GERMAN ECONOMIC TEAM IN BELARUS

76 Zakharova Str., 220088 Minsk, Belarus. Tel./fax: +375 (17) 294 1147, 294 4395
E-mail: research@ipm.by. Internet: http://research.by/

PP/03/06

Economics of Nuclear Power Development in Belarus

Contents

1. Introduction

Nuclear power is back on the energy policy agenda, in particular in the emerging market economies and the transition countries of Eastern Europe and the CIS, including Belarus. In particular, nuclear power is sometimes considered as a panacea for import-dependent countries facing an increasing domestic electricity demand. What is often forgotten in the debate though, is that the development of nuclear power is technically complex, and particularly expensive. This regards both the power plant equipment itself and the up- and downstream fuel cycle. In no market economy around the world, any privately owned utility without state backing or take-off guarantees has invested in nuclear power over the last 25 years!

Until now Belarus did not suffer from any energy crisis, but it is currently facing a particularly delicate situation with regard to its primary energy and electricity supply: the largest share of primary energy has to be imported from Russia (about 80%, almost exclusively natural gas). The domestic reserves of conventional energy are low, peat resources are relatively dirty and uneconomic, and the potential of renewable energy is low. Yet diversification strategies are currently pondered, one amongst which is to construct a nuclear power plant in Belarus to assure approximately 11% of the primary energy consumption in 2020. A 2-GW plant might generate 12 TWh yearly to cover about 30% of the forecasted electricity consumption. As of today, there is no analysis of the project explicitly examining the generation costs of a nuclear power plant for Belarus.

Against this background, the German Economic Team (GET) has initiated an economic study of nuclear power in Belarus. The objective of the study is to provide a balanced assessment of the benefits and the costs of nuclear power development, and to give neutral policy advice. The remainder of this study is structured in the following way: the first part of section 0 sketches out the different technologies of producing nuclear power today or in the future. Belarus has the option to invest in traditional Russian nuclear technology or to import Western reactors. Section 0 then provides an economic analysis of nuclear power world-wide. The following two sections analyze the economics of nuclear power in Belarus more in-depth. Section 0 assesses the flaws of the current Belarusian energy policy. Section 0 provides a financial feasibility study, based on available information and experts assumptions of future developments of the electricity sector.

2. Nuclear Power Technology and Economics: State of the Art

2.1. Current technological trends

This section describes the technical options that are theoretically available for Belarus. Nuclear reactors can be classified into different generations. Generation I reactors were developed in the 1950s and 1960s. They are mostly based on natural uranium as fuel and graphite as moderator, thus missing inherent security. The majority of reactors in use are generation II reactors. They include boiling water reactors and pressurized water reactors, use enriched uranium as fuel and water as coolant and moderator in most cases. Generation III reactors, with enhanced safety and efficiency, are currently being developed to be more cost competitive. The first ones are operating in Japan. The new generation IV reactors are still in planning phase. They will not be operational before the year 2025 or later and cost estimates are uncertain. Generation I-III reactors recycle plutonium (and possibly uranium), while generation IV reactors are expected to have full actinide recycling[1].

Worldwide circa 440 generation II reactors are in use. About one half of them is installed in Europe (including the former Soviet Union). The majority is either based on

[1] Table 1 provides an overview of the nuclear technologies used around the world in 2003.

the pressurized water reactor (PWR) or the boiling water reactor (BWR). The PWR is the most used type of reactor. Ordinary water serves as coolant and moderator. The design is characterized by two cycles. The primary cooling circuit flows through the core of the reactor. In the secondary circuit steam is generated via a heat exchanger to drive the turbine and produce electricity. There exist two types of PWR, the American Westinghouse and the Soviet VVER. The VVER 440/230 is the oldest reactor of the VVER series. It has different construction and safety faults and is classified as a reactor of high risk. The European Union has suggested that this type of reactor can not be modernized and has to be closed down in near future (Agenda 2000, 15.07.1997).

The Boiling Water Reactor has just one single circuit. The steam passes directly to the turbines, which are thus part of the reactor circuit. With this technology heat losses can be minimized. The water around the core of a reactor is always contaminated with traces of radio-nuclides; thus, the turbines have to be shielded.

The Advanced Gas-cooled Reactor (AGR) is the second generation of British gas-cooled reactors. Graphite is used as moderator, carbon dioxide as coolant and uranium oxide as fuel. This type of reactor was a military development[2]. The AGR was developed from the Magnox reactor, also graphite moderated and CO_2-cooled. A number of these reactors are still operating in the UK.

Last but not least, the light water graphite-moderated reactor (Reactor Bolshoi Moshchnosti Kanalni, RBMK) is a Soviet type of reactor developed from plutonium production reactors. 14 are operating worldwide, all in the former Soviet Union[3]. It is a boiling water reactor with pressure tubes, graphite moderator and water as coolant. Low-enriched uranium oxide is used as fuel. With moderation largely due to the fixed graphite, excess boiling can reduce the cooling and neutron absorption without inhibiting the fission reaction so a positive feedback problem can arise. In the case of leakages at the pressure tubes, cooling stops but the chain reaction continues. The reactor overheats which leads to serious security problems[4].

2.2. Economic analysis of NPPs in the international context

Especially under the aspect of carbon dioxide reduction the discussion about building nuclear reactors has intensified in last years. The worldwide installed nuclear capacities are likely to increase, especially in Asian countries and Russia. In Europe, the building of a new reactor has been approved and is under way in Finland, and France is currently pondering the generation III reactors. Overall, today 20 reactors (14 GW) are under construction[5], 39 (41.4 GW) are planned and another 73 (58.1 GW) are proposed[6].

The two most recent economic and technical studies on nuclear power were carried out by the Massachusetts Institute of Technology (MIT, 2003) and the University of Chicago (2004). The studies focus on the potential role of nuclear power to be an option to reduce carbon emissions. Thus, nuclear power is analyzed in particular in its competition with conventional power generation by coal and natural gas. The MIT-study concludes that in markets facing considerable uncertainties and at current raw material prices, the heavy capital intensity makes nuclear power uncompetitive when compared to conventional thermal power plants based on coal or gas (MIT, 2003, p. ix). The study of the University of Chicago (2004) focuses slightly more on economic issues, but its results confirm those of the MIT-study: when comparing the magnitude

[2] Reactors with graphite moderator are suited for plutonium production for nuclear weapons.
[3] E.g. RBMK 1500 in Ignalina (Lithunia), which is the largest reactor worldwide.
[4] The disaster of Tschernobyl (RBMK 1000) was caused by these circumstances.
[5] Romania (1), Russia (4), Canada (1), Argentina (1), China (2), India (8), Iran (1), Japan (1), Korea (1).
[6] Retrieved September 5th, 2005, from www.world-nuclear.org.

of levelized cost of electricity (LCOE), nuclear power is systematically more expensive than coal or natural gas plants (Table 2).

Table 1: Nuclear Power Plants operating in 2003

Reactor type	Main Countries	Amount	GW	Fuel	Coolant	Mode-rator
Pressurised Water Reactor (PWR)	US, France, Japan, Russia	263	237	enriched UO_2	water	water
Boiling Water Reactor (BWR)	US, Japan, Sweden	92	81	enriched UO_2	water	water
Gas-cooled Reactor (Magnox & AGR)	UK	26	11	natural U, enriched UO_2	CO_2	graphite
Pressurised Heavy Water Reactor CANDU (PHWR)	Canada	38	19	natural UO_2	heavy water	heavy water
Light Water Graphite Reactor (RBMK)	Russia	17	13	enriched UO_2	water	graphite
Fast Neutron Reactor (FBR)	Japan, Russia, France	3	1	PuO_2 and UO_2	liquid so-dium	none
TOTAL		439	361			

Source: World Nuclear Association[7].

In addition to high economic uncertainty the other factors pose severe problems to the deployment of nuclear energy:

- *Safety:* beyond traditional safety issues, the MIT-study concludes that little is known about the safety of the overall fuel cycle, i.e. beyond reactor operation (MIT, 2003, p. ix). This includes the fuel reprocessing plants, but also the threat of terrorist attacks is much higher than the one of reactors (MIT, 2003, p. 51);
- *Waste*: as of today, the issue of waste treatment has not been resolved in a sustainable manner in any country using nuclear power. Geological disposal has yet to be demonstrated to be safe for thousands of years to come. The closed fuel cycle still contains risks and is expensive. The MIT-study therefore recommends that over at least the next 50 years, the best choice to meet these challenges is the open, once-through fuel cycle (MIT, 2003, p. x). There is no shortage of uranium that would restrict this strategy;
- *Proliferation:* this is not a risk specific to Belarus, but it is an important – often neglected- aspect of nuclear energy. The MIT-study concludes that "the international safe guards regime is inadequate to meet the security challenges of the expanded nuclear deployment. The reprocessing system now used in Europe, Japan, and Russia that involves separation and recycling of plutonium presents unwarranted proliferation risks" (MIT, 2003, p. ix).

To compare the costs of different power generation technologies in the international context a net-present-value model has been designed. The model calculates the annual cost and results in a price per kilowatt-hour. The costs contain the necessary investment costs, the expenses for fuel and personnel as well as auxiliary and disposal cost. For nuclear power costs of reprocessing spent nuclear fuel and decommissioning costs are calculated additionally. Besides the monetary inputs, technical specifications for each plant type have to be made. The financial and technical assumptions are based on international standards and experiences.

Our model comparison confirms the MIT and Chicago studies: nuclear power plants are uncompetitive compared to coal or gas fired base load plants (Table 2). The model used here indicates costs of 5.1 US ct/kWh for a standard reactor (with the main assumptions of the MIT study) and 3.4 and 3.5 US ct/kWh for coal and gas-based electricity generation[8]. All studies relied on general assumptions that are not suited for a

[7] Retrieved September 5th, 2005, from www.world-nuclear.org .

[8] For reactor types with half of the typical overnight costs (~1,000 US$/kW) results for nuclear energy converged to the generation costs of coal and gas (but still being slightly higher).

country specific analysis. The special conditions investment projects have to face in Belarus will be considered in the following sections.

Table 2: Generation costs of power plants

Energy Source \ Study	MIT	Chicago	EE^2 model
Nuclear	6.7 US ct/kWh[9]	5.1-8 US ct/kWh	5.1 US ct/kWh
Coal	4.2 US ct/kWh[10]	3.7-4.8 US ct/kWh	3.4 US ct/kWh
Gas (CCGT)	4.1 US ct/kWh[11]	3.8-4.0 US ct/kWh	3.5 US ct/kWh

3. Electricity System in Belarus and Need for Reforms

3.1. Overview

The Belarusian today's electricity sector is governed by the Belenergo (Belarusian State Power Engineering) concern, which was created in 1995. It is subordinated to the Ministry of Energy and owns a number of enterprises. Among them are the six regional power enterprises (Oblenergos). Belenergo is responsible for:

- the management of the Belarusian power-engineering system,
- generation, transmission and distribution of electric and heat energy,
- the maintenance of power plants and electric and heat network systems,
- the operative-dispatch control of the process of generation and supply of electric energy, and
- the technical supervision of the conditions of power plants and network objects.

The Ministry of Economy sets the energy tariffs[12]. Belenergo calculates at the concern level for the electricity sector, while heat calculations are done in the Oblenergos and afterwards aggregated to the concern level. Tariffs for all public utility services are regulated by the Council of Ministers. Prices for electricity increased in 2000-2005 by 51% (187.5% for households) and meanwhile cover generation costs, except for households and utility services. They vary from 2.66 to 6.02 US ct/kWh. Cross-subsidization still continues (Table 3): household tariffs are significantly below industry tariffs, although distributing electricity to households is more expensive.

Table 3: Electricity production costs and prices for different groups of consumers, US ct/kWh

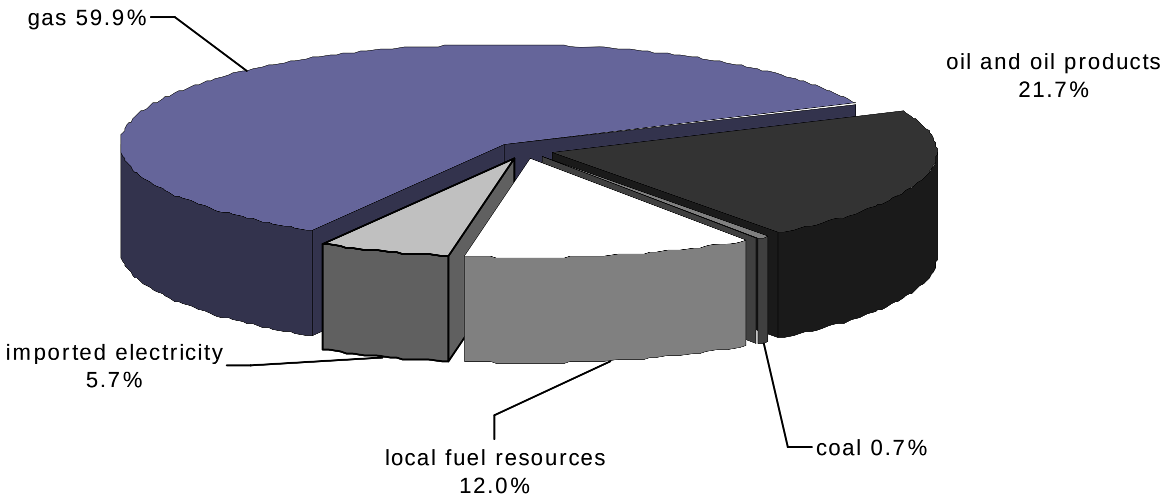
Prices for… \ As of January…	2000	2001	2002	2003	2004	2005	increase '00-'05
State financed organizations	3.50	3.39	3.39	3.00	4.02	4.02	14.86%
Industry	4.30	4.15	4.15	4.41	6.02	6.02	40.00%
Households	1.20	1.26	1.19	2.39	3.32	3.45	187.50%
Utility Services	3.58	3.53	3.39	2.44	2.66	2.66	-25.70%
Other Enterprises	4.30	3.39	4.15	4.41	6.02	6.02	40.00%
costs	**2.60**	**2.53**	**2.02**	**2.32**	**3.21**	**3.5**	**34.62**

Source: Rakova, Belarusian Infrastructure Monitoring, 2005; own calculation.

A look at the consumption of primary energy reveals that gas and oil play the main role with 59.9% and 21.7% respectively in 2003. Local resources as peat, wood, saw-dust and biomass accounted for 12.0%. Potential sites of domestic reserves are being explored at the moment, but little promising[13].

[9] Assuming a 1 GW NPP with 40 years of economic life.
[10] Without carbon tax.
[11] Moderate gas, without carbon tax.
[12] Heat tariffs have to be agreed with regional executive committees, because produced and sold locally.
[13] There are some potential sites of oil (3 bn tons industrial reserves) and brown coal (150 m t industrial reserves) in the south of Belarus (Ministry of Energy, 2005).

Figure 1: Structure of primary energy consumption (2003)



Source: the Ministry of Energy

According to Belenergo, the enterprise is capable to satisfy Belarus' demand for electricity completely and for heat up to 50%. Currently the mainly thermoelectric power stations provide about 7.8 GW of installed capacity. Together with some hydroelectric plants and block stations they generated 30.4 TWh in 2004 and cover 70-80% of the growing domestic demand. 4 TWh were imported, mainly from Lithuania and Russia. It is noteworthy that electricity imports decreased by 46.5% in 2004, compared to 2003.

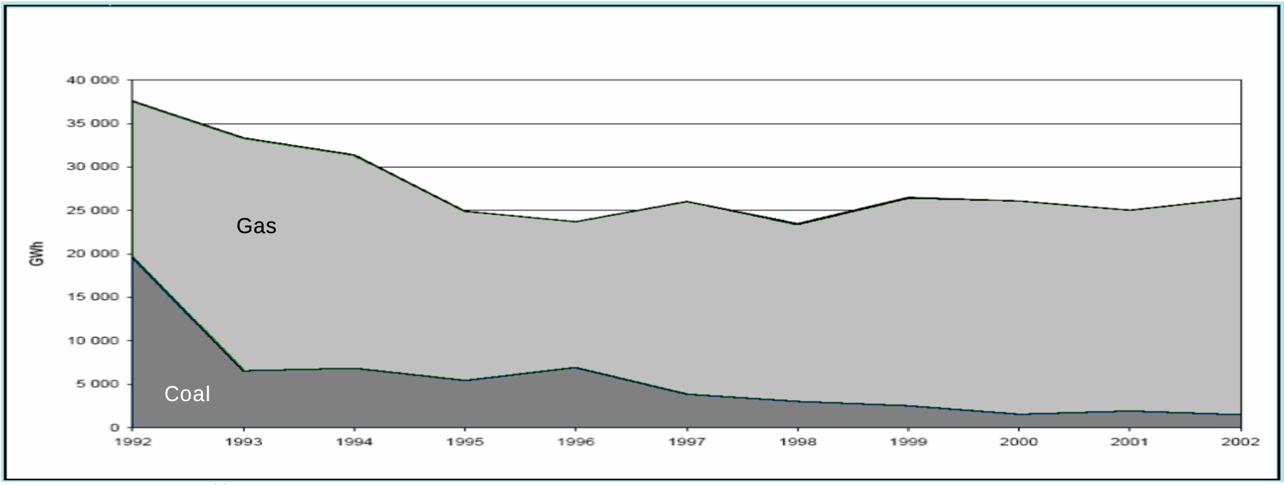
In 2003, about 80% of electricity consumption stemmed from local generation. Industrial consumers use more than 60% of the electricity, urban population about 20%. Electricity consumption is currently slightly rising and is forecasted to reach about 41 TWh by 2020 according to official scenarios while imports are decreasing.

3.2. Need for reforms

Under the current institutional conditions, it will not be possible to modernize the sector to assure efficient functioning. Although some progress has been made over the last years regarding payment discipline, debt and barter reduction and transparency of the pricing system, fundamental reforms still have to be undertaken. One of the basic problems remains the dependence on Russian gas (99% of all gas imports; Rakova, 2004, p. 4) used to generate the bulk of electricity (Figure 2). As 95% of all electricity is generated by burning gas (Pavel & Rakova, 2005b, p. 2) Belarus is highly vulnerable against price increases.

The depreciation of the capital stock reached 60.7% at the beginning of 2005 (Presidential Decree No. 399, 2005). By 2009/2011 power plants need a full modernization (Pavel & Rakova, 2005b, p. 2). In consequence, a large share of the installed capacity is simply not available for generation (Figure 3).

Figure 2: Evolution of Electricity Generation by Fuel from 1992 to 2002 in Belarus



Source: IEA (2005)[14].

Figure 3: Depletion of capital assets of the enterprises of the Ministry of Energy

Source: the Ministry of Energy.

The centralized fully state owned power system together with the current "cost-plus" pricing does not provide adequate incentives to the power enterprises. If they manage to reduce costs, the Ministry of Economy regularly demands a tariff reduction thereby lowering margins of profits which are actually needed for re-investment. The inefficient and non-transparent pricing system with politically motivated cross-subsidies leads to distorted incentives to consumers, e.g. by softening budget constraints of privileged enterprises and lowering the willingness among the population to use energy more efficiently. Also, this practice leads to additional burdens for the energy sector: power enterprises are not compensated for expenses from preferential tariffs to several groups of customers. As mentioned above, non-industry tariffs (households, utility services, etc.) do not cover the long-run marginal costs of production.

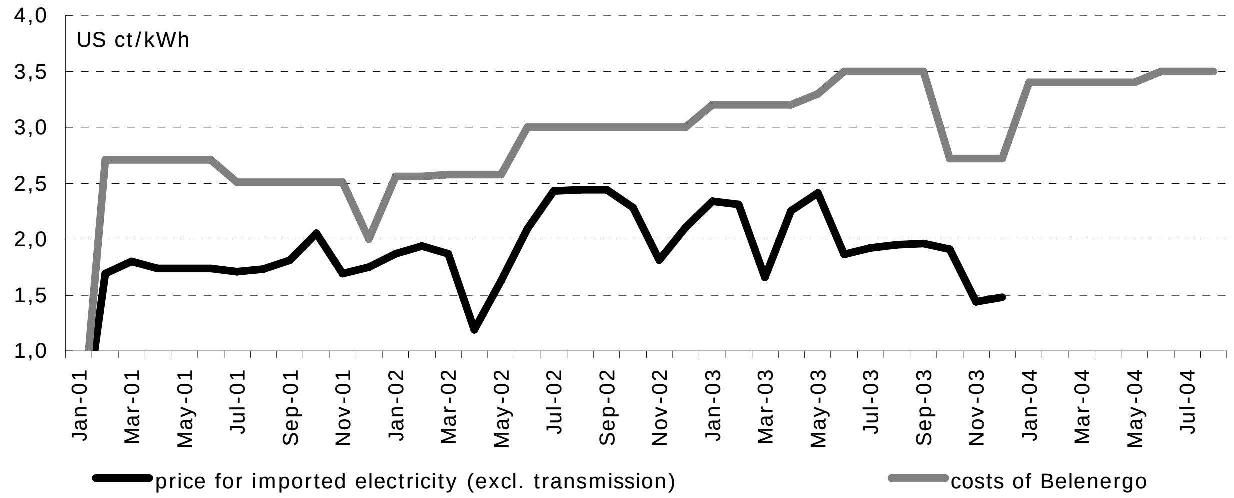
Delays in customers' payments as well as non-monetary payments could be reduced due to government policies. The most disciplined payers are the private sector and population. However, around 40-44% of all arrears in Belarusian economy are from the energy sector (Rakova, 2004, p. 5). Although payment discipline improved, many enterprises – especially from agriculture – are simply not able to operate under the

[14] Retrieved October 18th, 2005 from IEA Energy Statistics http://www.iea.org/statist/index.htm).

stricter conditions (Babicki *et al.*, 2005, p. 23). While lowering the tariff markups for non-monetary payments and thus softening the enterprises' budget constraints, this will not protect from serious consequences for ailing enterprises. To avoid this, a growing number of enterprises provides themselves with energy from own sources. This lead to increasing costs to the energy providers in turn (Rakova, 2004, p.4). Not surprisingly, electricity generation costs are not competitive. This can be shown by comparing prices for imported electricity with Belenergos generation costs (Figure 4). The difficult internal situation is getting even more complicated when looking at rising energy prices, especially for gas.

Against this background, an ambitious State Program on the Modernization of the Energy Sector for the period of 2006-2010 was launched in August, 2005 (Presidential Decree N° 399). The resulting Concept of Energy Security of Belarus (Ministry of Energy, 2005) aims to rise the share of domestic energy sources up to 25% and to cover electricity consumption totally from own generation. The share of gas shall be reduced from 95.4% to 83% in the electricity sector and from 78.2% to 60-64% in the fuel balance. Energy imports from Russia, which account for 98% at current, are aimed to be at 84% by 2020. Huge investments in the capital assets intend to reinforce about one third of the equipment. This would also lower the ratio of gross capacity of power stations to maximal burden in the energy system (goal: from 140.6% to 115%). A budget of 12 bn US$ was adopted to finance these measures (Figure 5). However, it is unclear to which extent this investment will be really available.

Figure 4: Prices for imported electricity and generation costs of Belenergo

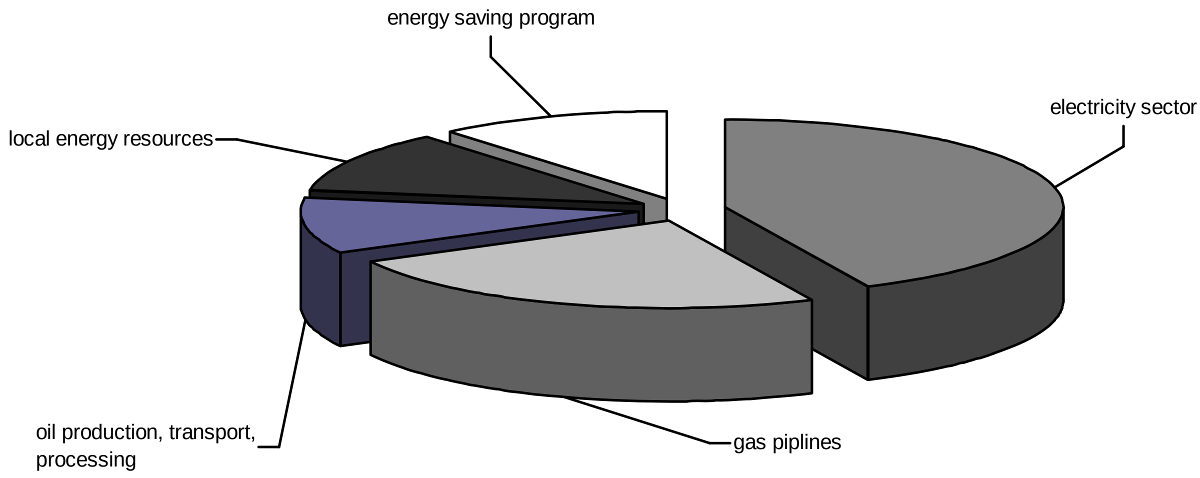


Source: Rakova (2004, p. 13).

Although critics doubt that the program will be fully realized, the program contains some important measures to improve the present situation of the Belarusian energy sector. The requirement to lift up the share of local energy resources is understandable given the political objective to limit the dependence on Russian fuel. However, there are several drawbacks of this strategy like the limited size of generation plants using renewable fuels, the availability of the needed amounts of fuel, the large investments and negative ecological consequences (Pavel & Rakova, 2005b, pp. 2-3)[15]. If the State Energy Efficiency Program will be realized, this could in fact lead to enormous economies in the range of 20-40% (Pavel & Rakova, 2005a).

[15] Carbon dioxide emissions will significantly rise when burning wood, peat, masut etc. Also, one must fear massive forest area damage and a destruction of swamps.

Figure 5: Amount of investments for Energy State Program



Source: the Ministry of Energy.

4. Perspectives of Nuclear Power for Belarus

4.1. Current discussion

The last few years nuclear power has become a topic in the mass media as well as in internal energy political discussions again, thus reviving plans from the mid 1990s to build a 1 GW nuclear power plant near Minsk (Smoliar and Ermashkevich, 2000, p. 9ff.). Nevertheless, the public discourse is rather based on speculations. One reason might be the fear to discuss the building of a NPP openly in Belarus, who suffered mostly from the Chernobyl reactor accident.

Official scenarios, however, seriously consider nuclear power as an alternative to diversify the energy mix[16]. According to official sources[17] planning of a NPP might take place by 2008 to start construction in 2009/10. A first 1.000 MW block could be start operation in 2015, the second 1.000 MW block in 2020.

A forecast on the structure of the fuel balance presented at the Minsk energy conference in November, 2005 includes a scenario for 2020 indicating a share of 11.3% for nuclear energy. This would reduce the share of imported natural gas from about 60% in 2003 to 38.7% in 2020 (47% without nuclear energy). A similar scenario is given for the structure of the fuel balance with 13.9% nuclear power in 2020 and 51.8% gas (compared to 77.1% in 2003). In October 2005, a research program was launched to study the feasibility of a nuclear power plant. At the moment, six potential sites are considered for a construction of a NPP (e.g. in the Mohilev oblast': Bychovskij or Shklovsko-Goretskij Point).

4.2. Choice of Russian reactor

Even though Belarus could choose from a variety of internationally available reactors, we assume that it would opt for a Russian reactor. This in both due to the political proximity to Russia and the fact that other countries would require stricter payment terms than the Russians. Therefore, our cost analysis considers (only) the four relevant Russian reactors:

---

[16] Presidential Decree No. 399, see above. A report of A. Jakushev from the Belarusian "United Institute of Energy and Nuclear research - Sosny" ("Predposylki razvitia atomnoj energetiki v Belarusi", Minsk, 02.11.2005) presents results from an economic study on average energy generation prices including nuclear energy. It assesses nuclear power as a realistic way to diversify and stabilize Belarus' energy supply.

[17] See Presidential Decree No. 399.

- **VVER 1000/ V-392:** the V-392 is an advanced version of the VVER-1000 type and a part of the nuclear power plant AES-392. The V-392 is being built in India and planned for Novovoronezh blocks 6 and 7. Also, it was bid for Sanmen and Yangjiang in China. There are one- to four-block systems à 640 or 1.000 MW, respectively;
- **VVER 1000/ V-428:** The V-428 is part of the AES-91 NPP and is equipped with Western control systems. It was earlier sold to Tianwan (China) and was bid for Finland in 2002. The V-428 has one or two blocks à 640 or 1.000 MW;
- **VVER 640/ RU V 407:** The V-407 with 640 MW has advanced safety features and was developed jointly with Siemens (now Framatom ANP). However, the only reactor of this type (at Sosnovy Bor, Leningrad Oblast) was not finished after funds had run out;
- **VVER 1500/ V-448:** Rosatom (the Russian Federal Atomic Agency) is recently designing this new 1500 MW pressurised water reactor. Design is expected to be complete in 2007 and the first units commissioned in 2012-13. It is expected that these can be built at the same cost as a V-320 type, i.e. two thirds the cost per kilowatt. Provisional sites for these larger units are Kursk and Leningrad power stations, which currently run 8 RBMK light water, graphite-moderated units between them, dating from 1974. The first unit is planned for Leningrad NPP-2[18].

4.3. NPP cost calculation for Belarus: Assumptions

In the paper by Hirschhausen and Rakova (2005) was applied to specific Belarusian conditions to estimate total production costs per kWh. Therefore, data were adjusted and several modifications introduced. All costs were calculated on the basis of 2005 prices. In the case of missing Russia or Belarus specific data, prices were set at 70% of the international average level[19] (e.g. auxiliary, disposal costs).

The capacity factor was set according to the Russian average at 0.7 (IAEA, 2005, p. 693), efficiency at 0.32 as in the MIT study. The calculation of nuclear fuel costs (without reprocessing and disposal) resulted in 0.271 US ct/kWh, for reprocessing 0.104 US ct/kWh were obtained. Decommissioning costs were estimated at 500 million EUR; personnel costs at 6.000 US$ p.a.

Regarding financial parameters it was supposed that the bulk of investment (80%) would be financed by credits. The interest rate for debts was set 13%, according to the current average of World Bank credits; the interest rate of equity was estimated 15% (as in the MIT study).

In addition to the costs accounted for in the general calculation, infrastructure costs directly related to the construction of a NPP were considered for the case of Belarus. These costs were treated like capital costs and estimated at half a billion US dollars.

4.4. Results

Costs were basically calculated as in the general model with the exception of the additional infrastructure costs. To gain a better understanding of the costs' structure, results were split into different blocks. The first block – construction costs – includes capital and infrastructure costs. For the considered Russian reactors these costs range from 2.54 up to 3.58 US ct/kWh. Operation and maintenance costs amount to 1.10 US ct/kWh (irrespective of the reactor type). Total costs, finally, additionally contain decommissioning costs (0.15 to 0.20 US ct/kWh) and range from 3.80 to

[18] Retrieved October 20th, 2005, from http://world-nuclear.org

[19] This is, of course, a rough estimation, but rational as a look on empirical data confirms: Russian oil, e.g., is purchased at 70% of the world market price in Belarus.

4.83 US ct/kWh. Assuming decommissioning costs of 5 bn US$ as reported for Ignalina aggregated total costs would sum up to 5.19 to 6.24 US ct/kWh.

Thus, total costs for producing 1 kWh by a nuclear power plant exceed today's average electricity production costs of 3.5 US ct/kWh (Rakova, 2004). Assuming decommissioning costs of 5 bn US$ as recently officially reported for the closure of the Ignalina NPP in Lithuania, results indicate costs varying from 5.2 to 6.2 US cent/kWh.

For an objective evaluation of the obtained results one has to bear in mind, that today's generation is highly ineffective due to outmoded generation and network facilities. The planned modernization of the energy sector should significantly reduce average generation costs. Moreover, these results present only minimal costs related with the generation of nuclear energy, as the model did not account for costs from modernization, potential hazardous incidents or disturbances, and ecological consequential costs.

Table 4: Results for Russian reactors

Type of costs	**Reactor: VVER…**	**1000** V 392 2x1.000MW	**1000** V 392 3x640MW	**1000** V 428 2x1.000MW	**640** V 407 3x640MW	**1500** V448 1x1.500MW
capital costs	US ct/kWh	2.388	2.004	2.448	3.042	2.466
infrastructure costs	US ct/kWh	0.514	0.535	0.514	0.535	0.685
construction	**US ct/kWh**	**2.902**	**2.539**	**2.961**	**3.577**	**3.151**
fuel costs	US ct/kWh	0.271	0.271	0.271	0.271	0.271
personnel costs	US ct/kWh	0.020	0.020	0.020	0.020	0.020
auxiliary costs	US ct/kWh	0.034	0.034	0.034	0.034	0.034
reprocessing costs	US ct/kWh	0.104	0.104	0.104	0.104	0.104
disposal costs	US ct/kWh	0.672	0.672	0.672	0.672	0.672
O&M	**US ct/kWh**	**1.100**	**1.100**	**1.100**	**1.100**	**1.100**
decommissioning costs	US ct/kWh	0.149	0.155	0.149	0.155	0.199
total costs	**US ct/kWh**	**4.151**	**3.795**	**4.211**	**4.832**	**4.450**
electricity generation p.a.	*TWh*	*12.3*	*11.8*	*12.3*	*11.8*	*9.2*
share of forecasted consumption		*0.30*	*0.29*	*0.30*	*0.29*	*0.22*

Even though we can only provide a stylized analysis the result from the economic calculations are clear: nuclear energy is not competitive in Belarus. Therefore, it seems unlikely that nuclear energy could help to relieve the problems of the energy sector, or to reduce the import dependences.

5. Conclusions and Policy Recommendations

The Energy System in Belarus currently is facing serious structural challenges, such as increasing prices for energy, high dependence on imports (especially from Russia) and upcoming power plant modernizations. An ambitious State Program was lunched to rise the share of domestic energy sources up to 25% and to cover electricity consumption totally from own generation. To achieve these goals a discussion about the possibilities of nuclear energy in Belarus arises.

Against this background this study aims to analyze the potential of building a nuclear power plant in Belarus. Beside technical and safety issues, the economics of such an important decision have to be reviewed in detail. A generation cost analysis has been undertaken, based on a net present value model. Beside the expenses for building and running the power plant, the costs for a fuel cycle process need to be regarded.

An international comparison of developments in the nuclear industries is quite sobering: in no market economy around the world, any private company has invested in a nuclear power plant over the last two decades. Nuclear power is only developed by emerging countries with very heavy state involvement and subsidies. The two most recent large-scale studies on nuclear power carried out by the MIT (2003) and the University of Chicago (2004) conclude that at current raw material prices and given inherent market uncertainties, the heavy capital intensity makes nuclear power uncompetitive, when compared to conventional thermal power plants (coal, gas).

In addition to high economic uncertainty, other factors pose severe problems to the deployment of nuclear energy: little is known about the safety of the overall fuel cycle, i.e. beyond reactor operation: this includes the fuel reprocessing plants, but also the threat of terrorist attacks. As of today, the issue of waste treatment has not been resolved in a sustainable manner in any country using nuclear power. Geological disposal has yet to be demonstrated to be safe for thousands of years to come. The closed fuel cycle still contains risks and is expensive. Proliferation is an important – often neglected- aspect of nuclear energy.

Based on a specific cost model for nuclear power, we compare the costs of the reactors that will be relevant for Belarus (VVER 1000/V-398, VVER 1000/V-428, VVER 640/RU V 407, VVER 1500/V-448). Total costs of generation are in the range of 3.8-4.8 US cent/kWh – not accounting for costs from modernization, potential hazardous incidents or disturbances, and ecological consequential costs. Thus, our results represent minimal costs of generation, which exceed the costs from currently used power plants of Belenergo (~ 3.5 US cents/kWh); imported electricity costs about 2 US cents/kWh.

Our analysis leads to the following policy recommendations:

- Given the current state of the Belorussian energy sectors and the high rate of capital depletion (~ 60%), large investments in the nuclear power cycle do not seem to be a feasible solution: The state is most likely unable to undertake such high investments with a doubtful outcome, and private investment does not seem to be forthcoming;
- nuclear power would not be economic in Belarus and it seems to be uneconomic in most other countries of the world. Belarus should not trust the myth of “cheap” nuclear power, which is in the fact one of the most expensive sources of electricity;
- the energy import dependency of Belarus would not be reduced, since the entire technology, know-how and reprocessing/disposal would have to be purchased from Russia. The government should not considered to develop its own fuel cycle, both for economic and technical reasons;
- in the short run, the import dependence of the Belarusian energy sector is unavoidable. In the medium term, increasing energy efficiency, raising prices and thus forcing a more rational use of energy, a modest increase of the role of renewable energies and conventional domestic fuels will dampen the import dependence. For a more in-depth analysis of related energy policy issues, see the policy papers by Cramon, et al. (2005) on renewable energies, and Pavel and Rakova (2005a) on energy efficiency;
- in the medium term, different options to diversify fuel supplies exist. Belarus could invest into coal power plants and start to import coal from Ukraine or Poland. The existing capital stock of power plants should be updated, and thus the fuel needs be reduced;

in the long run, Belarus should intensify its electricity link with its Western neighbours, the UCTE. A HVDC (high voltage direct current) connection with Poland would make electricity imports technically feasible, thus further diversifying the import portfolio.

Prof. Dr. Christian von Hirschhausen, Ina Rumiantseva, Elena Rakova (lector), Ricardo Giucci (lector)

Minsk, March 2005