FORECASTS FOR ENERGY DEVELOPMENTS IN CHINA, JAPAN, AND KOREA BASED ON THE GLOBAL ENERGY MODEL

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Overview

All scientists know that modeling is a process of turning a problem into a mathematical statement, where it has to be decided what to keep and what to "put out" of the model. Our problem was the question: what energy technologies will be used and how intensively they will be used in Japan/Korea, China, and former Soviet Union in the future. The GEM-Dyn model, which was modified 2010-2011 in Moscow's Energy Research Institute and in Irkutsk's Energy Systems Institute based on the GEM-10R model developed previously in the same institutes, delivered scientifically founded answer on these questions.

The GEM-Dyn model is a large-scale mathematical construct designed to replicate how energy technologies are used in all three above mentioned macro-regions and is the principal tool used to generate detailed region-by region projections for various scenarios including the "realistic" scenario, the scenario "without ecological constraints" and some other scenarios. Modified over two last years, the model consists of three main modules: electricity, heat, chemical and mechanical energy generation; refinery/petrochemicals and other transformation; fossil-fuel supply. At the same time CO_2 and some other pollutant emissions and investment are modeled (see Part "Methods").

The modeling horizon in this article is 2050. We base our modeling on scenario "without ecological constraints".

Methods

Mathematical description. GEM-Dyn is a linear dynamic optimization model with detailed description of many technologies in extraction, conversion, transportation, import/export, and consumption of energy; also pollution removement technologies are analyzed. The model has a set of constraints (resources, ecology, finance, and energy needs) and forecasts long-term tendencies in the global and mega-regional energy developments: extent of the energy technologies developments, energy consumption and energy production structure, emisiions (CO_2, Ash, NOx, SOx) etc. The model's goal function and constraints are presented below.

Goal function is:

$$Z = \sum_{t=2010,\Delta t=10}^{2050} \varphi_t \left(\left(\sum_{r=1}^{10} \alpha_{tr} \sum_{j \in J} c_{trj} x_{trj} \right) + \sum_{j \in J} c_{tr_{k1}r_{k2}j} y_{tr_{k1}r_{k2}j} \right) \to \min_{X,Y}$$

, – here c_{trj} – specific costs of technology j in region r for the period t, x_{trj} – installed capacity (or productivity) of technology j in region r for the period t, α_{tr} – weight factor of region r for the period t, $c_{trk1k2j}$ – specific costs of technology j in direct energy deliveries from region r_{k1} into region r_{k2} for the period t, $y_{trk1k2j}$ – installed capacity (or productivity) of technology j in direct deliveries from region r_{k1} into region r_{k2} for the period t, φ_t –discounting factor for the period t. Due to changing the weight α_{tr} in the range from 0 to 1 we could consider interests of regions; in particular case, when weigths α_{tr} are equal to 1, then goal function is considered to be "standard". The model considered the period 2010-2050, as consisting of 5 periods (each as long as 10 years), i.e. T = {2010, 2020, 2030, 2040, 2050}. This goal function was subject to different regional and global constraints as described below.

Regional constraints are:

- $\sum_{j \in J_1} a_{rij}^{(t)} x_{trj} \le b_{ri}^{(t)}$ - extractions constraints for primary energy, $i \in I_1$, $r \in R$, $j \in J_1$, $t \in T$;
- $\sum_{j \in J_1} a_{rij}^{(t)} x_{trj} + \sum_{j \in J_2} a_{rij}^{(t)} x_{trj} - \sum_{j \in J_3} a_{rij}^{(t)} x_{trj} - \sum_{j \in J_4, J_5} a_{rij}^{(t)} x_{trj} = 0$ - balance equations for primary energy, $i \in I_1$, $r \in R$, $j \in J_{1,2,3,4,5}$, $t \in T$;
- $\sum_{j \in J_4} a_{rij}^{(t)} x_{trj} + \sum_{j \in J_2} a_{rij}^{(t)} x_{trj} - \sum_{j \in J_3} a_{rij}^{(t)} x_{trj} - \sum_{q \in J_{4,5}, q \ne j} a_{riq}^{(t)} x_{trq} = 0$ - balance equations for secondary energy, $i \in I_2$, $r \in R$, $j \in J_{2,3,4,5}$, $t \in T$
- $\sum_{j \in J_5} a_{rij}^{(t)} x_{trj} \ge b_{ri}^{(t)}$ - final energy production constraints, where $i \in I_3$, $r \in R$, $j \in J_5$, $t \in T$
- $-\sum_{j \in J_6} a_{rij}^{(t)} x_{trj} + \sum_{q \in J_{1,2,3,4,5}} a_{riq}^{(t)} x_{trq} \le b_{ri}^{(t)}$ - pollution constraints, $i \in I_5$, $r \in R$, $j \in J_6$, and $q \ne j$, $t \in T$
- $\sum_{j \in J_{1,2,3,4,5,6}} a_{rij}^{(t)} x_{trj} \le b_{ri}^{(t)}$ - investments constraints, $i \in I_6$, $r \in R$, $j \in J_1$, $t \in T$
- $lb_{trj}^{\min} \le x_{trj} \le ub_{trj}^{\max}$ - lower and upper bound constraints $j \in J_{1,2,3,4,5,6}$, $r \in R$, $t \in T$.

Special regional constraint is:

- $\sum_{j \in J_4} a_{rij}^{(t)} x_{trj} + \sum_{r \in R} \sum_{j \in J_2} a_{rij}^{(t)} x_{trj} - \sum_{p \in R} \sum_{j \in J_3} a_{pij}^{(t)} x_{tpj} - \sum_{q \in J} a_{riq}^{(t)} x_{trq} \ge b_{ri}^{(t)}$ - electricity production constraints, $i \in I_4$, $r \in R$, $j \in J_4$, and $q \ne j$, $t \in T$;

Global constraints are:

- $\sum_{r \in R} \sum_{q \in J_{1,2,3,4,5}} a_{riq}^{(t)} x_{trq} - \sum_{r \in R} \sum_{j \in J_6} a_{rij}^{(t)} x_{trj} \le b_i^{(t)}$ - global constraint for CO_2, $i \in I_5$, i corresponds to CO_2, and $q \ne j$;
- $\sum_{r \in R} \sum_{q \in J_2} a_{rij}^{(t)} x_{trj} - \sum_{p \in R} \sum_{j \in J_3} x_{tpj} = 0$ - balance constraints for import and export of primary and secondary energy resources and investments, $i \in I_{1,2,6}$, and $p \ne r$.

In this formulation I_1 is the set of the primary energy resources, I_2 is the set of the secondary energy resources, I_3 is the set of the final energy (mechanical, chemical, electrical, heat), I_4 is the set of electricity production regimes, I_5 is the set of the pollution types (Ash, NO_x, SO_x, CO_2), and I_6 is the set of the investments resources. At the same time J_1 are extraction technologies, J_2 / J_3 are energy import / export technologies, J_4 are conversion to secondary energy technologies (including electrical energy accumulation), and J_5 are final energy production technologies, J_6 are pollution removal technologies, q≠j, R is the list of the mega-regions. The dynamics of every technology j was described with additional constraints like $x_{hhj} - x_{htj} \geq 0$ where h - the time period in which technology were introduced, t – the current time period, and t≥h.

In other words we tried to minimize the costs of energy technologies used in the world where scares resources are extracted, then transformed into secondary and then final energy to satisfy macro-regional energy needs, where different pollutant are emitted, and where financial and/or ecological constraints exist.

Equalities and inequalities. Let us consider equalities and inequalities of the model, I = {I_1, I_2, I_3, I_4, I_5, I_6}. The number of constraints in the model varies with the number of macro-regions and time periods. For example, if we model 3 macro-regions (Japan/Korea, China, former Soviet Union) for 2010, then for every equality / inequality constraint we use 3 equations / inequalities in the model, if we model 3 macro-regions for 2 time periods, then we use 6 equations / inequalities in the model etc.. Most part of the inequalities have sign "less or equal", but some inequalities have sign "more or equal"[1]. Tables below show the short specifications for all constraints {I_1, I_2, I_3, I_4, I_5, I_6} used in the model.

Table 1: List of all constraints, set I (total 100 constraints)

'Ash', 'Bio1', 'Bio2', 'Bio3', 'BioA', 'CO2', 'Chem', 'CoalA', 'Col1C', 'Col2C', 'Col3C', 'Col4C', 'Col5C', 'Col6C', 'Col7C', 'Col8C', 'Elec', 'Gas1C', 'Gas2C', 'Gas3C', 'Gas4C', 'Gas5C', 'Gas6C', 'Gas7C', 'Gas8C', 'GasA', 'Geo1', 'Geo2', 'Geo3', 'HCap, 'Heat', 'Hydr0', 'Hydr1', 'Hydr2', 'Hydr3', 'Inv', 'Mech', 'NOx', 'Oil1C', 'Oil2C', 'Oil3C', 'Oil4C', 'Oil5C', 'Oil6C', 'Oil7C', 'Oil8C', 'OilA', 'Power', 'RAE', 'RAM', 'RAQ', 'RCC', 'RCE', 'RNE', 'RNM', 'RNQ', 'RSE', 'SOx', 'Sol1', 'Sol2', 'Sol3', 'Space', 'U51C', 'U52C', 'U53C', 'U54C', 'U55C', 'U56C', 'U57C', 'U58C', 'U5A', 'U81C', 'U82C', 'U83C', 'U84C', 'U85C', 'U8A', 'Wind1', 'Wind2', 'Wind3', 'Wind4'

Source: authors' work

Table 2: List of constraints, set I, "more or equal"

'Chem'; 'Elec'; 'HCap'; 'Heat'; 'Mech'; 'Power'; 'RAE'; 'RAM'; 'RAQ'; 'RCC'; 'RCE'; 'RNE'; 'RNM'; 'RNQ'; 'RSE'

Source: authors' work

Table 3: List of constraints, equalities, set I

'&Coal', '&Gas', '&Gsln', '&H2', '&Mtnl', '&Oil', '&Orst', '&U235', '&U238', 'Bio', 'Coal', 'Gas', 'Gsln', 'H2', 'Mtnl', 'Oil', 'Orst', 'U235', 'U238'

Source: authors' work

The short specification 'Ash' means the constraint for maximal amount of ash pollutions (mln t/yr), for given time period, for given macro-regions; the short specifications 'Bio1', 'Bio2', 'Bio3' mean generation of cheap, expensive and very expensive bio-energy (mlnTJ/yr) etc.

[1] This is important for writing code of the program

Table 4: List of constraints, set I_1, (extraction of resources), total 61 constraints

'Bio1', 'Bio2', 'Bio3', 'BioA', 'CoalA', 'Col1C', 'Col2C', 'Col3C', 'Col4C', 'Col5C', 'Col6C', 'Col7C', 'Col8C', 'Gas1C', 'Gas2C', 'Gas3C', 'Gas4C', 'Gas5C', 'Gas6C', 'Gas7C', 'Gas8C', 'GasA', 'Geo1', 'Geo2', 'Geo3', 'Hydr0', 'Hydr1', 'Hydr2', 'Hydr3', 'Oil1C', 'Oil2C', 'Oil3C', 'Oil4C', 'Oil5C', 'Oil6C', 'Oil7C', 'Oil8C', 'OilA', 'Sol1', 'Sol2', 'Sol3', 'Space', 'U51C', 'U52C', 'U53C', 'U54C', 'U55C', 'U56C', 'U57C', 'U58C', 'U5A', 'U81C', 'U82C', 'U83C', 'U84C', 'U85C', 'U8A', 'Wind1', 'Wind2', 'Wind3', 'Wind4'

Source: authors' work

Table 5: List of constraints, set I_1, (primary resources balance, equalities), total 6 constraints

'Coal', 'Gas', 'Oil', 'U235', 'U238', 'Bio'

Source: authors' work

Table 6: List of constraints, set I_1, (secondary resources balance, equalities), total 4 constraints

'Gsln', 'Mtnl', 'Orst', 'H2'

Source: authors' work

Table 7: List of constraints, set I_3, (final energy production), total 4 constraints

'Chem'; 'HCap'; 'Heat'; 'Mech'

Source: authors' work

Table 8: List of constraints, set I_5, (ecology constraints), total 13 constraints

'Ash', 'CO2', 'NOx', 'SOx', 'RAE', 'RAM', 'RAQ', 'RCC', 'RCE', 'RNE', 'RNM', 'RNQ', 'RSE'

Source: authors' work

Table 9: List of constraints, set I_6, (investments), total 1 constraint

'Inv'

Source: authors' work

Table 10: List of constraints, set I_4, (power generation), total 2 constraint

'Elec'; 'Power'

Source: authors' work

Table 11: List of constraints, set I_5, (global CO2 constraint), total 1 constraint

'CO2'

Source: authors' work

Table 12: List of constraints, sets $I_{1,2}$, (primary and secondary energy "trade"), total 11 constraints

'&Coal', '&Gas', '&Oil', '&U235', '&U238', '&Gsln', '&H2', '&Mtnl', '&Orst',

Source: authors' work

To solve the model we used the simple linprog method of Matlab solver (Mathworks product). Objective function were the total costs of using the given technology set in the given regions in the given time periods. The lower bounds were mostly all zeros; the upper bounds were usually set as low as possible to obtain a feasible initial point.

The constraints were for: resources extraction, investments, ecology, and demography and energy consumption; in total, 81 balance inequalities blocks and 19 balance equations blocks[2].

Results

First of all we run the model separately for each of three macro-regions: for former Soviet Union, for China, and for Japan/Korea. The most remarkable result was the fact that only former Soviet Union would survive under the conditions of "realistic" scenario, China and Japan/Korea would have problems (China due to ecology, Japan/Korea due to resources; the solution was feasible for China under the "without ecological constraints" scenario, the solution was feasible for Japan/Korea under scenario "with ressource abundance").

Then we run model three times for different pairs: former Soviet Union and Japan/Korea, former Soviet Union and China, Japan/Korea and China. The most remarkable result here was the fact that both pairs with former Soviet Union were feasible under "realistic" scenario. The pair Japan/Korea and China was feasible only under scenario "with resource abundance" (obviously due to Japan/Korea resource constraints).

Finally, we run model for three macro-regions: Japan/Korea, China and former Soviet Union. Here the solution was feasible under the "without ecological constraints" scenario. We run the model 5 times:

1. First run, for 2010 only;
2. Second run, for 2010-2020;
3. Third run, for 2010-2030;
4. Fourth run, for 2010-2040;
5. Fiftn run, for 2010-2050.

Some results of these runs are discussed in the text, some results are not in the article because of volume limitations.

Table 13: Balance of chemical energy production and consumption for 2010 based on run for 2010 only

	Chemical Energy Production Technologies, GW			Chemical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Chemical Energy	110,1194	65,02407	241,6667	2,37858	1,40452	5,22
Gas into Chemical Energy	0	0	0	0	0	0
Methanol into Chemical Energy	0	0	0	0	0	0
Total				**2,37858**	**1,40452**	**5,22**
Need for Chemical Energy				2,37858	1,40452	5,22

Source: authors' work

Let us describe more profoundly the first and the last runs. In the first run, chemical energy production for the period 2010, was mainly produced from gasoline[3]. Electricity was mainly produced from gas and coal, but also from nuclear, hydro and wind capacities (see table below).

[2] It is worth mentioning here, that upper limits for variables were set to be 483 GW for first four runs, and 1342 GW for the fifth run.

Table 14: Balance of electricity production and consumption based on run for 2010 only

	Electricity Generation Technologies, GW			Electricity Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Oil rest into el.-base	0	0	0	0	0	0
Oil rest into el.-peak	0	0	0	0	0	0
Gas into el.-base	0	0	0	0	0	0
Gas into el.-peak	116,1136	403,863	846,2176	0,402833	1,401123	2,935785
Coal conventional into el.-base	56,53801	490,3203	986	1,235527	10,71498	21,54708
Coal advanced into el.-base	0	0	0	0	0	0
Coal super into el.-base	0	0	0	0	0	0
U235 into el.	63,7	36,2	108,1	1,491144	0,8474	2,530496
U238 into el.	0,001	0	0	2,3E-05	0	0
Biomass into el.	0	0	0	0	0	0
Methanol into el.-base	0	0	0	0	0	0
Methanol into el.-peak	0	0	0	0	0	0
H2 into el.-base	0	0	0	0	0	0
H2 into el.-peak	0	0	0	0	0	0
Hydro existent into el.	21,85176	53,78896	40,34172	0,329345	0,810696	0,608022
Hydro cheap into el.	1,147284	0	0	0,01689	0	0
Hydro expensive into el.	0	0	0	0	0	0
Hydro very expensive into el.	0	0	0	0	0	0
Solar cheap into el.	0	0	0	0	0	0
Solar expensive into el.	0	0	0	0	0	0
Solar very expensive into el.	0	0	0	0	0	0
Wind very cheap into el.	4,535147	0	0	0,03974	0	0
Wind cheap into el.	4,488781	0	0	0,039334	0	0
Wind expensive into el.	0	0	0	0	0	0
Wind very expensive into el.	0	0	0	0	0	0
Geo cheap into el.	0	0	0	0	0	0
Geo expensive into el.	0	0	0	0	0	0
Geo very expensive into el.	0	0	0	0	0	0
Space LPS simple into el.	0	0	-1,4E-15	0	0	-1,38E-17
Space LPS complex into el.	0	0	0	0	0	0
Total				**3,554835**	**13,7742**	**27,62139**
Need for Elec Energy, mln TJ/yr				3,35124	5,72904	6,496

Source: authors' work

As could be seen from the tables on the next page heat energy was produced from gas, coal, oil-rest, electricity, methanol and biomass. In Japan/Korea also nuclear capacities were used. The mechanical energy was produced from gasoline, and only in China also from gas.

[3] For the period 2010 the four runs produce the same result, the fifth run brought different results, since there macro-region SU used gas and not gasoline in chemical energy production. For the period 2020 the second and third runs brought similar results: main chemical energy production was from gas and gasoline (methanol was used in chemical energy production only in Japan/Korea, in the fourth run). For the period 2030 Russia used gas, Japan/Korea and China used gas and gasoline in different proportions. Also, some small pattern differencies could be seen in the results for 2040 (using the fourth and fifth runs).

Table 15: Balance of heat energy production and consumption based on run for 2010 only

	Heat Energy Production Technologies, GW			Heat Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Oil-Rest into Heat Energy	0	0	439,5651	0	0	5,95565
Gas into Heat Energy	639,8852	986	1479	8,669779	13,35927	20,03891
Coal into Heat Energy	13,5	13,5	13,5	0,182911	0,182911	0,182911
Bio into Heat Energy	8,85	8,85	8,85	0,119908	0,119908	0,119908
U235 into Heat Energy	0,0001	0	0	1,35E-06	0	0
Methanol into Heat Energy	0	0	85,88083	0	0	1,163596
H2 into Heat Energy	0	0	-4,63E-14	0	0	-6,28E-16
Elec into Heat Energy	0	463,7034	1229,06	0	6,677329	17,69847
Total				**8,9726**	**20,33942**	**45,15944**
Need for Heat Energy, mln TJ/yr				8,07534	18,30548	40,6435

Source: authors' work

Table 16: Balance of mechanical energy production and consumption based on run for 2010 only

	Mechanical Energy Production Technologies, GW			Mechanical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Mech Energy	249,7222	265,5037	623,7359	1,3485	1,43372	3,368174
Gas into Mech Energy	0	0	474,5049	0	0	2,562326
Methanol into Mech Energy	0	0	0	0	0	0
H2 into Mech Energy	0	0	0	0	0	0
Elec into Mech Energy	0	0	0	0	0	0
Total				**1,3485**	**1,43372**	**5,9305**
Need for Mechanical Energy				1,3485	1,43372	5,9305

Source: authors' work

The fact that in the model the scenario "without ecological constraints" was used, could be seen from the table on the next page (the limits for different pollutant were set as 999999, i.e. very high, so, there was no need for pollution removal capacities; of course, these findings are not very realistic).

Main findings however were results from overall primary, secondary energy balances and import/export balances. Macro-region SU exported all kinds of primary energy to JK and CH (at the same time macro-region CH exported some coal to macro-region JK). Macro-region SU also exported all kinds of secondary energy resources, at the same time macro-region CH imported all secondary energy resources, macro-region not only imported gasoline, oil-rest, and hydrogen, but also exported some methanol.

In the last run we had very interesting sequence of chemical, electrical, mechanical, and heat energy balances (since we modeled scenario "without ecology constraints" the pollution was not relevant again). Also, the sequence of overall primary, secondary energy balances and import/export balances was of great interest.

As could be seen from the sequence of chemical energy balances for 2010-2050 time peridos in JK the shift from gasoline to gas in producing chemical energy occurs. In SU there is strong occurrence of gas (in chemical energy production). In CH there is also shift from gasoline to gas, but only in the last time period. All three macro-regions use gas for chemical energy production in 2050 (and only SU uses gas for this purposes in 2010).

Table 17: Balance of pollution removal, based on run for 2010 only

	Pollution Removal Technologies, GW JK	SU	CH	Harmful Substances Removal / Production, mln TJ/yr JK	SU	CH
SOx removal in el. production	0	0	0	0	0	0
NOx removal in el. production	0	0	0	0	0	0
NOx removal in heat production	0	0	0	0	0	0
NOx removal in mech.	0	0	0	0	0	0
				0	**0**	**0**
Ash removal in el. production	0	0	0	0	0	0
Ash removal in heat production	0	0	0	0	0	0
Ash removal in mech.	0	0	0	0	0	0
				0	**0**	**0**
CO2 removal in el. production	0	0	0	0	0	0
CO2 removal in fuel conversion	0	0	0	0	0	0
				0	**0**	**0**

	Total Harmful Substances Production, mln TJ/yr JK	SU	CH
Total SOx production	2,756437	18,26602	41,11782
Total NOx production	7,245201	22,04628	55,88929
Total Ash production	3,545945	25,38918	52,23728
Total CO2 production	2758,638	4640,556	10347,47
Constraint for SOx Emission	999999	999999	999999
Constraint for NOx Emission	999999	999999	999999
Constraint for Ash Emission	999999	999999	999999
Constraint for CO2 Emission	999999	999999	999999

Source: authors' work

Table 18: Balance of chemical energy production and consumption for 2010 based on run for 2010-2050

	Chemical Energy Production Technologies, GW JK	SU	CH	Chemical Energy Production, mln TJ/yr JK	SU	CH
Gasoline into Chemical Energy	110,1194	-3E-16	241,6667	2,37858	-6,48E-18	5,22
Gas into Chemical Energy	1,44E-14	65,02407	-2,84E-14	3,11E-16	1,40452	-6,14E-16
Methanol into Chemical Energy	-2,48E-12	7,78E-13	-5,85E-13	-5,35E-14	1,68E-14	-1,26E-14
Total				**2,37858**	**1,40452**	**5,22**
Need for Chemical Energy				2,37858	1,40452	5,22

Source: authors' work

Table 19: Balance of chemical energy production and consumption for 2020 based on run for 2010-2050

	Chemical Energy Production Technologies, GW			Chemical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Chemical Energy	5,68E-14	0	411,8394	1,23E-15	0	8,895731
Gas into Chemical Energy	129,7106	78,12037	11,60967	2,80175	1,6874	0,250769
Methanol into Chemical Energy	9,33E-12	-2,65E-12	3,19E-17	2,02E-13	-5,72E-14	6,89E-19
Total				**2,80175**	**1,6874**	**9,1465**
Need for Chemical Energy				2,80175	1,6874	9,1465

Source: authors' work

Table 20: Balance of chemical energy production and consumption for 2030 based on run for 2010-2050

	Chemical Energy Production Technologies, GW			Chemical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Chemical Energy	-4,44E-16	1,24E-14	527,5848	-9,59E-18	2,69E-16	11,39583
Gas into Chemical Energy	131,8171	102,0208	27,27628	2,84725	2,20365	0,589168
Methanol into Chemical Energy	-1,12E-12	-1,22E-12	-1,56E-19	-2,41E-14	-2,63E-14	-3,38E-21
Total				**2,84725**	**2,20365**	**11,985**
Need for Chemical Energy				2,84725	2,20365	11,985

Source: authors' work

Table 21: Balance of chemical energy production and consumption for 2040 based on run for 2010-2050

	Chemical Energy Production Technologies, GW			Chemical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Chemical Energy	30,01977	-3,23E-12	522,5029	0,648427	-6,97E-14	11,28606
Gas into Chemical Energy	98,03116	102,0208	38,88596	2,117473	2,20365	0,839937
Methanol into Chemical Energy	1,49E-13	0	0	3,21E-15	0	0
Total				**2,7659**	**2,20365**	**12,126**
Need for Chemical Energy				2,7659	2,20365	12,126

Source: authors' work

Table 22: Balance of chemical energy production and consumption for 2050 based on run for 2010-2050

	Chemical Energy Production Technologies, GW			Chemical Energy Production, mln TJ/yr		
	JK	SU	CH	JK	SU	CH
Gasoline into Chemical Energy	0	0	0	0	0	0
Gas into Chemical Energy	121,2718	101,675	571,8333	2,61947	2,19618	12,3516
Methanol into Chemical Energy	0	0	0	0	0	0
Total				**2,61947**	**2,19618**	**12,3516**
Need for Chemical Energy				2,61947	2,19618	12,3516

Source: authors' work

The tables for chemical energy production show that mostly gasoline and gas are used for this purpose. The tables for electricity show that gas, coal, U-235 and cheap hydro technologies are used for electricity generation. Tha tables for mechanical energy show that only gasoline and gas are used for mechanical energy production. The overall balances tables show the pattern with which the primary and secondary energies are produced. Also, clearly Russia emerges as a main energy exporter, and China and Japan/Korea as energy importer.

Discussion

The obtained model results showed some strange patterns. For example, electricity was used for mechanical energy production in 2010, but was not used for mechanical energy production in 2020-2050, etc.. Also, according to BP Statistical Yearbook of World energy the total electricity generation in 2010 was 21325,1 TWt-hr (if average load was as high as 6000 hours / year, then the total installed capacity in the world could be estimated to be 3,554 TW, or 3554 GW; if we would look at the table 41, then we would see that total installed capacity is estimated as high as 6080 GW). So, clearly the model needs further improvement since there exist some bottle-necks[4].

Conclusion

The presented paper presents a modified GEM-model developed in Moscow's ERIRAS institute and in Irkutsk' ISEM SO RAS institute. Also, it presents results obtained using the GEM-model for 2010-2050 periods. The most remarkable result was the fact that in the model with three macro-regions (former Soviet Union, Japan/Korea, and China) the conditions of "realistic" scenario didn't allowed for feasible solution, the feasible scenario was first "without ecological constraints" scenario, and also there some technologies should be installend in 1000 GW amounts for making constraints of the model feasible. This means not only that model has to be optimized, but also that the world energy needs some new developments in energy technologies area for making world energy developments sustainable.

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[4] It is important to say that these findings should be regarded as an approximation of the world energy system.

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