ENERGY COST MODELLING OF NEW TECHNOLOGY ADOPTION FOR RUSSIAN REGIONAL POWER AND HEAT GENERATION

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Abstract

Russia is frequently referred to as a country with sufficient energy efficiency potential. Although an improvement has been shown (energy-GDP ratios were improved by 35% between 2000-2008 [2]), the contribution of technological progress is estimated to account for only 1% of the energy-GDP ratio reduction, the existing share of renewable energy sources (RES) based electricity generation is estimated at 0.1%. Analysis shows that regional and federal levels of governance in Russia are missing efficient mechanisms for stimulation of energy saving and technological development [7]. This research aims to develop an analytical tool for energy sector economic analysis for technological development planning to support policy decision making. The paper adapts the levelized cost of energy (LCOE) methodology of Wagner and Foster [9], which has been upgraded to facilitate combined energy generation processes, to examine the cost structures associated with energy system and applies it to a Russian regional case study. The model run for two fuel price scenarios allowed us to conclude that the regional energy supply system is dependent on natural gas price. Strong political and financial support is needed to boost technological development and RES application.

Introduction

Russia is frequently referred to as a country with sufficient energy efficiency potential estimated as 45% of primary energy use or 282 mtce[1], carbon emissions reduction potential is estimated as 793 million tons of CO_2 or approximately 2.9% of global energy-related CO_2 emissions [1]. The potential reduction of energy distribution and final use losses in heat supply is estimated to be 53% of total heat consumption [2].

Although Russia has showed an improvement in decreasing energy intensity over the last decade - energy-GDP ratios were improved by 35% between 2000-2008 [2], the current value of energy-GDP ratio is still 2.5-3 times higher than in developed countries [2, 3]. Scientists and economists advocate a need for a strong policy in the energy sector to "realize the energy efficiency potential the Russian economy is "pregnant with" [3].

The contribution of technological progress is estimated to account for only 1% of the energy-GDP ratio improvement in Russia [3]. Operating energy systems are sufficiently depreciated - more than 90% of operating power stations, 83% of houses, 70% of boilers, 66% of the heating network were build before 1990 [2]. The existing share of renewable energy sources (RES) based electricity generation in Russia is estimated at 0.1%[2] [4]. Current regulation sets national targets in RES development as shares: for 2015 - 2.5%; for 2020 - 4.5% [5].

Improvement in energy efficiency and energy saving were recently made a national goal by the President of the Russian Federation - 40% reduction of energy intensity by 2020 with improvement of energy generating technology and adoption of RES identified as the key to achieve the goal [2]. Federal and regional governments have developed energy efficiency and energy saving programs [6] to address this national goal with substantial budget funding is to be allocated for the programs [2, 7].

However, insufficient incentives exist to support RES based energy production in Russia [4]. Experts emphasize that among problems associated with improvement in energy efficiency in Russia there exists a lack of information

[1] Mtce (million tons of coal equivalent) is a standard energy unit used in Russian national statistics.
[2] Excluding hydroelectric power plants with above 25MW installed capacity.

to support decision-making and institutional capacity to develop and implement economically efficient and timely decisions [7]. International comparative analysis shows that regional and federal levels of governance in Russia are missing efficient mechanisms for stimulation of energy saving and technological development [8].

Economic theory suggests that there is no better incentive for industry development than the one provided by marginal costs reduction. By addressing the identified information problems, this research aims to develop an analytical tool for energy sector economic analysis for technological development planning to support policy decision making. This paper proposes a cost of energy modelling tool which allows for comparison of new energy generating technology costs parameters relevant to specific Russian conditions including the wide application of cogeneration technologies for simultaneous electricity and heat provision [9].The model explores the limitations of methods and data currently available for economic analysis of energy systems in Russia and contributes to the current discussion on the development of energy sector data and tools for decision making. The paper also addresses issues of technological development and RES utilisation for the Russian regional energy sector development.

Regional energy sector data in Russia – research limitation and challenge

One of the major limitations of the research in the energy sector in Russia is data availability. International and national organisation reports concerning energy measures and data collection in Russia identify a lack of energy sector data, existing data is often regarded as insufficient and inconsistent [1, 3, 7, 10]. For example, according to International Energy Agency (IEA) nearly 50% of data required for energy efficiency (EE) indicators is not available in Russian statistics (table 1). IEA also a noticed a break in the data bases, crucial lack of data in service sectors, disaggregated data in transport sector [1].

Table 1 Data required for EE indicator development and its availability in Russia

End-use sector	Number of indicators		Major problems outlined by IEA
	Required	Available	
Industry	22	22	- not constant currency (RUR) used for value-added calculations; - time series breaks; - limited coverage (industry boundaries)
Residential sector	32	13	- data collection required for end users in space heating and cooling, water heating, small appliances
Service sector	12	3	- lack of data collected
Transport	29	8	- lack of data on separate consumption in transport sector

Source: author's summary of IEA report [1]

Regional energy data collection and analysis is more problematic. Kalashnikov et al. [11] reported that regional energy balances data was not collected in Russia since 1990, data collection procedures in place are not compliant with OECD practice, they identified incomplete and contradictory data in energy demand, supply, export and import.

To address the identified information problems we have developed an analytical tool for energy sector economic analysis based on international technology datasets [12-14] which were validated against and complemented by data from current energy generating companies [15-17]. Economic and financial parameters were developed specifically for Russian regional conditions.

Before introducing the model a general overview is provided on the energy production features for the Moscow region which will determine model specifications such as generation technology types, renewable energy targets and cost parameters.

A specific feature of Russian energy generation patterns is the wide application of combined heat and power (CHP) generation technologies. Russia is one of the leading countries in the usage of CHP technologies which are often characterised as reliable, cost-effective technologies which can make an important contribution towards GHG reduction. The CHP share of Russian national power production is above 30% (the second world largest

CHP installed capacity), and is the highest share of electricity generation by means of CHP (over 30%) [9]. At the same time, according to IEA, a lack of reliable information exists on the efficiency of existing CHP plants in Russia [18]. Russia still has potential for CHP expansion with in light of energy demand growth [9]. Therefore cost modelling in this research aims to contribute to the literature on existing technologies energy efficiency estimation.

Energy production patterns in Russian regions differ significantly due to climate, infrastructure, economic development and manufacturing structural factors. The Moscow region energy supply is mostly provided by thermal power plants (93-97%) [19] mostly operating in CHP generation cycle. The commonly used steam turbines are produced by the Ural Turbine Works. The decision to install new generation options has favored combined cycle gas turbines (CCGT) which are produced by domestic or international companies.

Market shares in the Moscow region are highly concentrated (table 2) at Mosenergo (in the electricity sector) and MOEK (in the heat sector). For example, the Herfindahl–Hirschman Index (HHI) for electricity and heat generation are 5627.9 and 6086.7 respectively which can be interpreted as nearly monopolistic nature of existing markets. The concentration ratios (based on the four biggest companies in the market) are 97.1% for electricity generation and 99.75% - for heat generation.

Even though electricity price liberalisation has begun to facilitate the move toward market pricing for most categories of consumers, electricity prices for households are still set by the governments as set tariffs, where households consume about 21% in Moscow [19, 20]. Heat prices are also set by the regional governments. The heat supply system has large EE potential, it crucially needs a reshaping of the tariff methodology, improvement of statistical data collection and sector coordination, provision of heat consumption measurement, and the transformation of mostly state owned producers to private entities [20].

This allows us to conclude that energy market prices are highly distorted. Therefore the development of a model for marginal price estimation for heat and electricity is of special interest for regional and federal governments, market operator, and research institutions.

Table 2 Market shares of electricity and heat markets of the Moscow region in 2010

Generating company	Installed capacity		Energy produced	
	Electricity	Heat	Electricity	Heat
OAO “Mosenergo” (www.mosenergo.ru)	62.8%	66.7%	73.6%	73.9%
OAO OGK-1 (www.ogk1.com/en)	9.7%	0.9%	8.4%	0.3%
Enel OGK-5 (www.enel.ru/en)	12.7%	0.2%	10.4%	0.3%
RusHydro (www.eng.rushydro.ru)	6.1%	0	2.2%	0
E.ON AG Russia (OGK-4) (www.eon-russia.ru)	7.6%	0.7%	4.7%	0.5%
OAO MOEK (www.oaomoek.ru)	1.0%	31.6%	0.7%	25.1%
OJSC “Mobile GTES”, OJSC “GT-TEC Energo”	0	0	0	0

Source: authors’ summary of companies annual reports [15-17], Russian national electricity market operator data [19]

Levelized cost of energy model outline

This research adapts the levelized cost of energy (LCOE) methodology of Wagner and Foster [21]. LCOE is a well developed and widely used energy cost model which has various applications in research as well as decision making processes. The model has been applied to energy generation processes modelling, optimisation of generation technologies mix, true energy cost estimation [21, 22] and at different governance levels – from national energy strategy determination and energy sector modelling [13, 23, 24] to local energy generating technology description [25]. However LCOE modelling has not yet been widely applied to the analysis of CHP technologies and Russian energy sector [12].

Several properties of LCOE establish the appropriateness of the model for the purposes of energy cost modelling within research in the emerging energy market in Russia. The LCOE model allowed:

1. building the model based on the international energy generation technology database which helped to solve the crucial data non-availability problem of the research.
2. incorporation of existing and new technologies as well as energy saving alternatives which is important in terms of the Russian national and regional EE goals.
3. accounting for financial, technological and other parameters specific for regions.

Furthermore, efficient energy pricing in Russia is itself an industry problem, especially for heat supply, where no sector development strategy at federal nor regional levels yet introduced, and prices are determined via centrally set tariffs [18]. The IEA emphasizes that there is a need to move toward cost-based energy pricing as one of the major issues influencing energy sector development in Russia [18]. Therefore the development of an LCOE analysis for a Russian region contributes to the discussion about tariff design methodology.

Levelized cost of energy model construction

LCOE function is defined as the sum of lifelong costs of energy production per unit adjusted to the current and predicted financial situation parameters. The following function is sourced from Wagner, Foster [21]:

$$LCOE_j = \frac{\sum_{t=1}^{n}\left(\frac{TOC(t)_j}{(1+WACC)^t}\right) + Capex_j}{\frac{\left(\sum_{t=1}^{n}(SO(t)_j) * CPI(t)_R\right)}{(1+WACC)^t}} \tag{1.1}$$

However this function needs to be transformed to allow for the incorporation of multiple energy outputs during production. Due to the dual nature of these outputs special economic and accounting approaches need to be adopted to separate costs between the two products. Failure of rational and efficient costs separation can lead to conclusions of technology inefficiency due to high costs. Recent discussion in the literature regarding CHP in Russia provides a good example of the generation costs separation importance [3, 27, 28]. Some authors and public authorities argue that heat supplied by co-generation is cost-inefficient due to high transportation cost and losses of heat provided centrally. Others argue that the cost calculation strategy which is currently in use has placed all the benefits of combined generation toward electricity. Heat in this case becomes a product of the same costs as if it was generated as a single product by boilers [29]. Others emphasize that since there cannot be found a reliable approach to costs separation based on physical processes and energy output properties, then the current separation practise is neither better nor worse than any other, but provides true estimates of production costs for each generated product [30].

We used coefficients reflecting proportional contribution of each product (electricity and heat) to the overall energy output, and transformed (1) as follows.

$$LCOE_j^E = \frac{\sum_{t=1}^{n}\left(\frac{TOC(t)_j^E}{(1+WACC)^t}\right) + Capex_j^E}{\frac{\left(\sum_{t=1}^{n}(\mathrm{SO(t)}_j^E) * CPI(t)_R\right)}{(1+WACC)^t}} \tag{1.2}$$

$$k_j^e = \frac{\overline{SO}(t)_j^e}{\overline{SO}(t)_j},\ k_j^h = \frac{\overline{SO}(t)_j^h}{\overline{SO}(t)_j} \text{ hence } k_j^e + k_j^h = 1,\ E \in (k_j^e, k_j^h) \quad (1.3)$$

$$\overline{SO}(t)_j^h + \overline{SO}(t)_j^h = \overline{SO}(t)_j \quad (1.4)$$

(1.5)

k_j^e - separation coefficient for costs associated with electricity production;

k_j^h - separation coefficient for costs associated with heat production;

$\overline{SO}$ - total output lever (in GJ) used for separation coefficients determination.

Table 3 Levelized cost of energy model technological parameters for CHP technologies

Parameter	Electricity ($E = k_j^e$) or heat ($E = k_j^h$) generation
Costs parameters	
Fixed operating and maintenance costs	$FOM\ (t)_j^E = FOM\ (t)_j \cdot E$ $FOM\ (t+1)_j^E = FOM\ (t)_j^E \cdot CPI\ (t)_C$
Variable operating and maintenance costs	$VOC\ (t)_j^E = VOC\ (t)_j \cdot E$ $VOM\ (t+1)_j^E = VOC\ (t)_j^E \cdot SO\ (t)_j^E \cdot CPI\ (t)_C$
Fuel cost	$Fuel(t)_j^E = \left(\frac{(HR_j * E) * CF_j^E * FC(t)_j}{1000}\right) \cdot SO(t)_j^E \cdot CPI(t)_C$
Total costs	$TOC(t)_j^E = Fuel(t)_j^E + FOM(t)_j^E + VOM(t)_j^E + CM(t)_j^E$
Capital costs	$Capex_j^E$
Technology depletion costs	$CM(t)_j^E = (\frac{CF_j^E \cdot Capex_j^E \cdot CPI_C}{life_j})$
Output and revenue parameters	
Energy produced (per annum) Auxilary energy use	$\mathrm{SO(t)}_j^E = \frac{size_j^E \cdot CF_j^E \cdot 8670 \cdot (1 - Aux_j^E)}{1000}$ $Aux_j^E = Aux_j * E$
Revenue flow from energy production	$\mathrm{SOR(t)}_j^E = \mathrm{SO(t)}_j^E \cdot CPI\ \mathrm{(t)}_\mathrm{R}$
Capacity factor	CF_j^E

We need to consider several approaches for cost separation for combined production technologies.

Approach 1: physical (balance) method

Physical method of costs separation is often referred to as by default method used by the Ministry of Energy of the Russian Federation [28] and therefore by the generating companies [15]. According to physical method costs for heat production are calculated as if the heat was provided by a boiler rather than in the co-generation cycle.

The supporters of this method advocate that it provides transparent and accountable results, doesn't suffer from unnecessary assumptions, and allows for seasonal fluctuations in output levels. The major disadvantage of the method, which has created continuing discussion, is that the cost decrease due to CHP generation is accounted for in the electricity production only. The cost of heat becomes high as if it was produced by a separate heat generating process with transportation costs on top [28]. At the same time electricity production costs become lower at CHP plants by comparison to large scale electricity plants. An example provided by Nagornaya et al. [28] shows that the average heat rate at TEC (CHP plants) when calculated according to the physical method becomes equal 0.18-0.25 kg ce/kWh in comparison to 0.32 kg ce /kWh at large scale power plants (GRES).

Approach 2: Ginter method

Another approach to the cost separation was introduced by a famous Russian engineer - L.L. Ginter (1876-1932) [31]. The approach was named the "Ginter triangle" and based on the same principle as the construction of budget line in microeconomic theory. The triangle is developed in two axes - production costs for electricity (RUR/kWh) and heat (RUR/GJ). Points A and B show unit costs if only one product was generated (expressed as a ratio of total production costs and amount of product produced over analysed period). The triangle allows finding unit cost of the second product assuming the unit cost of the first one [29].

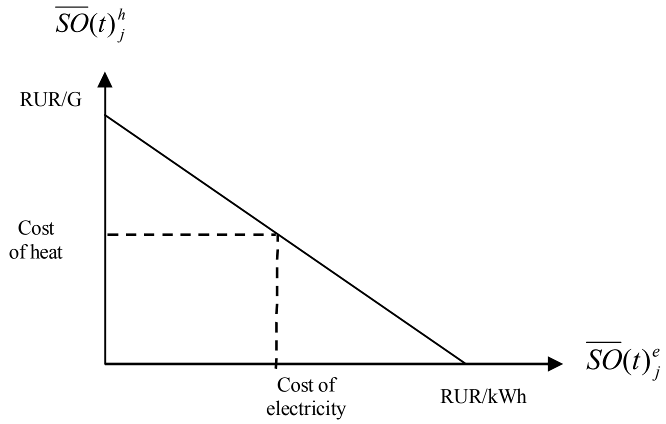

Figure 1 Ginter triangle for cost separation

Consequently, cost separation for multiproduct energy generation is subject to discussion in the literature and a problem which hasn't yet been solved. The importance of this issue becomes obvious in centralised systems where energy prices are determined as set tariffs. We will apply the Ginter method for the cost separation with separation coefficients for existing technologies sourced from data reported by generating companies in the Moscow region

Let us now introduce main parameters of the LCOE model which are separated into two groups (technological and financial parameters) and justified below.

Financial parameters of the LCOE Model

Long term strategies of social and economic development are currently under development at federal and regional levels in Russia. Therefore long-run projections of financial parameters such as price indexes (CPI) are not yet available. The Ministry of Economic Development of the Russian Federation has recently published price index projections for selected industries where CPI is expected to decrease from 5.1% in 2015 to 2.5% by 2030 (long run average - 3.4%) [32].

However historical price indexes show that 3.4% would be unreasonably optimistic assumption for our model. According to Russian national statistics over the past 11 year period, average consumer and producer price indices reached 12.2% and 11.5% respectively, with average index for mining industries output - 23.7%, for produced gas, electricity and water –17.8%. Therefore the inflation parameter in the model should reflect a higher speed of growth of prices for mining output which determine input prices for power generating companies. On the other hand the inflation parameter should reflect a strategic goal of monetary policy in the country – decrease of inflation. Consequently, a value of 6% value was taken as an approximation of expected CPI with pass through rate of 1 for costs ($CPI(t)_C$) and to 0.75 for revenues ($CPI(t)_R$) which reflect the observed ratio of price indices (23.7%*0.75=17.8%).

Weighted average cost of capital (WACC) is applied in the model to incorporate current financial parameters of the national and regional economies and to take into consideration opportunity cost of capital. To account for inflation process in the cost of capital determination WACC will be calculated in real value terms as well. Post tax real WACC was used for LCOE modelling by Wagner, Foster [21].

The following conventional function for WACC was used:

$$WACC_{Post-TaxNominal} = \frac{E}{V} * R_e + \frac{D}{V} * R_d (1 - T_e) \tag{1.6}$$

To obtain WACC in real terms CPI was accounted for as following.

$$WACC_{Post-TaxReal} = \left(\frac{1 + WACC_{Post-TaxNominal}}{1 + CPI_C} \right) - 1 \tag{1.7}$$

Price of equity was determined using Capital Asset Pricing Model (CAPM):

$$R_e = R_f + b(R_m - R_f) + R_c \tag{1.8}$$

Limited studies were found where WACC was defined and applied for industries or firms' cost of capital estimation in Russia. Gardner et al. [33] calculated WACC for emerging markets in Russia exploring a case study of the cellular telephone industry. Cost of debt was calculated based on prices and payments on bonds. The cost of equity was obtained as a sum of risk free rate of return and risk premium. Values for beta as a measure of systematic risk were taken equal to 1.61, 1.98, and 1.00 for the three telephone firms considered. Tax rate considered was equal 0.24. The obtained values of post-tax WACC were 11.71%, 14.65%, 11.85%. For this research data was sourced from Internet-based data bases. However the study doesn't provide details on the parameters used for calculations, assumptions, types and periods of bonds chosen.

Vashakmadze [34], in his empirical research, argues that commonly used figures (9-11%) to describe WACC for Russian companies are not high enough to describe existing risks. Salomons et al. [35], as a result of their empirical research, concluded that equity risk premium (return on equity minus the risk-free rate of return) should be higher in the emerging rather than in the developed markets. Several studies have been undertaken and published on electricity companies asset evaluation during reorganization of RAO EES as a part of the electricity reform in Russia [36-38].

According to the current legislation the WACC is used for cost of capital evaluation for capacity reserve payments[3]. The Ministry of Energy of the Russian Federation [39] recommends WACC estimates for the wholesale electricity and capacity markets participants to determine contracts parameters, and as a discount factor for cash flow analysis. Current legislation in place requires the independent market operator (NP) to set a WACC annually and currently the value set by the NP is 14% [40, 41].

Based on the previous research outcomes, current financial situation the assumptions has been made and justified for financial parameters of the model (table 4).

Romanova et al (2004) defined equity and debt shares for Reftinskaya GRES as 67% and 33% respectively referring to these values as reflecting on average Russian companies capital structure. However, Ivanov [38] suggests more extreme values for OGK-2 – 93% and 7%. Given the monopolistic nature of the Moscow regional

[3] Federal Tariff Service of Russia, The Order of March, 3 No. 57-e

energy market, for modeling the purposes proposed values for equity and debt shares in capital are selected to be 80% and 20% respectively.

Current legislation in place defines the risk free rate of return as a rate of return of the long-term government bonds of the Russian Federation issued for a term 8 - 10 years (currently at 8.5%). Previous research, however, applied values of the USA long term government obligations rate to estimate risk free rate of return (from 4.81% [38] to 9% [36]).

Table 4 Financial parameters of the LCOE Model

Notation	Parameter	Assumed values
E/V	Equity capital share	80%
D/V	Debt capital share	20%
R_d	Cost of debt	10%
R_f	Risk free rate of return	8.5%
R_m	Market rate of return	13.5%
$(R_m - R_f)$	Market risk premium	5%
T_N	Nominal rate of profit tax	24%
T_e	Effective tax rate	24%
R_e	Cost of equity	15.5%
β	Equity beta	1
R_C	Country risk	2%
$WACC_{Post-TaxNominal}$	Post tax nominal WACC	13.92%
$WACC_{Post-TaxReal}$	Post tax real WACC	7.47%

For equity beta coefficient determination Romanova et al. [37] referred to the USA generating companies' statistics and used a value of 0.27. OLMA (2004) attached different beta coefficients between 1 and 2 to energy companies under valuation. For Mosenergo they used 1 which we have implemented in our analysis.

CAPM applications often consider other risk factors such as country risk, small stock risk or company size premium or company specific risk [37, 38]. We accounted for country risk which is was included in the equity cost estimation for Russian energy companies as 2% [37, 38]. Consequently cost of equity assumed for the model is 15.5% which is comparable to values obtained for generation companies in previous research : 9.53% [37], 12.56% [38] and 20.8% [36].

For the cost of debt estimation current Russian legislation recommends to use the Central Bank of the Russian Federation refinancing interest rate increased by 2% [42]. Since the current rate is 8% [43] for modeling purposes we assumed therefore R_d = 10%. The corporate tax in Russia is 24% [44]. Since no tax exemptions or credits exist for selected generation technologies including renewable the current profit tax rate of 24% was taken as an effective rate. Consequently the obtained value for post tax nominal WACC is 13.92%. It is close to recommended by NP values for 2012 (14%) which in turn justifies the assumptions done for our LCOE model.

Technological parameters of the LCOE Model

Fuel prices and scenario analysis

Figures on price dynamics across fuel types in Russia are sourced from the Federal Statistics Service (table 5). The figures reported by the fuel industry consumers and producers vary sufficiently – the difference starts from 27.2% (e.g. oil prices for 2011) and 48.6% (e.g. auto gasoline prices, 2010) and up to 280.7% (e.g. coke coal,

2010) and 441% (e.g. natural gas, 2009). This deviation can be explained by transportation costs, taxes and supplementary costs accounted for in the consumer's prices only. For the modelling purposed we considered consumers prices, transferred to RUR per GJ values[4] for 2010.

Table 5 Fuel prices according to national statistics

Fuel type	Consumer price, RUR			Producer prices, RUR			Assumptions (based on 2010)	
	2009	2010	2011	2009	2010	2011	heat of combustion, GJ/tonne, GJ/m^3	RUR/GJ
Coal, tones	1620	2082	2228.1	624.4	683.09	1004.8	25.7	81.2
Coal coke (coke), tones	3782	5920	6504.8	1025.9	1555.1	2456.1	25.7	230.8
Brown coal (lignite), tones	815	895	906.8	364.7	405.0	458.7	14.9	60.3
Oil, tones	7429	11045	12416.9	6633.0	7566.5	9765.0	41.0	269.4
Gas natural, '000 m^3	2764	3081	3562.4	510.1	625.7	685.6	35.5	86.8
Gasoline for automobiles, tones	23377	24814	28775.1	13830.7	16698.6	18576.0	43.0	577.1
Diesel, tones	19661	24157	30488.4	11937.6	16339.6	20765.5	42.7	565.7
Fuel oil (mazut), tones	11594	12058	13856.1	7584.1	7805.2	8843.0	39.2	307.6
Peat fuel milling, t	-	-	-	220.3	224.4	258.7	11.6	19.4
Fuel wood, tightly m^3	-	-	-	349.73	373.84	409.13	9.55	39.2[5]

Source: authors' analysis based Federal Statistics Service database [45].

Table 6 Average gas price for regions and export prices

Average natural gas price	2006	2007	2008	2009	2010
As reported by Gazprom (sales to regions)[6]					
Sold in Russia					
RUR/1 000 m^3	1,125.4	1,301.1	1,652.8	1,885.0	2,345.5
RUR/GJ[7]	31.7	36.7	46.6	53.1	66.1
Sold in Western Europe (former Soviet Countries)					
RUR/1 000 m^3	2,007.4	2,672.9	3,693.9	5,483.7	6,416.5
RUR/GJ	56.5	75.3	104.1	154.5	180.7
Sold in other countries					
RUR/1 000 m^3	5,238.5	5,181.9	7,521.5	7,216.6	7,420.7
RUR/GJ	147.6	146.0	211.9	203.3	209.0
As reported by Federal Statistic Service (export gas prices)					
RUR/1 000 m^3	6390	7020	10620	7470	8190
RUR/GJ	180.0	197.7	299.2	210.4	230.7

Source: authors' summary of Gazprom report [1, 46], Federal Statistics Service database [45].

[4] For all the prices except peat fuel and fuel wood, not available for consumers reports in the Federal Statistics Service.
[5] Calculated as 1 cubic meter of fuel wood =0.266 tce=0.266*29.3 MJ=7.794 MJ=0.007794 GJ.
[6] Price net value-added tax, excise duty and customs duty.
[7] Values of per GJ prices are calculated by author assuming gas heat of combustion at 35.5 GJ/m^3.

Capital costs determination

However, domestic natural gas prices in Russia are relatively low in comparison with international (table 6). Given that Russia is widely involved in international trade of natural gas, prices of gas sold overseas can be considered as the shadow price (opportunity cost) of gas used domestically for power production. The question raised by the model are then: how sensible the LCOE values for different technologies to the change of fuel prices? If domestic gas prices increase what will it mean for current and new technology production costs and energy costs as a result? To address these questions we applied scenario analysis and tested two natural gas prices: current domestic price and shadow price. Prices for the first scenario were assumed as described above.

To determine the shadow price of natural gas we have considered export prices reported by Gazprom (table 6) and the Federal Statistic Service. We considered a price of RUR210/GJ as an approximate shadow price of natural gas. We will explore later how the shadow pricing of natural gas change the modelling results.

The power system in Moscow has a significant history with outstanding technological decisions represented, for instance, by plants operating since 1892. Construction data for generating plants currently operating in Russia are available for single plants or blocks, which makes data not consistent or site-specific. Therefore the model assumptions on construction costs were based on international databases often applied in energy economics research [14, 21]. Available data for the Russian Federation and the region were used for scaling and verification of international statistics figures. For example we compared figures from current legislation for capacity trading in Russian Federation[8] with values obtained from international databases (table 7). These values in comparison show that capital costs estimates for gas based technologies are very close in international data to associated values established for long-term capacity trading contracts by the current Russian legislation. Values for coal based generation technologies in international database exceed associated values set by Russian legislation. One of the reasons is that database describe emerging coal based generating technologies such as supercritical power plants not yet (widely) used in Russia.

Overall given consistent data is not available for generation technologies in Russia we have used international database values as an approximation of capital costs for LCOE modeling for new technology generation. However, to define existing plants we applied values determined by the Russian legislation as described in Table 7.

Table 7 Capital costs of new generating capacity according to current legislation

Russian legislation[9]		International dataset	
Generation type	**RUR/ kW**	**Generation type**	**RUR/kW**
Natural gas based generation			
Capacity above 250 MW	33,085.5	CCGT (700 MW)	33,750
Capacity (150 MW-250 MW)	39,606	Small CCGT (300MW)	35,438
Capacity below 150 MW	48,127.5	Very Small CCGT (50 MW)	58,687
Black coal based generation			
Capacity above 225 MW	56,551.25	Supercritical PC (750MW)	81,021
Capacity not above 225 MW	61,467.5	Small Supercritical PC (450 MW)	96,413

Source: authors' analysis based on data sources from current legislation [47], international database [14].

Therefore for modelling the following assumptions have been made from combination of international databases [14] and data available for Russian electricity market operators[10].

[8] As suggested by the legislation these figures are supposed to be used to calculate capacity costs for long-term capacity trading contracts.

[9] Values are accounted for climate zone coefficient - Moscow and Moscow region are defined as the third (III) temperature zone with coefficient 1.15 to be applied for capital costs estimation.

[10] For existing technology plants we assumed 5 years as a construction term with equal proportions (20%) construction every year.

Table 8 Construction costs and period assumptions

Technology	Capital costs (RUR/kW)	Cost depletion coefficient	Construction time
IGCC - Brown coal	172101.7	-0.81%	1
IGCC - Black coal	143193.4	-0.80%	4
Supercritical PC - Brown coal	112245.5	-0.18%	4
Supercritical PC - Black coal	81020.6	-0.15%	4
CCGT	33750.0	-1.00%	2
OCGT	24660.0	-1.07%	1
Solar Thermal - Parabolic Trough w 6hrs Storage	247378.9	-0.53%	2
Solar Thermal - Central Receiver w 6hrs Storage	246136.0	-0.88%	2
Photovoltaic - PV Fixed Flat Plate	123303.6	-1.27%	1
Photovoltaic - PV Single Axis Tracking	167340.6	-1.27%	1
Photovoltaic - PV Two Axis Tracking	184074.7	-1.27%	1
Wind - Small scale (50 MW)	83523.0	0.89%	2
Wind - Medium scale (200 MW)	77448.6	0.89%	2
Wind - Large scale (500 MW)	74411.4	0.89%	2
Biomass	125151.9	-0.51%	2
Small IGCC - Black coal	143193.4	-0.80%	4
Small Supercritical PC - Black coal	96413.0	-0.15%	4
Small CCGT 300MW	35437.5	-1.00%	2
Very Small CCGT	58687.2	-0.78%	2
Existing Mosenergo Gas Average	33085.5	-1.00%	5

Notes: *-values provided starting from 2015; **-exchange rate assumed is 30 RUR/AUD;
Source: authors' analysis based on international database [14], companies' reports [15], current legislation [47].

Operating and maintenance costs parameters

Values assumed for fixed and variable operating and maintenance costs parameters are presented in Table 9. Based on international dataset we have calculated values of fixed costs for new technology plants in Russian region.

To allow for cogeneration in our model for FOM assumptions we considered size of the plant as a sum of heat and electricity capacity installed. We used adjustment coefficients for heat and electricity FOM separation.

To verify the assumptions and set values for existing technologies, in the model we have collected data from annual reports of the three major generating companies in the Moscow region – Mosenergo, OGK-1, OGK-5 for 2010 and undertook a comparative analysis. Based on the data collected from Mosenergo for CHP plants variable costs (VOC) in 2010 on average accounted for RUR1602.63/MWh including RUR1083.16/MWh of fuel costs, fixed costs accounted for 22,680 mln roubles or 1.910 mln RUR/MW per year. On the other hand current legislation for capacity trading suggests estimates for capacity operating costs (FOM): RUR960,000/MW per annum as approximation of annual operating costs for gas-based electricity generation and RUR1,476,000/MW per annum for coal-based generation (table 10).

Comparison of factual and set by the legislation figures shows that the latter are approximately twice lower for gas-based generation. These results are expected due to several reasons:

1. Capacity pricing mechanisms underestimate costs for long-term capacity trading due to the assumption that generating companies make profits which should partly cover O&M costs;
2. Costs separation methods used by Mosenergo when calculating annual report data is not specified and hence fixed and variable costs estimates are subject to the costs separation method choice[11];

[11] However we can expect the method used by Mosenergo to be traditional physical method outlined above.

3. Given energy industry shortage of investments, depletion of generation technologies and infrastructure, we should expect higher costs of operating existing generating plants than expected for newly installed capacity.

Table 9 Operating and maintenance costs assumptions

Technology	Variable O&M (RUR/MWh)	Fixed O&M (RURM pa)	Capex Main Rate
IGCC - Brown coal	453	1890	0.22%
IGCC - Black coal	384	1533	0.22%
Supercritical PC - Brown coal	153	922.5	0.23%
Supercritical PC - Black coal	138	742.5	0.23%
CCGT	60	294	0.31%
OCGT	75	43.2	0.15%
Solar Thermal - Parabolic Trough w 6hrs Storage	0	468	0.13%
Solar Thermal - Central Receiver w 6hrs Storage	0	468	0.13%
Photovoltaic - PV Fixed Flat Plate	63.3	64.05	0.06%
Photovoltaic - PV Single Axis Tracking	63.3	70.5	0.08%
Photovoltaic - PV Two Axis Tracking	63.3	78	0.10%
Wind - Small scale (50 MW)	0	63	0.10%
Wind - Medium scale (200 MW)	0	234	0.10%
Wind - Large scale (500 MW)	0	555	0.10%
Biomass	105	60	0.30%
Small IGCC - Black coal	384	985.5	0.22%
Small Supercritical PC - Black coal	138	445.5	0.23%
Small CCGT 300MW	60	126	0.31%
Very Small CCGT	60	21	0.31%
Existing Mosenergo Gas Average	519.46	1528	0.21%

Source: authors' analysis based on international database [14], companies' reports [15], current legislation [47]. Capital maintenance rate values are sourced from Wagner and Foster [21].

Table 10 Operating costs for generating plants considered at capacity markets

Generating technology type	Monthly capacity operating costs, RUR/MW	Capacity operating costs per annum, RUR/MW
Natural gas based generation	80 000	960,000
Coal fuel based generation	123 000	1,476,000
Hydro power plants	63 000	756,000

Source: current legislation [47], national market operator database [19].

Overall we can conclude that values for gas based generation vary in the assumptions for new technology generation in comparison with existing and legally set parameters. It doesn't allow validitation of assumptions but it allows us to add existing technologies parameters to the model.

Heat rates, capacity factor and auxiliary energy use

The heat rate (HRj) is one of the most important characteristics of generating technology which reflects efficiency of fuel inputs. The general decision rule should be: the lower the heat rate, the cheaper the generation process, the more efficient the plant [21]. In the model we applied tce measures, traditional for Russian statistics, transferred to MJ to make the outcomes comparable to international studies. Heat rate increases can reflect a decrease in generating efficiency which can also be considered in the model for future periods. However, depletion speed is determined by a maintenance program and operating features [21]. We incorporated maintenance costs parameter

(CM) as a cost offsetting the thermal efficiency depletion (table 11) assuming that proper capital maintenance can offset technology depletion over operating time between major overhauls.

Another acknowledgment needs to be done to the fact that heat rate value is correlated with capacity factors. However, since this dependence is contradictory and cannot be specified for each technology considered, we have assumed constant heat rates for technologies over the time of operation.

On the other hand heat rate parameter can be used to allow for technological progress in the modelling. We assumed that the later new generation technology plant starts operating the more thermally efficient it is.

For modelling existing technologies we have assumed values for heat rates for existing technology as reported by Mosenergo for 2010.

Capacity factors (CF_j) characterise level of intensity of the technology use over time [48]. The market operator (NP Market Council) reported aggregated values of capacity factors for generating companies in the Moscow region equal to 52.5% and 57.1% (as oppose to Russian averages of 46.7% and 49.3%) [19]. Following values reported by Mosenergo [15] we assumed CF for electricity production – 62.3%.

Capacity factors for new generation technologies were sourced from international datasets [14] (table 11). Generally it can be observed that CF for Russian power plants are sufficiently lower than for new generation technologies. On the one hand, it reflects strict reservation standards in place in Russia, on the other – it provokes current discussion in the literature whether the use of installed capacity and hence the capacity factor should be improved. For instance, Nigmatulin [27] argues that capacity factor should be increased by 15-20% to hit European level.

Table 11 Thermal efficiency, auxiliary use and capacity factor assumptions for generation technologies

Technology	Heat rate (MJ/MWh)	Auxiliaries (Sent Out % of Generated)	Capacity Factor (%)
IGCC - Brown coal	12413.8	75.9%	87.0%
IGCC - Black coal	8780.5	82.4%	87.0%
Supercritical PC - Brown coal	11612.9	89.7%	93.0%
Supercritical PC - Black coal	8867.0	90.2%	93.0%
CCGT	7324.0	97.1%	92.0%
OCGT	10947.9	99.0%	45.0%
Solar Thermal - Parabolic Trough w 6hrs Storage	3600.0	90.0%	39.0%
Solar Thermal - Central Receiver w 6hrs Storage	3600.0	90.0%	39.0%
Photovoltaic - PV Fixed Flat Plate	3600.0	100.0%	19.0%
Photovoltaic - PV Single Axis Tracking	3600.0	100.0%	24.0%
Photovoltaic - PV Two Axis Tracking	3600.0	100.0%	30.0%
Wind - Small scale (50 MW)	3600.0	100.0%	31.0%
Wind - Medium scale (200 MW)	3600.0	100.0%	31.0%
Wind - Large scale (500 MW)	3600.0	100.0%	31.0%
Biomass	11538.5	100.0%	90.0%
Small IGCC - Black coal	8780.5	82.4%	87.0%
Small Supercritical PC - Black coal	8955.2	90.2%	93.0%
Small CCGT 300MW	7324.0	97.1%	92.0%
Very Small CCGT	7265.0	97.1%	92.0%
Existing Mosenergo Gas Average	5373.1	96.7%	62.3%

Notes: * - value refers to 2015 when the technology is assumed to be available [14]

Source: authors' analysis based on international database [14], companies' reports [15], current legislation [47].

Current legislation regulating capacity markets in Russia sets auxiliary energy use coefficient as 1.033 for natural gas based generation technologies, 1.069 for coal fuel based generation (GRF 2010b). We used these values to describe existing technologies.

Results and scenario outcomes

Having outlined the model, explored and validated the general assumptions we can now run the model for two scenarios of interest.

Scenario 1 – Domestic natural gas prices

The LCOE values obtained for the listed technology types are ranked and presented in the Table 12, Figure 2. Generating costs comparison shows that CCGT based technologies were favored due to levelized costs – the unit cost of energy produced by large CCGT is RUR1419.8, with small (300 MW) and very small (50 MW) plants size options ranging RUR1442.2 and RUR1743.6 respectively. Consequently CCGT outperform existing conventional technologies which LCOE value equals RUR 2489.5.

This conclusion corresponds with the current trend in energy system strategy development whose CCGT based units have been recently launched at several power plants in the Moscow region. It has been also recently proposed that Mosenergo targets increasing the number of CCGT installations [15]. Consequently current regional government and private firms do acknowledge the economical and environmental advantages of new CCGT plants over existing aged plants even though the latter have sufficient excess capacity.

The modeling outcomes show that photovoltaic and solar thermal technologies are unreasonably costly to be developed and used in the Moscow region. Both technologies cost structures over the next 30 years exceed the unit costs of other generating options (LCOE for photovoltaic technologies is RUR7794.8, for solar thermal options – from RUR9054.3). Less costly RES options are biofuel and wind based, but the costs parameters obtained still exceed existing and new gas and coal based technological solutions.

It raises questions about the feasibility of RES development objectives set by the regional government as to whether the achievement of 4.5% energy generation based on RES by 2020 is possible. The regional energy efficiency program states that RES technologies that are to be developed within the program realization period (by 2020) will be subsidiesed directly by the government. However, the question remains whether we can expect this support to be economically efficient, given the technologies cannot compete with either conventional or new gas fired technologies.

Table 12 LCOE values for Scenario 1

Technology type	LCOE
CCGT	1419.8
Small CCGT 300MW	1442.2
Very Small CCGT	1743.6
OCGT	2007.2
Existing Mosenergo Gas Average	2489.5
Biomass	2544.9
Supercritical PC - Black coal	2557.9
Small Supercritical PC - Black coal	2759.0
Wind - Large scale (500 MW)	3299.5
Supercritical PC - Brown coal	3390.9
Wind - Medium scale (200 MW)	3441.0
Wind - Small scale (50 MW)	3710.1
IGCC - Black coal	4126.0
Small IGCC - Black coal	4431.0
IGCC - Brown coal	5343.6
Photovoltaic - PV Two Axis Tracking	7794.8
Photovoltaic - PV Fixed Flat Plate	8381.9
Photovoltaic - PV Single Axis Tracking	8822.7
Solar Thermal - Central Receiver w 6hrs Storage	9054.3
Solar Thermal - Parabolic Trough w 6hrs Storage	9095.2

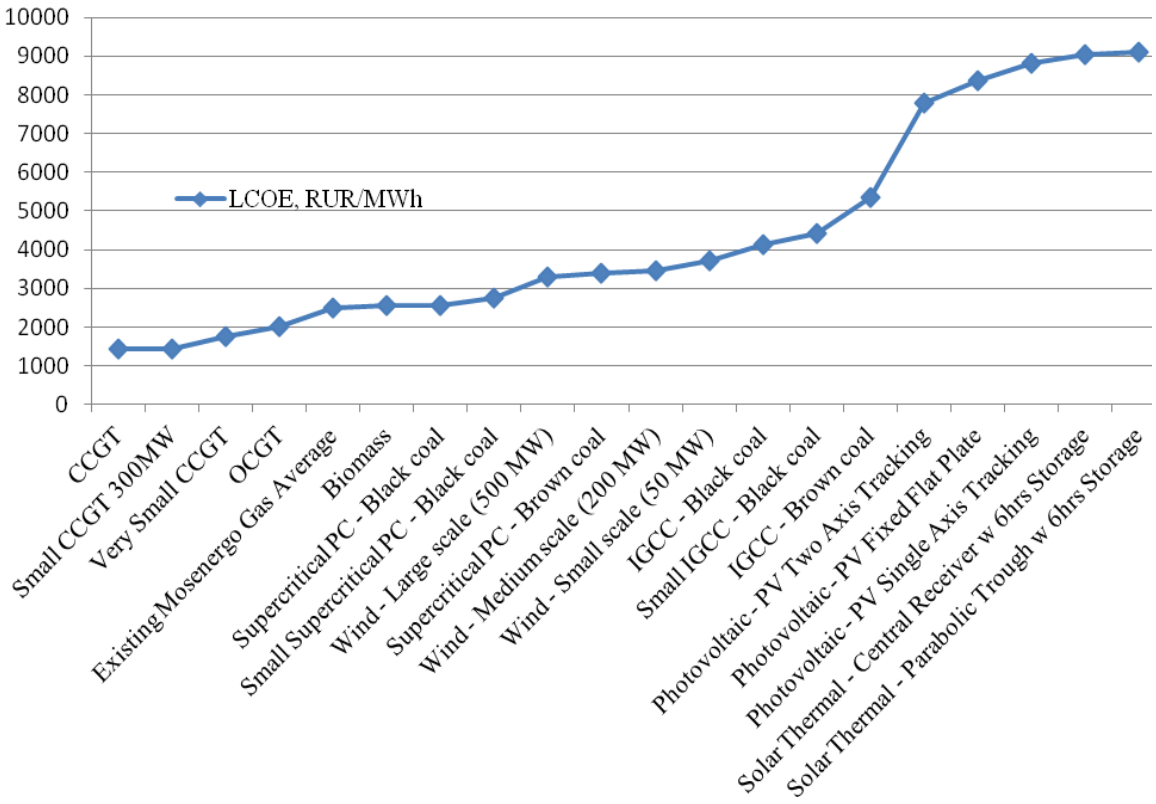

Figure 2 LCOE values for Scenario 1

Another concern is that given monopolistic nature of the current energy production sector in the Moscow region what will be the real cost of alternative energy generation? Unless wind turbine installation and maintenance is heavily supported by the government and the regulator gives priority to alternative energy generation, the chance of their development given large capital costs in the region is minor.

Scenario 2 – Natural gas priced at opportunity cost (shadow price)

Table 13 and Figure 3 introduce modelling results for Scenario 2. Apparently the shadow price of natural gas has sufficiently changed the modelling results. The lowest cost generation option (by LCOE) is now biomass based generation. CCGT still outperform existing technologies and so do coal based supercritical generation both black and brown coal based. Interestingly wind based technologies compete closely with existing plants in costs levels.

Consequently the shadow pricing of natural gas resulted in an increase in gas prices by 150% which in turn caused an increase in electricity production cost for conventional existing technologies by nearly 36.5%. So Scenario 2 shows that the regional energy supply system is heavily dependent on gas price, the economic costs of energy produced by conventional plants when opportunity costs are accounted for, increased giving priority to alternative technologies such as CCGT. However solar technologies remain too costly to be considered as an option.

In terms of public policy, natural gas dependence can be interpreted as affecting energy system security of the region given the mono-technology nature of supply at the moment. Technological diversity should be considered when developing of public programs and measures since natural gas price increase would dramatically affect electricity prices for consumers and/or have an impact on state budget which will be used to compensate for increase in prices. It is especially important given current processes of the energy sector reconstruction and market introduction in electricity supply. Furthermore the gas and heat sectors are also awaiting for market introduction and regulatory reform.

Table 13 LCOE values for Scenario 2

Technology type	LCOE
Biomass	2544.91
Supercritical PC - Black coal	2557.925
CCGT	2602.949
Small CCGT 300MW	2625.308
Small Supercritical PC - Black coal	2758.95
Very Small CCGT	2917.15
Wind - Large scale (500 MW)	3299.517
Supercritical PC - Brown coal	3390.874
Existing Mosenergo Gas Average	3399.31
Wind - Medium scale (200 MW)	3440.983
Wind - Small scale (50 MW)	3710.048
OCGT	3717.35
IGCC - Black coal	4125.946
Small IGCC - Black coal	4431.02
IGCC - Brown coal	5343.589
Photovoltaic - PV Two Axis Tracking	7794.815
Photovoltaic - PV Fixed Flat Plate	8381.939
Photovoltaic - PV Single Axis Tracking	8822.71
Solar Thermal - Central Receiver w 6hrs Storage	9054.29
Solar Thermal - Parabolic Trough w 6hrs Storage	9095.188

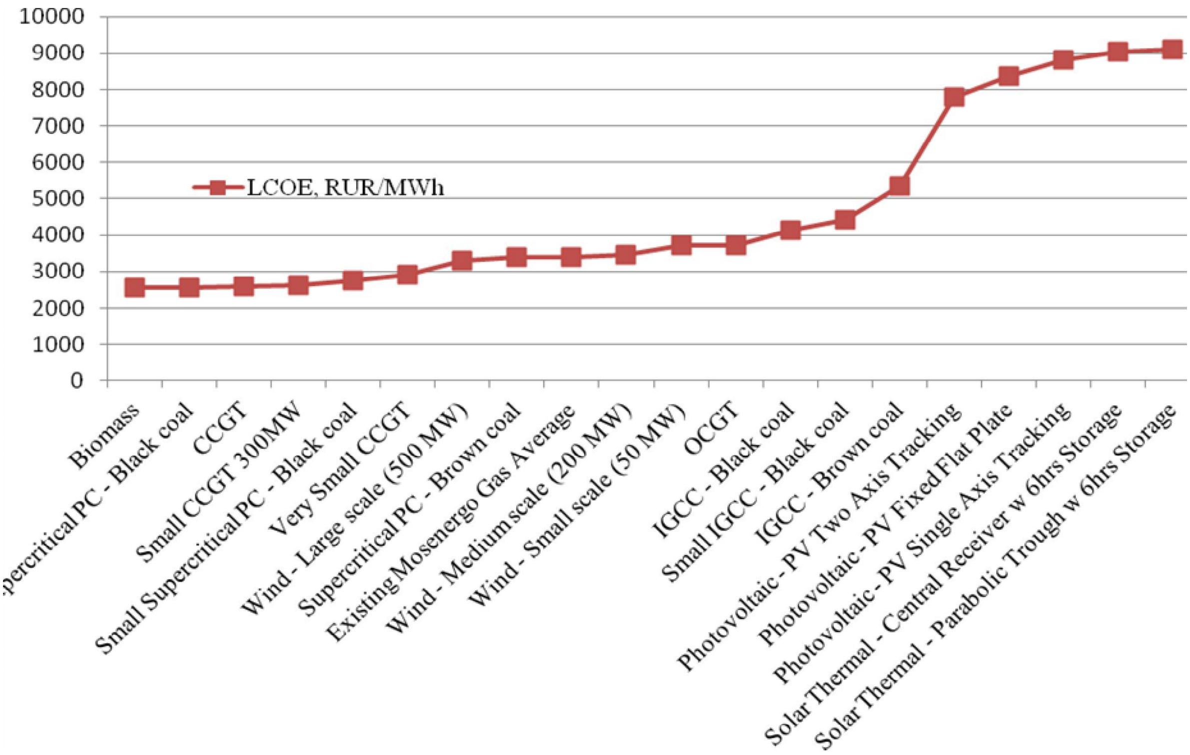

Figure 3 LCOE values for Scenario 2

Consequently given the scarcity of budget resources, energy policy should consider the costs parameters of generation for both electricity and heat. The considered view is required to achieve state and regional goals of energy efficiency, energy infrastructure modernization, and RES based technology development. LCOE can provide valuable information for decision makers to evaluate which technologies should be supported today to compete and achieve efficiency in the future.

Conclusions and discussion

This paper describes an approach to address energy generation modeling issues using an adapted LCOE methodology which has been upgraded to facilitate combined generation and multi-product energy production processes. The model developed is tested on a Russian regional case study and provides an interesting insight into the generation costs assessment process for the specific economic and industrial conditions of Russian regions.

This model also provided a framework to analyze costs structures for each of listed technological types and apply sensitivity analysis to the different cost elements. Two gas fuel costs scenarios were tested to allow for generation costs sensitivity analysis. It showed that if the domestic gas prices in Russia could reach parity with international prices it would cause a significant increase in gas-based generating cost parameters. As a consequence electricity generation from biomass and supercritical PC technologies would be able to outperform CCGT's and biomass followed by wind options which would become the best RES solution. Overall the model recommends that CCGT with a priority for small scale plants is the most cost-efficient new energy generation technology.

We have also concluded that market mechanisms in the energy sector in Russia are not yet suited to create incentives for new technologies which include RES development and their implementation. The modeling showed that due to the high cost of capital in Russia, technologies with higher construction costs will not be able to compete with conventional generation. Furthermore we can also assert that strong political and financial support is needed to boost technological development and RES application. Solar based technologies are not expected to take off shortly and reach competitive costs given Russian regional conditions.

The regional authorities of Russia and CIS countries could benefit from the application of this model for the planning of their energy system development and public programs management. The model has been tested with regional specific data and could be applied in regional energy system planning decision making in conditions of restricted data availability. However, better regional technology specific data is required for more reliable results. Furthermore to improve the usefulness of this framework more data from current power plants will need to be collected for further research and current system state cost modeling.

Assumptions done in the model both for technological and financial parameters can be disputed. International datasets applicability to Russian conditions is another issue for discussion. However, the data used were tested against current energy generation parameters whenever it was possible. On the other hand given energy sector data non-availability the research showed particular areas where sufficient data is missing which limits economic analysis and research for the sector. Suggested data collection directions can be valuable for state government when development of statistical system especially in the proposed movement toward fully market-based pricing for electricity (2014 for all consumers including households) and reconstruction of the heat system.

Further direction of the research is to run the model in the full scope with the two energy products separation (electricity and heat) which we were not able to do yet due to data limitations. At the next stage we will also introduce three CHP options for different power plant sizes.

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