**Inter-Sector Inter-Region Analysis of Interactions between National Economy as a Whole and Its Energy Production Seсtor**

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1. **Introduction**

The paper discusses an approach to a long-term inter-sector and inter-regional analysis of interactions between a national economy and its energy production segment. It is based on an optimization multi-sector multi-regional model (OMMM) which includes a natural block of energy production, processing and transportation (OMMM-Energy) [Suslov et. al., 2007]. The latter, in its turn, is an advanced version of the model suggested and developed by Prof. Alexander Granberg [Granberg, 1973] – a famous Soviet and Russian economist who has made a noticeable contribution to the theory of regional structure analysis. At present, this version combines 45 products of different economic sectors including 8 ones of an energy sector (rough oil, gas and coal, two kinds of petroleum products, coal processing, electricity and heat), and 6 Russian macro-regions; it is a composition of two sub-models for 2 time periods: 2008**-**2020 and 2021-2030. Each of the sub-models treats time changes in simplified manner – it means that all the variables are defined for the last year of the period and the variables of the basic year are fixed as exogenous ones.

The dynamics of investments into fixed capital is treated as non-linear functions being adapted with the help of linearization techniques.

A basic advantage of the OMMM-Energy is a combination of different approaches such as the input-output, inter-regional and energy balances. This allows evaluating the complex effects and efficiencies of the policy measures undertaken in the spheres of production, processing and consumption of energy. Previously, the model was applied to evaluating economic consequences of the:

* concentration of energy-intensive productions and gasification in the South Siberia regions;
* fast development of nuclear energy in the national economy;
* a reduction of energy intensity of production in the national economy;
* wide application of heat pumps technologies in the different regions of the national economy;

and many others but less significant issues.

The next section of the paper briefly describes a history of how the Soviet Union applied and later Russia continued to apply the input-output interregional analysis and OMMM, and what are their basic characteristics in comparison with IO, IRIO and MRIO approaches. The section 3 discusses both methodology and history of developing the original OMMM resulted in an OMMM-Energy version of the model. The section 4 presents some results of our analysis conducted by applying the model, and finally, the last section presents our conclusions.

**2. OMMM: Identification and History**

Russia is the largest country in the world covering 12% of the Earth's land area and spanning four climate zones (Canada, being the second largest country, covers twice less area). Russia extends from the East to the West for about ten thousand kilometers. The enormous size of Russia results in the different climate conditions, landforms and remoteness of many regions from the seas. Average January temperatures in different regions varies from 6°C to −50 °C; June ones – from 1°C to 25 °C; and atmosphere precipitations – from 150 to 2000 mm per year. The extent of permafrost is 65% of a total Russian territory (in the regions of Siberia and the Russian Far East). Moreover, the natural resources are unevenly distributed within the territory of the country – about 80% of them are concentrated in the western areas (in Siberia and the Far East). The proximity of the Russian European regions to seas and European markets, as well as historical factors made these regions more economically developed. These regions cover 23% of the total area of Russia; 82% of all the Russian population lives here and they produce ¾ of the Russian GDP. There are 83 administrative regions in Russia, and the difference between them in levels of production and populations’ incomes per capita is rather high.

Due to the high environmental and economic heterogeneity of the Russian territory, the development and implementation of regional policies becomes one of the key factors of the national development. Awareness of this fact resulted in the progress of regional studies in the Soviet Union and later in Russia. In the 1960s we started the application of MRIOs.

The OMMM was proposed in the 1960s and described in [Granberg, 1973] for the first time. The first Soviet Union experimental forecasts for 1966-1975 involving 16 economic sectors and 11 regions were made in 1967. Another series of forecast calculations for 1975-1990 was made in the next years up to 1978. MRIOs of a Siberian type were involved in the UN Project on The Future of the World Economy in 1978-1982 at the suggestion of the UN AG Secretariat. Two systems of models – SYRENA and SONAR, both OMMM-based ones – were developed in the middle of the 1980s. The first model focuses on a national economy–region problem, while the second one (consisting of OMMM-Energy and several models for economic sectors) – addresses a national economy–economic sector problem. Since that time such OMMM was applied to forecast economic regional and sector development as well as to analyze how regions and sectors interact. This model also allows understanding how the supply shocks and investment project impact upon the national economy and regional ones.

To model regional interactions instead of specifying trade coefficients, the import/export of products to/from neighboring regions are added to the equations for balances of products. Therefore, such model includes not only production IO matrixes, but also matrixes of the inter-regional transportation of products (Fig. 1). An international export-import is represented only for regions capable to do so, i.e. the frontier ones. In such basic model, which we describe here, the volumes of export/import are determined for each identified sector; however, in some further versions of this model, they are endogenous, and the models include a national foreign export -import balance assuming that the country has a zero balance of trade (in the prices of the world markets) [Granberg et al., 2007].

In our opinion, such approach to modeling regional interactions has its advantages and disadvantages. The fact that it hampers an analysis of spillovers between regions – it is difficult to find out the dependence of output increments and final demand – make up such disadvantage. Moreover, a number of methodical and informational issues concern a transportation block – no counter flows are included into models of sector products transportation, and this brings about the roughening solutions which are the higher, the bigger the level of aggregation of sectors is. Certain difficulties lie in calculating coefficients of intra- and inter-regional transportation. In fact, a segment of demand for transportation sectors has to be set endogenously (to include counter flows costs) while coefficients of transportation costs – proportionally to average distances of transportation. [Granberg, 1973, Suslov et. al., 2007].

However, the transportation matrixes introduced into such model allows an optimization setting of the problem which is also desirable. This, in its turn, makes the structure of production and transportation more flexible, and this fact can be regarded vital for long-term forecasting made by applying such models. A comparative analysis of production efficiencies in different regions is available too as well as an introduction of additional alternative production technologies to produce a product of one species. However, as the model is linear, it is supplemented with the constraints for the output variables – (5).

An investment block of the model reflects the dynamics of production. All the variables of output, final demand, interim demand and demand for production factors in each region are defined for the last year of the time period of the model. Total investments for each kind of fixed capital are also specified. This is done through setting a law of investment growth and such laws for each kind of fixed capital as well. Generally, a power law is applied to specify functional dependencies of investments made in the last year of the time period on total investment made over the whole time period. Such dependencies enter the model as linear approximations. There are two kinds of output variables to model an investment process – the outputs received on production capacities existed up to the beginning of the period (old capacities) and those received on production capacities incorporated during the period (novel capacities) the investment coefficients for which are calculated according to different techniques.

An objective function of the model is households’ total consumption including consumption of public goods. Generally, such model has the fixed sector and regional structure of consumption. A sum of  coefficients in the constraint (1) is equal to 1: 

and the model is resulted to be a closed one for most variables of the final demand such as capital investments, investments in reserves (they are included in the sector’s consumption of their own products  - see the balance constraints 1), population’s consumption, and variables of domestic net export.

We present principle constraints of the basic OMMM below. It includes *n* segments of products and services (except transport services), *T* kinds of transport and *R* regions. Within the model there are several investment-generating sectors (which enter a set *G*) and as many kinds of investment, respectively. Each regional block *r* includes 5 kinds of constraints – the inequalities (1)-(5). The objective function is set not for a regional block but for the model in whole.





,  (5)

 (6)

Here endogenous variables are:

- production outputs of *i*-sector in *r*-region obtained by old and novel production capacities;

 - transportation work made by transport of kind *τ* in *r-*region within the framework of transport capacities of the transport infrastructure available as of the beginning of the period and that one developed over the period, respectively;

- a volume of capital goods *i* invested in *r-* region in the last year of the period;

Z - total consumption of households;

-– a fraction of output of *i*-sector transported from *r*-region to *s*-region;

Exogenous variables are:

 - intra-regional input coefficients (*i*-sector product per output of *j*-sector in) in *r*-region at old and new production capacities correspondently;

 - amount of transport service of kind *τ* consumed per a unit of sector *i* product at old and new production capacities correspondently;

- - amount of transport service of kind *τ* consumed to bring a unit of sector *j* product from *s*-region *r*-region;



- labor input coefficients at old capacities and novel capacities in production sector *j* and transport sector respectively in *r*-region;

- investment input coefficients of *g-* kind of investment good at old capacities and novel capacities in production sector *j* and transport sector respectively in *r*-region;

 - a share of sector *i* from region *r* in the Russian total volume of consumption;

 - investments of kind *g* made in *r-*region in a basic year;

 - net international export (export minus import) of products of *i*-sector from *r-*region;

- a fixed share of demand for products of *i*-sector in *r-*region.

The inter-regional production and distribution balances of products and services (except transportation services) reflect both intraregional consumption flows and export ones (1). However, how the exported products and services are going to be consumed is not presented in these balances while the imported products and services are included into domestic consumption. The export and import between counties are fixed values in this version of the model.

The transportation balances reflect intra-regional transportation flows as well as export/import ones. The  coefficients are calculated on the basis of both average transfer distances and indices of weight of a transferred product unit of a given sector.

The labor balances are the constraints describing labor demand in a given region, while supply is specified exogenously on the basis of the demographic forecasts available.

The investment balances specify the investments made not over the last year of the period but over the time period in whole. They balance the demand represented as a sum of the output multiplied by investment coefficients and total output of capital goods produced over the whole period. The functions  which represent a total volume of *g-* investment made in *r-*region play a key role. In assumption that  where  isan average annual rate of growth of *g*-investment made in *r*-region, the functions depend on  and could be easily calculated and then substituted by their linear approximations. In fact, it is the rates of investment growth  which we approximate.

Modern versions of OMMM are based on the following statistical data:

* Aggregated Input-Output Tables for the Russian national economy for each year from 1995 up to 2004 which include 20 sector products;
* tables of goods and services consumed in Russia (in consumer prices of next year) which include 20 sector products,
* Russian National Input-Output Table for 1995 which includes more than 100 sector products, and
* other statistics provided by the Russian Statistics (ROSSTAT).

There some difficulty in calculating regional input-output tables. Unfortunately, neither ROSSTAT, nor regional statistical bodies have started with issue such data since the beginning of the economic reforms, at least in regularly and in complete patterns. That is why we, since the end of 1980s, have to adjust regional differences of input coefficients to update current regional IO tables. For this purpose we apply certain kinds of RAS methods.

**3. OMMM-Energy**

Russian energy sector is the largest and most important one for the economy of the country. Russia possesses about 13% of the world oil reserves, more than 35% of the world gas reserves and 12% of the world coal reserves, and this could be regarded as a basic competitive advantage of our economy which could last long. The energy sector produces about 15% of GDP while it consumes approximately a quarter of the national investments. However, it produces about 60% of a total Russian export and as many percents of a consolidated budget of the Russian Government. This fact displays that energy production has an extremely strong indirect influence on the economy of Russia, and therefore, there is a need for a comprehensive analysis of interrelations between the national economy and its energy sector. Moreover, given the extremely heterogeneous distribution of energy resources – mostly in Siberia and the Far East regions, and high concentration of the population and non-energy productions in European area of the country, of inter-regional interactions plays a key role.

The studies on interactions between the national economy and its energy sector, which has brought the relatively noticeable results, started only the 1970s due to the energy crisis [Mann, 1978, Bullard and Pilati, 1976, Dantzig and Parikh, 1976, Hogan, 1976, Hudson and Jorgenson, 1974, Van der Voort, 1982]. They applied both large models with an energy sector included and combinations of economic and energy models united in a general model. The researchers’ priority issues were the problems of tax and trade policies and how prices for energy resources influence the structures of energy consumption and national economy. Later, the modeling focuses on long-term forecasting of energy consumption, the development of fuel-energy complexes and what such complexes could contribute to economic development of the country [Chateau and Quercia, 2003, The Energy Market, 2002, The National Energy, 2009, Voß et. el., 1995, Wade, 2003]. These studies were made in the Soviet Union and later in Russia by the ISEM SB RAS, INEI RAS, IEIE SB RAS [\*\*] by applying OI models. Having started the development of its own approach since the 1980s, the IEIE SB RAS applies a multi-regional IO model, later called as OMMM-Energy.

OMMM-Energy is an optimization multi-sector multiregional model which presents an energy sector and its energy production in their physical indicators. It was developed on the basis of “classical” OMMM discussed before. A current model includes 45 economic sectors, with 8 products among them, and 6 Russian economic zones (the European zone, Ural region, Tyumen Oblast, West Siberia, East Siberia and Far East). It succeeds basic advantages and disadvantages of the OMMM-prototype and differs from the latter in a number of aspects.

Firstly, it is a two-period forward recurrence model containing two sub-models – one for 2008-2020 and the second - for 2021-2030. The investment dynamics is reflected in both of them through an OMMM-prototype; this means that a law of investment growths is set as a non-linear one and then it is linearized. The solutions of the first model become basic indicators for the second one.

Secondly, the energy sectors are presented in greater detail. This was done, among other purposes, to present energy products in physical indicators. A current model includes 8 energy products such as solid fuel, processed coal, oil and associated gas, gas and condensed fluid, dark- oil products, light oil, electric power and heat. This allows monitoring ratios between primary and final energy produced.

Thirdly,some non-energy sectors which are important for analyzing the energy sector were specified such as the industry producing equipment required for production, transportation and consumption of energy, petroleum chemistry and some others.

Finally, we modified the model to allow for the specifics of how any fuel-energy complex can operate such as:

* specific reproduction of capacities in the oil-and-gas sector;
* the development of resource industries highly depends on whether geophysical prospecting have been done and its results if it has been done; it also depends on to what degree the fuel resources have been developed in different regions and in the country in whole;
* complementary outputs of different energy technologies (e.g. oil and associated gas, or gas and condensed fluid)
* specific transportation of oil and gas (a pipeline system); and
* availability of alternative technologies for energy and heat production at heat stations, condensing plants, nuclear power plants, boiler plant, and etc. which operate on different fuel (coal, fuel oil, and gas).

A classic OMMM assumes that any sector product is manufactured by “old” and “novel” production capacities. The capacities, which operated from the beginning to the end of a predictable period and by which the product was produced over the period, we consider as old ones. Those, which were produced through investments into extension of capacities to yield a sector output growth, we consider as novel ones. A notion of “old capacities” for resource industries differs from that for processing industries as the resource industries deal with production of irreproducible resources. In this context, each share of investments requires an additional share of the commercial oil and gas reserves and can be regarded as new capacities costs. Moreover, an annual volume of capacities retired in oil-and-gas sectors is relatively high.

Due to the said specifics, we applied another approach to modeling reproduction process in these industries, not that one which was applied in the OMMM prototype, i.e. the variables of investments are considered as nonlinear functions of extracting capacities put into operation over the predictable period. Such functions, firstly, reflect the rises in costs for new capacities because of transition from more to less efficient oil and gas fields, and secondly, they allow us to take into account an increased volume of capacities retired.

In addition, we introduced a new block of oil-and-gas reserves which reflect a ratio between novel production capacities and new commercial reserves put into operation in a given region or in the sector in whole. To do so, we consider urgent as we need know a ratio between a degree of redundancy of oil reserves and annual gas production. According to the reproduction laws for these industries, such redundancy lies in certain fixed limits. If it is higher than an allowable value, the freezing of large funds invested into geological prospecting may occur; if it drops below the bottom, our forecasts of oil-and-gas production may happen unreliable. Thus, such degrees of redundancy being fixed serve as an upper limit for variables of commissioning novel facilities while the investments into reserves (geological prospecting) are included into a total investment balance.

**4. Application of OMMM-Energy: Some Results**

A basic advantage of the OMMM-Energy is a combination of different approaches such as the input-output, inter-regional and energy balances. This allows evaluating the complex effects and efficiencies of the policy measures undertaken in the spheres of production, processing and consumption of energy. Previously, the model was applied to evaluating economic consequences of the:

* concentration of energy-intensive productions and gasification in the South Siberia regions;
* fast development of nuclear energy in the national economy;
* a reduction of energy intensity of production in the national economy;
* wide application of heat pumps technologies in the different regions of the national economy;

and many others but less significant issues.

To illustrate what can be obtained by applying such models, we present the results of our analysis concerning the efficiency of different arrangements undertaken to widen application of heat pump technologies in Russia and Russian regions. For this purpose we applied a previous OMMM-Energy covering 1999-2010 which is practically analogous to the above model.

Table 1

Consequences of Heat Pump Technologies Applied in Russia and Russian regions

(providing that transformation coefficient is 3; and heat pumps cover 10% of electricity demand)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | National Economy | | European Area of Russia | | Western Siberia | | Eastern Siberia | |
|  | Incre-ment | % | Incre-ment | % | Incre-ment | % | Incre-ment | % |
| GDP,  million Rubles of the year 2000 | -20328 | -0,10 | -22678 | -0,11 | 4492 | 0,02 | 1609 | 0,01 |
| Consumption of households, mill. Rubles of 2000 | -28613 | -0,27 | -27288 | -0,26 | 3342 | 0,03 | 1085 | 0,01 |
| Investment over the period, million Rubles of the year 2000 | 37017 | 0,10 | 18098 | 0,05 | 6307 | 0,02 | 3665 | 0,01 |
| Energy consumption including indirect needs,  million ton of coal equivalent | -1 | -0,08 | 2 | 0,21 | -3 | -0,25 | -3 | -0,25 |
| Electricity consumption including indirect needs,  billion kWt-hours | 80 | 7,0 | 61 | 5,3 | 5,6 | 0,49 | 6,0 | 0,52 |
| Energy intensity of GDP, % |  | 0,02 |  | 0,32 |  | -0,27 |  | -0,26 |
| Increment of GDP per increment of energy consumed by heat pumps,  Rubles/thousand. kWt-hours | -273 |  | -406 |  | 761 |  | 271 |  |

A heat pump is a machine or device that transfers thermal energy from one location, called the "source" (of a natural or anthropogenic character), which is at a lower temperature, to another location called the "sink" or "heat sink", which is at a higher temperature. The heat transferred to a consumer may be several times higher than energy of the source, i.e. a transformation coefficient lies in the range of 3-7 times. Widened application of heat pumps, on the one hand, reduces the application of traditional heating technologies and, thus, the fossil fuel consumed; on the other hand, it requires additional electric power inputs.

According to the forecasts made by International Energy Agency, the shares of heat pumps may achieve 70% of total heat supply in economically developed countries by 2020. We assume that this Russian figure may be 10% of supply since today Russia is in its start of application such technology.

In our forecasting, we assume that: 1) heat pump technologies ensure 10% of heating supply in regions, providing that governmental and regional supports are available; 2) no other factors such as the nuclear- and hydro-power industries as well as non-traditional energy sectors won’t affect. This means that introducing such new technologies, the programs of higher production of nuclear- and hydro powers do not change while such new technologies ate introducing; and thus, 3) any increase in demand for fuel can be covered only by coal.

We carried out several series of calculations, each of them included 6 variants, varying transformation coefficient from 3 to 6. The first variant (a national scenario) analyzes what effect could occur if 10% of the national heating demand is covered by applying this new technology. Each of the next five (regional scenarios) considers what effect could be if such technology is applied only in a given region. Then we compare a system of optimal indicators obtained for each variant with relative ones describing the variant which does not provide for such technology. The variant showing the increment of GDP and households’ consumption, providing that there are enough investment made can be regarded as an efficient; and the reduction of GDP display inefficiency. Such national approach to assessing efficiency of new technologies implies, in particular, that having applied a new technology in a certain region, a national effect can be calculated as a sum of increments of GDP and households’ consumption obtained for all regions.

Interpreting the results obtained we should have in mind that heat pumps require for their operation another kind of energy, i.e. electricity, which is more qualitative and expensive than heat generated.

Thus, the greater the application of heat pumps is, the lower the fuel demand of boiler plants and individual boiler houses is, while the electric power demand increases a need in additional power generating capacities and fuel inputs, both transferred from the eastern regions of Russia.

Our general conclusion is the higher the transformation coefficient is, the higher the efficiency of heat pump technology is. This is firstly. Secondly, the less strained the electricity balance is, the higher such efficiency of heat pumps technology applied in a given region is, providing that the heat substituted, on the contrary, is rather expensive. Here we fragmentarily present our results and not all of – only one series of calculations – those which are of a “threshold character”. Given the transformation coefficient at the level of 3, a heat pumps technology becomes efficient in Siberia, whereas in the European regions of Russia it is economically sound at the level of 5. Moreover, the Table 1 shows, that an effect of substituting heat pump technologies for traditional heat ones is higher in West Siberia than in East Siberia. As for European regions of Russia, application of these technologies means a reduced volume of heat produced by the heat sources operating on gas and; thus, a reduced volume of gas consumed may become available to produce heat by heat pumps technologies. However, this “disengaged” gas cannot fully cover an increase in electricity demand, and therefore, an additional volume coal is required, but this volume coal is transported from Siberia and the costs of its production at the Kuznetsk Coal Basin, as stated above, exceeds the effect of fuel saving. Moreover, a fact of a lower performance index of plants operating on coal in comparison of those operating on gas should not be ignored.

It is coal but not gas is saved by application of heat pumps technologies in Siberia; therefore, only coal (both “disengaged” and transported to Siberian heat power plants from the coal basins of Kuznetsk and Kansk-Achinsk) is used to cover additional demand for electricity. However, length of hauls is 3-4 times less than those from Siberia to Europe. It appears that at a given level of transformation coefficient, the saving obtained through substitution heat pump technologies for traditional ones exceeds the growth of total costs of additional production of electricity.

This effect is much higher for Western Siberia than for Eastern Siberia despite the less costs of electricity production in the latter. This can be explained by the fact that in Eastern Siberia the marginal fuel is Kansk-Achinsk brown coal, which is much cheaper than black coal produced by Kuznetsk mines and consumed by Western Siberia. However, given the current coal firing technologies in Russia, the more qualitative coal does not give more advantages than less qualitative one, at least, according to their performance indices. Thus, the total saving by fuel economy calculated per a unit of increment of demand in electricity proved to be less in Western Siberia than in Eastern Siberia (Fig. 1, Comparative data for the Western and Eastern Siberia regions).

**5. Conclusion Remarks**

OMMM-Energy is an optimization multi-sector multiregional model which presents an energy sector and its energy production in their physical indicators. It was developed on the basis of “classical” OMMM discussed in the section 2 of this paper. A current model includes 45 economic sectors, with 8 products among them, and 6 Russian economic zones (the European zone, Ural region, Tyumen Oblast, West Siberia, East Siberia and Far East). It succeeds basic advantages and disadvantages of the OMMM-prototype and differs from the latter in a number of aspects.

This model has been applying in IEIE SB RAS since the middle of 1980ths. A basic advantage of the OMMM-Energy is a combination of different approaches such as the input-output, inter-regional and energy balances. This allows evaluating the complex effects and efficiencies of the policy measures undertaken in the spheres of production, processing and consumption of energy.

Further use of this model is associated with conducting scenario analysis of energy sector and national economy interactions within the future period up to 2030.

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