
Nuclear Futures?

A Survey of Nuclear Energy in Eastern Europe

Christian von Hirschhausen and Sophia Rüster



Technische Universität Dresden
EnergyEconomics

SESSA / Berlin
10.12.2004

Agenda

1. Overview

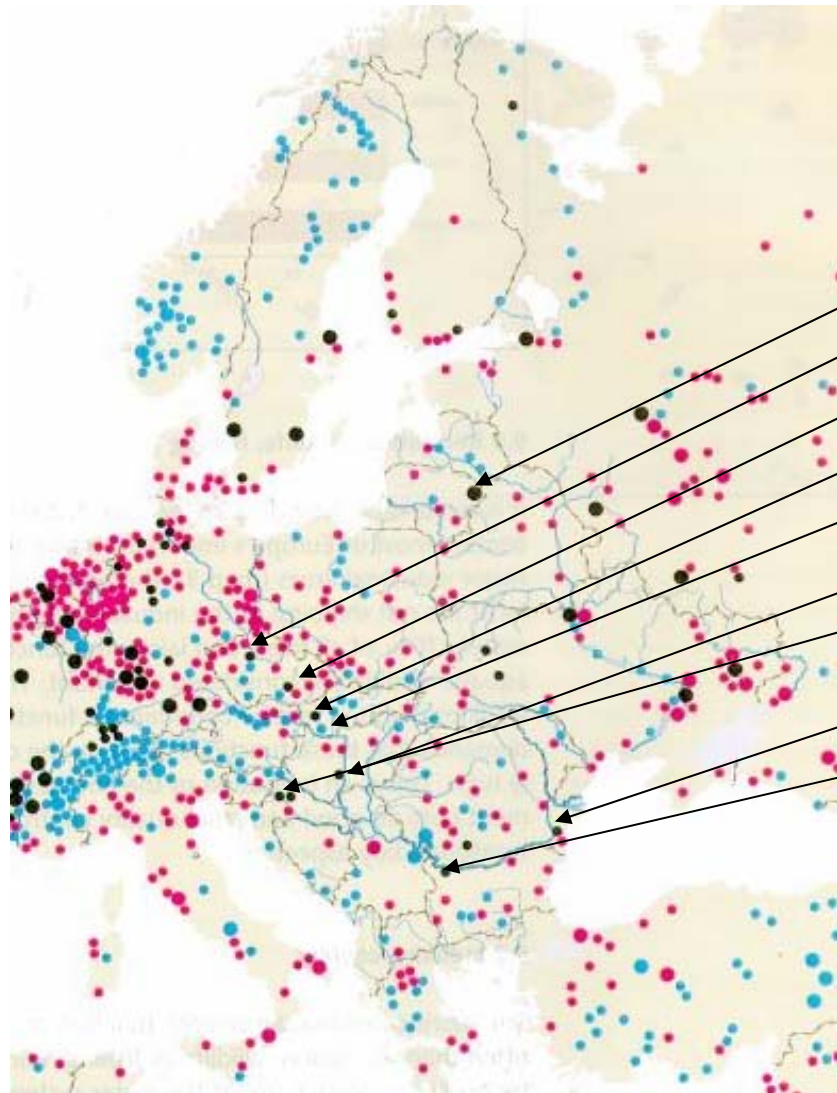
- **Nuclear Power Plants in Eastern Europe**
- **Technical Description / Share of Nuclear Energy**
- **Failures & Accidents**

2. MIT-Study

3. Cost Comparison

4. Conclusion

Nuclear Power Plants in Eastern Europe



Country	Location
Lithuania	Ignalina
Czech Republic	Temelin Dukovany
Slovakia	Bohunice Mochovce
Hungary	Paks
Slovenia	Krsko
Romania	Cernavoda
Bulgaria	Kosloduy
Russia	10 locations
Ukraine	4 locations

- Traditional Power Plant
- Hydro Power Plant
- Nuclear Power Plant

Technical Description I

	Location	Type of Reactor	Capacity (MW/net)	Legal Status	Technical Status
CZ	Temelin	DWR, WWER 1000 DWR, WWER 1000	1 x 981 1 x 981	- -	- -
	Dukovany	DWR, WWER 440/213	4 x 417	-	modernization program
SK	Bohunice	DWR, WWER 440/230 DWR, WWER 440/213	2 x 408 2 x 408	closure in 2006 closure in 2008	improvements in safety, 1996 started program of incremental reconstruction → life time increase
	Mochovce	DWR, WWER 440/213 DWR, WWER 440/213	2 x 408 2 x 408	- under construction	
H	Paks	DWR, WWER 440/213	4 x 430	closure > 2020	recent problems of block 2 resolved
SLO	Krsko*	Westinghouse DWR	1 x 632	closure in 2023	modernization took place
RO	Cernavoda	Canadian Deuterium-Uranium-Reactor, CANDU 600	1 x 630 1 x 630 3 x 630	- under construction 1 block completion 2006 2 blocks completion 2010	safety improvements
LT	Ignalina	RBMK 1500, water cooling, graphite moderator	2 x 1185	1 block closure in 2007 1 block closure in 2008	adjustment: 1300MW gross, improvements
BG	Kosloduy	DWR, WWER 440/230 DWR, WWER 440/230 DWR, WWER 1000	2 x 408 2 x 408 2 x 953	closed in 2003 closure in 2006 modernization	improvements in control technology/cooling/radiation- & fire protection
	Belene	DWR, WWER 1000	2 x 953	construction stop in 1990	

Sources: Jahrbuch der Atomwirtschaft 2001;
<http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity>;
<http://www.iaea.org/programmes/a2/index.html>

DWR: Druckwasserreaktor → Pressurized Water Reactor
 * 50 % Property of Croatia

Technical Description II

	Location	Type of Reactor	Capacity (MW/net)	Legal Status	Technical Status
UA	Rowno	DWR, WWER 440	2 x 370	-	-
	Rowno	DWR, WWER 1000	2 x 950	-	1 just finished 10/04
	South-Ukraine	DWR, WWER 1000	3 x 950	-	-
	Kmelnitzki	DWR, WWER 1000	2 x 950	-	1 just finished 08/04
	Kmelnitzki	DWR, WWER 1000	2 x 950	under construction	-
	Saporoschje	DWR, WWER 1000	6 x 950	-	-
RUS	Bilibinsk	LWGR	4 x 11	-	total capacity of nuclear power plants increases → 2010 about 170 TWh per year
	Nowo Woronesch	DWR, WWER	2 x 385	-	
	Nowo Woronesch	DWR, WWER 1000	1 x 953	-	
	Kola	DWR, WWER 440	4 x 410	-	
	Belojarsk	SNR, FBR BN 600	1 x 560	-	
	Kursk	LWGR, RBMK 1000	4 x 925	-	
	Kursk	LWGR, RBMK 1000	1 x 925	under construction	
	Sosnowi Bor	LWGR, RBMK 1000	4 x 925	-	
	Smolensk	LWGR, RBMK 1000	3 x 925	-	
	Kalinin	DWR, WWER 1000	2 x 953	-	
	Kalinin	DWR, WWER 1000	1 x 953	under construction	
	Balachowo	DWR, WWER 1000	4 x 953	-	
	Balachowo	DWR, WWER 1000	1 x 953	under construction	
	Rostow	DWR, WWER 1000	1 x 953	-	
Rostow	DWR, WWER 1000	1 x 953	under construction		

DWR = Druckwasserreaktor → Pressurized Water Reactor

SNR = Schneller Brüter → Fast-Breeder Reactor

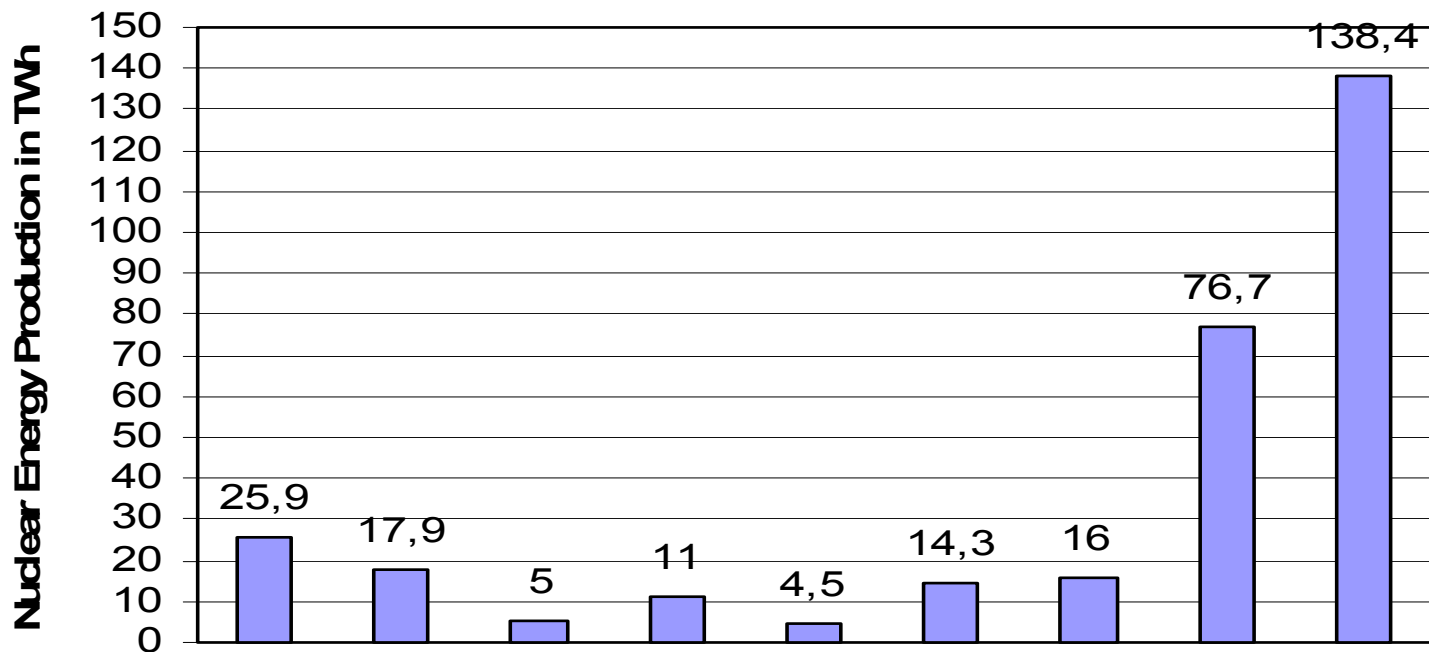
GLWR = Graphite Moderator

LWGR = Water Cooling, Graphite Moderator

Sources: <http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity>, <http://www.iaea.org/programmes/a2/index.html>;

Jahrbuch der Atomwirtschaft 2001

Share of Nuclear Energy (2003)



Country	CZ	SK	SLO	H	RO	LT	BG	UA	RUS
Nucl. Power Prod. in TWh	25,9	17,9	5	11	4,5	14,3	16	76,7	138,4
Total Power Prod. in TWh	83,2	31,1	12,3	33,7	48,6	17,9	42,5	167	836,9
Share in %	31,1	57,6	40,7	32,6	9,3	79,9	37,6	45,9	16,5

Failures & Accidents (selected list)

- **Tchernobyl: 26.04.1986 Greatest possible accident**
Explosion and release of nuclear radiation
- **Paks / Hungary (2003)**
10.04.2003: leakiness at block 2 → emission of radio-active gas
Classification 3rd degree (highest one) → closure of the reactor until 03.09.2004
- **Temelin / Czech Republic**
Until September 2004 more than 70 failures

Sources: <http://www.reyl.de/tschernobyl/>; <http://www.haea.gov.hu>; <http://www.anti.atom.at/>

Situation in Eastern Europe

Three Tasks in the Nuclear Sector

Improvement of safety	Finish constructions	Construction of new NPP
<ul style="list-style-type: none">- existing NPP economic, often completely deducted → just operating costs- partially russian types → safety problems!!→ credits by EURATOM & European Bank of Re-building and Development→ Tacis-program: 774 Mio € (former Soviet Union)→ Phare-program: 192 Mio € (Eastern Europe)	<ul style="list-style-type: none">- financial problems in many Eastern European states → constructions stopped- uncertain future (financial problems, safety regulations of the EU, ...)	<ul style="list-style-type: none">- new NPP mostly not economic (compare with the following study)- NPP = base load, base load in some Eastern European countries in over-capacity

Agenda

1. Overview

2. MIT-Study

- Situation on Energy Markets in general
- Costs of Electric Generation Alternatives
- Results

3. Cost Comparison

4. Conclusion

Situation on Energy Markets in general

Nuclear power plant:	high capital costs, low marginal operating costs → just suitable for baseload
Traditional industry:	risks born by consumers rather than by suppliers
Competitive generation:	risks born by investors rather than by consumers
Additional problem:	regulatory & political challenges associated with obtaining a licence for building a nuclear power plant



Investors favor less capital-intensive investments!



Can nuclear power plants be an attractive investment?

When are nuclear power plants economic?

MIT-Study: Costs of Electric Generation Alternatives

	Nuclear	Coal	Gas
Construction costs	2000 \$/kWe	1300 \$/kWe	500 \$/kWe
Operational costs → escalation rate	1.5 Cents/kWh 1.0 % per year	1.2 \$/MMbtu 0.5 % per year	3.5 \$/MMbtu 1.5 % per year
Construction period	5 years	4 years	2 years
Capacity factor	85 %	85 %	85 %
Equity	50 % 15 % nominal net of income taxes	40 % 12 % nominal net of income taxes	40 % 12 % nominal net of income taxes
Debt	50 % 8 % nominal	60 % 8 % nominal	60 % 8 % nominal
Inflation	3 %	3 %	3 %
Income tax rate	38 %	38 %	38 %
Project economic life	25 years	25 years	25 years

Results

Nuclear: 7.0 cents/kWh

Coal: 4.4 cents/kWh

Gas: 4.1 cents/kWh

Possibilities to reduce nuclear costs and resulting costs

- **Reduce construction costs (25%): → 5.8 cents/kWh**
- **Reduce construction time by 1 year: → 5.6 cents/kWh**
- **Reduce costs of capital to be equivalent to coal & gas: → 4.7 cents/kWh**



**A new nuclear power plant is more expensive than gas or coal,
even if costs were reduced!**

Agenda

1. Overview

- Nuclear Power Plants in Eastern Europe
- Technical Description / Share of Nuclear Energy
- Failures & Accidents
- Situation in Eastern Europe / Way of the EU

2. MIT-Study

- Situation on Energy Markets in general
- Costs of Electric Generation Alternatives
- Results

3. Cost Comparison

- German versus Eastern European Country
- Transport Costs

4. Conclusion

Definition of Generation Costs

Generation Costs = Capital C. + Fuel C. + Personnel C. + Auxiliary C. + Disposal C.
 (fix) (var.) (var.) (var.) (var.)

$$GC = \frac{r * OC}{1 - e^{-rT}} + \frac{c_F}{\eta * H_U} + \frac{E * c_E}{\tau} + c_A + c_D$$

Assumptions:

		Germany	Eastern Europe
Overnight Costs	OC	1 500 €/kW	1 150 €/kW
Discount Rate	r	0,12/year	0,15/year
Life Time	T	60 years	40 years
Specific Fuel Costs	c_F	3,5 Mio €/t	3,0 Mio €/t
Efficiency	η	0,32	0,32
Net Calorific Value	H_U	0,82 bn kWh/t	0,82 bn kWh/t
Number of Employees	E	0,08/MW	0,16/MW
Specific Personnel Costs	c_E	61 600 €	20 000 €
Full Load Hours	τ	7008 h	6570 h
Auxiliary Costs	c_A	0,05 ct/kWh	0,04 ct/kWh
Disposal Costs	c_D	1 ct/kWh	0,8 ct/kWh
Resulting Variable Costs	VC	0,0245 €/kWh	0,0203 €/kWh
Resulting Fixed Costs	FC	0,0206 €/kWh	0,0197 €/kWh
Resulting Total Costs	TC	0,0451 €/kWh	0,0400 €/kWh

Results:

Sources:
 Steven Stoff
 „Power System Economic
 2002
 Prof. Gampe
 Technical University of
 Dresden

German versus Eastern European Country

Annual Revenue Requirement per kW (ARR) – Base: European Pressurized Reactor

$$ARR = FC + Cf * VC$$

$$FC = \frac{r * OC}{1 - e^{-rT}}$$

T: Life Time of NPP
 OC: Overnight Costs
 FC: Fixed Costs
 Cf: Capacity Factor
 VC: Variable Costs
 r: Discount Rate

Assumptions:

	OC	r	T	Cf	VC (gross)
Germany	1 500 €/kW	0,12/year	60 years	0,80	0,0306 €/kWh
Eastern European Country	1 150 €/kW	0,15/year	40 years	0,75	0,0271 €/kWh

Results:

	FC	ARR
Germany	180,13 €/kW _y	0,0451 €/kWh
Eastern European Country	172,93 €/kW _y	0,0400 €/kWh

Sources: Steven Stoft „Power System Economics“ 2002;

Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Transport Costs

Is it economic to trade nuclear electricity from East to West Europe?



Total Costs = Production Costs + Transport Costs

Transport Costs = average distance * average costs per km

$$TrC = 2000km * 0,05 \frac{ct}{100km * kWh} = 0,01 \frac{\underline{\underline{\text{€}}}}{\underline{\underline{kWh}}}$$

	Germany	Eastern Europe
Production Costs	0,0451 €/kWh	0,0400 €/kWh
Transport Costs	0,0000 €/kWh	0,0100 €/kWh
Sum	0,0451 €/kWh	0,0500 €/kWh



Transport of nuclear electricity from Eastern to Western Europe is not economic.

Agenda

1. Overview
2. MIT-Study
3. Cost Comparison
4. Conclusion

4. Conclusion

- **Nuclear Energy is considered as a serious option by many new member countries, and even more so by Russia and Ukraine.**
- **Back of the rough calculations indicate that East European nuclear generation costs are lower than West European, but only by a small margin.**
- **Transportation costs and bottlenecks may limit the potential of trade.**
- **Intensive East-West-trade of nuclear electricity seems unlikely.**

Types of Reactors I

Pressurized Water Reactor:

- water = cooling and moderator
- primary (cooling-) cycle and secondary cycle
- failures sometimes in the cooling cycle
- American Westinghouse or Sowjet WWER

WWER 440/230:

- = oldest of the WWER series
- different construction- and safety faults (= reactor of high risk)
- European Union: Agenda 2000, 15.07.1997: this type of reactor can not be modernized
- necessity of closure in close future

WWER 440/213:

- = technical further development of WWER 220/230
- tower of condensation → in case of a leak in Primary Cycle, resulting vapour can condense
- still construction faults (e.g. insufficient fire protection, just 1 standby-system for 2 reactors)

WWER 1000:

- same reactor pressure tank, higher power density → quicker corrosion of the walls!

Fast-Breeder Reactor:

- additional to energy production: resulting plutonium
- fast neutrons necessary → sodium as coolant, 3 cycles
- sodium and water react heavy exotherm → risk of fire

Types of Reactors II

Reactor Bolshoi Moshchosti Kanalni (RBMK):

- boiling water reactor with pressure tubes & graphite moderator
- Soviet construction, 14 worldwide, all in former Soviet Union
- risk of leakages at the pressure tubes → cooling stops in case of failure → chain reaction continues (moderator graphite is still there) → overheating/fire (→ disaster of Tschernobyl)

RBMK 1000: → Tschernobyl

RBMK 1500: → Ignalina (Lithuania) = biggest reactor of the world

Canadian Deuterium-Uranium Reactor (CANDU):

- cooling and moderator: heavy water (deuterium)
- safest existing reactor!

Advanced Gas Cooled Reactor (AGR):

- cooled by carbondioxide, moderator: graphite, fuel: uranoxide
- = military development (reactors with graphite moderator are suited for plutonium production for nuclear weapons)

European Pressurized Water Reactor (EPR):

- = future type (constructed by Siemens/Framatom/Electricité de France & German Energy Suppliers)
- different improvements, e.g. EPR forms „nuclear island“: whole plant-system wrapped by concrete
 - fuel: MOX, lifetime: 60 years
 - could be the safest power plant

Sources: <http://www.wien.gv.at/wua/atom/glossar/w.htm#wwer440213>;

Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Sources I

Amberger Bürgerinitiative: <http://www.asamnet.de/oeffentl/bi/310304g.htm>

Antiatom International: <http://www.unet.univie.ac.at/~a9406114/aai/index.html>

Apfelbeck, Baidatsch, Pessier, 2004: „Comparing Efficiency in Central European Electricity Distribution“, Dresden University of Technology

Atw – International Journal for Nuclear Energy, 2003, Booklet 10, pp. 624-641

Booklet of the conference “Atomausstieg in Osteuropa”, 30.04.-01.05.1999, Dresden

Bundesministerium für Umwelt, Naturschutz, Reaktorsicherheit: Themenpapier Atomkraft
<http://www.google.de/search?q=rowno+rum%C3%A4nien+atom&btnG=Suche&hl=de>

City Wien: <http://www.wien.gv.at>

Deutch, J./Moniz, E.J., Massachusetts Institute of Technology 2003,
„The Nuclear Power – An Interdisziplinäre Study“, Washington D.C.

Die Partei, Landesverband Hessen: <http://www.reyl.de/tschernobyl/osteuropa.html>

Energy, Information, Administration, Official Energy Statistics from the U.S. Government
<http://www.eia.doe.gov/emeu/international/electric.html#IntlCapacity>

Europäische Union/Energie: <http://europa.eu.int/scadplus/leg/de/s14000.htm>

Greenpeace Deutschland: <http://archiv.greenpeace.de>

Hungarian Atomic Energy Authority: <http://www.haea.gov.hu>

Sources II

International Atomic Energy Agency: <http://www.iaea.org/programmes/a2/index.html>

Jahrbuch der Atomwirtschaft 2001, INFORUM Verlag u. Verw. Ges., Bonn

Kasper, K.J. Dr.-Ing., 1998: „Der Europäische Druckwasserreaktor – EPR“, VGB Kraftwerkstechnik 2/98

Österreichisch-Tschechisches Anti-Atom-Komitee: <http://www.anti.atom.at>

Sattari, J., Research Project Energy Policy: <http://www.anti-atom.de>

Umweltinstitut München e.V.: <http://www.umweltinstitut.org>

Voß, Prof. Dr.-Ing. Alfred, IER Uni Stuttgart, Forum in Berlin, 12.03.2003

“Nachhaltigkeit & Klimaschutz – Wettbewerbsfähigkeit & Versorgungssicherheit: ohne Kernenergie möglich?”

Wirtschaftsverband Kernbrennstoff-Kreislauf e.V. Berlin: <http://www.kernbrennstoff.de>

World, Economy, Ecology & Development: <http://www.weed-online.de>

World Information Service on Energy: <http://www.antenna.nl/wise/>
