01	36,05	8,74	22,11	92,66	183,88	3,14
sec17	DK	4,63	2,83	1,18	3,74	3,61	6,31	0,48
sec18	DL	1,65	1,40	0,18	1,15	0,72	1,81	0,10
sec19	DM	2,27	2,58	0,69	7,91	1,47	3,36	0,61
sec20	DN	1,44	0,70	0,16	0,92	1,37	2,41	0,18
sec21	E_distr	29,98	39,73	6,57	12,40	115,64	61,15	50,93
sec22	E_ely	66,17	66,15	30,01	50,49	258,00	286,14	199,84
sec23	F	-	-	-	-	-	-	-
sec24	G	-	-	-	-	-	-	-
sec25	H	-	-	-	-	-	-	-
sec26	I_cmn	-	-	-	-	-	-	-
sec27	I_trn*	30,16	34,33	19,54	47,67	101,04	38,01	20,90
sec28	J	-	-	-	-	-	-	-
sec29	LO	0,56	0,99	0,38	1,14	2,22	0,93	0,78
sec30	K	2,31	2,23	0,62	3,02	9,94	1,71	1,14
sec31	M	-	-	-	-	-	-	-
sec32	N	-	-	-	-	-	-	-

* including cars, trains, and heavy road machinery

Table 15. Regional emissions of SO2, thousand tonnes

sust-rus sectors		FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	0,21	0,60	0,93	3,49	0,50	1,42	0,16
sec2	B	-	-	-	-	-	-	-
sec3	CA_col	0,09	1,66	0,21	0,02	0,18	11,19	0,15
sec4	CA_gas	-	0,15	0,16	0,41	7,79	0,08	0,01
sec5	CA_oil	-	10,88	1,44	19,59	50,00	2,12	0,11
sec6	CB	1,94	20,95	1,14	1,25	3,06	66,83	6,44
sec7	DA	2,37	4,80	1,67	3,34	0,44	7,77	0,51
sec8	DB	0,51	0,37	0,19	0,58	0,05	0,48	0,02
sec9	DC	0,48	0,20	0,19	0,35	0,05	0,54	0,01
sec10	DD	0,24	1,20	0,05	0,44	0,11	1,78	0,07
sec11	DE	6,07	17,27	1,24	6,74	0,43	14,96	0,29
sec12	DF	13,58	5,03	5,52	38,22	12,30	57,13	0,84
sec13	DG	3,38	5,67	1,68	16,51	0,66	16,06	0,14
sec14	DH	0,05	0,03	0,02	0,15	0,01	0,15	0,00
sec15	DI	2,94	3,55	1,77	4,58	0,83	6,44	0,20
sec16	DJ	91,54	305,84	60,01	217,99	273,02	1 681,03	12,66
sec17	DK	1,25	1,61	0,57	2,62	0,61	3,72	0,11
sec18	DL	0,67	1,21	0,13	1,19	0,20	1,66	0,04
sec19	DM	0,82	1,97	0,44	7,33	0,35	2,69	0,19
sec20	DN	0,11	0,11	0,02	0,19	0,06	0,39	0,01
sec21	E_distr	19,17	53,52	7,52	20,48	47,31	85,70	27,11
sec22	E_ely	58,25	122,32	47,83	116,16	138,91	544,85	137,59
sec23	F	-	-	-	-	-	-	-
sec24	G	-	-	-	-	-	-	-
sec25	H	-	-	-	-	-	-	-
sec26	I_cmn	-	-	-	-	-	-	-
sec27	I_trn	34,16	12,51	19,76	27,07	12,12	19,12	6,26
sec28	J	-	-	-	-	-	-	-
sec29	LO	0,18	0,67	0,21	0,91	0,51	0,68	0,24
sec30	K	7,12	14,69	3,29	23,03	23,13	12,19	3,65
sec31	M	-	-	-	-	-	-	-
sec32	N	-	-	-	-	-	-	-

* including cars, trains, and heavy road machinery

Table 16. Regional emissions of NOx, thousand tonnes

sust-rus sectors		FD1-Central	FD2-Northwest	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	0,60	0,45	1,71	4,43	0,90	0,69	0,12
sec2	B	-	-	-	-	-	-	-
sec3	CA_col	0,43	2,00	0,62	0,04	0,53	8,69	0,19
sec4	CA_gas	-	0,06	0,16	0,28	7,76	0,02	0,00
sec5	CA_oil	-	4,76	1,55	14,48	52,59	0,60	0,05
sec6	CB	2,82	7,89	1,05	0,79	2,77	16,21	2,47
sec7	DA	5,10	2,68	2,30	3,15	0,59	2,80	0,29
sec8	DB	0,93	0,17	0,22	0,47	0,05	0,15	0,01
sec9	DC	0,09	0,01	0,02	0,03	0,01	0,02	0,00
sec10	DD	1,12	1,44	0,16	0,89	0,32	1,38	0,08
sec11	DE	8,12	5,98	1,06	3,94	0,36	3,34	0,10
sec12	DF	8,31	0,80	2,16	10,24	4,69	5,84	0,14
sec13	DG	8,40	3,66	2,67	17,99	1,02	6,67	0,09
sec14	DH	0,46	0,09	0,10	0,64	0,07	0,24	0,01
sec15	DI	28,02	8,74	10,73	19,07	4,93	10,22	0,49
sec16	DJ	16,15	13,98	6,75	16,84	30,00	49,49	0,59
sec17	DK	4,39	1,47	1,29	4,03	1,34	2,18	0,10
sec18	DL	1,85	0,86	0,22	1,43	0,35	0,76	0,03
sec19	DM	1,76	1,10	0,61	6,89	0,47	0,97	0,11
sec20	DN	0,46	0,12	0,06	0,35	0,14	0,26	0,01
sec21	E_distr	31,58	22,85	7,90	14,77	48,55	23,56	11,79
sec22	E_ely	121,28	66,00	63,49	105,87	180,15	189,29	75,61
sec23	F	-	-	-	-	-	-	-
sec24	G	-	-	-	-	-	-	-
sec25	H	-	-	-	-	-	-	-
sec26	I_cmn	-	-	-	-	-	-	-
sec27	I_trn	609,52	243,31	352,12	516,23	276,82	373,11	115,05
sec28	J	-	-	-	-	-	-	-
sec29	LO	0,21	0,20	0,15	0,46	0,37	0,13	0,07
sec30	K	7,94	4,24	2,34	11,23	16,05	2,27	1,07
sec31	M	-	-	-	-	-	-	-
sec32	N	-	-	-	-	-	-	-

* including cars, trains, and heavy road machinery

Table 17. Regional emissions of CnHm, thousand tonnes

sust-rus sectors		FD1-Central	FD2-Northwe	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	0,32	0,46	1,41	4,09	0,66	0,54	0,01
sec2	B	-	-	-	-	-	-	-
sec3	CA_col	17,62	158,78	39,78	2,58	30,02	525,56	1,72
sec4	CA_gas	-	1,07	2,29	4,47	96,75	0,28	0,00
sec5	CA_oil	-	42,66	11,11	116,14	334,13	4,07	0,05
sec6	CB	0,11	0,59	0,06	0,05	0,15	0,92	0,02
sec7	DA	0,40	0,41	0,28	0,43	0,06	0,32	0,01
sec8	DB	0,03	0,01	0,01	0,03	0,00	0,01	0,00
sec9	DC	-	-	-	-	-	-	-
sec10	DD	0,01	0,03	0,00	0,02	0,01	0,02	0,00
sec11	DE	0,07	0,10	0,01	0,06	0,00	0,04	0,00
sec12	DF	11,81	2,20	4,75	25,23	9,15	12,21	0,04
sec13	DG	2,17	1,83	1,07	8,04	0,36	2,53	0,01
sec14	DH	0,29	0,11	0,10	0,71	0,06	0,23	0,00
sec15	DI	0,34	0,20	0,20	0,40	0,08	0,18	0,00
sec16	DJ	0,21	0,36	0,14	0,38	0,54	0,96	0,00
sec17	DK	0,12	0,08	0,06	0,20	0,05	0,09	0,00
sec18	DL	0,28	0,25	0,05	0,37	0,07	0,17	0,00
sec19	DM	0,17	0,20	0,09	1,14	0,06	0,14	0,00
sec20	DN	0,05	0,02	0,01	0,06	0,02	0,04	0,00
sec21	E_distr	3,99	5,59	1,55	3,23	8,42	4,38	0,33
sec22	E_ely	0,36	0,38	0,29	0,55	0,74	0,83	0,05
sec23	F	-	-	-	-	-	-	-
sec24	G	-	-	-	-	-	-	-
sec25	H	-	-	-	-	-	-	-
sec26	I_cmn	-	-	-	-	-	-	-
sec27	I_trn	556,78	358,01	377,06	775,22	544,70	359,10	91,68
sec28	J	-	-	-	-	-	-	-
sec29	LO	2,93	5,50	3,37	11,29	7,08	2,71	0,23
sec30	K	1,61	1,67	0,74	3,96	4,48	0,68	0,05
sec31	M	-	-	-	-	-	-	-
sec32	N	-	-	-	-	-	-	-

* including cars, trains, and heavy road machinery

Table 18. Regional emissions of VOC, thousand tonnes

sust-rus sectors		FD1-Central	FD2-Northwe	FD3-South	FD4-Volga	FD5-Urals	FD6-Siberian	FD7-FarEast
sec1	A	0,15	0,17	0,67	1,82	0,29	0,25	0,04
sec2	B	-	-	-	-	-	-	-
sec3	CA_col	0,02	0,17	0,05	0,00	0,04	0,70	0,01
sec4	CA_gas	-	0,58	1,57	2,89	62,05	0,19	0,02
sec5	CA_oil	-	70,50	23,18	228,97	652,99	8,37	0,69
sec6	CB	0,31	1,30	0,18	0,14	0,38	2,53	0,37
sec7	DA	2,39	1,89	1,64	2,37	0,35	1,87	0,19
sec8	DB	0,18	0,05	0,07	0,15	0,01	0,04	0,00
sec9	DC	0,01	0,00	0,00	0,01	0,00	0,00	0,00
sec10	DD	0,47	0,90	0,10	0,60	0,17	0,82	0,05
sec11	DE	1,28	1,42	0,25	1,00	0,07	0,75	0,02
sec12	DF	62,57	9,04	24,68	123,84	44,51	62,62	1,40
sec13	DG	11,15	7,31	5,38	38,36	1,71	12,62	0,16
sec14	DH	1,93	0,55	0,63	4,31	0,37	1,46	0,05
sec15	DI	2,22	1,04	1,30	2,43	0,49	1,16	0,05
sec16	DJ	1,25	1,63	0,79	2,09	2,93	5,45	0,06
sec17	DK	2,18	1,09	0,97	3,21	0,84	1,54	0,07
sec18	DL	1,41	0,99	0,26	1,75	0,34	0,83	0,03
sec19	DM	2,51	2,36	1,31	15,80	0,85	1,96	0,21
sec20	DN	0,69	0,27	0,14	0,84	0,27	0,57	0,02
sec21	E_distr	0,62	0,68	0,24	0,47	1,21	0,66	0,32
sec22	E_ely	0,41	0,34	0,33	0,58	0,77	0,92	0,35
sec23	F	-	-	-	-	-	-	-
sec24	G	-	-	-	-	-	-	-
sec25	H	-	-	-	-	-	-	-
sec26	I_cmn	-	-	-	-	-	-	-
sec27	I_trn	9,00	15,29	11,07	39,53	36,00	9,83	4,28
sec28	J	-	-	-	-	-	-	-
sec29	LO	0,32	0,46	0,36	1,13	0,70	0,28	0,15
sec30	K	6,44	5,18	2,89	14,64	16,43	2,62	1,19
sec31	M	-	-	-	-	-	-	-
sec32	N	-	-	-	-	-	-	-

* including cars, trains, and heavy road machinery

Table 19 summarizes our calculations explained above. Below emissions are shown by type of emissions, region and are aggregated to 4 sectors (instead of the full 32 sector disaggregation used in SUST-RUS). From the data it is clear that the Central region (which includes Moscow) is the largest emitter of CO2 and NOx, this is caused mainly by the energy and transport[3] sector. The Urals region is the largest emitter of PM10 and NMVOC, which is mainly caused by the manufacturing sector. Siberia emits the largest amount of SOx, which is due to a high intensity of coal in the energy inputs there.

[3] Transport emissions are added to the 'Services' sector in this table.

Regional disaggregation of emission data is done proportionally to the SUST-RUS regional output data. Total emissions by each industry, reported by ROSSTAT, are distributed among regions of the SUST-RUS model with the help of the RAS procedure, so that total emissions for a given region coincides with the published data.

Table 19: Emissions baseline 2006 - by region and by sector[4]

Emissions	Sectors	Central	North West	South	Volga	Urals	Siberia	Far East
CO2 (Mtonnes)	**Agr**	0.28	0.07	0.28	0.34	0.10	0.19	0.05
	Manuf	111.49	54.29	25.87	81.65	102.26	72.38	8.74
	Energy	257.79	79.12	63.15	157.67	103.06	106.74	45.57
	Services	54.33	20.03	15.59	24.37	27.93	20.65	10.12
CO2 total		423.89	153.51	104.89	264.03	233.35	199.96	64.47
SOx (ktonnes)	**Agr**	0.21	0.60	0.93	3.49	0.50	1.42	0.16
	Manuf	126.05	382.50	76.46	321.49	350.16	1875.03	21.81
	Energy	77.41	175.84	55.35	136.64	186.22	630.55	164.69
	Services	44.99	43.76	27.83	73.84	54.50	48.38	14.90
SOx total		248.66	602.70	160.56	535.45	591.38	2555.38	201.55
NOx (ktonnes)	**Agr**	0.60	0.45	1.71	4.43	0.90	0.69	0.12
	Manuf	88.41	55.81	31.73	101.54	108.00	109.81	4.76
	Energy	152.86	88.85	71.40	120.65	228.70	212.85	87.40
	Services	617.67	247.75	354.61	527.93	293.24	375.50	116.20
NOx total		859.54	392.86	459.45	754.54	630.84	698.85	208.48
PM10 (ktonnes)	**Agr**	1.93	2.69	4.67	12.15	8.57	6.37	2.22
	Manuf	118.68	150.61	38.36	115.79	386.13	427.80	37.03
	Energy	96.15	105.88	36.58	62.89	373.64	347.29	250.77
	Services	33.03	37.55	20.54	51.84	113.20	40.65	22.82
PM10 total		249.79	296.73	100.14	242.67	881.56	822.10	312.84
NMVOC (ktonnes)	**Agr**	0.15	0.17	0.67	1.82	0.29	0.25	0.04
	Manuf	90.58	101.10	62.51	428.74	768.37	103.48	3.41
	Energy	1.04	1.02	0.57	1.05	1.98	1.58	0.67
	Services	15.76	20.93	14.32	55.30	53.13	12.74	5.62
NMVOC total		107.53	123.22	78.06	486.91	823.77	118.05	9.74

2.1.4 Mathematical formulation of emissions module

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 of 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.

$$EMSECF_{emis,ii,i,r} = IOE_{ii,i,r} \cdot \varepsilon use_{ii,i,r} \cdot \varepsilon conv_{ii,i,r} \cdot \varepsilon coeff_{ii,i,r} \quad (2.1)$$

For NOx and SOx emissions, the amount of relative abatement of emissions (*ABAT*) is determined endogenously (see section 2.2) for each sector. For other pollutants, abatement is fixed to nil. The total

[4] Emission data in this tables matches fuel use in the regional social accounting matrices, thus there are discrepancies from Russian official emission statistics reported by ROSSTAT. All data manipulations are documented in the model code.

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 sector (end-of-pipe) level.

$$EMSEC_{emis,i,r} = \left(1 - ABAT_{emis,i,r}\right) \cdot \sum_{ii} EMSECF_{emis,ii,i,r} \tag{2.2}$$

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).

$$\sum_{r} DEMANDETS_{r} = \sum_{r} SUPPLYETS_{r} \text{ if } r \in ETS \tag{2.3}$$

While the supply of permits is determined based on the previous period (year) reduced emission, the demand for permits is directly dependent on the emissions of all sectors which take part in the ETS system. In principle, permit supply is determined exogenously, as the reduction target is fixed every year as well as the growth of emission.

$$DEMANDETS_{r} = \sum_{i \in ETS} EMSEC_{i,r} \tag{2.4}$$

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

$$PPSEC_{emis,i,r} = PPETS_{emis}\left(r \in ETS\right) + PPETSREG_{emis,r}\left(r \notin ETS\right) \tag{2.5}$$

2.2 Abatement options

2.2.1 Types of abatement options included in the model

In the SUST-RUS model we consider the following abatement options:

- Decline in production;
- Technological update;
- Substitution of fuels within existing technologies;
- End-of-pipe abatement.

Firstly, environmental constraints increase output prices, thereby depressing demand for the good and leading to output reduction. Secondly, there is a scope for exogenously given technological change which might lead to higher energy efficiency. We account for autonomous energy efficiency improvements using reference case projections from IEO (2010). The latter provides data on energy consumption and gross domestic product for Russia from 2005 to 2035. Thirdly, there are substitution possibilities of fuels within the existing technology and lastly, and most importantly for non-CO_2 emissions such as SO_2 andNOx, there exist bottom-up abatement options. Figures 2 to 7 present the marginal abatement cost curves that were estimated using the data from the GAINS-Europe model.

2.2.2 Data source for abatement technologies

SO_2 bottom-up abatement options

In order to derive the sectoral abatement curves for SO_2, we were considering 75 observations which aimed at abating 1,7 Mt of SO_2. The observations were assigned to the SUST-RUS sectors and used to estimate abatement options applying several alternative specifications:

$$\text{relative cost} = \alpha * \text{abatement}^{\beta} * (\gamma - \text{abatement})^{\delta} \qquad \text{(a)}$$
$$\text{relative cost} = \alpha * (1 - \text{abatement})^{\delta} \qquad \text{(b)}$$
$$\text{relative cost} = \alpha * \text{abatement}^{\beta}, \qquad \text{(c)}$$
$$\text{relative cost} = \text{cons} + \beta * \text{abatement} \qquad \text{(d)}$$

where α, β, γ, δ, and cons are estimated parameters.

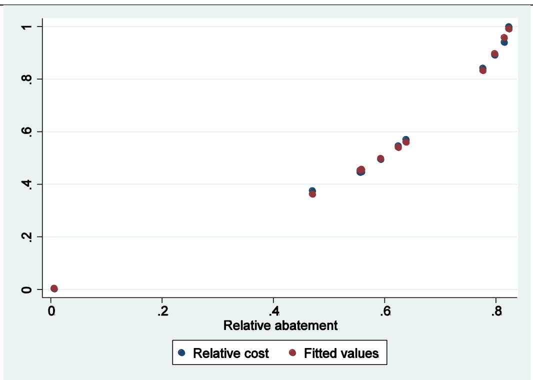
To estimate these parameters for each sector we used Non-Linear Least Squares method. After the estimation for each sector we compared different specifications and took the specification with the minimal Root Mean Squared Error.

Figure 2 to Figure 7 show the respective abatement curves; in the appendix we report the estimated coefficients. We conclude that there exist non-negligible differences in terms of abatement possibilities across the sectors. For example, in the chemical sector the curve is relatively flat at the beginning indicating that there are cheap abatement options for a relatively high amount of emissions (60% of total emissions). In contrast, SO_2 abatement curve in the electricity generation and distribution is much steeper indicating that mitigation activities might be costly even at the initial stages.

Figure 2: SO_2 abatement options in the refining industry (sec12), in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Refineries: 13 observations, total emissions 70.59 kt, total cost 56.9 million euro

(a)



(b)

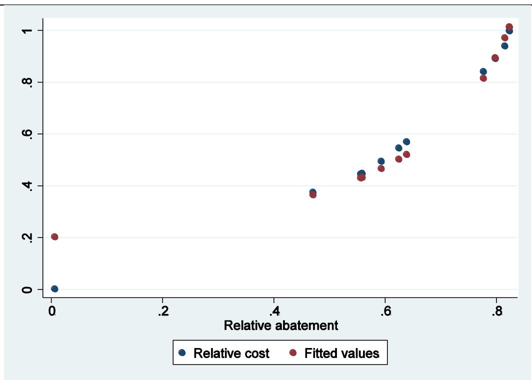


Figure 3: SO_2 abatement options in the electricity generation and distribution (sec21 and sec22) , in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Electricity generation and distribution (sec21 and sec22): 11 observations, total emissions 876.35 kt, total cost 623.9 million euro

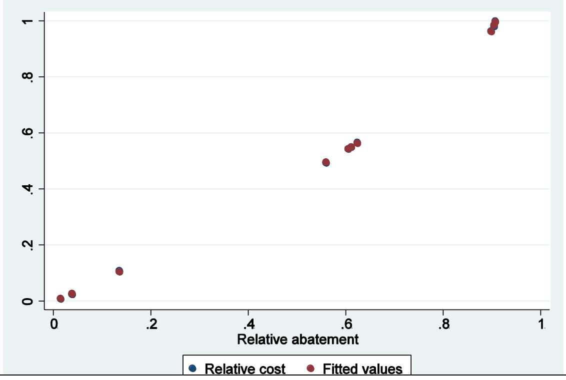
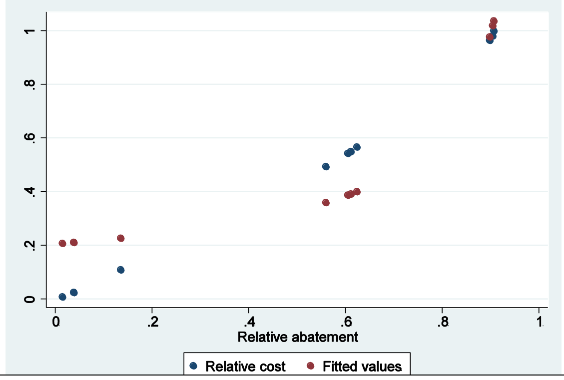
(a)	(b)
	

Figure 4: SO2 abatement options in the chemical industry (sec13) , in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Manufacturing of chemicals (sec13): 6 observations, total emissions 45.1 kt, total cost 84.3 million euro

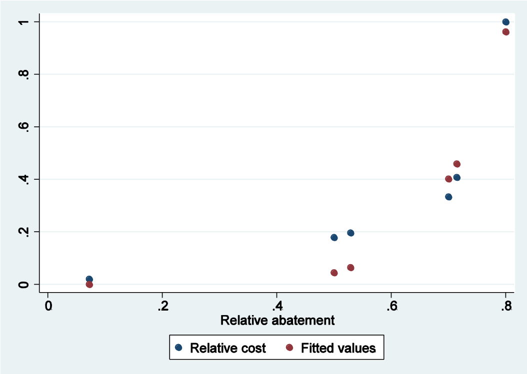
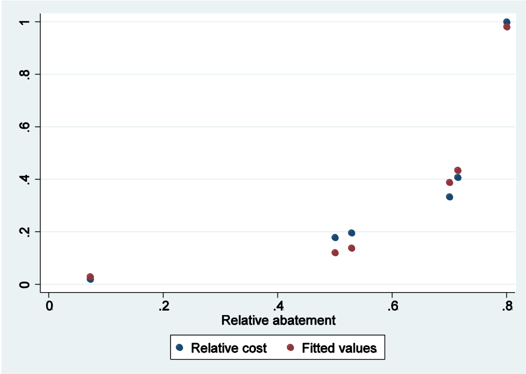
(a)	(b)
	

Figure 5: SO2 abatement options in the basic metals industry (sec16) , in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Manufacturing of basic metals (sec16): 5 observations, total emissions 159.0 kt, total cost 49.4 million euro

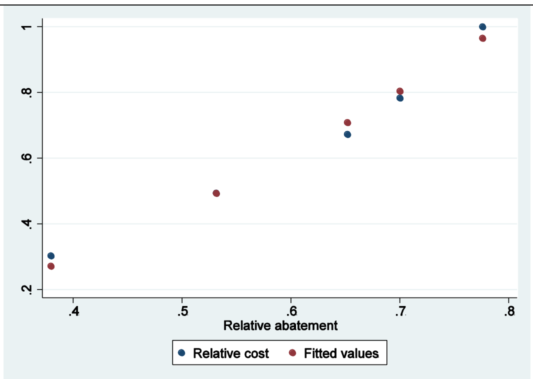
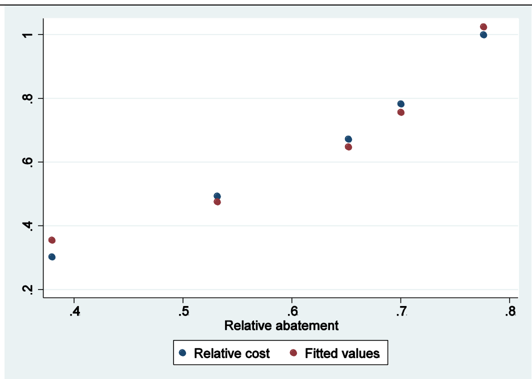
(a)	(b)
	

Figure 6: SO_2 abatement options in gas and oil production (sec4, sec5), in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Gas and oil production (sec4, sec5): 5 observations, total emissions 165.8 kt, total cost 85.2 million euro

(a) (b)

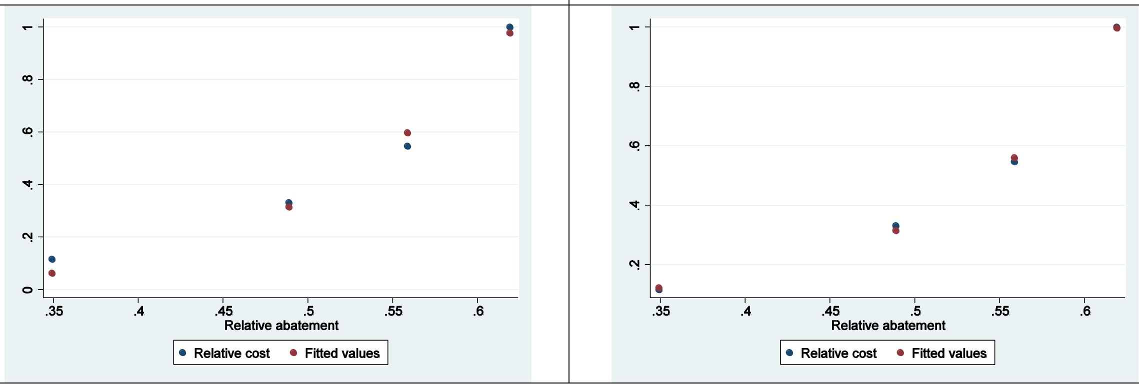
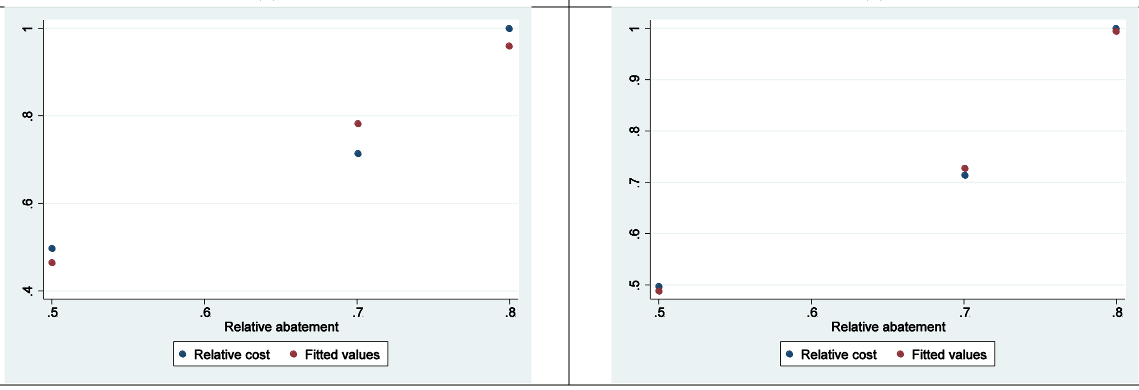


Figure 7: SO_2 abatement options in non-metallic minerals production (sec15) , in terms of relative abatement (x-axis) and relative to total cost (y-axis)

Non-metallic minerals production (sec15): 3 observations, total emissions 4.34 kt, total cost 7.7 million euro

(a) (b)



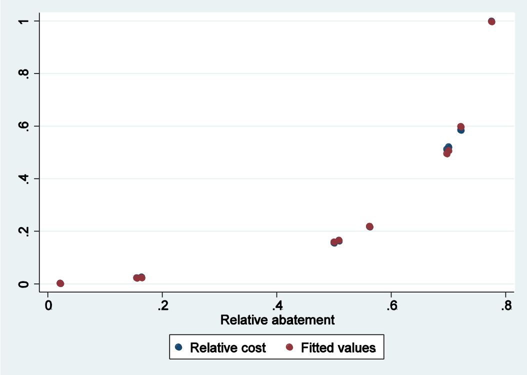
NOx bottom-up abatement options

In order to derive the sectoral abatement curves for NOx we considered 93 observations which aimed at abating 1,7 Mt of NOx. Again, the observations were assigned to the SUST-RUS sectors and used to estimate abatement options applying two alternative specifications as indicated above. Figure 8 to Figure 13 show the respective abatement curves; in the appendix we report the estimated coefficients. For oil producing industry we, however, were able to estimate the coefficients using only the specification (a).
We observe that some sectors – f.e. electricity generation and distribution and non-metallic minerals production– have rather cheap abatement options, while other industries, in particular chemical sector, have more expensive abatement options. Interestingly, for the later abatement options for NOx and SO_2 differ significantly in terms of costs and abatement potentials.

Figure 8: NOx abatement options in the refining industry (sec12)

Refineries: 14 observations, total emissions 38.6 kt, total cost 86.0 million euro

(a)



(b)

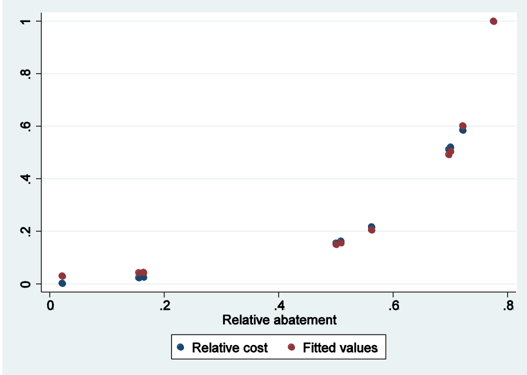
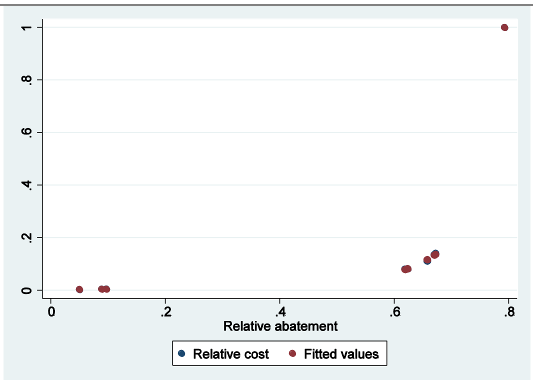


Figure 9: NOx abatement options in the electricity generation and distribution (sec21 and sec22)

Electricity generation and distribution (sec21 and sec22): 14 observations, total emissions 1234.72 kt, total cost 3158.6 million euro

(a)



(b)

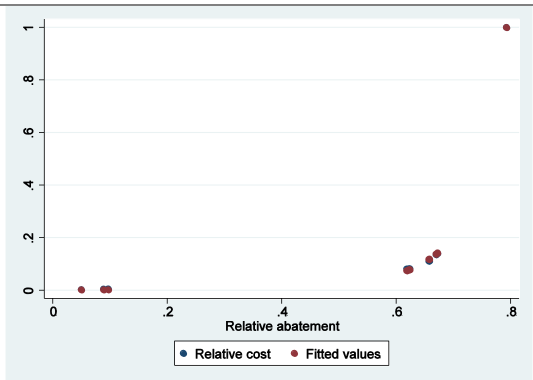
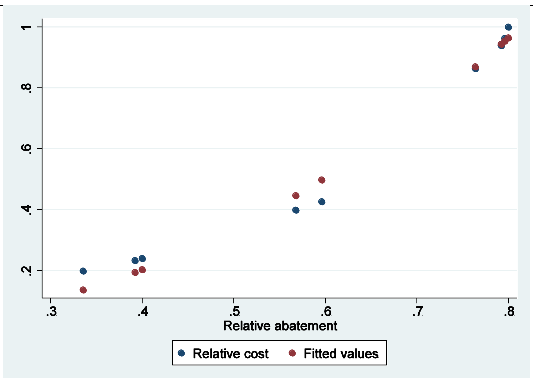


Figure 10: NOx abatement options in the chemical industry (sec13)

Manufacturing of chemicals (sec13): 9 observations, total emissions 84.8 kt, total cost 56.0 million euro

(a)



(b)

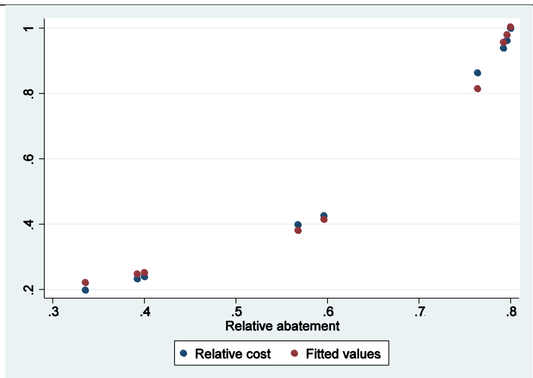
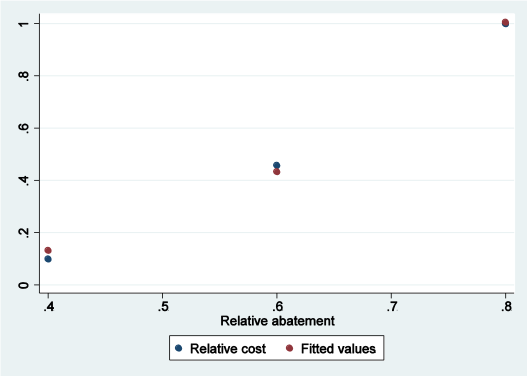


Figure 11: NOx abatement options in the basic metals industry (sec16)

Manufacturing of basic metals (sec16):3 observations, total emissions 19.2 kt, total cost 50.4 million euro

(a)



(b)

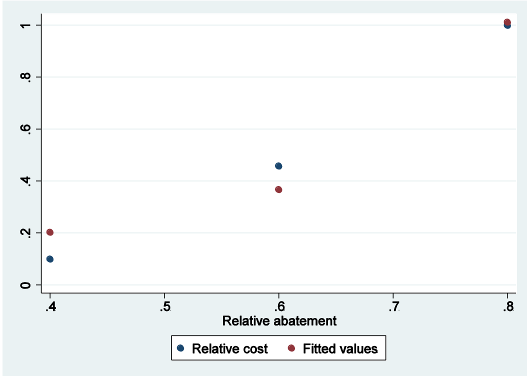
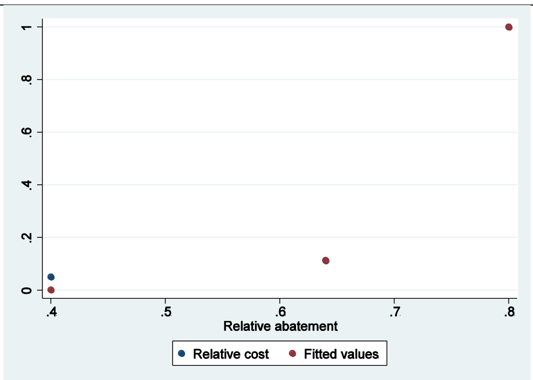


Figure 12: NOx abatement options in non-metallic minerals production (sec15)

Non-metallic minerals production (sec15): 3 observations, total emissions 20.3 kt, total cost 5.4 million euro

(a)



(b)

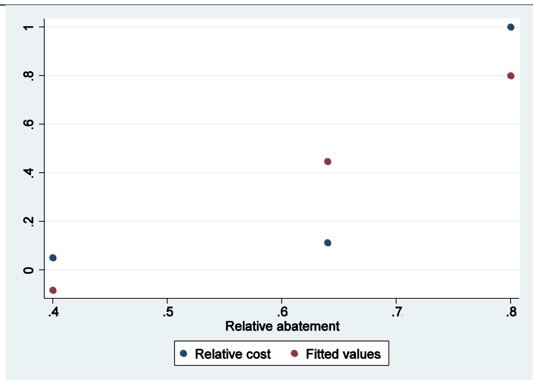
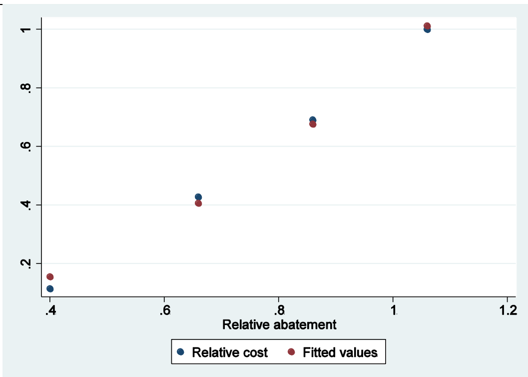


Figure 13: NOx abatement options in oil production (sec5)

Gas and oil production (sec5): 3 observations, total emissions 38.6 kt, total cost 41.5 million euro

(a)



As indicated previously, in this model version we do not account for bottom-up abatement options for CO_2 but this model extension can be easily introduced based on Bashmakov et al (2008).

2.2.3 Mathematical formulation of abatement curves

The total cost of abatement (*COSTABAT*) is determined by the amount of relative abatement of emissions (*ABAT*) and three cost function parameters (a, β, δ) as described in the general formula below

$$COSTABAT_{emis,i,r} = \alpha \cdot ABAT_{emis,i,r}{}^{\beta} \cdot (\gamma - ABAT_{emis,i,r})^{\delta} \tag{2.6}$$

The marginal abatement curve (*MACC*) is the derivative of the total abatement cost curve above

$$MACC_{emis,i,r} = \alpha \cdot \begin{bmatrix} \beta \cdot ABAT_{emis,i,r}{}^{\beta-1} \cdot (\gamma - ABAT_{emis,i,r})^{\delta} \\ -\delta \cdot ABAT_{emis,i,r}{}^{\beta} \cdot (\gamma - ABAT_{emis,i,r})^{\delta-1} \end{bmatrix} \tag{2.7}$$

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.

$$TAXENV_{emis,i,r} = PPSEC_{emis,i,r} + emisTax_{emis,i,r} = MACC_{emis,i,r} \tag{2.8}$$

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

$$IOABAT_{ii,i,r} \cdot P_{ii,r} \cdot (1 + txc_{ii,i,r}) = \sum_{emis} COSTABAT_{emis,i,r} \cdot coeffabat\cos t_{emis,ii} \tag{2.9}$$

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 $\delta_{reduction}$ determines the external amount of imposed emission reduction, χ_{exempt} the amount of emissions that are grandfathered, and *PPSEC*, the auxiliary permit price.

$$RENTS_{emis,i,r} = EMSECLAG_{emis,i,r} \cdot (1 - \delta_{reduction}) \cdot \chi_{exempt} \cdot PPSEC_{emis,i,r} \tag{2.10}$$

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

$$PEXPEND = \sum_{emis,i,r} PPSEC_{emis,i,r} - RENTS_{emis,i,r} \tag{2.11}$$

3. International trade module

3.1 Literature review on international trade and CGE modelling

The SUST-RUS project aims to build a computable general equilibrium (CGE) model of the Russian economy incorporating environmental and socio-economic aspects of human economic impact. The Russian economy is open, with large shares of its output and inputs going in and out of the country; accordingly, any realistic disaggregated economic model of Russia should account for extensive international economic links. Following the long tradition in CGE modelling, the SUST-RUS team can rely on a robust way of dealing with international trade flows in general equilibrium modelling. On the other hand, CGE models started incorporating Foreign Direct Investment (FDI) flows explicitly only recently, and probably, the way it is done now is not yet well established.

The purpose of this literature review is to explore the way existing CGE models deal with international trade and FDI flows so as to better address issues relevant for Russia while building the international module of the SUST-RUS model. Idiosyncratic features of CGE international trade modelling stem from the underlying economic theory, so section 3.1.1 of the review is concerned with modern theory. Section 3.1.2 deals with applied models and introduces the pervasive Armington assumption along with the way to deal with explicit FDI flows. In section 3.1.3 we take a closer look at Jensen, Rutherford and Tarr's model as it supplies an example of handling FDI flows in a CGE model, and moreover, Jensen, Rutherford and Tarr apply all this methodology to Russia. The final section 3.1.4 supplies the conclusion.

3.1.1 Modern theory of trade and foreign domestic investment

Modern theoretical tradition in explaining international trade and, by extension, FDI flows start with what is known as the concept of *comparative advantage*. First satisfactorily explained in 1819 by David Ricardo in his treatise *The Principles of Political Economy and Taxation*, the concept of comparative advantage is concerned with advantages in production that nations acquire as compared to other nations (not necessarily in absolute terms). Given that the factors of production are scarce, the country with the best absolute advantage in producing a particular good will produce that good (as it will be able to command the biggest purchasing power in exchange with other nations). But then the production of another good will necessarily falls to another nation, even though it might not have the "absolute advantage" in its production. In this case, it is said that the second nation has comparative advantage (over the first nation and the rest) in the second good. Notice that comparative advantage of the second nation comes not only from its relative efficiency (as compared with the third nation and so on), but also from the efficient employment of the factors of the first nation producing the first good. Here, the first nation might have been more productive than the second nation in producing the second good as well (claiming absolute advantage in both goods), but the fact that its productive capacity and factors are employed best in producing the first good opens up the way for the second nation to produce the second good.

Thus, from the beginning the comparative advantage turned out to be a general equilibrium notion where advantage of one nation depends not only on its own characteristics, but also on characteristics of competing nations. Comparative advantage also provides a compelling reason for trade between nations, and so is good as a foundation for a theory of trade. As such, the neoclassical theory of trade has been developed in the 1960s in the form of Heckscher-Ohlin model, its extensions and variants. This approach builds upon the concept of comparative advantage, utilizing the well-developed formal general equilibrium setting under assumptions of perfect competition and constant returns to scale.

Studying FDI flows and, more broadly, the nature of multinational enterprise, presents unique challenges to economists. Initially, FDI flows were considered in the traditional framework of financial economics concerned with diversifying investment in a portfolio (see (Dunning and Lundan 2008)). Although providing an explanation for the direction of FDI flows, this theory did not address the specific nature of this form of investment and, eventually, turned out to be deficient in explaining it.

In the 1960s it was recognized that to understand FDI, one should understand the nature of an enterprise and boundaries of the firm. Thus the industrial organization approach to FDI was born, where the emphasis was put on strategic considerations exploiting monopoly power and transaction costs that lead to setting up foreign affiliates (see (Hymer 1960)). An alternative approach tried to explain FDI using a product cycle framework was first suggested by (Vernon 1966). This theory was concerned with maturity of an imperfectly substitutable product and argued that when the product reaches the peak of its cycle and the original firm is the most efficient in its production, the firm will try to set up foreign affiliates so as to capture foreign markets. Afterwards, when the technology becomes widely available, the competition from local producers will probably drive the original firm out of the foreign market.

The dissatisfaction with the explanatory power of (neo) classical theories of international trade and FDI flows led to the industrial organization and product cycle approaches to explaining international trade and FDI flows in the 1960s and 1970s. The search was focused on areas where Heckscher-Ohlin model assumptions seemed the most implausible – constant (or declining) returns to scale, perfect markets and perfect competition. The development of a comprehensive theory, though, was hampered by the lack of analytical tools to address the issues. The situation tuned around when in the late 1970s (Dixit and Stiglitz 1977) suggested an approach to modelling imperfect competition and increasing returns to scale that allowed their incorporation into a general equilibrium framework. Following this breakthrough, a "new trade theory" was born shortly afterwards (Helpman and Krugman 1985).

The new trade theory exploits the concept of monopolistic competition, which allows it to dispense with strategic considerations and yet to retain increasing returns to scale, important in answering the question of when firms choose to export their products. The Dixit-Stiglitz production (or utility) function introduces the "love of variety" in the economy, which leads to the desirability of new entrants with their own brands of an imperfectly substitutable good. The nice collapsible nature of the Dixit-Stiglitz formula allows for reducing the variability of individual producers into a few parameters and, as a result, makes the model tractable. Moreover, a degree of variation in costs of individual firms might be retained and exploited in addressing the question of what type of producers might prefer to export or sell only locally (see (Melitz 2003)).

A closely related development was the proliferation of the "new economic geography" literature in the 1990s (see (Fujita, Krugman, and Venables 2001)). This modelling tradition tried to address the question of the geographical distribution of enterprises using the Dixit-Stiglitz formulation of monopolistic competition, increasing returns to scale of individual producers and transportation costs in "iceberg" form. The last element is crucial in explaining agglomerations (or, alternatively, concentration of multinational enterprise activity and FDI flows in a given country) and accounts for transportation costs as a loss of the good transported proportionately to the distance travelled. The distance is not necessarily taken literally and might include cultural differences, ease of doing business, tariffs and so on.

Treatment of FDI (as opposed to international trade) still needed special care, and in the modern tradition it was provided by (Markusen 2004). Markusen maintains a crucial distinction between horizontal and vertical FDI flows. The horizontal FDI happens when the investment is made by the parent firm in the same activity in which it operates at home (see (Martens 2008)). Thus, if a firm sets up a factory abroad producing the same final product which it sells at home, whether for selling in the host country or exporting it to third countries, then this investment is characterized as horizontal. The vertical FDI is made in an affiliate whenever it takes part in an intermediate stage of production process of the parent firm. Markusen takes note that this distinction is not clear-cut, as horizontal FDI usually involves some vertical elements as well: rarely is the production at a foreign affiliate completely independent from that in the home country. Many of the business services necessary for the efficient operations, such as management, engineering, marketing and finance, are supplied by the head office.

Still, the distinction between vertical and horizontal investments is useful as they tend to be undertaken in different circumstances and under different motives. This distinction is supported by available empirical evidence (Markusen and Maskus 2001), which shows that the horizontal FDI is more significant than vertical FDI, especially in cases of FDI flows between similar countries. According to Markusen, the models in neoclassical tradition of international trade, even if they account for FDI in their setup, provide reasons only for vertical FDI. Thus, in a classical setup with perfect markets, firms might consider setting up a foreign affiliate so as to capture local advantages in factors of production (such as cheap labour in China, for example) and delegate to that affiliate the stages of production that depend crucially on those factors. To account for empirical irregularities, exhibited by neoclassical theory, (Markusen 2004) proposes a knowledge-capital model, which allows for the existence of both vertical and horizontal investments.

Markusen introduces two sectors in an economy: one with relatively knowledge-intensive product and one unskilled-labour intensive. The unskilled-labour intensive sector is neoclassical: constant returns to scale and produced in a perfectly competitive market. The knowledge-intensive sector exhibits increasing returns to scale of production with intra-firm public nature of knowledge-based assets so that the costs of establishing a new plant are small compared with costs of establishing a local plant from scratch. Furthermore, the participation of knowledge-based assets in production is decoupled from its physical location: the parent firm may supply its technical (marketing, financial and so on) expertise to its affiliate with small additional costs. Finally, to account for increasing returns in production and their impact on competition, Markusen considers an oligopolistic setup with Cournot competition in the knowledge-intensive sector.

The simulation results of this model reveal the reasons for horizontal and vertical investment flows. Thus, similar counties in terms of relative skilled-labour endowment and size, in the presence of non-negligible transportation costs, tend to favour horizontal FDI. Substantial reduction of transportation costs leads to trade substituting FDI activity away (multinational firms prefer to export their goods instead of establishing a second plant in the foreign country). At the same time, the value of vertical FDI is the highest when one country is both small and skilled-labour abundant. In this case the multinational firms with headquarters in the small country establish production facilities in unskilled-labour abundant large foreign country, serving both home and host countries with the produced goods.

Thus, Markusen's knowledge-capital model captures both vertical and horizontal FDI and also addresses the question of when FDI and trade are substitutes (horizontal investment) and when they are complements (vertical investment). Many of the results of this model are borne out by empirical evidence (Markusen and Maskus 2001).

3.1.2 Applied models

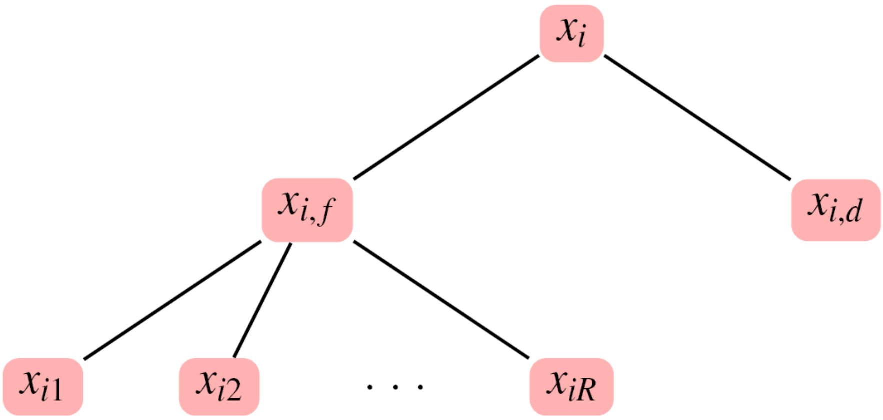
Unlike theoretical models, the applied kind strives to deal with more realistic details. The purpose of an applied model is not to distil a particular feature of reality and explore its implications in an environment free of irrelevant distractions. On the contrary, many small seemingly irrelevant features turn out to be important in applied work as they make for predictive power of the model and thus contribute to the policy discussion.

Getting back to computable general equilibrium (CGE) methodology, notice that in international trade the most important question to address is the way we incorporate imports and exports into the general equilibrium framework of a domestic economy. The main distinctive feature of CGE models is their disaggregated nature; accordingly, import and export data are also supplied by sector in the economy. Clearly, consumers and firms in the markets for intermediate goods find imported goods desirable and substitutable with domestically produced counterparts, up to a degree. Thus, it might be possible to incorporate imported goods directly into consumers' preferences and production functions of firms. Then again, imported goods are classified according to industrial sectors, which might make the task of specifying import-enhanced consumers' utility functions and producers' production functions quite formidable, if at all possible.

On the other hand, many of the imported goods find close substitutes in their domestic counterparts; thus, it is natural to capture this distinctive kind of substitution parametrically in a familiar CGE fashion – using a nested CES function. This paves the way directly to the Armington assumption (see (Armington 1969)). Under the assumption, a specific good consumed in the economy, along with the intermediate good of the same specification used in production, is not an actual good, but the CES composite[5] of the good produced domestically (indexed below by *d*) and the one imported (indexed by *f*):

Figure 14. The typical Armington structure of the demand

$$x_i = ces_{\sigma_i, a_{i,d}, a_{i,f}}(x_{i,d}, x_{i,f}). \tag{3.1}$$



Moreover, if the model is concerned with trade flows between separate distinct countries (regions) and import data is available not only by sector *i*, but also by country of origin $r\,(r = 1, \dots, R)$, then this can easily be accommodated by the Armington structure:

$$x_i = ces_{\sigma_i, a_{i1}, \dots, a_{iR}}(x_{i1}, \dots, x_{iR}). \tag{3.2}$$

To capture the special status accorded to domestic producers as opposed to any of the foreign ones, many models use a nested structure, where the final good is composed according to (3.1), whereas the "imported" good $x_{i,f}$ is itself a composite (3.2) of goods sorted by countries of origin (see Figure 14).

Export is treated in a similar manner in this framework. Any good y_i produced in the domestic economy is split between the domestically supplied variety y_{id} and the exported one y_{if} according to the constant elasticity of transformation (CET) function, which happens to be the same as a CES function (with re-parameterization of the elasticity parameter[6]):

$$y_i = ces_{-\sigma_i^x, a_{i,d}, a_{i,f}}(y_{i,d}, y_{i,f}). \tag{3.3}$$

In the same way as we think of the import Armington structure as an "additional layer" of production, producing final composite good x_i using inputs x_{id} and x_{if}, we think of the exported and domestically supplied goods as final outputs of a "production process" that uses the original final good y_i as input.

The Armington assumption endured criticism all the time it was extensively (if not exclusively) used by CGE community. The main thrust of the criticism is that there is scant evidence supporting the claim of the stable substitutability relationship between imported and exported goods. Microeconomic foundations suggest that substitutability between goods should be based on technological or marketing differences as they anchor more clearly consumer tastes (or producer's preferences for intermediate goods). The country of origin might serve only as a proxy for fundamental reasons behind imperfect substitutability, and its instability as a measure of substitutability might be exacerbated by aggregation issues, when we do not distinguish between particular categories of products within an industrial sector.

[5] For the definition of a generic CES function $ces_{\sigma, a_1, \dots, a_n}(x_1, \dots, x_n)$ see CEFIR (2009).

[6] Technically speaking, we should also allow negative values for σ in the definition of the function $ces_{\sigma; a_1, \dots a_n}$ in CEFIR, 2009.

Another line of criticism concerns the so-called "small share problem" (see, e.g., (Komorovska, Kuiper, and van Tongeren 2007)). When the initial share of an imported good in the baseline model is small, it tends to stay small no matter what changes in the tariff structure are introduced. It happens since the share parameter in the CES function is estimated using the baseline data, and a small share parameter inside the CES specification tends to depress the impact of trade even after liberalization of trade. This feature is especially troubling as CGE models are used to estimate effects of trade liberalization in countries with high initial level of tariffs that were sufficient for shutting down trade in certain dimensions.

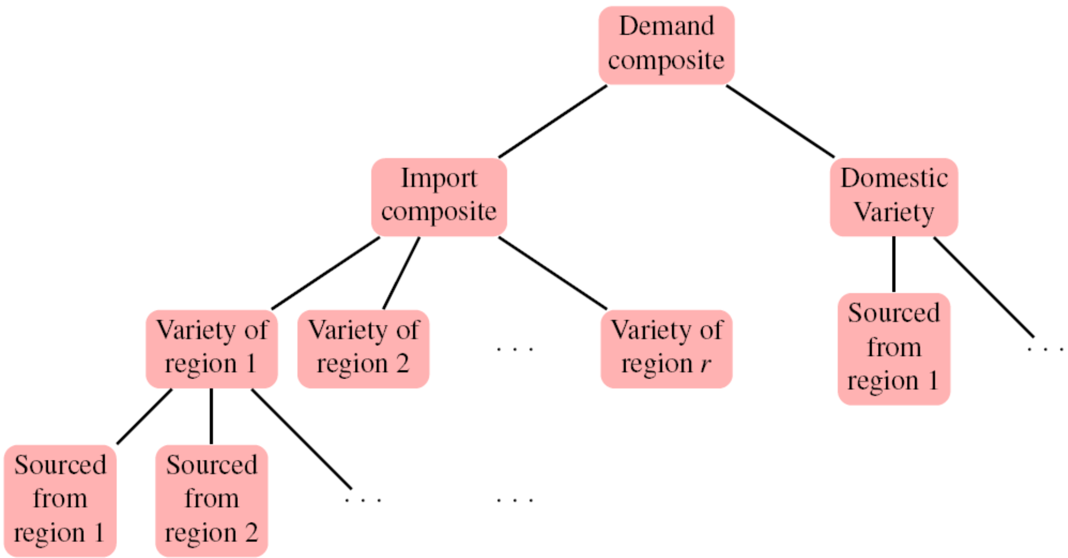
Justified criticism notwithstanding, the Armington assumption has clear benefits making it a workhorse of the applied work. The possibility to use data broken down only by country of origin and industrial sector (as opposed to brand names and more specialized technical distinctions in single product categories) is one of them. Other benefits concern the parsimonious nature of modelling trade flows in and out of a country and the seamless integration with the CGE environment.

As of this date, all the CGE models known to the author use the Armington assumption in their modelling of international trade flows. See, for example, models GEM-E3, EPPA in (Paltsev et al. 2005), GTAP in (Hertel and Tsigas 1997).

Unlike trade flows, foreign direct investment came to be incorporated into CGE models only recently. The explanation probably lies in the quite recent availability of disaggregated data on FDI flows. The pioneering work on incorporation of FDI data into the CGE framework was done by (Petri 1997), and the majority of CGE modellers interested in FDI flows follow in his footsteps.

First, Petri accommodates the distinction in the outputs of domestic firms, multinational firms selling domestically and multinational firms selling abroad. To deal with this issue, Petri introduces a *regional variety* of a particular good, which is the composite of the goods produced in the region but sourced from different regions in terms of enterprise ownership. Particular regional varieties corresponding to foreign regions enter the right-hand side in (3.2) to get the import composite good on the left-hand side, which, along with the domestic region variety, enters the right-hand side in (3.1) to produce the final composite good on the left-hand side (see Figure 15).

Figure 15. Demand system with FDI (adapted from (Petri 1997))



The presented structure of domestic demand for a good has some intrinsic flaws that might be hard to address properly. Notice that the structure does not allow for specifying close substitution between the imported good of a particular region and the one produced domestically, but sourced from that region. In many situations it might be plausible to assume that these two goods are close substitutes, but the two goods in question meet in the nested structure only at the highest level. Similarly, the same argument can be applied to the importation of "own" varieties of goods, produced by the home-grown multinational firms in a foreign country. In fact, the last issue is partially addressed in (Lee and Mensbrugghe 2005), where the imports of "own" varieties are assigned a separate branch in the import goods composite. Even though they are treated distinctly from the rest of imported goods, it is not yet possible to properly parameterize close substitution between imported "own" varieties and those produced domestically.

In the second important step of his model setup, Petri elaborates on the structure of capital allocation, which should now account for FDI flows. Thus, regional assets can be invested in a particular sector i as in the ordinary model. But then, assets invested in the sector i can be invested either at home or abroad. Finally, assets invested abroad might be invested in different (foreign) regions r in the form of FDI. This tree-like structure incorporates CES functions at each of its nodes. For example, assets invested abroad turn out to be a CES composite of assets invested in specific foreign regions. The total amount of investment in assets, as is customary in static CGE models, is determined by the amount of savings, coming from solving the consumer's problem (where cost of investment is given by the inverse of the rate of return). Then the allocation of capital across sectors, yet further down across domestic and foreign regions, and finally across specific foreign regions, is given by optimizing the corresponding nested CES investment function. Justifying the existence of such a function, it is usually argued that it serves as a proxy for risk aversion manifesting itself in the desire to diversify across sectors and regions. Besides, the investment function is purported to capture adjustment or management costs and other dimensions of investment activity not captured by the expected rates of return (Petri 1997).

Finally, Petri is concerned with modelling vertical FDI under assumptions of constant returns to scale, so the only difference between foreign affiliates and domestic firms is in their use of intermediate inputs: the foreign firm imports some of them from the home country, while domestic firms employ domestic intermediate inputs. To facilitate modelling and comparison, Petri aggregates capital and labour in a value-added nest in production, which then is combined with intermediate inputs. In this way the common factors of production for both types of firms are conveniently tucked into the same composite good of value added.

3.1.3 Jensen, Rutherford and Tarr's model of Russia

While Petri was concerned with generic modelling of FDI flows, not distinguishing between specific multinational firms, C. Jensen and Meyer (2005) narrow their focus to multinational firms providing business services. As FDI flows in this case have a distinct flavour, the modellers are not confined to a generic form of production function for both domestic and multinational firms. Moreover, the Russian setting allows modellers to disregard questions of the export of "own" goods produced by home-grown multinationals abroad and the mirror phenomenon in foreign countries.

At the same time, (J. Jensen, Rutherford, and Tarr 2004) extend the model to include increasing returns to scale in the monopolistically competitive environment. Thus, both domestic and foreign services providers produce their corresponding composites according to Dixit-Stiglitz formulas:

$$Z_d = \left(\sum_{i=1}^{n_d} z_d^{(\sigma_d - 1)/\sigma_d} \right)^{\frac{\sigma_d}{\sigma_d - 1}} \tag{3.4}$$

and

$$Z_m = \left(\sum_{i=1}^{n_m} z_m^{(\sigma_m - 1)/\sigma_m} \right)^{\frac{\sigma_m}{\sigma_m - 1}}, \tag{3.5}$$

where both elasticities of substitution σ_d and σ_m are greater than 1. Each of the firms exhibits constant marginal and fixed costs so that the total costs are given by ($l = d, m$)

$$C^l = c_l z_l + f_l. \tag{3.6}$$

Assuming infinitesimal contribution of an individual firm (both n_d and n_m are large), we can solve the profit maximizing problem of the firm to get

$$p_{z_l} = \frac{\sigma_l}{\sigma_l - 1} c_l \tag{3.7}$$

Furthermore, the free entry condition implies that profits of any firm should equal zero; thus the output of firm is given by

$$z_l = (\sigma_l - 1) \frac{f_l}{c_l}. \tag{3.8}$$

Jensen, Rutherford and Tarr assume that marginal costs and fixed costs are proportional to each other (with possibly different coefficients ϕ_l for domestic and foreign firms), which greatly simplifies model calibration, especially important in the environment with scarce data. As a corollary of this assumption, we see from formula (3.8) that the output per firm will be determined only by the corresponding coefficient ϕ_l and the elasticity of substitution between monopolistically competitive good σ_l. Thus, Jensen, Rutherford and Tarr's model only accounts for changes in the number of domestic and foreign firms, but not in the scale of production. Still, these changes might play an important role in contributing to the general equilibrium welfare effects, as the cost of obtaining the composite intermediate good in question is inversely related to the number of firms: $p_{Z_l} = p_{z_l} n_l^{1-\sigma_l}$ (remember that $\sigma_l > 1$). In other words, greater variety leads to better provision of services in question.

Finally, the marginal cost function in the model comes from the usual constant returns to scale production technology generated by nested CES functions. Both domestic and foreign firms employ local factors of production (mobile capital, sector-specific capital, unskilled and skilled labour) and common intermediate goods. On top of that, foreign affiliates also employ a specialized input produced abroad (managerial expertise, specialized engineering knowledge or marketing skills presumably transferred from the parent company).

3.1.4 Conclusion

The computable general equilibrium tradition has long tackled issues of international trade where its unique general equilibrium nature and disaggregated approach provided a fortuitous environment for informing policy-makers. Being rooted in the economic theory foundations, CGE models provided a degree of certainty in those areas where the nature of data did not allow for more robust statistical inferences. Even though trade flows treatment in the CGE tradition, based on the Armington assumptions, is not completely satisfactory theoretically, its ease of implementation, appealing intuition and interpretable results made for its predominant status in the field of the policy analysis.

Recent developments in modern economic theory brought forth the new trade theory and new economic geography that properly address increasing returns and imperfect competition in environments with obstacles to trade. A new crop of CGE models successfully incorporate the new tools made available by theory.

The recent availability of disaggregated data on cross-border investment flows raised new challenges for CGE modellers who for a long time had to disregard foreign direct investment in international trade. Addressing issues of Asian international trade (Petri 1997) has introduced a satisfactory way of accounting for FDI flows in a computable general equilibrium framework. Following in his footsteps, several CGE models successfully employed his approach in different settings. In particular, (J. Jensen, Rutherford, and Tarr 2004) incorporated cross-border investments in business services in the setting of the Russian economy and used this state-of-the-art model to find welfare effects of the putative trade liberalization in Russia.

The body of knowledge to date, both theoretical and applied, supplies sufficient and adequate tools for a CGE modeller interested in accounting for international trade and FDI flows in his specific model. This report reviewed the available tools that might be useful in constructing the international module of the SUST-RUS model and, hopefully, might contribute towards successful conclusion of this ambitious modelling exercise.

3.2 Description of the elements of the international module

3.2.1 Stabilization fund of the Russian federation

Due to its richness in natural resources, Russia's economy strongly depends on exports of primary energy inputs to the rest of the world. Almost two thirds of the total export is directly related to the export of coal, goal or gas. While being a steady source of income for the federal budget, a resource-dependent economy is very susceptible to volatility of prices on the world market. We illustrate the wealth of Russia, but also its fragility to price changes in Table 20, showing the IMF predictions of the current account surplus in 2009 up to 2014.

The actual data for 2010-2011 can differ, as after 2009 a strong recovery of oil prices in the end of 2010 and 2011 was observed. However, the historical trend and economic logic behind the prediction is apparent.

Looking further ahead, we assume only relatively small further increases in oil prices above current levels and projected medium-term developments in Russia's external current account are driven by the interplay of two long-term trends. First, the volume of Russian oil and gas production and exports is expected to grow only slowly because the scope for further exploration is limited and the marginal costs of extraction from new, more remote fields are high. Second, domestic demand is projected to grow relatively strongly which, on the basis of historic elasticities, implies a rapid increase in imports. The combination of strong increases in imports and slow increases in oil and gas exports makes that Russia's current account balance is expected to deteriorate over time (IMF Russia team).

It means that the large current account surplus the Russian Federation has in the base year of our social accounting matrix (2006) is remarkably unstable and volatile. This provides a problem, as computable-general equilibrium logic is based on more-or-less 'stable' systems.

Table 20: Prediction of current account until 2014 (source: IMF 2009)

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
CA	84.4	94.3	76.2	102.3	6	19	13	14.6	-6.9	-34.3
%GDP	11	9.5	5.9	6.1	0.5	1.4	0.9	0.8	-0.4	-1.5

Actually the Russian government has itself formulated an answer to this problem. To insure budgetary stability and to avoid rapid inflation within the Russian domestic economy a stabilization fund (Стабилизационный фонд Российской Федерации) was established by resolution of the Russian government on January 1, 2004, as a part of the federal budget. This fund actually accumulated the excessive income from the export of primary energy inputs (mainly petrol export) and channelled into investments abroad.

We can derive the value of the stabilization fund directly from the social accounting matrix, which we show in Table 21. Using national account data of 2005-2006 we determine the amount of financial obligations of the Russian Federation abroad (1) and the net amount of household income held in foreign assets (2). The remaining number is derived by balancing the social accounting matrix (3). The result is 2.878 billion rubbles as shown in the Table 21. The stabilization fund of the Russian federation in 2006 in the same period, held about 2.200 billion rubbles at the end of 2006. So by slightly rebalancing our SAM, we were able to reproduce the value of the stabilization fund to a relatively close match.

Table 21: Small SAM of Russian Federation (absolute values in million roubles)

	Products	Production	VA	Taxes	HH	Gov	Invest	Exports
Products		22574710			11477044	4729288	5514918	7205326
Production	46338693							
VA		22522104						
Taxes		1241879			1179455	1616	213975	1715865
HH			22522104			2272868		
Gov				1241879	6425286			
Invest					3942736	3774305		890086(1)
Imports	5162594				1770450(2)i		2878234(3)	

Based on our experience we decide that introducing the stabilization fund as a part of our dynamic framework will improve the prediction power of the SUST-RUS model.

3.2.2 Trade margins on export

The international module of the SUST-RUS model explicitly takes into account the existence of trade margins on exports. The importance of trade margins is illustrated in Table 22. The trade margins are applied by removing a certain share of the trade and transport margins of producing sectors (Wholesale trade, communication and transport) and adding it to the respective products. The correction factors are based on the EXIOPOLL database for the Russian Federation.

Table 22: Comparison of product specific export, before and after trade margins

Products	Before Trade Margins	After Trade Margins	Correction (Exiopoll)	%of Total Before	%of Total After
Coal	60310.89	165597.51	0.06	0.01	0.02
Gas	57884.03	677889.13	0.33	0.01	0.09
Oil	1302577.25	1735231.69	0.23	0.18	0.24
Mining	111716.96	302477.74	0.10	0.02	0.04
Food	73109.34	118137.80	0.02	0.01	0.02
Petrol & cokes	709338.23	866454.81	0.08	0.10	0.12
Chemicals	276440.45	379172.43	0.05	0.04	0.05
Rubber	66411.78	79254.55	0.01	0.01	0.01
Non-metal	16960.50	22548.06	0.00	0.00	0.00
Basic metal	1052769.06	1162212.21	0.06	0.15	0.16
Machinery	390400.52	400446.78	0.01	0.05	0.06
Trade	1766829.72	109170.72	-0.94	0.25	0.02
Transport	435499.79	219302.58	-0.50	0.06	0.03

To keep consistency with the social accounting matrix, we redefine the export prices. The equation below illustrates how the export price is derived from the world price. The price of export (*PE*) is equal to the world price of the good, multiplied by the exchange rate (*ER*), corrected for the export taxes (*texp*) and the trade and transport margins on export (*trmexp*) multiplied by the price of export margins (*PTME*).

$$PE_i = PW_i \cdot ER \cdot (1 - texp) - trmexp_i \cdot PTME \qquad (3.9)$$

To keep consistency with the normal trade and transport margins module, the price of export margins is calculated from the normal sales price (*P*) and a Leontief coefficient (*atmexp*) which is also the share of commodity used for production of export margins.

$$PTME = \sum_{i,r} atmexp_{i,r} \cdot P_{i,r} \qquad (3.10)$$

3.2.3 Extended Armington and CET functions

The international module of the SUST-RUS model was extended to take into account trade links with different world regions, with specific detail for the EU. Following the DoW of the SUST-RUS project, disaggregated data on the structure of import and exports was collected at regional level. The corresponding database was based on GTAP 7.

Table 23: World regions (destinations) considered in the international module

EU regions	ROW regions
Western Europe	Middle East
Eastern & Central Europe	Africa
Scandinavia	America (USA, Canada and South America)
Baltics	China
Southern Europe	Japan
	Ukraine
	Former Soviet Union (FSU)
	RoW

A new nest is introduced for each region, allowing distinguishing the origin of imports and exports by the world region described in the above table.

Exports to each particular region follow the CET functions below, with exports from each region to Europe (*EEUCNT*), exports to world regions (*EROWCNT*), total export to Europe (EEU) and to the rest of the world (EROW), export price to EU (PEEUCNT) and to the rest of the world (PEROWCNT), CET parameters of export to EU ($\gamma TN1$) and to the rest of the world ($\gamma TN2$) and the scaling parameters of export to EU ($\alpha TN1$) and to the rest of the world ($\alpha TN2$).

$$EEUCNT_{cnt,i,r} = \frac{EEU_{i,r}}{aTN1} \cdot \sum_{cnt} \left[\begin{array}{l} \left(\gamma TN1_{i,cnt,r}\right)^{\sigma TN} \cdot \\ \left(PEEUCNT_{cnt} - trmexp_{i,r} \cdot PTME\right)^{\left(1-\sigma TN_{i,r}\right)} \end{array} \right]^{\frac{\sigma TN}{\left(1-\sigma TN_{i,r}\right)}} . \qquad (3.11)$$

$$EROWCNT_{cnt,i,r} = \frac{EROW_{i,r}}{aTN2} \cdot \sum_{cnt} \left[\begin{array}{l} \left(\gamma TN2_{i,cnt,r}\right)^{\sigma TN} \\ \cdot \left(PEROWCNT_{cnt} - trmexp_{i,r} \cdot PTME\right)^{\left(1-\sigma TN_{i,r}\right)} \end{array} \right]^{\frac{\sigma TN}{\left(1-\sigma TN_{i,r}\right)}} \qquad (3.12)$$

Imports from each European region (*MEUCNT*) or world region (*MROWCNT*) are given by the Armington functions below with total import from Europe (MEU) and from the rest of the world (MROW), import price from EU (PMEUCNT) and from the rest of the world (PMROWCNT), Armington parameters of import from EU ($\gamma AN1$) and from the rest of the world ($\gamma AN2$) and the scaling parameters of import from EU ($\alpha AN1$) and from the rest of the world ($\alpha AN2$).

$$MEUCNT_{cnt,i,r} = MEU_{i,r} \cdot \left(\frac{\gamma AN1_{i,r}}{PMEUCNT_{cnt,i,r}} \right) \cdot \left(PMEU_{i,r}\right)^{\sigma T_{i,r}} \cdot \left(aAN1_{i,r}\right)^{\sigma T_{i,r}-1} \qquad (3.13)$$

$$MROWCNT_{cnt,i,r} = MROW_{i,r} \cdot \left(\frac{\gamma AN2_{i,r}}{PMROWCNT_{cnt,i,r}} \right) \cdot \left(PMROW_{i,r}\right)^{\sigma T_{i,r}} \cdot \left(aAN2_{i,r}\right)^{\sigma T_{i,r}-1} \qquad (3.14)$$

3.2.4 Domestic and foreign varieties

Following (J. Jensen, Rutherford, and Tarr 2004), we introduce foreign varieties in our monopolistic competition module.

The monopolistic price is calculated as the competitive price (*PDD*) multiplied by a mark-up (*AUXV*) which depends on the firm-level externalities.

$$PDC_{i,r} = PDD_{i,r} \cdot AUXV_{i,r} \qquad (3.15)$$

We apply the assumptions of large scale monopolistic competition. This means that the share of the firm in the domestic market is sufficiently low to assume that it perceives a constant elasticity of demand.

The number of foreign firms (*NFF*) is directly related to the production of foreign firms in Russia (*XDF*), the fixed costs associated with capital (*fck*) and labour (*fcl*) and the perceived elasticity of the firm (εF_r). Similarly the number of domestic firms (*NFH*) depends directly on the amount of domestic production (*XDH*) its fixed costs and the elasticity perceived by the firm (εH_r).

$$NFF_{i,r} \cdot (fckF_{i,r} + fclF_{i,r}) \cdot INDEX_r = XDF_{i,r} / \varepsilon F_r \quad (3.16)$$

$$NFH_{i,r} \cdot (fckH_{i,r} + fclH_{i,r}) \cdot INDEX_r = XDH_{i,r} / \varepsilon H_r \quad (3.17)$$

The auxiliary variable (mark-up or externality) is calculated as below.

$$AUXV_{i,r} = \left[NFF_{i,r}^{\rho/\rho FR} + NFH_{i,r}^{\rho/\rho HR} \right]^{\frac{x}{\rho}} \quad (3.18)$$

where $\rho FR = \frac{1}{1 - elasFR}$

and $\rho HR = \frac{1}{1 - elasHR}$

If we assume that $\rho FR = \rho HR = \rho$ then we can simplify this to

$$AUXV_{i,r} = \left[NFF_{i,r} + NFH_{i,r} \right]^{\frac{x}{\rho}} \quad (3.19)$$

The expression above is almost equal to the normal set-up of the monopolistic competition module, with the main difference being the differentiation of foreign level varieties (see section 3.2.5 below).

$$KD_{i,r,t} = (1 - \partial_i) \cdot KD_{i,r,t-1} + INV_{i,r,t} \quad (3.20)$$

3.2.5 FDI in the recursive dynamics structure

The recursive dynamics of the SUST-RUS model differs from deterministic dynamic of 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. DCGE models applies Ramsey setting to an economy with multiple sectors and households, sometimes including a public sector (for applied examples see Heer and 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 stock cannot adjust instantaneously, but needs 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 distributed from the total country investment pool. We distinguish two types of investments, those of 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*).

$$KD_{i,r,t} = (1-\delta_i)\cdot KD_{i,r,t-1} + INV_{i,r,t} \tag{3.21}$$

$$KF_{i,r,t} = (1-\delta_i)\cdot KF_{i,r,t-1} + FDI_{i,r,t} \tag{3.22}$$

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

$$INV_{i,r,t} = DOMINV_t \cdot \eta\,\mathrm{Re}\,g_r \cdot \eta Sec_{r,i} \tag{3.23}$$

$$FDI_{i,r,t} = IROWT_t \cdot \eta\,\mathrm{Re}\,gF_r \cdot \eta SecF_{r,i} \tag{3.24}$$

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 2004). This is a simplification of the exponential share module used (for example) within the GEM-E-3 model and the MIRAGE model.

With *RGD* and *RGDT* being respectively the nominal rate of return and the total return on capital, investment shares on regional level are calculated as:

$$\eta\,\mathrm{Re}\,g = \frac{\sum_i KD_{i,r,t}}{\sum_{i,rr} KD_{i,rr,t}}\cdot\left[1+\beta_r\cdot\left(\frac{RGD_r}{RGDT}-\frac{RGD^0}{RGDT^0}\right)\right] \tag{3.25}$$

$$\eta\,\mathrm{Re}\,gF = \frac{\sum_i KF_{i,r,t}}{\sum_{i,rr} KF_{i,rr,t}}\cdot\left[1+\beta_r\cdot\left(\frac{RGD_r}{RGDT}-\frac{RGD^0}{RGDT^0}\right)\right] \tag{3.26}$$

Investment shares on sector and regional level are calculated as:

$$\eta Sec_{i,r} = \frac{KD_{i,r,t}}{\sum_{ii} KD_{ii,rr,t}}\cdot\left[1+\mu_i\cdot\left(\frac{RK_r}{RGD_r}\right)\right] \tag{3.27}$$

$$\eta SecF_{i,r} = \frac{KF_{i,r,t}}{\sum_{ii} KF_{ii,rr,t}}\cdot\left[1+\mu_i\cdot\left(\frac{RK_r}{RGD_r}\right)\right] \tag{3.28}$$

The dynamic structure of SUST-RUS represented here has the required properties:

- the rate of return is calculated in a way respecting the economic theory of investment;
- total investments at a country level are consistently assigned to each region.

4. The social module

4.1 Literature review and database description

The purpose of this literature review is to explore the ways CGE models deal with influence of environmental pollution on human health, income distribution and poverty. The review helps to choose the most relevant method for SUST-RUS model taking into account the availability of data, the structure of the model and computational constraints. Section 4.1.1 provides general features of existing approaches to model health effects of air pollution. Section 4.1.2 offers detailed description of the health-related blocks of the most known European CGE model – GEM-E3. Section 4.1.3 deals with the approach to introduce health costs of environmental pollution into CGE framework used in the EPPA model. Section 4.1.4 describes different approaches using CGE models to analyse poverty and income distribution. Section 4.1.5 describes the data used for calibration of the social block of SUST-RUS model.

4.1.1 Environment and Health in computable general equilibrium models

The most known computable general equilibrium models with the environmental and health components are the European General Equilibrium Model for Energy-Economy-Environment (GEM-E3) and the American Emissions Predictions and Policy Analysis (EPPA). The standard versions of GEM-E3 take into account both costs and benefits of environmental policy. They include an environmental quality function that depends on the emissions and affects agents' welfare through their utility function. It is assumed that environmental quality provides a separable contribution to the consumers' welfare. The EPPA model is widely used to study climate change policies. It provides a detailed representation of economic activity that contributes to emissions of polluting substances.

The extensions of the GEM-3 and EPPA models that allow feedback effects related to the health impacts of air pollution are discussed in (Mayeres and Van Regemorter 2003) and (Paltsev et al. 2005). These papers integrate health effects into the models, allow for inclusion of more routes through which air pollution affects the economic agents, and provide more encompassing endogenisation of these effects.

4.1.2 Computable general equilibrium model for studying Economy-Energy-Environment Interactions for Europe and the World (GEM-E3)

GEM-E3 is designed around a basic general equilibrium core in a modular way. This makes it rather flexible and suitable for different innovations. (Mayeres and Van Regemorter 2003) used this feature and made a modification that allows estimating the feedback effects of air pollution for households' behaviour and welfare. Modification of GEM-E3 concentrates on health impact of air pollution. It incorporates the influence of air pollution on medical spending by the consumers, on the available time of the consumers and labour productivity.

Health block of the model is based on the health production function approach. Health production function relates a continuous health variable to exogenous (e.g., pollution) and choice variables (such as consumption and medical care).

Authors' innovations relate to the household problem. The representative consumer's utility function is a two-level nested LES utility function as in the standard GEM-E3 model, but with one more component linked to health. The utility function (U°) is a LES function defined additively separable over logarithms of excess consumption $(C-\bar{C})$, excess leisure $(l-\bar{l})$ and excess health $(H-\bar{H})$. It is also a separable function of the ambient concentration of the different air pollutants.

$$U^0 = \alpha_1^0 \ln(C-\bar{C}) + \alpha_2^0 \ln(l-\bar{l}) + \alpha_3^0 \ln(H-\bar{H}) - \sum_{m=1}^{M} \alpha_{H,m}^0 \cdot A_m \tag{4.1}$$

$\bar{C}$, $\bar{l}$ and $\bar{H}$ are subsistence levels of consumption, leisure and health. α_n^0 ($n=1,\ldots,3$) are parameters of the LES function and $\alpha_{H,m}^0$ is the marginal utility of a decrease in the ambient concentration of pollutant m ($m=1,\ldots,M$) $\alpha_{H,m}^0 > 0$. The ambient concentration A_m of air pollutant m is assumed to be a function of the emissions of the various air pollutants w.r.t. reference equilibrium (EM_{po} with $p_o = 1, \ldots, PO$):

$$A_m = A_m(EM_1, \ldots, EM_{p0}) \forall m \tag{4.2}$$

The excess health included into the utility function is obtained by subtraction of subsistence level of health from the health index. Health index H in turn is defined through exogenous level of health $H*$ (no air pollution and no consumption of any medical services), impact on health of air pollution and of consumption of medical services.

$$H = H* - \sum_m \beta_{1,m} A_m + \beta_{2,m} MED \tag{4.3}$$

The utility function is maximized subject to standard budget constraint that includes also the cost and consumption of medical care:

$$p_c C + p_{MED} MED \le Y \tag{4.4}$$

It states that total spending on consumption, leisure and medical care cannot exceed total income.

Total income is defined through non-labour income P and the product of wage w and total available time T.

$$Y = w\left(T - \sum_{m=1}^{M} \theta_m A_m\right) + P \tag{4.5}$$

Due to its health effects air pollution reduces total available time by a certain amount θ_m per unit of change in the concentration of each air pollutant m w.r.t. reference situation. It is assumed that the time costs of bad health are borne partly by the consumers and partly by the production sectors.

Solving the household problem we receive household's demand for consumption, leisure and medical care. The solution indicates that growth of air pollution increases the demand for medical care, reduces consumption and leisure.

At the lower level of the nested LES function, consumption is allocated over twelve commodities (excluding medical care), as in the standard GEM-E3 model.

The GEM-E3 distinguishes several production sectors. Each of them produces according to CES production technology using capital, labour, electricity, fuels and electricity as inputs.

The extension of the GEM-E3 model in the production sectors takes into account that air pollution affects the number of days active people are ill. It is assumed to influence only partly the income of the consumers, which implies that the productivity of labour in the production sector is affected. A rise in air pollution reduces labour productivity: more labour is needed to produce one unit, given the other input (capital) fixed. This increases cost of labour and induces a substitution towards the other production factors.

For given capital price *r* and gross wage rate w^g the simplified cost minimization problem of production sector *j* $\left(\forall_j\right)$ is standard

$$\textbf{Min } rK_j + w^g L_j \tag{4.6}$$

s.t

$$X_{Dj} = \left[\alpha_{K_j}^{\frac{1}{\alpha_j}} K_j^{\frac{\sigma_j - 1}{\sigma_j}} + \alpha_{L_j}^{\frac{1}{\sigma_j}} \left(L_j \left(1 - \gamma \left(A_1, \ldots, A_m \right) \right) \right)^{\frac{\sigma_j - 1}{\sigma_j}} \right]^{\frac{\sigma_j}{\sigma_j - 1}}$$

but with the inclusion of γ Y – the percentage of working days lost due to air pollution.

The government budget in the extension of GEM-E3 model is affected directly by increase in air pollution that leads to increase in total subsidies for medical care, and indirectly through the impact of air pollution on the consumption of taxed commodities and labour supply.

This approach was applyed for estimation of the environmental cost by the European research project ExternE (1996, 1998 and 2000 see http://www.externe.info/). The cost estimates are decomposed into components that are relevant to the presented analysis. The following pollutants are considered in the model: particulate matter (PM 2.5 and PM_{10}), ozone (O_3) and sulphur dioxide (SO_2).

Calibration of the model requires determination of the parameters of the utility function, the health production function and the production function.

The calibration process of the utility function parameters is such that the total marginal willingness-to-pay (*MWTP*) of the consumers for a reduction in air pollution corresponds with the values used in ExternE and in the standard GEM-E3 model for the ex-post evaluation.

$$MVTP_{A_m} = -\frac{\partial V / \partial A_m}{\partial V / \partial Y} = \varpi \theta_m - p_{MED} \left(\frac{\left(\partial H / \partial A_m \right)}{\left(\partial H / \partial MED \right)} \right) + \alpha_{H,m}^0 Y^d \tag{4.6}$$

V is indirect utility and Y^d Y^d is disposable income:

$$Y^d = w\left(T - \sum_{m=1}^{M} \theta_m A_m \right) + P - p_c \bar{C} - w\bar{l} - p_{MED} \frac{\bar{H} - H * + \sum_m \beta_{1,m} A_m}{\beta_2} \tag{4.7}$$

The parameters σ of the LES utility function are calibrated such as to keep the same labour supply elasticity in both the standard and extended GEM-E3 model. The parameter representing the percentage of working days lost due to air pollution is given by the ratio between the working days lost or gained due to change in air pollution and the number of working days in the reference equilibrium, so it is zero by definition in the base year.

Finally, after the simulation of the extended GEM-E3 model, the authors conclude that the modelling framework implemented in the model allows for three channels through which the feedback can occur: a decrease in medical expenditure, an increase in the consumers' available time and an increase of labour productivity in the production sector. The results show that explicit modelling of the health related effect of air pollution allows for a better evaluation of the impact of environmental policies on private consumption and employment. However, in terms of global effect, the impacts of the feedback are small, compared to the standard GEM-E3 model where health related benefits are evaluated ex-post.

4.1.3 Emissions Prediction and Policy Analysis model – Health Effects (EPPA-HE)

Modification of the MIT Emissions Prediction and Policy Analysis model (EPPA-HE), offered by (Paltsev et al. 2005), aims to estimate the health effects from exposure to air pollutants. Unlike GEM-E3 this model accepts both current and accumulated exposure to air pollutants.

Inclusion of health effects in basic EPPA model involves valuation of non-wage time (leisure) lost due to illness and inclusion of a household production of health services into the Social Accounting Matrix (SAM). Simplified SAM is presented in Table 23, where the extensions of the model are highlighted in italic bold.

Table 23: Expanded Social Accounts Matrix for EPPA-HE

	Production sectors	Household production	Final consumption
Production sectors	Input/Output ***Medical services for air pollution***	Household transportation ***Household mitigation of pollution health effects***	Goods and services ***Pollution health services*** ***Leisure***
Factors	Labour, capital, resources	***Household labour***	***Total consumption=total factor income***

Source: Figure 1 in (Paltsev et al. 2005)

The basic SAM includes the inter-industry flows (input-output tables) of intermediate goods and services among industries, delivery of goods and services to final consumption, and the use of factors (capital, labour and resources) in production, while extended SAM includes some additional components.

The EPPA-HE model includes modified household production sector that provides a «pollution health service» to final consumption to capture economic effects of morbidity and mortality from acute exposure. This household production sector is represented as «household mitigation of pollution health effects». It uses «health services» (e.g., hospital care and physician services) from standard EPPA and newly added household labour to produce a health service. The household labour is drawn from labour and leisure and thus reduces the amount available for other uses (e.g., an illness results in purchase of medical services and/or patient time to recover when they cannot work or participate in other household activities).

Changed pollution levels are modelled as a Hick's neutral technical change: higher pollution levels require proportionally more of all inputs to deliver the save level of health service.

The key additions to the model in the sense of household production are leisure as a component of consumption and the Household Health-care (HH) sector that includes separate production relationships for health effects of each pollutant. The HH sector is Leontief in relationship to other goods and services and among pollutant health endpoints. Mortality effects simply result in a loss of labour and leisure, and thus are equivalent to a negative labour productivity shock.

Health effects present themselves as both market and non-market effects. Death or illness of someone in the labour force means that person's income is no longer part of the economy, clearly the market effect. Death and illness also involve loss of non-paid work time, a non-market impact (this likely involves a loss of time for household chores or a loss of time spent on leisure activities).

EPPA-HE considers four main pollutants: particulate matter ($PM_{2.5}$ and PM_{10}), ozone (O_3) and sulphur dioxide (SO_2) – as GEM-E3 and also includes two additional pollutants: nitrogen dioxide (NO_2) and carbon monoxide (CO). For each pollutant authors use estimated by other researchers' morbidity effects, mortality effects and effects on asthmatics in the corresponding category. Actually they know how exposure to a pollutant (μg/m3) over a year affects health (changes in probability of illness and associated with each disease time-costs and changes in mortality). Authors consider costs related to hospital costs as a demand for medical services, lost work time they treat as a reduction in the labour force (in dollar equivalents), and damages beyond these market effects as a loss of leisure.

To deal with mortality and chronic exposure the authors construct a simple age cohort population model for explicit calculation of the cumulative exposure over time (and the changes of annual exposure) and for tracking the changes in deaths as they occur over time.

The EPPA-HE model has been applied to the U.S. for the historical period from 1970 to 2000 to compare obtained estimates with estimates from a major U.S. EPA study (U.S. EPA, 1999), and to calibrate the model.

After testing and calibration the two counterfactual scenarios are considered for the period 1970-2000. One scenario simulates the U.S. economy as if there had been no air pollution regulation over this period. The second scenario simulates the U.S. economy with pollution at natural level. Then these counterfactual cases are compared to the simulations with historical emissions levels. Thus, in the first case, the estimates of benefits from the air pollution regulation policy are obtained, and in the second case, the burden on the economy of the existed air pollution is assessed.

The results indicate that the benefits from air pollution regulation rose steadily from 1975 to 2000 from $50 billion (1997 USD) to $400 billion (1997 USD) (from 2.1% to 7.6% of market consumption). The estimated remaining burden of air pollution has been high and gradually rising in absolute dollar terms (from about $200 to $250 billion from 1975 to 2000), but has fallen as a percentage of total consumption (from 7.8 to 4.7% between 1975 and 2000), however, mostly because pollution levels have fallen due to regulation. Finally, they conclude that in terms of both benefits and remaining burden, the effects of tropospheric ozone and particulate matter are the most important in terms of suggested estimate of economic impact, while the effects of other pollutants are quite small in comparison. Mortality due to chronic exposure of PM is an important component of the costs, and this is one of the more controversial effects of pollution.

4.1.4 Approaches to analyse poverty and income distribution in CGE models.

In recent years there has been rich literature devoted to poverty analysis in CGE models. It can be divided into three groups:

- CGE models with representative agents (CGE-RH)
- Integrated multi-households CGE models (CGE-IMH)
- Sequential micro-simulation approach (CGE-SMS)

All these approaches are based on CGE models and distinguished by the way the impact on poverty and inequality is modelled.

CGE model with representative agents is the oldest and the simplest approach for modelling inequality. (Dervis, de Malo, and Robinson 1984) have applied this approach, as well as (Janvry, Sadoulet, and Fargeix 1991), (Colatei and Round 2000) and (Agénor, Izquierdo, and Fofack 2003). The model divides all population into several groups which consist of representative households. Differences in their characteristics lead to different impact of external shock on their welfare. The main drawback to this approach is that it ignores intra-group income distribution change while average behaviour of a specific group is biased towards the richest in the group.

Integrated multi-households CGE model (CGE-IMH) includes as many households as what is found in income and expenditure household surveys. The main advantage of CGE-IMH comparing to CGE-GH is that it allows for intra-group income distributional changes as well as leaving the modeller free from pre-selecting household grouping or aggregation. The modeller can perform any decomposition of poverty and income distribution analysis since all, or a large sample, of the household survey is directly used in the model. (Cockburn 2002) on Nepal, (Cororaton 2003) for the Philippines and (Boccanfuso et al. 2003) in

Senegal applied this approach to real country data. This approach has one important disadvantage - the size of the model. Inclusion of thousands of economic agents leads to resolution difficulties especially if there are nonlinear equations in the model.

Sequential micro-simulation approach (CGE-SMS), used in (Orcutt et al. 1961), (Bourguignon, Robilliard, and Robinson 2003), consists of two stages. At the first stage experts use the standard CGE-RH model to generate a price vector (including wage rates). At the second stage received price vector is used in household micro-simulation (HHMS) model, to calculate the household behaviour (consumption and labour supply). These vectors are then fed into the CGE model in which they are now exogenous variables and the iteration process continues until the difference, between two iteration processes for all variables, is negligible. The main advantage of this approach is that it provides richness in household behaviour, while remaining extremely flexible in terms of specific behaviours that can be modelled. There are sometimes, however, problems with coherence between the macro and micro models.

4.1.5 Data sources for the social block of SUST-RUS.

Two main sources of data for the social block of SUST-RUS are ROSSTAT and RLMS.

ROSSTAT, or Federal State Statistics Service (www.gks.ru), is the federal executive body discharging the functions of forming official statistical information on social, economic, demographic, ecological and other social processes in the Russian Federation.

RLMS, or *Russian Longitudinal Monitoring Survey* (http://www.cpc.unc.edu/projects/rlms-hse) is a nationally representative panel survey of approximately 4,000 households reporting on a large number of issues. The panel started in 1994 and is still followed. The number of surveyed people is approximately 10,000 in each round. The data contains detailed information on household composition and labour market history of adult household members, as well as on household income and expenditures. Given that SUST-RUS Model uses input-output tables and SAM data for 2006 year (the latest available data), it also uses RLMS data for 2006 year. Below is the description of the main social figures used in SUST-RUS Model.

Population and population growth rate by federal regions. Data on *population number* are reported by ROSSTAT[7]. The main source of these data for ROSSTAT is population censuses. Birth and death data are used as well. *Growth rate* is calculated as a percentage change in population number in current year with respect to the previous year.

Skills of labour force. Skills are defined on the base of one-digit International Standard Classification of Occupations (ISCO). The detailed description of skill levels is presented in Table 24.

Table 24: Skills and ISCO codes

Level of skills	ISCO codes	Occupations
Low	9	Elementary (unskilled) occupations
Medium	3-8	Technicians and associate professionals, clerks, service workers and market workers, skilled agricultural and fishery workers, craft and related trades, plant and machine operators and assemblers
High	1-2	Legislators, senior managers, officials and professionals

According to RLMS the biggest group of worker is medium skilled workers. They constitute two thirds of all workers. High skilled and low skilled workers represent 22% and 12% of all workers respectively.

Household types. We divide households into three types according to their income per capita. To reach interregional comparability income data are corrected by regional subsistence level. Households in the first (lowest) quintile of income distribution are considered as low income families. Medium income and high income households are those in the second and in the third (richest) quintiles of income distribution.

[7] http://www.gks.ru/wps/wcm/connect/rosstat/rosstatsite/main/population/demography/#

According to RLMS 26% of workers live in low income households, 32% of workers live in medium income families and 41% in high income households.

Share of wage income by skill type, household type and district. The figures are calculated on the base of RLMS data. We consider wage income as monthly labour income at the main job of individual. The example data are presented below inTable 25.

Table 25: Share of wage income by skill type, household type and district

District	Income type	Skill type	Share of wage income
Central	Low income	High	14%
Central	Low income	Medium	74%
Central	Low income	Low	12%

From the table 7 one could see that the biggest part (74%) of the wage bill of workers from low income families in Central district is associated with medium skilled labour. Putting it differently, medium skilled workers earn 74% of total labour income in low income households in Central region. 14% of wage bill in households of that type is made by high skilled workers and 12% – by low skilled workers.

Distribution of skills by district and household type. Table 26 represents an example of data on distribution of skills by district and household type. It turned out that labour force in Central district in low income families consists of 69% of medium skilled workers, 16% of high skilled workers and 15% of low skilled employees. RLMS is used to get the data.

Table 26: Distribution of skills by district and household type

District	Income type	Skill type	Share
Central	Low income	High	16%
Central	Low income	Medium	69%
Central	Low income	Low	15%

Level of unemployment by skills. Unfortunately there is no direct way to get data on level of unemployment by skills for Russian federal regions. Rosstat does not report such data and there is no information on skills for unemployed in RLMS data set. We use the following procedure to calculate requested data:

a. We take data on unemployment level by educational group in Russian regions from Rosstat publications (year 2006);

b. Then we derive educational structure of workers by skills in each region from RLMS, 2006;

c. Combining data from (a) and (b) we get data on unemployment level by skills. Rather strong assumption is used in this computation. We suppose that educational structure by skills is similar for employed and unemployed.

Pollution costs. Pollution costs data are adopted from (Mayeres and Van Regemorter 2003). In the paper costs of pollution are evaluated in ECU 1995. We use inflation data for EU from EconStats (http://www.econstats.com) to convert ECU 1995 into EUR 2006.

GDP per capita in EU is higher than in Russia. So we correct the costs of pollution in the following way:

$$Costs\_Russia = Costs\_EU * \frac{GDP\_per\_capita\_RUS}{GDP\_per\_capita\_EU} \quad (4.8)$$

Finally costs were converted into roubles on the basis of the annual average exchange rate.

4.2 Description of the elements of the social module

4.2.1 Labour market

The modified labour market of the SUST-RUS model takes up the idea of differentiated skill use by sector.

The data was based on the ILO database for the Russian Federation. This data was only available at the national level for one-digit NACE sectors; as such it was necessary to apply the same shares at regional level as at national level and to assume that the demand for skills is similar for a set of two-digit NACE sectors (mainly within the manufacturing sector).

Table 27: Share of skill use within sector, source: ILO database (average 2006-2007)[8]

	LS	*MS*	*HS*
Total	*0.117*	*0.642*	*0.240*
A Agriculture, Hunting and Forestry	0.184	0.750	0.066
B Fishing	0.169	0.721	0.110
C Mining and Quarrying	0.076	0.751	0.173
D Manufacturing	0.125	0.676	0.199
E Electricity, Gas and Water Supply	0.074	0.727	0.200
F Construction	0.127	0.677	0.197
G Wholesale and Retail Trade	0.089	0.767	0.144
H Hotels and Restaurants	0.134	0.779	0.088
I Transport, Storage and Communications	0.089	0.767	0.144
J Financial Intermediation	0.024	0.426	0.549
K Real Estate, Renting and Business Activities	0.120	0.458	0.421
L Public Administration and Defence	0.121	0.369	0.510
M Education	0.121	0.369	0.510
N Health and Social Work	0.089	0.626	0.285
O Other Community, Social and Personal Service Activities	0.152	0.580	0.268
P Households with Employed Persons	0.525	0.450	0.025
Q Extraterritorial Organizations and Bodies	0.250	0.000	0.750
Unemployed	0.228	0.676	0.095

The data in Table 27 has one more problem. It refers to the amount of employees within each sector, but does not take into account the 'wage share' within each sector. As our economic data is in monetary units, we cannot apply it directly. Therefore, it is necessary to estimate the wage differential of low, medium and high skilled employees in each region.

Table 28 presents the average wage for each skill level in each region. The SUST-RUS model assumes full labour clearing within each region, meaning that skill is equally rewarded, independent of the sector. This allows us to apply the wage differentials of each region directly on the numbers in Table 27[9].

[8] Own calculations based on the ILO database. High skilled = isco1, isco2, medium skilled=isco3, isco4, isco5, isco6, isco7, low skilled=isco 8 and isco 9. The data is based on the share of employees, not corrected for wages.

[9] This means that we assume that the difference in wages between sectors is explained fully by the different skills demanded by each sector.

Table 28: Average wage by skill level in each region

		HS	MS	LS
Central	reg1	20114.356	13075.75	7436
North Western	reg2	19014.388	14264.29	7494
South	reg3	11670.255	8619.949	4367
Volga Basin	reg4	12922.245	9945.456	4777
Ural	reg5	21737.174	15955.16	7419
Siberian	reg6	15915.056	11911.5	5607
Far Eastern	reg7	21934.625	16106.03	7169

The resulting shares are used to disaggregate labour demand (*LED*) within each sector to 3 skill levels. The labour demand by skill level is derived by the following standard CES equation.

$$LED_{i,ed,r} = L_{i,r} \cdot \left(\frac{\gamma ED_{i,ed,r}}{PL_{ed,r}} \right)^{\sigma ED_{i,r}} \cdot PLT_{i,r}^{\sigma ED_{i,r}} \cdot aED^{\sigma ED_{i,r}-1} \quad (4.9)$$

The price of labour by sector and region (*PLT*) is derived from the demand for skills at the sectorial level at the labour clearing price rate (*PL*). We assume that the wage differences between sectors are fully explained by the different demand for skills at the sectorial level.

$$PLT_{i,r} = \sum_{ed} PL_{ed,r} \cdot LED_{i,ed,r} \quad (4.10)$$

Following our assumption on labour mobility between sectors we know that the total labour supply (*LS*) minus unemployed labour (*UNEMP*) is equal to the labour demand for skills (*LED*).

$$LS_{ed,r} - UNEMP_{ed,r} = \sum_{i} LED_{i,ed,r} \quad (4.11)$$

Following our simple formulation of the labour market (Deliverable D3.1, p.30), we assume that there is a basic link between the price of labour and the unemployment rate. Applying this 'wage curve' for each skill level, we get the following formula:

$$\left(\frac{PL_{ed,r} / INDEX_{r}}{PLZ_{ed,r} / INDEX_{ed,r}} \right) - 1 = elasWage_{ed} \left(\frac{UNRATE_{ed,r}}{UNRATEZ_{ed,r}} - 1 \right) \quad (4.12)$$

Referring to (Shilov and Mueller 2008), who estimated a wage curve applicable to Russia, we know that the mean elasticity at the margin would be around -0.104. As no disaggregated estimate was available on the level of the skills, the safest assumption is to put the elasticity of the curve as equal among different skill levels. It would however be interesting to apply slightly different estimates for each skill level. Following the literature on the wage curve, values between -0.15 and -0.13 would be preferable for the lower skilled workers, while higher skilled workers would perceive elasticities from -0.09 to -0.06. The logic behind the different elasticities, would be related to tightness of the labour market[10]. The wages of high skilled labour can be expected to change less, in function of unemployment.

[10] elasWage = $\frac{d\log(wage)}{d\log(unemp)}$

Skill level	elasWage
LS	-0.135
MS	-0.104
HS	-0.075

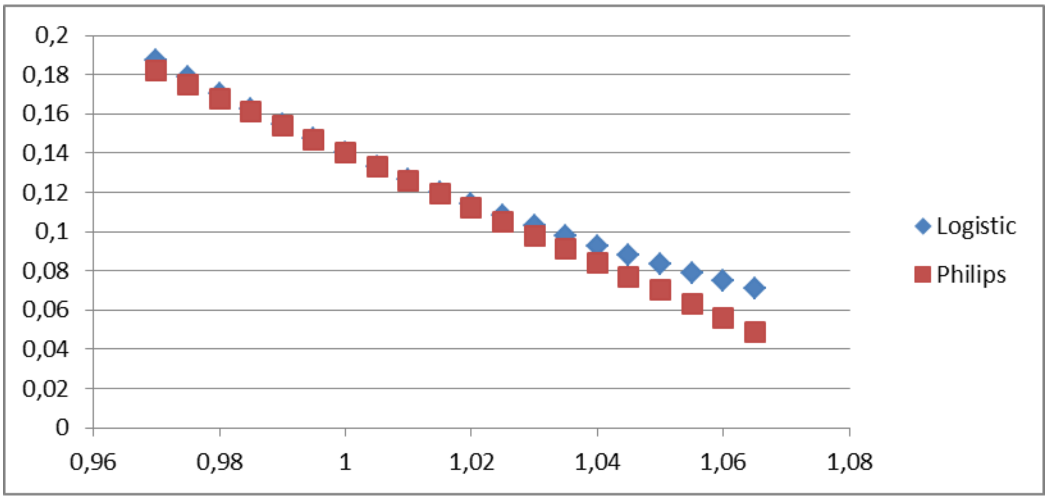
Following (Blanchflower and Oswald 2005), we can also relate this formula to the 'labour matching equation'. It is interesting to see that applying this general logistic formula of the matching function (Petrongolo and Pissarides 2000) would lead to almost equal results for reasonably low elasticities and small variations around the margin. We check if it is preferable to use the formulation below, instead of the 'Philips' curve[11]. The equation of the 'logistic wage curve' is given by the equation below, where $\alpha_{ed,r}$ and $\beta_{ed,r}$ are calibrated parameters of the function and *PW* represents the real wage.

$$UNRATE_{ed,r} = \frac{1}{1+e^{\alpha_{ed,r}+\beta_{ed,r}\cdot\frac{PW_{ed,r}}{PWZ_{ed,r}}}} \tag{4.13}$$

$$PL_{ed,r} = \frac{PL_{ed,r}}{INDEX_{ed,r}} \tag{4.14}$$

Comparing the 'Philips type curve' with the 'logistic wage curve' in a spread sheet format with on the x-axis the change in real wage from the equilibrium wage and on the y-axis the unemployment rate, we see that the difference between the 2 formulation is indeed minimal around the equilibrium point. However, theoretically the Philips curve can predict negative unemployment if the change in real wage is larger than 10%.

Figure 16: Comparison logistic wage curve and 'Philips' formulation[12]: change in real wage (horizontal axis) versus unemployment rate (vertical axis)



[11] Phillips curve is a historical inverse relationship between the rate of unemployment and the rate of inflation in an economy. Stated simply, the lower the unemployment in an economy, the higher the rate of inflation. While it has been observed that there is a stable short run tradeoff between unemployment and inflation, this has not been observed in the long run.

[12] Calibrated for initial unemployment equal to 0.14 and wage elasticity equal to -0.1

Taking an applied example, we introduced the logistic wage curve into the SUST-RUS model and applied a unilateral decrease of 5% for the entire labour supply, independent of skill level or region. This is a very unrealistic simulation and the model is expected to overreact to the simulation, however this illustrates the difference between the assumptions on the labour market very well.

Table 29: Macro level indicators – comparison of wage curve formulation with 5% decrease in labour supply

Macro indicators	Philips	Logistic
GDP (bil. Rubles)	-302.2	-333.5
Welfare (bil. Rubles)	-190.6	-198.1

Table 30: Unemployment in the central region – comparison of wage curve formulation

Unemployment (Central region)	sim	Philips	Logistic
Unemployment rate	Base case	0.037	0.037
	Simulation	0.019	0.022
Unemployment rate HS	Base case	0.018	0.018
	Simulation	0.006	0.009
Unemployment rate LS	Base case	0.097	0.097
	Simulation	0.074	0.075

While giving similar results, the logistic formulation predicts higher losses in GDP and overall economic welfare and lower changes in unemployment, especially for the higher skilled labour.

4.2.2 Income by household type

The income of each household is calculated from the total income of each production factor. It is composed from a supply of labour from each type of education level (as a proxy for skill) (*LS*), minus the fraction of unemployed labour, multiplied with the endogenous price of labour by education level (*PL*).

The income to each household is attributed by a fixed factor (*shareWage*), which is calculated from the specific endowment of each type of labour of the household. Capital income is calculated from the capital stock (*K*), multiplied with the return on capital (*RK*) as explained in Deliverable D3.1. However the new social module introduces 2 extra changes. Households can have a fixed share in the capital income of another region (*shareKY*). Also, for public sectors, such as the health sector, education, government services and additionally a large share of the capital income of the gas and electricity sectors are attributed to the government sectors, rather than the household income (*sharePublic*). The sum of total capital income for the households is again distributed to each household type by an exogenous factor (*shareCap*), reflecting the capital ownership of each household type.

(4.15)

$$Y_{th,r} = \left[\sum_{ed} \left(LS_{ed,r} - UNEMP_{ed,r} \right) \cdot PL_{ed,r} \cdot shareWage_{th,ed,r} \right]$$
$$+ \left[\sum_{i,rr} K_{i,r} \cdot RK_{i,r} \cdot shareKY_{rr,r} \cdot \left(1 - sharePublic_{i,r} \right) \right] \cdot shareCap_{th,r}$$

The consumption budget equation is only slightly modified, introducing household income from government transfers for each household type (*TRF*), household savings by household type (*SH*) and transfers to unemployed (*UNEMP*).

$$CBUD_{th,r} = Y_{th,r} \cdot (1 - ty_t) + TRF_{th,r} \cdot GDPDEF - SH_{th,r} + \left[\sum_{ed} UNEMP_{ed,r} \cdot PL_{ed} \cdot trep_{ed.r} \cdot shareUnemp_{th,ed,r} \right] \quad (4.16)$$

4.2.3 Environmental damages to household health

We follow (Mayeres and Van Regemorter 2003) in introducing a module for medical expenditures into the SUST-RUS model. We introduce health preference as an element in the utility function, following the LES-type utility introduced in Deliverable D3.1. As only limited information was available for the calibration of this module, the subsequent formulation is tentative only and should be seen as an optional module. We will apply the module in chapter 5 and analyse its effect on the results.

The full formulation of the household consumption function now becomes:

$$\begin{aligned} &C_{th,i,r} \cdot P_{th,i,r} \cdot (1 - sc_{i,r} + tc_{i,r}) = \\ &P_{th,i,r} \cdot (1 - sc_{i,r} + tc_{i,r}) \cdot muH_{th,i,r} + \\ &PMED_r \cdot \frac{HEALTH_{th,r} - H * + ENVDAMHH_{th,r}}{betaMed} \\ &+ \alpha \cdot \left[CBUD - \sum_i P_{th,i,r} \cdot (1 - sc_{i,r} + tc_{i,r}) \cdot muH_{th,i,r} - PMED_r \cdot \frac{HEALTH_{th,r} - H * + ENVDAMHH_{th,r}}{betaMed} \right] \end{aligned} \quad (4.18)$$

if (*i*=*health*)

The main difference between this equation and the original equation for the household consumption is related to medical expenditures. The parameter *muH* represents the minimal consumption under the LES function. Instead of determining the minimal consumption of health (*muH*) directly from the frish parameter and income elasticity of consumption, it is determined from the health and environmental damages to the region. The household is assumed to have a certain preference over health, which is not separable from the utility function.

Health (*HEALTH*) is determined from an exogenous amount of health (*H*), medical expenditures (*CMED*) multiplied by the relative effect of medical expenditures to health β and environmental damages to each household (*ENVDAMMHH*).

$$HEALTH_{th,r} = H * - ENVDAMHH_{th,r} + CMED_{th,r} \cdot \beta Med_{th,r} \quad (4.17)$$

The price for medical equipment is the market price for consumers.

$$PMED_r = P_{health,r} \cdot (1 - sc_{i,r} + tc_{i,r}) \quad (4.18)$$

Damages from emissions and household related damages would preferably be calculated directly from the concentration level of polluting substances however the required information was not available. Due to the limited information available, the calibration of the module needed to be simplified.

1. The value of health was calculated as the total medical expenditures, divided by a discount factor[13].

[13] A discount factor of 0.1 was chosen

2. It was assumed that a certain share[14] of the medical expenditures of the household are related to environmental damages

3. ExternE was consulted on the damages from emissions, rather than damages directly from concentration levels.

The environmental damages to each household are calculated as the total environmental damages (*ENVDAM*) from all emissions, weighted by the share of health damages and then multiplied with ($\beta dam_{th,r}$). βdam is a calibrated parameter, based on the estimated medical expenditures due to pollution related damages.

$$ENVDAMHH_{th,r} = \beta dam_{th.r} \cdot \sum_{emis} ENVDAM_{emis,r} \cdot shareHealthDam_{emis,reg} \tag{4.19}$$

Total environmental damages are calculated as the total emissions, multiplied with a damage coefficient.

$$ENVDAM_{emism,r} = \sum_{i} EMSEC_{emis,i,r} \cdot \beta emisDam_{emis,i,r} \tag{4.20}$$

The emission damage coefficients used are based on ExternE values for Eastern European countries (Romania, Poland, Bulgaria, and Hungary). Low, medium and high values for pollution damages were derived. However the “low” values are taken as the standard values. Due to a lack of information it was chosen to use the same damage coefficients for all regions and all sectors. Given the differences in population density between Russian federal regions and the differences in baseline ‘concentrations’ of emissions, this is probably not a good assumption.

Table 31: High, Medium and Low estimates for emission damage coefficients (based on ExternE)

Pollution Damages (/tonne)	Pollutants	Euro	Rubles
HIGH	Sox	8400	286440
HIGH	Nox	7300	248930
HIGH	PM10	20000	682000
HIGH	CO2	32	1091.2
HIGH	NMVOC	1500	51150
MEDIUM	Sox	4900	167090
MEDIUM	Nox	5400	184140
MEDIUM	PM10	12000	409200
MEDIUM	CO2	18	613.8
MEDIUM	NMVOC	860	29326
LOW	Sox	1800	61380
LOW	Nox	840	28644
LOW	PM10	4300	146630
LOW	CO2	8	272.8
LOW	NMVOC	230	7843

[14] Low income households = 10 %, medium income households = 5% and high income households = 1%

5. Simulation: Emission tax of 1 euro (38 roubles) / ton on primary pollutants

5.1 Structure of the report

Set-up of the simulation

The goal of this simulation is to check the new environmental module of the SUST-RUS model in a set of semi-realistic simulations. In these simulations, we treat the effect of introducing a 1 euro emissions tax / tonne for the primary pollutants: Carbon dioxide (CO2), Nitrates (NOx), Sulphur dioxide and derivatives (SOx) and particulate matter (PM). We will treat the greenhouse gasses (carbon dioxide emissions) and non-greenhouse gasses (NOx, PM and SOx) separately as both socio-economic and environmental effects of implementing the tax are relatively diverse.

The following assumptions are made on closure of the model and recycling of tax revenues.

- The collected tax revenue is recycled through government savings
- Exchange rate is considered to be fixed, meaning that the balance of trade is kept by increasing or reducing foreign savings/debts
- A static run is performed with the model, based on the 2006 database
- There are no end-of-pipe abatement possibilities for carbon dioxide, but there is abatement possible for non-greenhouse gasses

The effect of the health impact and monopolistic competition module

For our simulation we activate both the monopolistic competition module and health impact module, described respectively in paragraph 3.2.4 and 4.2.3. However, we start by checking if the modules are not severely distorting the results of the model. The full range of model runs is performed, switching the modules on and off. In total 16 model runs are performed, 4 runs for each pollutant (CO2, NOx, Sox and PM) with and without monopolistic competition and the health impact module.

Our first table (Table 32) shows how the aggregate indicators of gross domestic product (GDP) and welfare measure in equivalent variation (Welfare) are reacting to the activation of each module. From the table it is clear that the modules are only having a marginal effect on the simulation's results. The monopolistic competition module (*MCOMP*) increases the negative effect on welfare and GDP with slightly over 2.5%.The effect of the health impact module is more modest. It increases the impact on GDP and reduces the impact on welfare with 0.01%-0.1%. The reduction of GDP is caused by reduced expenditures on the health sector due to less environmental damages to the household.

Table 32 mainly shows how modest the effects of the introduced modules actually are.

Table 32: Emissions tax of 1 euro (38 roubles) / tonne – comparison with (On) and without (Off) health impact module and monopolistic competition module

			HEALTHIMPACT	
Indicator	Emissions Tax	MCOMP	Off	On
GDP	CO_2	Off	-48246.8	-48252.3
		On	-49567.1	-49575.2
	NOx	Off	-99.3	-99.6
		On	-101.2	-101.4
	PM_{10}	Off	-124.3	-124.6
		On	-128.4	-128.7
	SOx	Off	-212.6	-212.8

		On	-223.7	-223.8
Welfare	CO2	Off	-27617.4	-27571.6
		On	-28362.5	-28316.0
	NOx	Off	-59.8	-57.3
		On	-60.8	-58.3
	PM10	Off	-67.5	-65.0
		On	-69.8	-67.2
	SOx	Off	-114.1	-112.5
		On	-120.1	-118.5

5.2 Tax on carbon dioxide (greenhouse gas) emissions

Economic effects

The impact of the carbon emissions tax on the national economy is substantial. GDP in real terms decreases by about -0.189% from the baseline value which is equivalent to 50 billion roubles in monetary value. Social welfare measured by equivalent variation is reduced by 28 billion roubles. This represents about 0.15% of national income. The tax represses exports of fuels through price increase in domestic market. Imports increase by a similar mechanism, but to a lower degree. This implies that the tax leads to a decline in trade surplus. However, the increase in tax revenues from the carbon emissions tax is substantial. The increase in tax revenue, net from possible decreases in other revenues is 25.8 billion roubles. The volume of collected tax would, in theory, be sufficient to offset the decrease in welfare for consumers.

Table 33: The impact of the carbon emissions tax on the Russian economy

Output	BC	%Change	Absolute
GDP real	105810.606	-0.189	-50.029
Welfare	N/A	-0.153	-28.560
Energy index	0.211	-1.135	N/A
Tax revenues	40429.842	0.255	25.819
Total exports	30245.124	-0.138	-10.425
Total imports	21665.648	0.022	1.168

Naturally, the energy intensity of the Russian economy is falling substantially. The measure equal to the ratio of the monetary value of primary energy consumption to total GDP decreases by more than 1%. In a disaggregate Table 34 below, we show the effects of tax on economy-wide value added. The demand for gas and coal is decreasing the most compared to the base case scenario. Petrol use is only marginally decreased.

Table 34: The effects of the carbon emissions tax on economy-wide value added

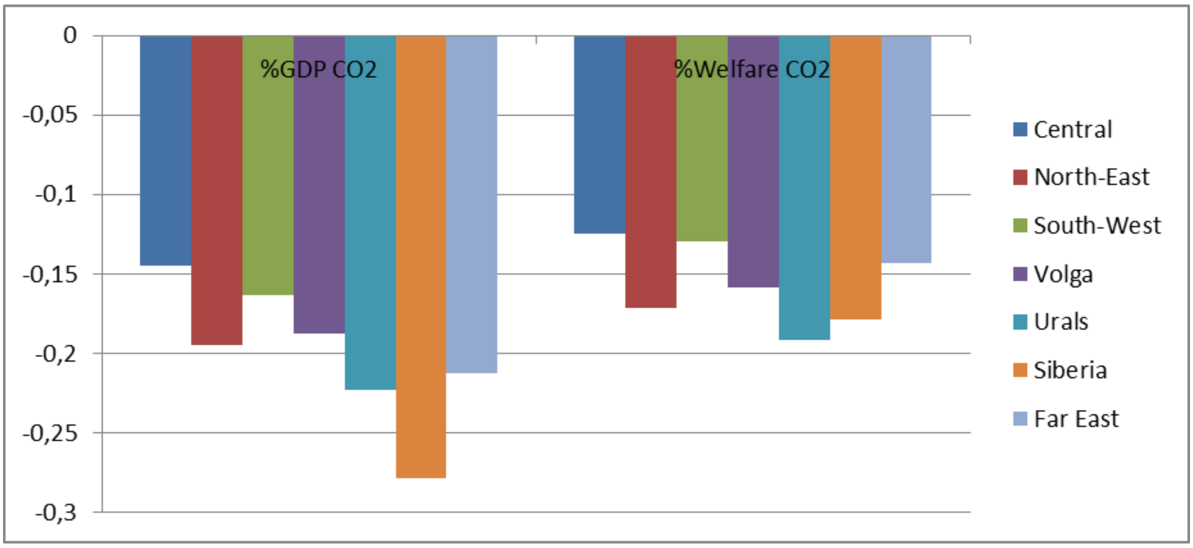
type	Bill. Rubles	%Change
Capital	0.41	0.00
Materials	-13.96	-0.06
Labour	-3.27	-0.03
Coal	-5.85	-2.43
Petrol	-0.70	-0.08
Gas	-11.73	-3.58
Electricity	-9.19	-0.63

Economic results at regional level

The economic effects at the regional level are quite diverse. We represent these graphically in the figure below. Relatively to the initial GDP the central region has the least effect of the carbon emissions tax. The reason for this is that central region has a larger service sector than the other regions and is thus less dependent on the production and export of primary energy. The central region also has more access to high value imported goods which are substitutes for more expensive domestic goods. The same is true for the North-East and South-West region.

This stands in contrast to the Urals and Siberian region. Siberia is especially very dependent on the use of coal based energy sources. Coal is the most carbon intensive energy source and the carbon tax has a relatively large impact on coal consumption. The economies of Ural, Siberia and to less extent Volga and Far East regions are not very diversified and very dependent on the resource extraction and carbon intensive manufacturing sectors. It contributes to the higher socio-economic impacts of emission tax increase.

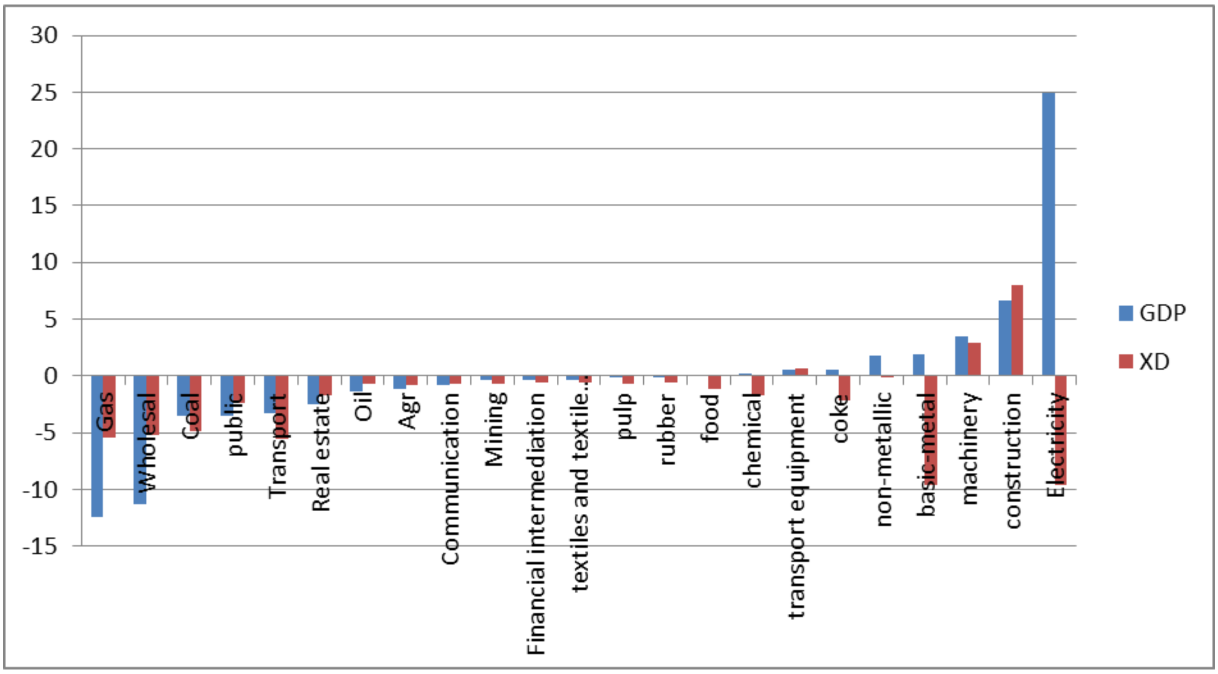
Figure 17: Relative change (%) in GDP (left) and Welfare (in % of national income) (right) by region



Economic results for key sectors

InFigure 18, we show economic effects in terms of GDP in current prices (GDP) and production (XD) in base prices.

Figure 18: Effects on GDP in current prices (GDP) and production (XD) in base prices

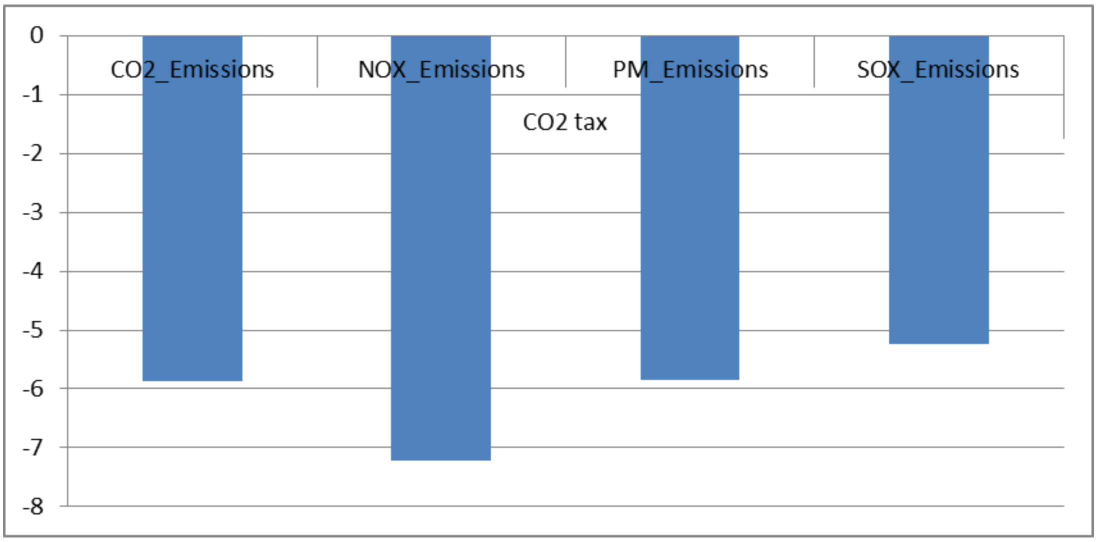


The results are ordered from left to right, based on the change in nominal GDP. Domestic prices of electricity, basic metals, machinery and other energy intensive goods increase considerably which offsets the decrease in production in real terms. Prices for primary energy fall (gas, coal and oil) as the emission tax distorts the market for energy inputs.

Environmental effects

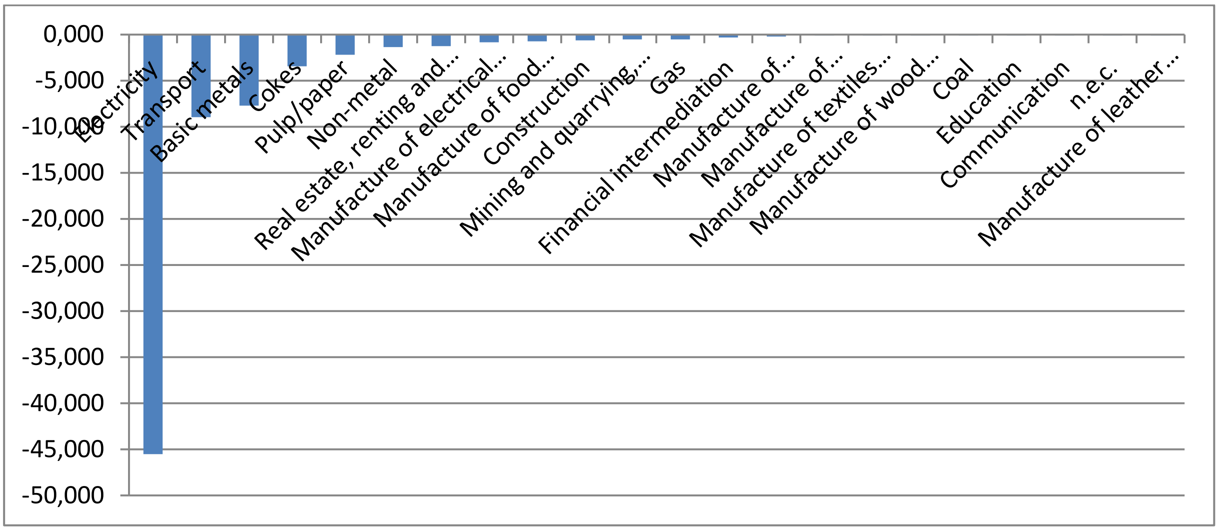
The carbon tax reduces emissions from all primary pollutants. The reason for this is that the tax leads to a reduced energy demand, as we assume that there are no end-of-pipe abatement possibilities for industries.

Figure 19. Effect of carbon dioxide emission tax on emissions of major pollutants (% change)



Below, we show the absolute amount of reduction in emissions of carbon dioxide (in Mtonnes) for each economic activity. As could be expected the largest reduction in emissions is originating from the electricity generation, transport and basic metals and cokes sectors.

Figure 20. The absolute amount of reduction in emissions of carbon dioxide (in Mtonnes), by economic activity

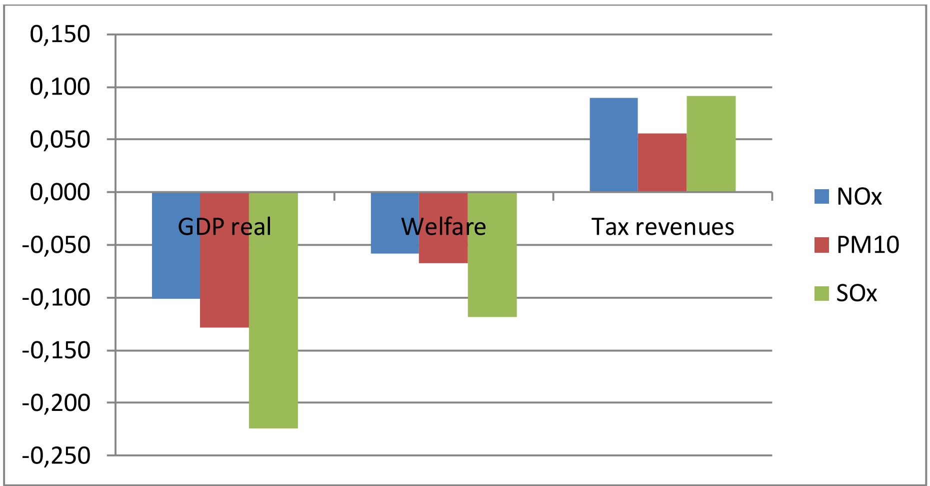


5.3 Tax on NOx, Sox and PM (non-greenhouse gas) emissions

Economic effects

Figure 19 reports changes in main economic indicators when ia 1 euro emissions tax on Nox, Sox and PM is applied. The effects of implementing an emission tax are relatively similar across pollutants. Implementation of an emissions tax on NOx pollutants has the lowest effect on GDP and welfare and the highest tax return. The tax on Sox which provides the same increase in tax revenues as tax on NOx leads to the highest decline in GDP.

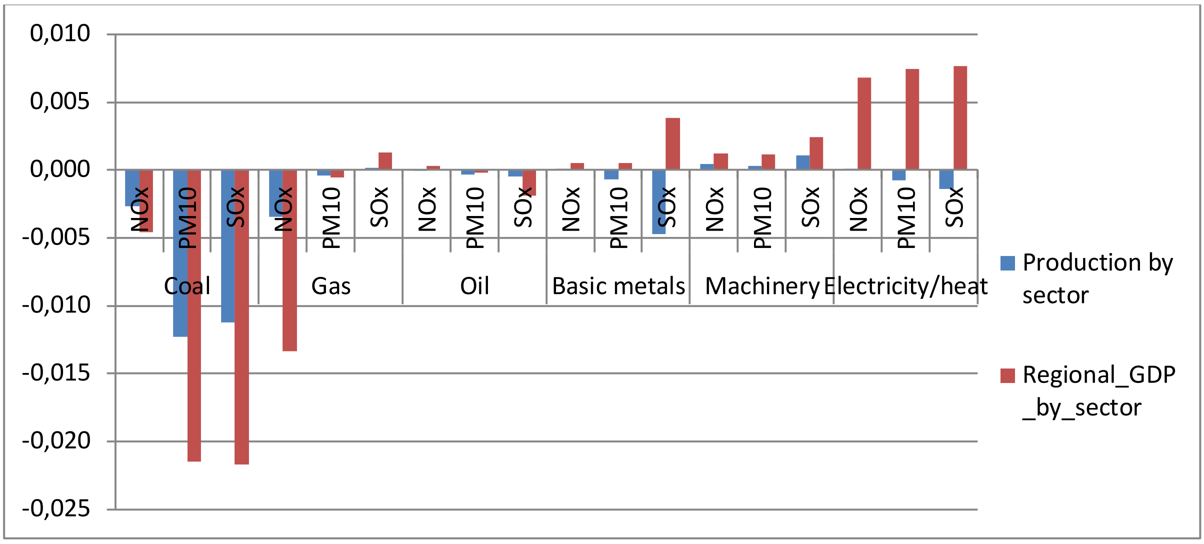
Figure 21: Economic effects of implementing emission tax (NOx, PM and SOx) in billions of roubles



Economic results for key sectors

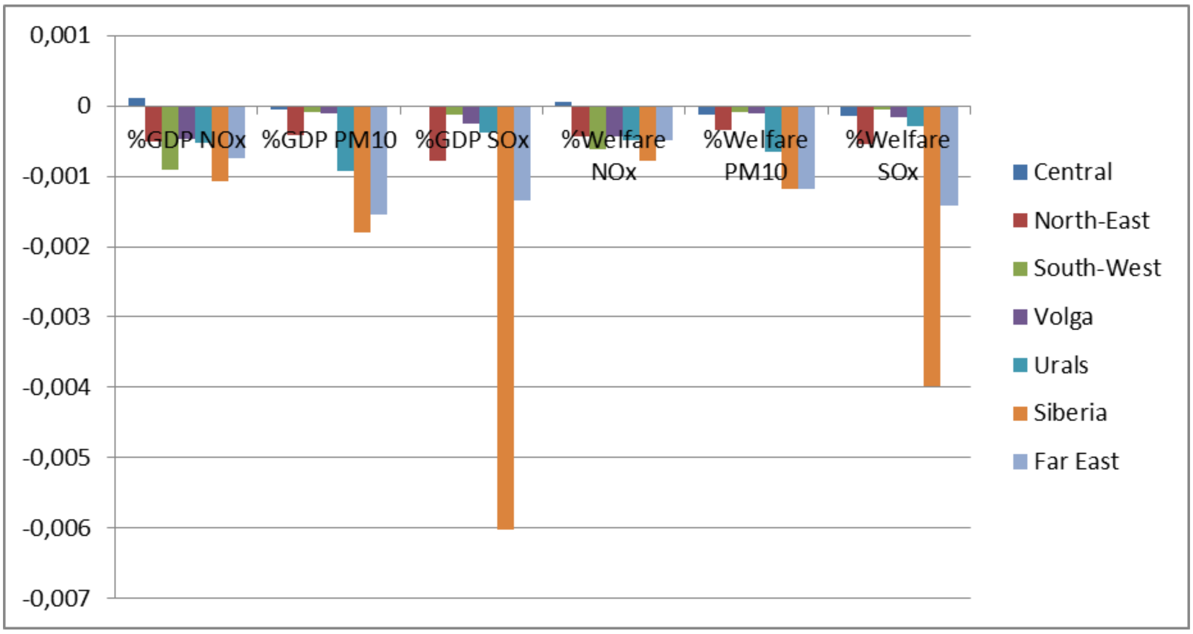
Figure 22 compares the relative changes in GDP and production when implementing the tax on emissions. While the effect is relatively similar in height, there are some notable differences. With a tax on NOx emissions the effect on coal is relatively limited. The demand and production of gas are reduced relatively to the initial GDP and income. The highest loss in welfare and GDP are realized in the regions of Siberia and Far East.

Figure 22: Comparison of GDP and production related effects in key sectors



Economic results at regional level

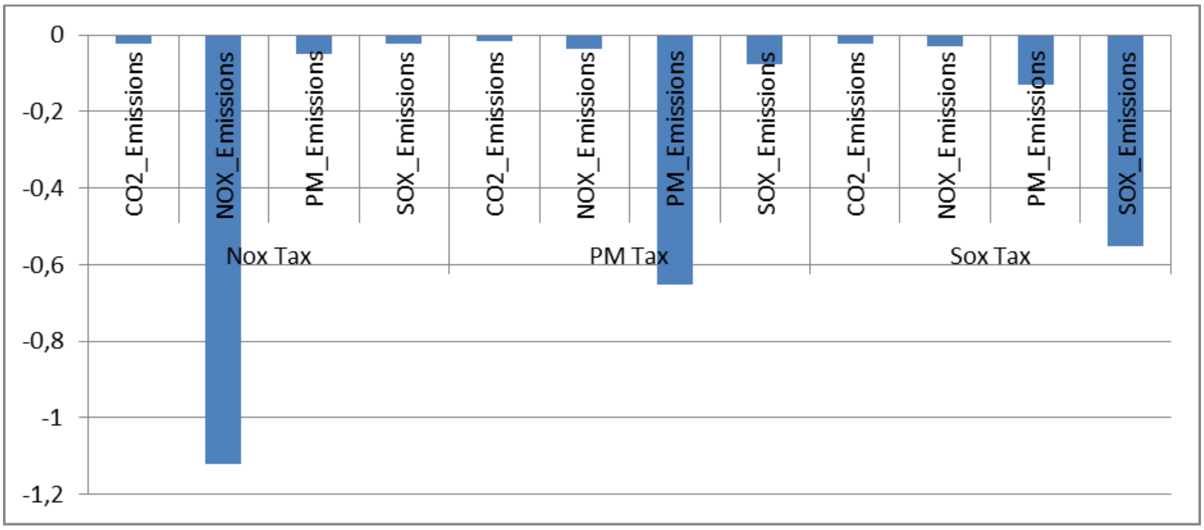
Figure 21: Relative changes (%) in GDP (left) and Welfare (right) (for NOx, PM and SOx) by region



Environmental effects

Figure 23 shows the effect of different emission tax schemes on total emissions. As the tax on emissions of particular pollutant decreases the overall demand for energy it has indirect effect on the other pollutants as well. Taxation of SOx related emissions, for example, has a relatively large effect on PM as it reduces the use of coal as a primary energy source.

Figure 23 Effect of emission taxes on NOx, SOx and PM on emissions of major pollutants (% change)



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