Section III

The Economics of Nuclear Power in the Turkish Context

III

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Executive Summary

The economics of nuclear power in the Turkish context is evaluated in this paper with particular focus on the Turkish Agreement with Russia to construct a four-unit plant with a total installed capacity of 4,800 MW in Akkuyu. In May 2010, Russia and Turkey signed an agreement that a subsidiary of Russia's state-owned atomic power company Rosatom would build, own, and operate a power plant at the Akkuyu site, on Turkey's Mediterranean coast, comprising four VVER units of 1,200 MW installed capacity each. The first unit is expected to enter service in 2019 with the other three coming online subsequently. The Turkish Electricity Trade and Contract Corporation (TETAS) has guaranteed the purchase of 70% power generated from the first two units and 30% from the third and fourth units over a 15-year power purchase agreement at an average price of 12.35 US cents per kWh excluding VAT.

The average wholesale electricity price in 2010 is calculated as 9.38 US ¢/kWh. When compared with the Akkuyu agreement prices for 2010 in real terms, it is seen that the wholesale price is about 60% higher than the highest price estimate for the Akkuyu agreement (Low discount rate scenario 5.84¢/kWh). The discrepancy is significantly higher (284%) for the high discount rate/low price scenario.

Considering the fact that the agreement refers to a price that is the average of a price for the period 2020-2035 and therefore almost two decades ahead, it appears to be an economically advantageous deal for Turkey (in the sense that the agreed-upon average purchase price can be expected to be considerably lower than end-use electricity prices by that time) provided that safety measures and regulations related to the construction, operation and maintenance of the reactor as well as related to waste transport and management activities are all well defined and provide convincing confidence and reliability regarding the risk of an accident and nuclear leakage. In addition, the project company is to transfer 15 % of its profits to the Turkish Treasury after the end of the purchasing commitment.

If the deal would have been possible without an intergovernmental agreement, as a stand-alone commercial agreement at the same terms, is rather questionable considering the economics and all the risks taken up by the Russian party. Other aspects such as the strong bilateral cooperation in the energy sector between Russia and Turkey and the promotion of Russian nuclear technology in new emerging markets might have been influential factors that contributed to this agreement. If Turkey is to have a nuclear future as envisaged in long-term official energy strategy, the agreement seems to be a good starting point economically as long as the possibility of leakage and a severe nuclear accident are excluded, waste management poses no concern, and the necessary regulatory and controlling mechanisms can be put in place successfully. The economics of a non-nuclear future, on the other hand, together with its feasibility and sustainability, is being discussed worldwide more extensively after the Fukushima accident.

1 Introduction

The economics of nuclear power in the Turkish context is evaluated in this paper with particular focus on the Turkish Agreement with Russia to construct a four-unit plant with a total installed capacity of 4,800 MW in Akkuyu. It should be stressed that this study does not provide an attempt to question the decision of installing Turkey's first nuclear power plant, but to elaborate on various aspects of this decision in relation to international standards and experience in order to better understand its implications for the country. In accordance with this aim, a comprehensive economic evaluation is presented in the following.

First, international experience regarding the cost of nuclear power generation worldwide is reviewed based on historically available data. Next, issues related to the economics of power generation implied by the Turkish Agreement with Russia are evaluated in comparison with international experience. Subsequently, the anticipated impact of nuclear power on electricity supply & prices in Turkey is discussed based on official supply / demand projections. The final section summarizes most important findings and concludes the study.

2 The Cost of Nuclear Power Generation - Worldwide

2.1 Investment Costs and Factors Affecting Recovery

The up-front expenditures of a nuclear power plant investment related to all planning, engineering, construction and licensing activities, must be recovered during the operation phase and are spread over the economic lifetime of the plant for capital recovery and added in annualized form to other annual costs of operation, maintenance etc. Since the fixed costs are to be recovered over the plant's lifetime generation, a lifetime capacity factor affects the recovery, in addition to assumptions of economic life and discount rate. All these issues are elaborated in this section.

2.2 Overnight Capital Costs

In addition to the bare cost of constructing a plant, usually identified as engineering-procurement-construction, investment costs of a nuclear power plant also include the cost of land, cooling infrastructure, administration and associated buildings, site works, switchyards, project management and licenses as well. This definition confirms with what is referred to as *overnight capital cost*. In the World Nuclear Association's recent report (WNA, 2011a) nuclear overnight capital costs are quoted from mid-2008 vendor figures to be just over $3000/kW for Advanced Boiling Water Reactor (ABWR) type reactors, just under $3000/kW for Economic Simplified Boiling Water Reactor (ESBWR) type reactors and about $3000/kW for AP1000 (a trademark of Westinghouse Electric Company LLC) Pressurized Water Reactor (PWR) types. According to a recent OCED study (OECD, 2010), the overnight capital costs (2008 values) ranged from US$ 1556/kW for Advanced Power Reactor (APR)-1400 type reactors in South Korea through $3009 for ABWR reactors in Japan, $3382/kW for Generation III+ reactors in USA, $3860 for the European Pressurized Reactor (EPR) at Flamanville in France to $5863/kW for EPR reactors in Switzerland, with world median $4100/kW. Belgium, Netherlands, Czech Rep and Hungary were all over $5000/kW. In China overnight costs were $1748/kW for Chinese Pressurized Reactor (CPR)-1000 (a Generation II+ pressurized water reactor) and $2302/kW for AP1000 type reactors. The overnight capital cost of a Russian Vodo-Vodyanoi Energetichesky Reactor (VVER)-1150 type reactor is given as $2933/kW.

The real investment cost, however, typically exceeds overnight capital cost due to the cost of financing and escalation in material and labour costs as has been experienced quite often recently (e.g. Romm, 2009; Kanter, 2009). According to a summary of cost estimates provided by Kennedy (2007), construction costs excluding Interest During Construction (IDC) are estimated at £ 500-1000/kW (2004 values), while they go up to £ 3000/kW (2004 values) with IDC. Drawing on largely unknown public records of French reactors, Grubler (2010) reveals specific reactor costs and their evolution over time, and finds substantial escalation of real-term construction costs. MIT (2009) estimates $4,200/kW for nuclear on average. This is in accordance with Joskow/Parson's (2009) assumption of $4,000/kW. The U.S. Department of Energy (2010), on the other hand, has a slightly higher estimate of $5,300/kW, which is in accordance with the result of a report published by the Moody's Investors Service (Moody's, 2007) that estimates the all-in cost of a nuclear generating facility at $5,000- $6,000/kW.

2.3 Capacity Factor

The capacity factor determines the amount of electricity produced and thus has a significant impact on unit generation costs. If the capacity factor is low, less electricity is produced and hence the investment costs, which are recovered over the lifetime power generation of the plant, are covered by a lower amount of production implying a higher unit cost. Since the fixed costs are to be recovered over the plant's lifetime generation, it is the lifetime capacity factor that is relevant for unit cost computations.

Joskow / Parsons (2009) found that U.S. nuclear plants have a lifetime capacity factor less than 80%. Their analysis at global level results in lifetime capacity factors at about 82 percent as of 2007. It is mentioned that only Finland has a fleet of nuclear plants with lifetime capacity factors greater than 90 percent, and only four other countries have fleets with lifetime capacity factors greater than 85 percent.

The MIT study "The Future of Nuclear Power" (MIT, 2003) employs 85% and 75% lifetime capacity factors in its base case scenario reflecting most reasonable estimates. However, in the 2009 update (MIT, 2009) it is mentioned that the fleet-averaged capacity factor since 2003 has been maintained at about 90%. In the update on the cost of nuclear power, an 85% capacity factor was assumed. The generic assumption of 85% has also been used in the OECD-study (OECD, 2010).

Koomey / Hultman's (2007) analysis on 99 nuclear reactors in the US reveals a median capacity factor of about 72% for earlier reactors and about 82% for the main sample.

2.4 Economic Lifetime

The economic lifetime plays a significant role in the determination of unit generation costs as well since it determines the lifetime power generation over which investment costs are to be recovered. Obviously, the shorter the lifetime the higher the unit generation cost and vice versa.

The OECD report on regulatory reform (OECD, 1997) has declared the typical economic lifetime of nuclear power plants as 40 years, which is also in accordance with commonly used assumption in recent modeling studies (e.g. Vaillancourt et al., 2008; Lenzen, 2008). In practice, however, an extension of plant lifetime is frequently observed as indicated below on the example of the United States.

The United States Nuclear Regulatory Commission NRC issues operating licenses for a maximum term of 40 years. However, in 1991 the NRC developed a set of procedures that features an extension of operating licenses by an additional 20 years. Since then the NRC has renewed licenses for 66 reactors (out of 104 operating reactors in the United States) and is considering 16 applications. The operating life of the nation's largest three-unit power plant has been renewed recently (Reuters, 21 April 2011).

2.5 Discount Rate

Naturally, interest rates and hence the discount rates investors use have a significant impact on the costs of investments in power generation. In computing levelized generation costs, investments costs are annualized using an assumed discount rate. The higher the discount rate, the higher the levelized generation costs. Typically, the real discount rate is assumed to be in the range of 5-10%. In the OECD-report (OECD; 2010), the values for investment, decommissioning and total levelized cost are reported for both 5% and 10% discount rates which makes explicit the significance of this assumption. The levelized cost of nuclear power generation for Belgium, for example, is computed as US$ 61.06/MWh at a 5% discount rate whereas it increases to US$ 109.14/MWh at a 10% discount rate.

2.6 O&M Cost

According to the OCED study (OECD, 2010), the O&M costs (2008 values) of nuclear power plants ranged from US$ 7.04/MWh for CPR-1000 type reactors in China through $29.8/MWh for PWR reactors in Hungary. The O&M cost of PWR reactors in Germany on the other hand is as low as $8.8/MWh. It should be noted that country-specific cost allocation schedules have a significant impact on the O&M costs item. The O&M cost of a Russian VVER-1150 type reactor is given as $16.8/MWh.

2.7 Construction Duration and Economic Impacts

Construction duration is defined as the time that elapses between the pouring of the first concrete and grid connection. Construction interest costs can be an important element of total capital costs, depending on the interest rate and construction duration. A study conducted at the University of Chicago (2004) shows that the interest payments during construction can amount to 30% of the overall expenditures under a five-year construction schedule, and to 40% under a seven-year schedule. A long construction period pushes up financing costs and therefore affects the economics.

The World Nuclear Association (WNA, 2011a) presents median construction duration of nuclear power plants as seven years. The median construction duration for US nuclear plants on the other hand is given by Koomey/Hultman (2007) as nine years. A review of various studies is done by Kennedy (2007) where the range of construction times is elaborated to be 60-120 months.

2.8 The Cost of a Nuclear Accident and Insurance Coverage

Operators of nuclear power plants are liable for any damage caused by them, regardless of fault. They therefore normally take out insurance for third-party liability, and in most countries they are required to do so.

The economic implications of a severe nuclear accident require valuation of death and illness (long-term and intergenerational) from radiation, compensation for lost work, radioactive contamination at sea and land, and massive evacuations for years. Estimates of the cost indicate a massive bill that may imply bankruptcy of a country; a bill which no insurance covers, and highlight as such one of the industry's key weaknesses.

The cost of a worst-case nuclear accident at a plant in Germany, for example, has been estimated to total as much as $11 trillion (Baetz, 2011). More conservative estimates given by governmental studies from the nineties amount to $7.2 trillion (Paulitz, 2008), which is way below the mandatory reactor insurance of $3.7 billion (beyond the insured amount, each reactor operator is liable with all its assets).

In Switzerland, the obligatory insurance is 1.8 billion Swiss francs ($2 billion), but a governmental agency estimates that a major nuclear disaster might cost about FS4.3 trillion which corresponds to nearly ten times- the country's gross domestic product (Guggenbühl, 2011).

In the United States (US), the liability of nuclear operators is capped at $375 million by federal law, with further claims funded by an industry liability pool up to a maximum of $12.6 billion. The bill of a major nuclear accident, however, is estimated to be about 55 times higher for property damage only: a 1982 study from Sandia National Laboratories (Strip, 1982), commissioned for the Nuclear Regulatory Commission (NRC), estimates the consequences of a nuclear meltdown as $314 billion (corresponding to $720 billion in year 2011 values) in property damage only. The 1982 study is –to our knowledge– the most recent cost estimate available for the US. Experts from the NRC, however, have declared that the agency is working on a new study which focuses on health impacts (Hargreaves, 2011).

Baetz (2011) reports that the nuclear industry is under-insured worldwide. It is emphasized that France requires an insurance of $134 million from plant operators, with the government guaranteeing liabilities up to $338 million only. Similar figures are in place for Britain, Russia and the Czech Republic.

3 The Cost of Nuclear Power Generation in Turkey

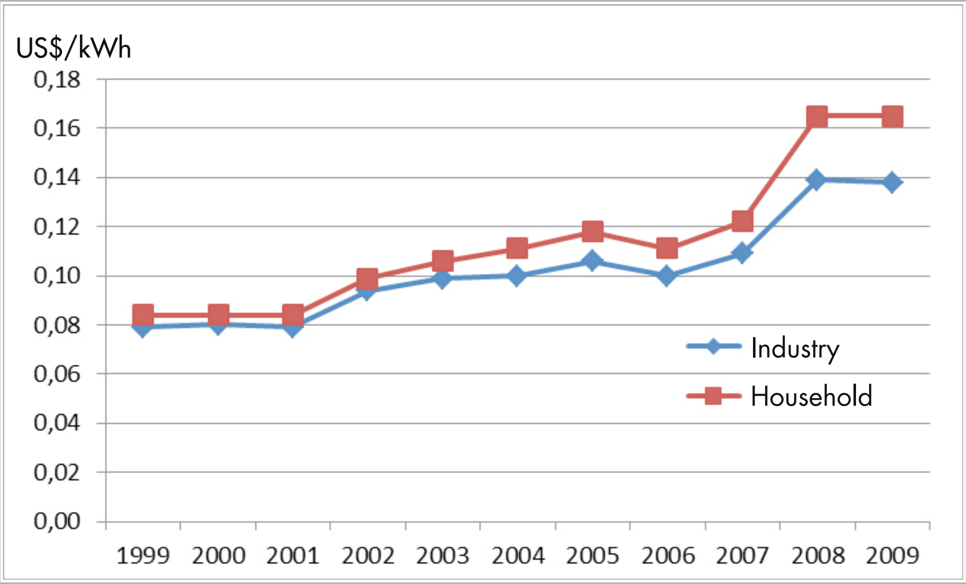
3.1 The Intergovernmental Agreement with Russia and İmplied Cost of Nuclear Power Generation

In May 2010, Russia and Turkey signed an agreement that a subsidiary of Russia's state-owned atomic power company Rosatom would build, own, and operate a power plant at the Akkuyu site, on Turkey's Mediterranean coast, comprising four VVER units of 1,200 MW installed capacity each. The first unit is expected to enter service in 2019 with the other three coming online subsequently.

The Turkish Electricity Trade and Contract Corporation (TETAS) has guaranteed the purchase of 70% power generated from the first two units and 30% from the third and fourth units over a 15-year power purchase agreement at an average price of 12.35 US cents per kWh excluding VAT. The quantity and price trajectories over the 15 years that make up this average price are not known/public. It should be noted, however, that this is a price quoted in *nominal* terms indicating the value of power averaged in the respective year of generation. A look at the historical evolution of *nominal* electricity prices in Turkey, depicted in Figure 1, helps to better interpret this number. During the period 1999-2009, the average annual growth rate has been 5.74% for industrial and 6.98% for residential prices including tax (which amounts to in aggregate an increase of 18.5% for industrial and 21.5% for residential end-use prices).

The power purchase agreement average price of US$ 0.1235/kWh corresponds to a value that is slightly above the end-use industrial price excluding tax (which corresponds to US$ 0.1125/kWh) and slightly below the household end-use price excluding tax (which corresponds to US$ 0.1295/kWh) for year 2009. Considering the fact that the agreement refers to a price that is the average of a price for the period 2020-2035 and therefore almost two decades ahead, it appears to be an economically advantageous deal for Turkey (in the sense that the agreed-upon average purchase price can be expected to be considerably lower than end-use electricity prices by that time) provided that safety measures and regulations related to the construction, operation and maintenance of the reactor as well as related to waste transport and management activities are all well defined and provide convincing confidence and reliability regarding the risk of an accident and nuclear leakage.

Figure 1: Evolution of End-Use Electricity in Turkey Prices (nominal values; inclusive tax)



Data source: International Energy Agency (2010)

It should be noted that, according to the intregovernmental agreement, after the power purchase agreement expiry dates, 20% of the Project Company's net profit shall be given to the Turkish party on an annual basis throughout the lifetime of the plant.

3.2 Technology-Specific Comparison of the Anticipated Generation (Levelized İnvestment, O&M) Costs in Turkey with Other Reactor-Level İnternational Data

Koomey/Hultman's (2007) reactor-level analysis evaluates busbar[1] costs during 1970-2005 for 99 nuclear reactors in the US. Assuming

- a 6% real discount rate
- a lifetime of 60 years for AP1000 type reactors and 40-years for all others

1- Busbar cost, also known as levelized costs, defines the cost of delivering electricity - beyond the generator but prior to the voltage transformation point in the plant switchyard.

in the calculation of a capital recovery factor for the levelization of investment expenditures, they find that all but one of 57 reactors finished in 1983 or before had busbar costs of 7 US cents (2004)/kWh or less, and that all but one of the reactors finished after 1983 had busbar costs greater than 5 US cents (2004)/kWh with the most expensive one generating at nearly 15 cents per kWh.

Kennedy's (2007) summary of cost estimates for nuclear generation reveals an average levelized cost of £32/MWh (2004 value) with a range of £12-60/MWh.

According to the OCED study (OECD, 2010), the levelized generation costs (2008 values) of nuclear power plants, under a discount rate of 10%, ranged from US$ 42.09/MWh for APR-1400 type reactors in Korea through $136.5/MWh for PWR reactors in Switzerland. The levelized generation cost of a Russian VVER-1150 type reactor is given as $68.15/MWh. It should be noted that a Russian nuclear reactor's levelized generation cost is much lower than European ones as indicated by the OÈCD report where only the Chinese and Korean reactors have lower cost figures.

When the levelized generation cost of Russian technology as reported by the OECD is compared with the agreed-upon average purchase price in the Akkuyu agreement, depending on the time value of money (i.e. discount rate used) there appears to be a very limited profit margin for the investors. The agreed-upon purchase price (average over 2020-2035) of 12.35 US cents per kWh in 2027 would be equal to 6.815 US cents per kWh in 2010 at a discount rate of 3.6%. In other words, in case the real discount rate over 2010-2027 turns out to be higher than 3.6%, the Russian party will make an economic loss from its nuclear investment in Turkey.

3.3 Technology-Specific Comparison of the Anticipated Generation Costs in Turkey with Assumptions Employed in Modeling Studies

Table 1 provides a summary of the technology-specific cost assumptions employed in modeling studies, including the implied unit generation cost. It can be seen that the cheapest nuclear power option is the AP1000 type of reactor with a levelized generation cost of US ¢ 4.09/kWh (2006 values). This is in accordance with the Chinese and Korean reactor data (using this type of technology) provided by the OECD as has been outlined in previous section. Assumptions for the PWR type reactor on the other hand remain below the figures indicated by the OECD.

Table 1: Technology Specific Nuclear Cost Assumptions Employed in Modelling Studies (2006 values)

Technology	Fixed O&M Cost [M£ / (GW x a)]	Variable O&M Cost [M£ / PJ]	Capacity Factor	Investment Cost [M£ / GW]	Economic Lifetime [a]	Generation Costs [US ¢ / kWh]
Advanced Gas-cooled Reactor (AGR)	42,8	0,045	%90	1913	35	5,33
AP1000 - 2010	0	0,77	%85	1625	50	4,09
EPWR – 2010	35	0,066	%85	1482,7	40	4,88
GTMH reactor - 2030	14,7	0,099	%90	1786,5	50	9,58
Pebble Bed Reactor (PBR) - 2030	0	0,385	%95	1786,5	50	6,93
PWR	42,8	0,045	%90	1913	40	5,18

Source: AEA Technologies

The levelized cost figures reported in Table 1 are comparable to the average purchase price of 12.35 US cents per kWh agreed upon in the agreement between Turkey and Russia - both are tax- and infrastructure (transmission & distribution) excluded values. It should be noted, however, that the agreement refers to a price in 2019 at the earliest whereas Table 1 provides year 2006 values. The time value of money needs to be taken into account when comparing these figures. Table 2 provides a comparison of the cost assumptions with the agreed upon purchase price of 12.35 US cents per kWh based on three real discount rate assumptions: 4.5% p.a. ("Low"), 7% p.a. ("Mid"), 10% p.a. ("High"). When the 2010 real values for both cases are considered, it can be seen that the "Mid" and "High" values for Akkuyu are lower than any cost assumption used in the modeling studies. Only the low discount rate case results in a value that is slightly higher than some modeling assumptions (the discrepancy in this case is limited: in comparison to the cheapest technology (AP1000) it is 33%). It should be noted that the lifetimes of Akkuyu and the modeling study assumptions are comparable as well: the economic lifetime of the plant to be build in Akkuyu is envisaged to be about 50 years as the Turkish Minister of Energy recently declared that the plant will be decommissioned in 2071 (NTVMSNBC, 2011).

Table 2: Comparison of Levelized Generation Cost Employed in Modeling Studies with the Turkey-specific Agreement Price

Technology	Levelized Generation Cost Assumptions [US ¢ / kWh]		Akkuyu Agreement 2020-2035 Average Purchase Price [US ¢ / kWh]	
	2006 nominal	2010 real[1]	2010 real	2027 nominal
AGR	5.33	5.71	Low (4.5% disc. rate): 5.84	
AP1000	4.09	4.38		
EPWR	4.88	5.23	Mid (7% disc. rate): 3.91	12.35
GTMH	9.58	10.27		
PBR	6.93	7.43	High (10% disc. rate): 2.44	
PWR	5.18	5.55		

1 The value of the deflator index used for 2006 is 103,257 and for 2010 it is 110,659. (1929-2010 US GDP Price deflator series, 2005=100, Bureau of Economic Analysis, US)

The Turkish Energy Market Regulatory Authority EMRA has announced the country's average wholesale electricity price for year 2010 as 14.07 Krş/kWh (EMRA Decision No: 2930; 16/12/2010). The average exchange rate for the same year has been announced as 1.5004 TL/US$ (Ministry of Development, 2011). Accordingly, the average wholesale electricity price 2010 is calculated as 9.38 US ¢/kWh. When compared with the Akkuyu agreement prices for 2010 in real terms shown in Table 2, it is seen that the wholesale price has been about 60% higher than the highest price estimate for the Akkuyu agreement (Low discount rate scenario – 5.84¢/kWh). The discrepancy is significantly higher (284%) for the low price scenario. Thus the agreed-upon average purchase price for Akkuyu appears to be an economically advantageous deal for Turkey.

3.4 Waste Management Costs: Turkey & International Comparative Analysis

According to the intergovernmental agreement between Turkey and Russia, the project company is being held liable for paying 0.15 US cents to the spent fuel fund for every kWh of electricity sold to the Turkish state owned electricity trading company TETAS. According to the same agreement, the project company is responsible for waste management and the spent waste can be shipped back to Russia for reprocessing. In that case, the spent fuel fund can be used to finance this operation to be carried out by the project company.

According to the World Nuclear Association (WNA, 2011a), the back-end of the fuel cycle, including used fuel storage or disposal in a waste repository, contributes up to 10% of the overall generation cost per kWh. It is noted that the US used fuel program is funded by a $1/MWh levy.

According to the OECD report, fuel cycle costs are in the range of $4-11.6/MWh with the mode being $9.33/MWh. These figures are reported to include both front-end costs as well as back-end costs associated with waste management. The World Nuclear Association (2011a) approximates the front-end cost of the fuel cycle to be $7.7/MWh. Adding a $1.5/MWh for the back-end, a total of $9.2/MWh is obtained, which indicates that the radioactive waste management accounting is in line with international experience.

3.5 Decommissioning Costs: Turkey & International Comparative Analysis

According to the intergovernmental agreement between Turkey and Russia, the project company is being held liable for paying 0.15 US cents to the decommissioning fund for every kWh of electricity sold to the Turkish state owned electricity trading company TETAS. According to the same agreement, the project company is responsible for the decommissioning of the Akkuyu nuclear power plant. In that case, the decommissioning fund can be used to finance this operation to be carried out by the project company.

According to the World Nuclear Association's report (2011a), decommissioning costs amount undiscounted to about 9-15% of the initial capital cost of a nuclear power plant. It is noted that they account for 0.1-0.2 cent/kWh in the United States.

Kennedy's (2007) summary of cost estimates for nuclear generation reveals a range of £195-500 million (2004 value) for decommissioning costs. In a conservative central case scenario, he assumes £0.7/MWh (2006 value).

3.6 Third Party Liability: Turkey & International Standards

There are two basic international regimes for nuclear third party liability in force:

i. the Vienna Convention on Civil Liability for Nuclear Damage (Vienna Convention), which was established in 1963 under the auspices of the International Atomic Energy Agency (IAEA) and entered into force in 1977.

ii. the Paris Convention on Third Party Liability in the Field of Nuclear Energy (Paris Convention), which was established in 1960 under the auspices of the OECD and entered into force in 1968.

Coverage under the Paris Convention is extended in 1963 by the Supplementary Convention on Third Party Liability in the Field of Nuclear Energy (Brussels Supplementary Convention). Furthermore, the Paris and Vienna Conventions have been linked in 1988 by the Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention (Joint Protocol) which entered into force in 1992. Parties to the Joint Protocol are treated as though they were Parties to both Conventions and a choice of law rule is provided to determine which of the two Conventions should apply to the exclusion of the other in respect of the same incident.

The Paris Convention and the Brussels Supplementary Convention have both been amended several times by additional protocols to provide for broader scope, increased amount of liability of the operator of a nuclear installation and enhanced means for securing adequate and equitable compensation (NEA, 2007). The recent amending protocol to the Paris Convention, signed in 2004, broadened the definition of "nuclear damage" to include environmental damage and economic costs, and set new limits of liability as follows: Operators (insured) €700 million, Installation State (public funds) €500 million, Collective state contribution (Brussels) €300 million implying a total of at least €1500 million (World Nuclear Association, 2011b). It should be noted that the 2004 amendment removed the requirement for a state to restrict the maximum liability of a nuclear operator, allowing states with a policy preference for unlimited liability to join the convention.

The international regimes prescribe some minimum liability requirements above which country-specific coverages may differ. However, in many countries the liability limits are still below the minimum requirements put forward by the 2004 amendment as can be seen in Table 3.

Turkey has ratified the Paris Convention in 1961 and the Joint Protocol in 2007.

Table 3: International liability and compensation coverage for various countries

Country	Operator Liability Limit	Financial Security Limit	Other Compensation: State+ Int. Fund
Argentina	$ 80 m	$ 80 m	-
Brazil	$ 160 m	$ 160 m	-
Austria	$ 106 m + 10% (I+L)*	$ 406 m + 10% (I+L)*	-
Belgium	$ 433.2 m	$ 433.2 m	0 + $ 197.6 m
Canada	$ 70.7 m	$ 70.7 m	-
China	$ 43.9 m	$ 43.9 m	$ 117.1 m + 0
Czech Republic	$ 445.7 m	$ 445.7 m	-
Finland	$ 276.6 m	$ 276.6	0 + $ 197.6 m
France	$133.3 m	$133.3 m	$ 144 m + $ 197.6 m
Germany	Unlimited	$ 2.5 b	$ 2.5 b + $ 197.6 m
Hungary	$ 158.1	$ 158.1	$ 316.2 + 0
Japan	Unlimited	$ 1.3 b	-
Korea	$ 474.2 m	$ 43.2 m	-
Morocco	$ 158.1 m		$ 7.9 m + 0
The Netherlands	$ 495.3 m	$ 495.3 m	$ 2.8 b + 197.6 m
Romania	$ 237.1 m	$ 237.1 m	$ 237.1 m + 0
Russian Federation	None specified	$ 350 m	-
South Africa	$ 322.4 m	$ 322.4 m	
Spain	$ 1 b + $1b (env. damage)	$ 1 b + $1b (env. damage)	0 + $ 197.6 m
Sweden	$ 474.2 m	$ 474.2 m	0 + $ 197.6 m
Switzerland	$ 960.7 m + 10% (I+L)*	$ 960.7 m + 10% (I+L)*	
UK	$ 227.6 m	$ 227.6 m	$ 49.6 m + $ 197.6 m
US	$ 11.6 b	$ 11.6 b	-

* I + L: Interest and legal charges

Source: IDSA (2010), based on OECD's Nuclear Energy Agency data from December 2009.

However, Turkey has neither ratified the Amendment Protocols to the Paris Convention, nor the Brussels Supplementary Convention yet.

Moreover, the intergovernmental agreement between Turkey and Russia did not introduce any thresholds regarding the çivil liability of the Project company in case of a nuclear accident. The Article 16 of the said agreement states that the third party civil liability will be determined according to the international agreements to which Turkey is or will be party to and to Turkey's domestic laws and regulations. At present according to the Code of Obligations, there is no limit to third party liability. Nonetheless negotiations have apparently been initiated with the Russian side to clarify this situation.

4 The Anticipated İmpact of Nuclear Power on Electricity Supply & Prices in Turkey

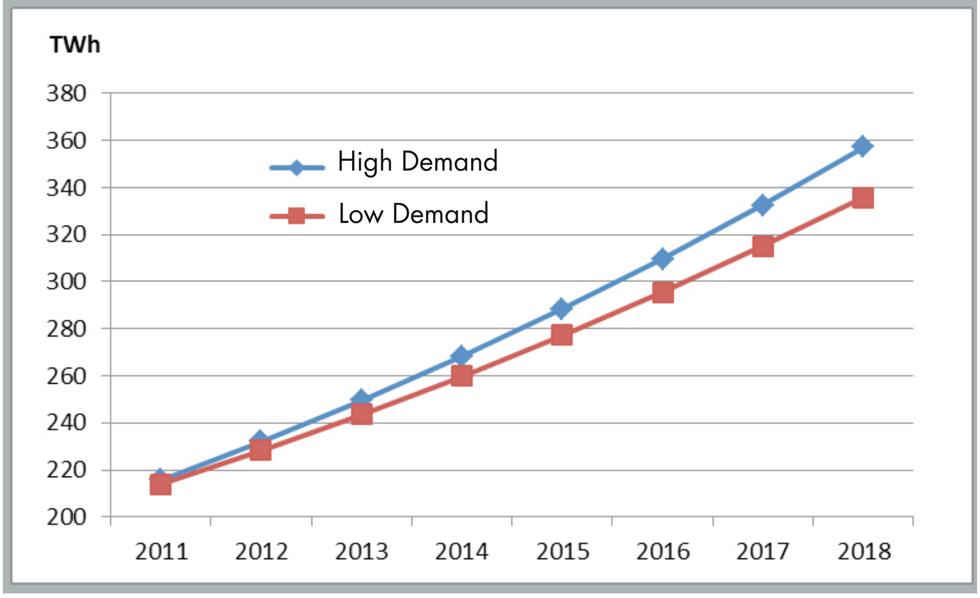
Electricity supply considerations in Turkey have been strongly driven by a rapid growth on the demand side and the historical dominance of hydropower and fossil fuel based thermal power generation on the supply side. Electricity demand has been growing at a remarkable average rate of 11.3% over the last 40 years, inducing annual investments in the generation, transmission, and distribution infrastructure in the order of US$ 4-5 billion. Installed generation capacity today is estimated to be around 48.6 GW as of December 2010 (EÜAS, 2011). Turkish electricity generation rests on hydropower and fossil-fueled thermal power generation. Of the total installed capacity, 31.8 GW is based on thermal power generation plants. In terms of generation shares the distribution is as follows: 45.9% of total electricity generation in 2010 has been produced using natural gas; 18.4% comes from domestic coal fired power plants, 6.9% from imported coal fired ones, 2.5% from liquid fuel fired ones, 1.35% comes from wind power, 0.47% from geothermal and 24.5% is generated by hydroelectric power plants. As a national policy priority it is aimed not to increase import dependence and therefore not to increase the share of imported coal and gas fired power plants. Only 2% of gas supply in Turkey has been coming from domestic sources in 2010, the rest being imported: 46% of the imported gas comes from Russia, 20% from Iran, 12% from Azerbaijan, 10% from Algeria, 3% from Nigeria and the rest is supplied from the spot market (EPDK, 2011). The use of coal, on the other hand, is accompanied by greenhouse gas and other pollutant emissions. It is therefore aimed to increase the share of nuclear and renewable power generation to meet the country's growing electricity demand. The expansion of nuclear capacity is planned well ahead as a result of long construction lead times and special purchase agreements.

The adoption and diffusion of new renewable energy technologies on the other hand is subject to subsidies and / or developments that bring down unit generation costs to a level where these technologies can actually compete with conventional technologies. Such developments can be conveniently represented by learning curves, which indicate the exponential reduction in the unit cost that can be expected as their cumulative production volume increases (e.g. IEA, 2000). Prospects for the diffusion of renewable energy technologies, however, are also affected by the high level of uncertainty that characterizes liberalized electricity markets (esp. regarding the price of and demand for electricity), and the way investors evaluate investment options under uncertainty.

4.1 Short-Term (Up To 2018) Impact on Supply Capacity and Electricity Prices

The latest capacity projection report from the Turkish Electricity Transmission Company (TEIAS, 2009) reports official supply / demand projections up to year 2018 which is a benchmark in terms of nuclear power as the first unit of the Akkuyu power plant is planned to feed electricity into the grid in year 2019.During 2011-2018, demand is projected to grow at an annual average rate of 6.7% reaching 336 TWh in 2018 in the low demand scenario, and at 7.5% reaching 357 TWh in the high demand scenario. The growth rate is assumed to be almost uniform as can be seen in Figure 1.

Figure 2 : Official Electricity Demand Projections until 2018

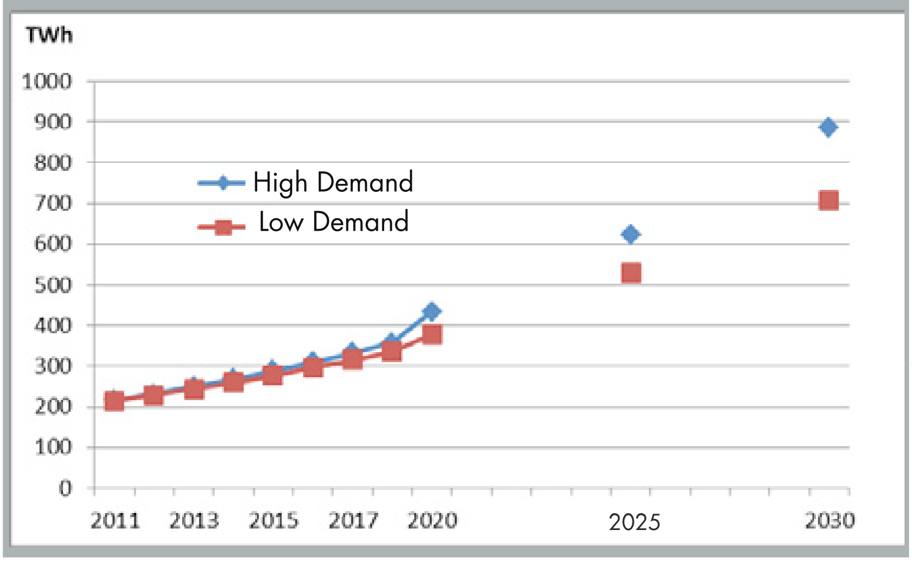


The projection of supply capacity, on the other hand, is based on applications for construction licenses and plants under construction. Two scenarios with differing assumptions on the construction durations are defined. Taking into account conservative estimates of hydroelectric power generation (i.e. based on reliable generation capacity factors in dry years) and the scenario assuming longer construction duration, it is found that there will be a shortage of capacity in 2014 if the high demand growth scenario materializes, and 2015 if the low demand growth scenario happens to be true. For the scenario with shorter construction durations, the shortage years are estimated to be 2015 and 2016 under high and low demand growth respectively. These figures are deferred by two years if non-conservative generation level estimates (based on project generation capacity factors) are used. In any case, additional capacity is needed before the nuclear power plant comes on-line. The fact that a significant amount of nuclear power generation capacity (with a power purchase agreement and relatively low marginal cost) will be added to the plant mix in subsequent years, however, may discourage private sector investors due to profitability concerns. Therefore, some measures need to be taken to avoid a possible supply shortage on the eve of the nuclear era.

4.2 Long-Term (2019-2030) Impact on Supply Capacity and Electricity Prices

Long-term projections of electricity supply and demand beyond 2018 are provided in 5-year intervals by the Energy Market Regulatory Authority of Turkey (EPDK) as shown in Figure 2. A slight reduction in growth is estimated in line with experience from other countries and expectations of structural changes in the economy. Accordingly, the average annual growth rate declines from 7.5% during 2020-2025 to 7.3% during 2025-2030 in the high growth scenario. In the low-growth scenario, on the other hand it declines from 6.9% during 2020-2025 to 5.9% during 2025-2030.

Figure 3: Official Electricity Demand Projections until 2030



On the supply side, two scenarios are considered: a fossil fuel oriented scenario with an additional 10,000 MW gas- and 5,000 MW oil-fired capacity; and a renewable oriented scenario with an additional 25,000 MW wind, 9,000 MW solar and 8,000 MW biomass capacity. In both scenarios, a nuclear capacity of 12,000 MW is considered, and all hydro and domestic coal potential is utilized. Accordingly, the share of nuclear capacity in 2030 is expected to amount to 7.4% in the fossil fuel oriented scenario, and 6.4% in the renewable oriented one. The impact of the nuclear capacity on electricity prices in the long term is thus limited to this share, and subject to the economics in power purchase agreements for new nuclear power plants to reach the 12,000 MW capacity level in excess of Akkuyu (which is envisaged to have a total capacity of 4,800 MW). For the Akkuyu plant, it is agreed upon that 30% of the generation of the first two units and 70% of the generation of the last two units shall be sold by the Project Company on the free electricity market via an energy retail supplier. The long-term design and structure of the Turkish electricity market will be decisive for a reasonable profit margin and controllable market power potential.

4.3 Impact on Private Sector İnvestment in Alternative Power Generation Technologies

Liberalization of electricity and other energy markets introduces much additional uncertainty, also and especially regarding the profitability of investments. With uncertainty, the risk profile of a particular technology influences the choice of the power generation mix, even when the technologies are commercially proven and have equal levelized costs. Table 4 presents a qualitative comparison of cost and risk characteristics for a set of selected generating technologies.

Table 4: Qualitative cost and risk assessment for different generating technologies

Technology	Unit size	Lead time	Capital cost per kW	Operating cost	Fuel cost	Regulatory risk
CCGT	Medium	Short	Low	Low	High	Low
Coal	Large	Long	High	Medium	Medium	High
Nuclear	Very large	Long	Very high	Medium	Low	High
Hydro	Very large	Long	Very high	Very low	Nil	High
Wind	Small	Short	High	Very low	Nil	Medium

Source: adapted from IEA (2003)

New renewable energy technologies for power generation (such as PV and wind power systems), on the one hand, have attractive low-risk characteristics, including short planning and construction lead times, no or low fuel cost and related greenhouse gas and pollutant emission, and low operating and maintenance costs. On the other hand, they are relatively capital-intensive - partly because the technologies are still fairly high up the learning curve, and partly because they have to concentrate a dispersed energy source. This is in contrast to, say, large hydro or nuclear power systems, which require large capital outlays, long lead times, long payback periods, and thus large investment risk. The flexibility characteristics and the risks that accrue from investment have a significant impact on private investors' technological choices, in addition to cost characteristics.

A purchase agreement that guarantees the purchase of produced power (as in Turkey's nuclear power agreement with Russia) features investment in capital-intensive high-risk technologies. This can be considered as a strategic subsidy to a new technology, without which its adoption could not be possible. The agreed upon addition of a considerable amount of nuclear capacity in Turkey may discourage investment into alternative technologies, especially renewables with high capital costs, unless their investment costs decline and/or subsidies assure a reasonable profit margin.

5 Conclusions

Regarding the economics of nuclear power in the Turkish context, the following conclusions can be drawn with respect to the agreement for the Akkuyu nuclear power plant.

- The average purchase price of 12.35 US cents per kWh in nominal terms, excluding VAT, appears to be economically advantageous for Turkey when international data on levelized generation costs, the historical evolution of end-use electricity prices, the long time horizon involved and the "Build-Operate-Own" investment model (according to which all financial risk is taken up by the project company) are considered
- More particularly the present value of the average purchase price has a range between 2.44¢/kWh and 5.84¢/kWh depending on the discount rate used. But even the higher price compares favorably with the average wholesale electricity price for 2010 of 9.38 ¢/kWh.
- With the price of 0.15 US cents per kWh to be paid on the account for spent fuel, radioactive waste management cost is in line with international estimates. The routes, means and security plans for the transportation of spent fuel are not detailed yet. This may be an item affecting economics due to a long international travel distance to Russia and possible public opposition along the way. The project company, however, is responsible for waste management and bears the financial risk.
- With the price of 0.15 US cents per kWh to be paid on the account for decommissioning, the cost is in line with international estimates. The project company is responsible for decommissioning and bears the financial risk.
- The cost of a severe nuclear accident (resulting in long-term/intergenerational health effects and deaths, radioactive contamination at sea and land and massive evacuations for years), besides the associated morale challenge, is estimated worldwide to be a multiple of national GDP figures and cannot be

covered by any insurance.[2] Typically, a liability limit is determined which is naturally a parameter that affects insurance dues and hence the economics of power generation – no such limit has been determined for the Akkuyu project. According to the agreement, third party liability for nuclear damage will be regulated in compliance with the international agreements and instruments that the Republic of Turkey is and will be a party and national laws and regulations of the Turkish party. Currently, there is no upper limit on liability according to the Turkish law on obligations. However, there might be a forthcoming agreement on this issue as it is being negotiated. If Turkey ratifies the Amending Protocol to the Paris Convention, operator liability will have to be regulated to cover at least €700 million.

- A long construction period pushes up financing costs and therefore affects the economics. It is planned that the first power unit in Akkuyu starts commercial operation in 2019, which implies a construction duration of seven years if construction starts in 2012. The responsibility to insure risks covering this period belongs to the project company. Furthermore, in case of failure, the Russian Party has the responsibility to designate a successor that possesses all necessary competencies and capabilities. Accordingly, there is no financial risk on the Turkish side related to possible construction delays, cost overruns or credit downgrades.
- Domestically produced material and equipment will be used in the construction of the plant (except the core) wherever economics and quality can be assured. This may boost the local economy during the construction phase to a limited extent (limited since Turkish companies may not have the know-how and production arrangement to produce economically at the required quality standards).
- The plant design is envisaged to be earthquake safe up to a magnitude of 9 on the Richter scale. However, earlier studies on the site's seismic properties are outdated and/or not reliable. Therefore, the Russian subsidiary company has outsourced independent measurements of seismic activity and other essential indicators like temperature, humidity and air salinity to evaluate the site-specific design safety. In case of increased seismic activity there could be a modification in design necessary, which would induce additional cost and affect the economics. The financial risk, however, is on the side of the project company.
- Electricity demand has been and is expected to continue to increase rapidly in Turkey in accordance with economic development. Supply shortage may be expected on the eve of the nuclear era unless new investment in excess of the existing construction license applications is initiated. The fact that a significant amount of nuclear capacity (with a power purchase agreement and relatively low marginal cost) will be added to the supply mix may discourage investment into alternative technologies, especially renewables with high capital costs, unless their investment costs decline and/or subsidies assure a reasonable profit margin.

2- The impossibility to put a value to human life, and the impossibility to correctly measure the loss from damage to environment and livelihoods should be noted.

In conclusion, as a final remark evaluating the findings of the study, it can be said that the agreement between Russia and Turkey appears to be an economically advantageous deal for Turkey. If the deal would have been possible without an intergovernmental agreement, as a stand-alone commercial treaty at the same terms, is rather questionable considering the economics and all the risks taken up by the Russian party. Other aspects such as the strong bilateral cooperation in the energy sector between Russia and Turkey and the promotion of Russian nuclear technology in new emerging markets might have been influential factors that contributed to this agreement. If Turkey is to have a nuclear future as envisaged in long-term official energy strategy, the agreement seems to be a good starting point economically as long as the possibility of leakage and a severe nuclear accident are excluded, waste management poses no concern, and the necessary regulatory and controlling mechanisms can be put in place successfully. The economics of a non-nuclear future, on the other hand, together with its feasibility and sustainability, is being discussed worldwide more extensively after the Fukushima accident.

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