

Energy Systems in OPEC Countries of the Middle East and North Africa  
System Analytic Comparison of Nuclear Power, Renewable Energies and  
Energy Efficiency

Wuppertal Institute for Climate, Environment, Energy

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## List of Abbreviations

AEA	Atomic Energy Act
APRUE	Algerian Agency for Promotion and Rationalisation of the Use of Energy
ARE	United Arab Emirates
ASPO	Association for the Study of Peak Oil and Gas
AU	African Union
Bbl	Barrel
BMU	Federal Ministry for the Environment, Nature Protection and Nuclear Safety
BP	British Petroleum
BWR	Boiling water reactor
CCS	Carbon Capture and Storage
CDER	<i>Center for the Development of Renewable Energies, Algeria</i>
CDM	Clean Development Mechanism
CEERS	Center for Environment and Energy Research and Studies
CER	Certified Emission Reduction
CHP	Combined heat and power
COMENA	Commissariat pour l'Energie Atomique
COP	Conference of parties
CREG	Electricity and Gas Regulatory Commission
CSP	Concentrating solar power
DLR	German Aerospace Center
DNA	Designated National Authority
DNI	Direct normal insolation
DZA	People's Democratic Republic of Algeria
ECO	Economic Cooperation Organisation
EE	Energy efficiency
EIA	Energy Information Administration
ENEC	Emirates Nuclear Energy Corporation, ARE
EPR	European pressurised reactor
EUROMED	Euro-Mediterranean Partnership
FTZ	Free trade zone
G77	Group of 77
GCC	Gulf Cooperation Council
GDP	Gross domestic product
GGFR	Global Gas Flaring reduction
GHG	Greenhouse gases

GIF	Generation IV International Forum
GMI	Global Market Initiative for Concentrating Solar Power
GW	Gigawatt
GWe	Gigawatt electric
HDR	Hot dry rock
HVDC	High voltage direct current
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IFCO	Iranian Fuel Conservation Organisation
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IRN	Islamic Republic of Iran
ISCC	Integrated solar combined cycle
ISN	International Relations and Security Network
LDC	Least Developed Countries
LEED	Leadership in Energy and Environmental Design
LEU	Light enriched uranium
LNG	Liquefied natural gas
MED-CSP	Name of research project on Mediterranean renewable energy potentials
MENA	Middle East, North Africa
MJ	Megajoule
MoE	Ministry of Energy, Iran
MoEM	<i>Ministry of Energy and Mines, Algeria</i>
Mtoe	Million tons of oil equivalents
MW	Megawatt
MWh	Megawatt hours
MWt	Megawatt thermal
NEA	Nuclear Energy Agency
NEAL	New Energy Algeria
NEPAD	New Partnership for Africa's Development
NPT	Non-Proliferation Treaty
OAPEC	Organisation of Arab Petroleum Exporting Countries
OECD	Organisation for Economic Cooperation and Development
OIC	Organisation of the Islamic Conference
OPEC	Organisation of Petroleum Exporting Countries
ORC	Organic Rankine cycle

OTEC	Ocean Thermal Energy Conversion
OWC	Oscillating water column
PDD	Project Design Document
PHWR	Pressurised heavy water reactor
PV	Photovoltaic
PWR	Pressurised water reactor
R&D	Research and development
RE	Renewable energies
SABA	Iranian energy efficiency agency
SME	Small and medium sized enterprises
SUNA	Iranian renewable energy agency
TAVANIR	Iranian national electricity company
TPES	Total primary energy supply
TWh	Terawatt hour
UMA	Arab Maghreb Union
UN	United Nations
UNEP	United Nations Environment Program
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework
USA	United States of America
WEC	World Energy Council

# 1 Scope of project and selection of countries

Climate change and energy security are global challenges that require concerted action by the community of states. Under these circumstances, energy exporting countries in North Africa and the Persian Gulf region experience further challenges, such as increasing domestic energy demand while energy exports have to be kept at high levels. The European Union is strongly affected by these domestic developments, as it imports crude oil and natural gas from these regions. The EU collaborates with North Africa and the Persian Gulf region on different levels, e.g. in the Euro-Mediterranean Partnership EUROMED (Barcelona Process) and through cooperation with the GCC.

Various options are discussed as potential solutions to climate change, sustained energy security and increasing demand in energy exporting countries themselves. In this context the project targets advantages of renewable energies and energy efficiency in comparison to nuclear energy within a systemic approach. On the one hand, nuclear power is currently experiencing interest in North Africa and at the Persian Gulf. Many countries are studying plans on integrating the nuclear option into their energy systems. This holds true especially for the OPEC members in the region. On the other hand, the potential roles of renewable energies and energy efficiency are not evolved on such system-wide level, although huge natural potentials are available, e.g. in the form of solar radiation.

Several focus questions constitute the frame of the project:

- What are possible motivations for the introduction of nuclear power in the selected countries?
- Which technological options are feasible in terms of renewable energies and energy efficiency (domestically and with medium- to long-term perspectives for exports)?
- Which implications do nuclear power, renewable energies and energy efficiency have in a system-wide perspective?

Following these questions the project team will analyse relevant aspects of the development of future energy systems in the listed countries. Hence the focus questions define the general objectives of the project:

- Inventory of renewable energies and energy efficiency options in North Africa and at the Persian Gulf on the basis of the analysed countries (generalisation of results)
- System-analytic assessment of renewable energies, energy efficiency and nuclear power: Creation of a detailed matrix for comparison with strong regard to regional conditions
- Support of the discussion process on the role of renewable energies and energy efficiency in North Africa and at the Persian Gulf

## 1.1 OPEC in the global energy system

### 1.1.1 Share of crude oil and natural gas production and consumption

The Organisation of the Petroleum Exporting Countries (OPEC) holds about 75 % of global oil reserves and about 50 % of global natural gas reserves (BP 2008). This share is not reflected in current and historic production shares: OPEC currently contributes between 40 and 50 % to total oil production (see Fig. 1-1) and well above 20 % to natural gas production. In former decades the share of OPEC in world oil production varied strongly: Before the first so-called oil price crisis its share was up to 55 %, in the mid-1980s it decreased to about 30 % (OPEC 2008).

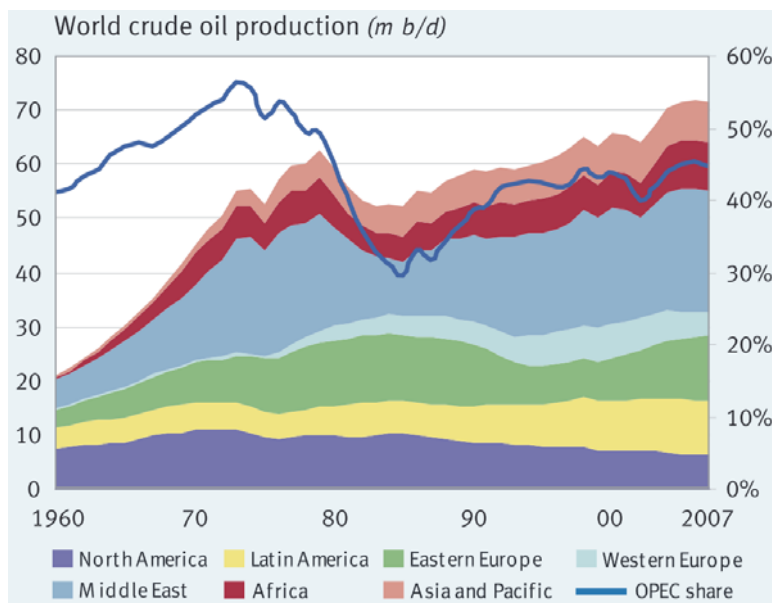


Fig. 1-1. World crude oil production in total and share of OPEC. In mb/d, conventional oil only. OPEC 2008.

In general, according to these data it can be stated that OPEC as an economic organisation has been one of the major influences on global energy markets, and its influence will grow significantly in the future as production capacities of other countries will continue to dwindle.

On the demand side, OPEC countries consume only a small share of their own crude oil production. OPEC's share in global oil products consumption stood at 9 % in 2007. However, its share is increasing steeply, which raises the question on OPEC's future crude oil exports (which will be analysed in detail in this project).

### 1.1.2 Role of OPEC in climate regime

OPEC countries are highly dependent on fossil fuel exports. The international climate change regime, the call for emission reduction and the expansion of renewable energies therefore touch many issues these countries have interests in. Although interests and positions within OPEC vary and the member countries face different challenges, OPEC has largely spoken with one voice in the past (Chatham House 2005). It was repeatedly pointed out by OPEC countries that measures taken by Annex I countries to decrease CO<sub>2</sub> emissions will have negative effects on

their economies if they lead to a downturn in fossil fuel demand. Especially Saudi Arabia, supported by a small number of other countries, has pushed for taking adverse effects of mitigation on OPEC countries more seriously (ibid.).

Through its member states as well as via its strong role within the G77, OPEC exerts a large influence on the UNFCCC and the Kyoto Protocol (ibid.). In its arguments, OPEC focuses on Annex I countries, since these are the main consumers of fossil fuels and their emission reduction targets will have a considerable impact on OPEC countries. OPEC successfully managed to include its concerns in articles of the Convention as well as in the Kyoto Protocol (ibid.). For example, Article 4.8 and subparagraph h of the UNFCCC address the necessity to fully consider the needs and concerns of countries that are highly dependent on fossil fuel exports. Article 2.3 and 3.14 of the Kyoto Protocol urge Annex I countries to implement policies, measures and emission targets in such a way as to minimize adverse social, environmental and economic effects on LDCs and countries highly dependent on exporting fossil fuels. OPEC countries have so far tried to avoid binding emission targets and far-reaching commitments.

Instead, OPEC promotes cleaner fossil fuel technologies as fossil fuels continue to play a dominant role in the energy mix in the foreseeable future, according to OPEC officials (OPEC 2007). OPEC supports carbon capture and storage (CCS), calls for greater efforts of industrialized countries to fund and execute CCS and pushes for making this technology eligible to CDM (OPEC 2006). It also stresses that dealing with climate change should not only be limited to mitigation, but also include adaptation measures. It therefore welcomed the development of an Adaptation Fund under the UNFCCC and urged the industrialized countries for further financial contributions (ibid.). In 2007, OPEC member countries additionally announced the creation of a fund aimed at investing in technological solutions and the protection of the environment. Saudi Arabia dedicated \$300 million to the fund and Kuwait, Qatar and the United Arab Emirates each supported it with \$150 million (OPEC 2007).

OPEC's positions on climate change have been very stable over the time. Yet, as more and more members of OPEC become aware of the negative direct effects of climate change on their countries, the positions taken by OPEC might change. Many OPEC countries struggle with converging trends, such as population growth, lack of employment opportunities and a poorly diversified economy. Many of them already face adverse climate change implications such as water scarcity, droughts and land degradation. Besides, some countries such as Bahrain and the United Arab Emirates show great interest in the development of alternative energy resources and are actively committed to renewable energies. This pluralism of issues and concerns might influence OPEC's position within the climate change regime in future more strongly than it did in the past.

## **1.2 Algeria, United Arab Emirates and Iran as relevant players in global and regional perspective**

The Islamic Republic of Iran, the People's Democratic Republic of Algeria, and the United Arab Emirates were selected for the analysis. These three countries are OPEC members and share several commonalities: Export of fossil fuels makes up a large share of the GDP in these countries and is therefore a central economic aspect. The selected countries strive to keep export

levels of fossil fuels high in order to generate income. Besides, studies predict a rising energy and water demand in Algeria, the ARE, and Iran. These three countries have large potentials for renewable energy production since they are located in the so-called Sunbelt. Nonetheless, they all are engaged in nuclear energy plans. In spite of these common features, the selected countries differ largely within regard to other relevant economic and social aspects such as population size and growth, size of fossil fuel reserves, unemployment rates etc.

## **1.2.1 People's Democratic Republic of Algeria, DZA**

### **1.2.1.1 General characteristics**

Concerning population size, fossil energy reserves, renewable energy potentials and economic ties with Europe, Algeria is one of the most important Northern African countries. After a devastating civil war from 1992-1998, the country has proven to be political stable though there are some tensions due to the struggle against radical Islamist groups such as Al-Qaida in the Islamic Maghreb.

Algeria has large reserves of oil and natural gas. According to OPEC, the proven Algerian crude oil reserves amount to 12.2 billion barrels and the proven natural gas reserves add up to 4504 billion cubic meters (OPEC 2007). Algeria's richness of fossil fuels is both a blessing and a curse for the country: Hydrocarbon exports represented nearly 97.8 % of total exports in 2007; the gas and oil sector account for 45.9 % of GDP (AfDB/OECD 2008). While large oil and gas revenues allowed for massive public investment programs resulting in strong growth rates especially in the 2000-2005 period (World Bank 2008), the dominance of the hydrocarbon sector hinders the development and diversification of the overall economy – a phenomenon that is usually referred to as “Dutch Disease”. The industrial sector represents only five % of the Algerian GDP (AfDB/OECD 2008). Although Algeria has fertile soils especially in its Northern part, agriculture accounted for merely 7.6 % of the GDP in 2007 (AfDB/OECD 2008). Overall exports from the non-hydrocarbon sectors reach 1.31 billion USD and are therefore too weak to contribute significantly to economic growth in Algeria.

One of the main challenges in economic as well as social and political terms is therefore the further diversification of the Algerian economy. Since unemployment is a massive problem in Algeria, a weak private sector and a poorly diversified industry might pose a threat to the future political stability and economic prosperity of the country. However, since 2001, unemployment has generally decreased through public spending programs to approximately 13.8 % in 2007, standing at 1.24 Mio in total numbers (AfDB/OECD 2008). Yet, youth unemployment remains high. 72 % of the unemployed are younger than 30 years (World Bank 2008). The Algerian state and state companies such as Sonatrach, which has a monopoly in the Algerian hydrocarbon sector, and Sonelgaz, which is the National Society for Electricity and Gaz, are still the largest employers.

Current and future challenges to Algeria, such as unemployment, water scarcity and a rising energy demand, might intensify as Algeria's population of 33.85 Mio is growing at an annual rate of 1.5 % (World Bank 2009). Although this is one of the lowest in the Arab world, Algeria has a very young population with more than one fourth being younger than 14 years and one fifth being between 14 and 24 years old. Less than 5 % of the Algerians are older than 65 years (UN

2008). In 2025, it is projected that Algeria's population will have risen to 42.7 million people (WRI 2006).

### **1.2.1.2 Regional Context of Algeria**

Algeria plays an important role in the Maghreb and the Mediterranean region. The country is a member of several regional organisations, such as the African Union, the Arab League and the Arab Maghreb Union (UMA) (which is paralysed due to the conflict between Algeria and Morocco). Algeria takes part in the newly created Union for the Mediterranean and is also engaged in the Barcelona Process (EUROMED).

Algeria and the EU are not only politically and historically but also economically closely linked. Algeria exports crude oil and – predominantly – gas to various countries of the EU. Algeria is in fact the most important North African energy exporter to the European Union: For example, in 2007, approximately 5.25 million tons of Liquefied Petroleum Gas (LPG) which is 71 % of Algeria's LPG exports and 38 % of its crude oil exports reached Europe (Sonatrach 2008). As member of the Barcelona Process, Algeria will take part in the projected Free Trade Zone (FTZ) with Europe. The FTZ is supposed to enhance and foster economic ties between the ten participating Arab countries and the EU starting in 2010.

As for its regional integration in the Maghreb, the foreign relations of Algeria are largely influenced by Algeria's fight against Islamic terrorism as well as its pan-Arab attitude. However, the differences between Algeria and Morocco over the West Sahara issue led to the stagnation of the Arab Maghreb Union (UMA), a trade agreement between Algeria, Lybia, Tunisia, Morocco and Mauritania, which was designed to foster political and economic unity in Northern Africa. Although President Bouteflika aimed at reviving the Maghreb Union there has been no progress on that issue so far.

After the end of its civil war, Algeria strengthened its engagement on the African continent. In December 2000, it mediated the cease-fire between Ethiopia and Eritrea and also took a mediating part in a range of other conflicts in sub-Saharan Africa. The country is also contributing troops to peacekeeping operations in Africa and developed close relationships with Nigeria and South Africa that resulted in the New Partnership for Africa's Development (NEPAD).

Algeria is highly interested in the use of nuclear energy (it already announced an atomic energy program in 1982) and stated support for Iran's right to use atomic energy for civil purposes. The Iranian President Ahmadinejad offered Algeria its nuclear expertise to support the Algerian nuclear energy efforts (ISN 2007). Besides, South Korea, Russia and China have close ties to Algeria and play an important role for realizing its nuclear energy plans.

## **1.2.2 United Arab Emirates, ARE**

### **1.2.2.1 General characteristics**

The United Arab Emirates is a federation of seven emirates<sup>1</sup> that are largely independent from each other with each one having its own legislation, policy and administrative structures. The

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<sup>1</sup> Abu Dhabi, Ajman, Dubai, Fujairah, Ras al-Khaima, Sharjah, Umm al-Qaiwain.



seven emirates vary greatly in terms of population size and economic strength. The ARE possesses the third largest natural gas reserves in the region and the fourth largest in the world. These reserves are estimated to last for over 150 years at the current rate of utilization and excluding any new discoveries (ARE 2005). The largest customer of oil from the ARE is Japan, receiving 62 % of the crude oil exports. Concerning gas exports, the ARE supply almost one eighth of Japan's entire requirements, exporting nearly all of its gas to Japan (ibid.).

The emirates are perceived in various aspects as front-runners in energy matters. The Masdar project is one example of their declared will to invest in sustainable energy supply paths. Nonetheless, in 2017 the ARE plans to bring the first nuclear power plant to the grid. The GCC already conducted a feasibility study on nuclear power.

Within the ARE, energy prices vary strongly. Emirati nationals receive highly subsidised electricity, whereas foreigners – about 75 to 80 % of total ARE population – have to pay higher prices. Another feature of the ARE's energy system is that there is no heat demand: Industrial heat demand is practically non-existent due to the almost negligible industry sector, and there is no heating of buildings necessary either. Instead, cooling (air conditioning) is an electricity intensive process. According to the government, domestic energy demand will be more than doubled by 2020. This increase is caused by a projected escalation of electricity demand from 15.5 GWe in 2008 to over 40 GWe in 2020 (World Nuclear Association 2009).

Due to the large independence of the single emirates, there are few reliable or at least consistent national statistics such as data on sectoral energy consumption in the emirates. According to experts in the ARE, energy statistics presenting national energy consumption are either “of very poor quality” or “totally wrong” (Interview 2009). This includes data from International Energy Agency (IEA) and Energy Information Agency (EIA) of the US Department of Energy. Therefore aggregated energy data have to be used with scepticism. According to experts, taking Abu Dhabi's and Dubai's energy consumption as 85 % of the ARE's total consumption plus an additional 15 % would yield the best results.

In general, due to the commercialisation of its oil and gas reserves the emirates witnessed a rapid economic growth after their independence in 1971. Yet, there is a large spread of income among the emirates with Abu Dhabi and Dubai dominating in respect to economic activity and growth. Abu Dhabi controls more than 85 % of the ARE's total oil output capacity, over 90 % of its crude oil reserves as well as 92 % of its gas reserves (ARE 2005). Dubai's oil and gas reserves are by far fewer and expected to be exploited within the next 20 years (ibid.). Still, on the back of the oil industry, Dubai, which has the largest population among the emirates, has developed a vivid banking, commerce, real estate and tourism sector. Apart from fossil fuel production and construction, there is hardly any industrial production in the ARE.

Over the last decades, the ARE have experienced a steep rise of the population, reaching 4.36 million in 2007 (World Bank 2009). Including foreign workers, the ARE's population grows at an annual rate of 2.9 % (UN 2008). The population of the ARE is very heterogeneous and characterized by a large share of expatriate workers from India, Pakistan and other Arab countries such as Egypt. The latest census in 2005 showed that emirate nationals make up for only approximately one fifth of the total population of the ARE (ARE Ministry of Economy 2006).

### **1.2.2.2 Regional Context of the ARE**

The ARE are member of the Gulf Co-operation Council (GCC) as well as the Arab League, the Organisation of the Islamic Conference (OIC), the OPEC and the Organisation of Arab Petroleum Exporting Countries (OAPEC). They have very close ties to other Arab countries in the region, especially Egypt that benefits greatly from extensive investments and contributions made by the ARE.

Yet, the ARE were or still are involved in various border disputes with Oman, Qatar, Saudi Arabia as well as Iran. Despite disagreements over three small islands in the Persian Gulf and its unease in the light of the Iranian nuclear programme, the ARE hold close economic ties with Iran. Against the background of its domestic nuclear energy plans, the ARE have expressed their concerns regarding the Iranian nuclear programme and sought reassurance that the programme is for peaceful purposes only. The ARE maintain close relations with the USA in terms of domestic nuclear plans, although there have been disagreements in the recent years over issues such as countering terrorism, the Israeli-Palestinian conflict etc.

Within the framework of the GCC, the ARE are also engaged in talks with the European Union about the establishment of a common free trade agreement. There are also some efforts made to initiate an EU-GCC clean energy network. The ARE strongly support international initiatives fostering the spreading of renewable energy. They were among the founding signatories of the International Renewable Energy Agency (IRENA) and have recently gained the interim headquarter of the agency (in Abu Dhabi and supposed to move to Masdar City when completed).

## **1.2.3 Islamic Republic of Iran, IRN**

### **1.2.3.1 General characteristics**

Its large oil and gas reserves as well as its mere size of 1.65 Mio km<sup>2</sup> and 66.5 million inhabitants make Iran an important player in the region of the Middle East as well as on an international level. Iran holds the third largest proven oil reserves and the second largest proven gas reserves and is therefore not surprisingly one of the most important oil and gas exporters worldwide with China being the number one importer of Iranian oil.

Although Iran's economy is still mainly state-driven and burdened by corruption and inefficiency, the country has witnessed an economic growth especially under the Khatami government when growth rates exceeded 6 %. Growth has slowed down under the current President Ahmedinedjad. For 2009, the World Bank estimates a 3 % growth of the Iranian GDP (World Bank 2009). Compared to 2008 this will be a 2.2 % decline (World Bank 2009).

In the past four decades, Iran's domestic energy consumption has been growing at a rapid pace. During the industrial transformation period between 1967 and 1977, the domestic energy consumption grew at an annual rate of 14.2 %. Following the Islamic Revolution and the war between Iran and Iraq, the rate decreased to 5.2 % and continued at that level later on (Hosni; Jaber 2008).

The Iranian government has made several efforts including constitutional changes to foster the development of a private sector. Success is emerging slowly, but it is likely that the increase in

private businesses will further raise the domestic energy demand. The country produces approximately 4 million barrels of oil a day of which about 1.5 million are consumed domestically (Hosni; Jaber 2008). The production of natural gas has also increased rapidly. Almost all of it is consumed domestically and the share of natural gas in total energy consumption has more than tripled - with a very significant portion of it used to generate power.

Iran's population is growing steadily, but the growth rate is expected to decline in the next decades and already is the lowest in the region. It is expected that the population growth rate will decline in the next decades from 1.33 % in 2010-2015 to 0.7 % in 2025-2030 (UN 2008). Nonetheless, the growing population as well as the increasing urbanization and the rising number of motored vehicles will lead to an increased domestic energy demand that is also supported by subsidized prices. In 2007, Iran's oil consumption reached 1.7 million bbl/d (EIA 2009). Since Iran is lacking refinery capacity for the production of light fuels, it already imports a large share of its gasoline demand. However, nearly 90 % of Iran's diesel demand is produced domestically (EIA 2009).

The Iranian economy is dominated by the services sector, contributing about 50 % to total GDP, followed by industry (about one quarter), agriculture (15 %) and the oil sector (ten %). However, strongly oscillating oil prices lead to oscillations in GDP. Exported goods are mainly crude oil, industrial pre-products and agricultural goods. The industry sector is dominated by the automotive industry. Its growth is driven by domestic demand in which the share of foreign cars is low – however, some car companies produce in Iran to serve the regional markets or allow Iranian companies to produce under licence. Religious foundations that are often seen as hindering economic reform processes dominate economic structures.

In 2007 inflation was estimated to be about 20 %, which led to fixing prices for certain products of everyday use by the government.

### **1.2.3.2 Regional Context of Iran**

Iran has strong political and economical links to states in the Caucasus as well as throughout the MENA region (especially Syria) and the rest of the Islamic world. The country is a member of the OIC, as well as the Non-Aligned Movement and the Economic Cooperation Organisation (ECO). Just recently, Iran has become a founding member of the International Renewable Energy Agency (IRENA). In terms of nuclear energy, Iran cooperates closely with Russia to build up its nuclear energy production capacities. Iran itself offered its nuclear energy expertise to Egypt and Algeria.<sup>2</sup>

Iran's hostile position towards Israel as well as its nuclear power plans are certainly the most dominating aspects in its relations with Western countries. The regime's reactions to the civil unrests following the June 2009 presidential elections have led to a further deterioration of Iran's relationship with the West. Before the election in Iran, the current president of the USA, Barack Obama, showed his willingness for dialogue with Iran.

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<sup>2</sup> Several websites have reported on these issues, such as:

<http://www.globalsecurity.org/wmd/library/news/iran/2007/iran-071119-irna01.htm>;

<http://www.algeria-events.com/article610.html> etc. (19.05.2009).

After relations to the countries of the Gulf Cooperation Council improved during the past years, there are currently new tensions arising with the small countries in the Persian Gulf as well as Saudi Arabia. The Wahabi kingdom and Iran are traditionally struggling over the hegemony over the Persian Gulf area and both showed great interest in the development in Iraq. Besides, the Iranian nuclear program raises great concerns among its Arab neighbour states. Furthermore, statements from the Iran calling Bahrain a “14<sup>th</sup> province of Iran”<sup>3</sup> and unresolved border issues with the United Arab Emirates fuel tensions. Furthermore, the conflict that broke out in Yemen between Houthi rebels and the government by the end of 2009 again sparked tensions between Saudi Arabia and Iran. Saudi Arabia accuses Iran to support the insurgency and to contribute to a destabilization of Yemen.

### 1.3 Conclusion on selection of countries

Algeria, Iran and the United Arab Emirates are of high relevance in the project context:

- They are leading members of OPEC
- They are among the most important energy suppliers for the global market
- They play leading roles within their regional context
- Introduction of nuclear power into national electricity systems is in different phases in Algeria, the ARE and Iran

They are also of high relevance in terms of social development with a very high population growth and high unemployment rates, particularly in Iran and Algeria. They also represent different types of industry sectors, which will generate different challenges for the introduction of new energy supply options in terms of socio-economic effects.

### 1.4 General remarks on data sources

For fossil fuel reserves and energy consumption as well as exports the *Annual Statistical Bulletin* by OPEC and the *Statistical Review of World Energy* by British Petroleum are used as standard data sources. Both are annually updated publications. Whenever possible, data of national statistics institutions were added. All data refer to the year 2007 except where indicated. National data sources are partially of low quality. These low quality data are often passed to international institutions like the International Energy Agency IEA that publishes these without commenting on the quality. This is e.g. the case for the United Arab Emirates (Interview 2009). Wherever possible, data were cross-checked with other sources.

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<sup>3</sup> Several online newspapers reported in this: <http://www.asharq-e.com/news.asp?section=2&id=15844>; <http://www.alarabiya.net/views/2009/03/03/67617.html> etc. (06.07.2009).

## 2 Methodological approach: scenarios, web diagrams

The assessment of technological options along a defined *set of criteria* opens the technological background of the analysis. The complete set will be described in section 2.2. The analysis of the energy and economic systems of Algeria, the United Arab Emirates and Iran follows, extended by some simplified energy scenarios, modelled anew or taken from detailed scenario studies (in the case of Iran). Together with the assessment of technologies it will then be possible to conduct the energy system analysis including energetic and non-energetic aspects. This holistic approach reveals system and country specific effects and generates results on the systemic impacts of energy supply options.

### 2.1 Work procedure for country specific assessment

A 4-step-procedure was chosen in the multi-criteria approach to generate results.

*First step:* Level-1-criteria will be assessed in detail. Via country trips and expert assessments (literature search, interviews) the influence of technologies on these criteria *in the context of the selected countries* are rated numerically: 5 for high impact, 1 for low/no impact.

*Second step:* Aggregation of level-1-criteria to according level-2-criteria by calculating arithmetic mean of expert assessments. Each level-2-criterion will get a value between 1.0 and 5.0.

*Third step:* Transformation of results of step 2 into a 3-options-matrix via proportional contraction of numerical values to reduce numerical complexity: the result is a matrix of three values *low* (1), *medium* (2) and *high* (3).

*Fourth step:* Generation of web diagrams and final analytic processing and discussion.

The resulting web diagrams will be analysed in two directions. Direction 1: Comparison of different technologies in one country: the larger the according hexagon, the more positive influence a technology (or set of technologies) will have on the chosen aspects of the country. This is then discussed in the country reports. Direction 2: Comparison of different countries. As the three countries are different in many aspects, such a cross-country comparison will reveal insights whether these differences proliferate into the impacts of technologies.

### 2.2 Characteristics of chosen parameters

*Levels of criteria.* In Tab. 2-1 criteria to assess different technology pathways are listed. It is not possible to integrate them all in one single web; therefore it was necessary to group them and to display the resulting groups in the web. Two different levels of criteria were chosen:

- Level-1-criteria allow analyses in detail
- Level-2-criteria represent groups of level-1-criteria

Example: Independence from depletable fuels and reducing national dependence on imported fuels are level-1-criteria that comprise one level-2-criterion: Independence.

Tab. 2-1. Level-1 and Level-2 criteria. Most of these criteria will be displayed in webs to generate comparability between technologies and countries.

Level 2 criterion	Level 1 criterion
Ecosystem stability	"Harmlessness" of total life-cycle on environment and humans: including production processes and disposal
	"Harmlessness" of technology on direct environment/ surrounding area and on humans (local effects during operation)
Micro- and macro-economic benefits	Job potential and potential for technology R&D for national development (technology multiplication effects)
	Affordable energy supply I: cost reduction potential in mid to long term
	Affordable energy supply II: redundancy of subsidies
Independence	Independence from depletable fuels (geological perspective)
	Reducing national dependence on imported fuels (political perspective)
Technical integratability to existing and growing systems	Flexibility of operation mode (possibility to make system more flexible)
	Rapid temporal availability of technology: short length of planning and build-up period
	Constancy/permanence of generation
	Possibility to integrate technology into the existing grid
	Technological status: market readiness of technology
Political stability	Potential to reduce conflicts over resources
	Contribution to transnational confidence building
	Infrastructural security (local level): resilience towards shocks (terrorism etc.)
	Military harmlessness
Climate Policy Benefits	CDM eligibility
	Adaptation facilitation: Contribution to reduction of water scarcity
	Reduction of GHG

*Direction of impact.* In general, parameters can point in two directions: they can be positive or negative. To generate a web all parameters have to point into the same direction. Positive directions were chosen for display, hence all parameters phrase *positive* influences. Example: infrastructural security as positive parameter was chosen instead of infrastructural insecurity (negative parameter). With the highest (most positive) influence being located at the margin (lowest influence on the parameter near the centre of the web), the larger the area of the web, the higher – and more positive – the effects of technologies will be.

### 2.3 Web diagram approach

The task is to cross system-intrinsic parameters of section 3 with country-intrinsic parameters of sections 4 - 6. The major challenge is to find an appropriate format to display the resulting criteria: The "web diagram" (see Fig. 2-1). The web links characteristics of different qualities/criteria and shows the size of their influences on the system as a whole. The critical points

are to find these criteria and to determine the direction of their influence/impact on the system. Specific nodes of the web display the strength/intensity of criteria: the nearer a node to the centre, the less significant the influence on the target criterion. Moving from centre to margin, the intensity increases, which can be quantified e.g. by the measures “low”, “medium”, and “high”.

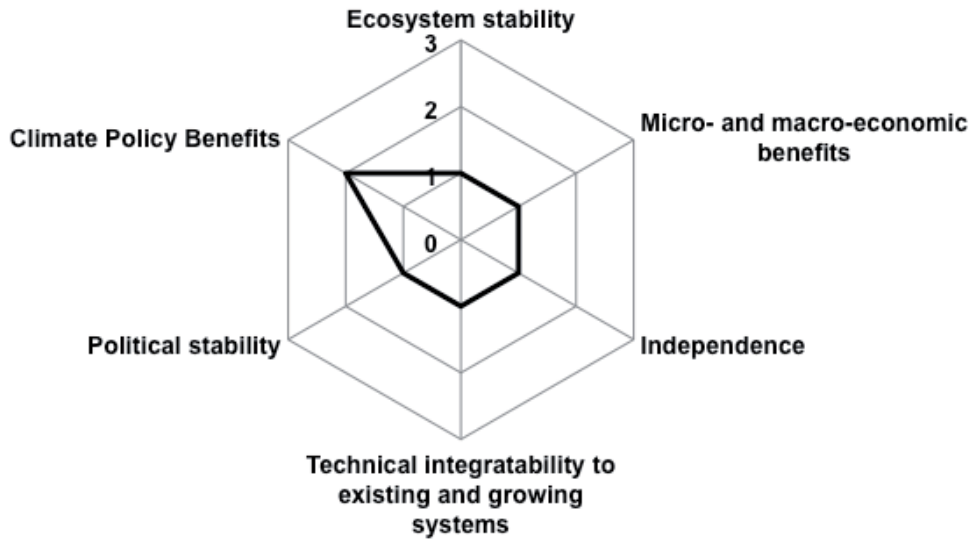


Fig. 2-1. Web diagram for different criteria, example. 1: Low positive influence on criterion, 2: Medium influence on criterion, 3: High positive influence on criterion.

## 3 Technology Options of Modern Energy Systems

Technology options that can become relevant in the chosen country and regional context will be assessed in brief. This assessment does not only include technological questions, it mainly concentrates on the various effects that energy utilisation and technologies can have on non-energetic aspects.

### 3.1 Selection of technologies

Algeria, Iran and the United Arab Emirates are not endowed with all types of renewable energies: e.g. biomass potentials are scarce. Therefore some technologies were excluded from the assessment. Nuclear energy and energy efficiency are included in this section.

### 3.2 Selection of criteria for comparison of technologies

Characterisation and assessment follow standardised structures:

- Micro- and macro-economic benefits
- Technical integratability to existing and growing systems
- Independence (from depletable and imported fuels)
- Ecosystem stability
- Political stability
- Climate polity benefits

These criteria are so-called level-2-criteria and are comprised by a set of level-1-criteria. This hierarchy allows on the one hand a very detailed analysis and on the other hand clear display of the results. Description of the methodology can be found in section 2.

Applying this set of criteria makes it possible to characterise technologies regarding their overall non-energetic effects. However, some criteria (e.g. climate policy benefits) are difficult to apply without reference to actors – in the case of this project to specific countries. Such country-specific technology assessment will be accomplished in sections 3 – 5.

### 3.3 Comparative analysis of technology options

In this section the selected technologies are reflected on the selected criteria above. Strong and weak points are discussed.

#### 3.3.1 Base load / peak load capability

**Nuclear power.** Due to high investment costs nuclear power plants are only economically feasible if they are operated under full load. Besides they have very low load acceptance rates, which means they aren't flexible in operation. Thus they are used for base load electricity generation and can't provide peak load electricity (BMU 2007).



**Solar energy.** Solar electricity generation in general, PV as well as CSP, is peak load capable because there is a good correlation of electricity supply and demand (WI/DLR 2008), especially electricity demand for air conditioning at noon. In combination with efficient heat storage and/or an optional additional firing, a CSP plant is even base load capable (BMU 2006).

**Wind energy.** Due to fluctuating generation, wind energy is only capable for base load supply if it is used in combination with energy storage technologies or other back-up systems (like diesel generators for single stand alone systems or gas and steam power stations for large wind farms) (WI/DLR 2008). Via grid connection also the combination with other (renewable) energy sources is possible: So-called “virtual power plants” combine different distributed energy generation technologies (e.g. wind, solar, biomass, CHP) to meet the consumer load. Small-scale projects to show the feasibility of this concept already exist (see [www.kombikraftwerk.de](http://www.kombikraftwerk.de)).

**Geothermal energy** is base load capable due to constant temperature level (Henricke/Fischedick 2007). It can also be regulated according to demand. Geothermal energy power stations could thus make a major contribution to the basic supply of renewable electricity (BMU 2006). Some concepts are not orientated on the electrical but on the thermal demand (heat-led CHP). In this case full electric output is only available in times of low thermal heat demand (normally in summertime).

**End-use energy efficiency** can reduce both base load (by a general reduction of energy consumption) and peak load (by means of load management).

### 3.3.2 Integration into existing energy systems

**General discussion of centralised and decentralised energy systems.** Energy technologies in general can be differentiated into two classes: Centralised and decentralised technologies (with overlapping shares). Centralised technologies are characterized by few but large power units. Typical examples are nuclear or coal power plants. New renewable energy systems (except hydropower) used to be decentralised systems in the early market phase. But nowadays e.g. great wind or solar CSP farms reach a scale that has to be classified more as being centralised than decentralised (see Tab. 3-1).

Tab. 3-1. Compilation of typical technologies for centralised respectively decentralised energy systems.

Technologies	Centralised	Decentralised
<b>Renewable Energies</b>	<ul style="list-style-type: none"> <li>- large hydropower (e.g. Three Gorges Dam/China) &gt; 1 000 MW</li> <li>- large offshore wind farms &gt; 100 MW</li> <li>- large solar thermal power plants (e.g. TREC project) &gt; 100 MW</li> <li>- large geothermal power plants (e.g. Island)</li> <li>- large biomass power plants (e.g. Penkun/Germany 20 MW)</li> </ul>	<ul style="list-style-type: none"> <li>- small hydropower &lt; 100 MW</li> <li>- wind energy: single plants (up to 6 MW) or small wind farms</li> <li>- small solar thermal power plants &lt;&lt; 100 MW</li> <li>- small geothermal power plants (e.g. Unterhaching/Germany 3,4 MW)</li> <li>- biomass power plants</li> </ul>

<b>Nuclear Energy</b>	- in general every nuclear power plant	- PV plants (< 100 MW) - no decentralised application
<b>Fossil Energy</b>	- in general coal power plants (especially lignite)	- in general medium and small gas and oil fired plants (especially CHP plants like block heat and power plants or combined-cycle plants)
<b>(End Use) Energy Efficiency</b>	- no centralised application!	- in general every end use energy efficiency measure

**Typical Stakeholders** for centralised technologies are great utilities, plant constructors, coal producers, lobby associations (water, gas, electricity...), research facilities (e.g. for nuclear energy, nuclear fission) and banks / investor groups. Stakeholders involved in decentralised technologies are municipal utilities, communes and building societies, manufacturers and plant constructors, associations (renewable energies, CHP...), craftsmen (heating installer, engineering offices, CHP designers...), farmers (biomass / wind energy plants) as well as citizens (e.g. shareholders of wind or solar stocks).

As Tab. 3-2 shows, both systems offer specific **advantages and disadvantages**. Due to thermodynamic phenomena large scale plants in centralised systems generally have a higher efficiency performance (e.g. great thermal or wind energy power plants). This leads to a better utilization of renewable, fossil or nuclear resources on the one hand and to lower specific investment (€/kW) and electricity generation (€/MWh) costs on the other hand. But the capital needs for centralised systems (e.g. 1 600 MW EPR nuclear power plant: ca. 4 billion €) are much higher than for small-scale systems. The latter can be erected in modules and financed step-by-step and allocated on a number of investors. The disadvantage of lower efficiency can be partly compensated by lower net losses for transmission and voltage transformation. Besides, CHP potentials can usually only be economically and ecologically reasonably used by decentralised systems nearby the heat sink. Due to their high redundancy a bulk of dispersed small-scale energy systems deliver higher supply security than few big centralised systems. In other words: To reach the same supply security level centralised systems need a higher expense for reserve keeping. While centralised systems rather win on points regarding costs and efficiency, decentralised systems are the better choice regarding aspects of system integration and social compatibility (Schneider 2000): Due to their long life (e.g. coal fired or nuclear power stations: 30 – 60 years) centralised systems aren't able to react flexibly to changing energy policy conditions (risk of "stranded investment"). Furthermore they suffer from a higher vulnerability with regard to sabotage or terroristic acts. Last but not least few but mighty stakeholders can lead to monopolistic / oligopolistic structures that harbour the danger of high political influence foiling democratic decisions and fair competition conditions as well.

Tab. 3-2. Strengths and weaknesses of centralised and decentralised systems.

Aspects	Centralised	Decentralised
<b>Technology</b>		
- Efficiency	+	-
- Net losses	-	+
<b>Costs</b>		
- Capital needs	-	+
- Specific investment	+	-
- Specific electricity generation	+	-
- Backup power	-	+
<b>System integration</b>		
- Supply security / redundancy	-	+
- Flexibility	-	+
- CHP potential	-	+
<b>Social</b>		
- Local codetermination / democracy compatibility	-	+
- Competition compatibility / chances for new market participants	-	+
- Vulnerability (e.g. against terror risks)	-	+

**Nuclear Power.** Large-scale power plants in base load operation tend to boost electricity consumption. Utilities have endeavoured to create steady consumer structures especially at night by delivering electricity for example to night storage heaters (e.g. pushed by German utilities in the sixties of the 20<sup>th</sup> century) or highway lightning (e.g. in Belgium). The electricity suppliers E.ON and Électricité de France state that nuclear and renewable energies can't be expanded simultaneously because the base-load character of nuclear energy generation doesn't match fluctuating renewable energy feed-in (FR 2009). Thus nuclear power neither fits to renewable energy systems nor to efforts in reducing absolute energy consumption.

The large power capacity and the inflexible load management of nuclear plants leads to high base-load generation, which, especially in small countries, doesn't always match consumption. Furthermore, large reactor blocks provide a higher blackout risk than decentralised energy generation (see also section 3.3.8.1).

The longer the projected running time of new nuclear power plants, the harder the market launch for new actors and operators of decentralized technologies and end-use energy efficiency gets (WI 2007). Long planning time, long operational life and high fixed costs cause greater vulnerability to long-term changes in the market and to short-term fluctuations than they can occur in a deregulated energy market (NEA 2003).

**CSP** plants are scalable from 10 kW<sub>el</sub> to 200 MW<sub>el</sub> and hence adaptable to local situations (Hennicke/Fischedick 2007). They can also be used for combined heat/cold and power generation (co-/trigeneration) and for desalination (BMU 2006). However, if plans like the DESERTEC project were to be realised, meaning that a bulk of electricity has to be transported from MENA countries to European countries, the CSP plants can't simply be integrated into existing grids. In that case a new interconnection infrastructure - favourable in HVDC<sup>4</sup> technology – would have to be built up.

**Wind energy.** Fluctuating feed-in is a problem for system integration of wind power electricity but the quality of wind forecast has increased steadily (Hennicke/Fischedick 2007). Bottlenecks in transmission lines have to be removed by grid extension, grid upgrade (e.g. from 220 kV up to 380 kV) and by intelligent grid management<sup>5</sup>. Especially the laying of cables for offshore plants is complex and expensive (BMU 2006). Modern wind generators can provide adjustable idle power to support grid stability.

**Geothermal energy.** Small base load units of geothermal power plants (several hundred kilowatt up to some megawatt) can easily be integrated into an existing energy system. But depending on the local conditions the usage of geothermal energy is only feasible if it is used for combined heat / cold and power generation (CHP). In this case a local thermal consumer is needed.

**Energy efficiency.** High end use energy efficiency means that less electricity has to be produced. This is unproblematic as long as the overall generation system isn't designed for high base load.

### 3.3.3 State of technology

**Nuclear power.** Nuclear reactors are based on nuclear fission: When the nucleus of unstable elements like plutonium and uranium is impacted by a neutron it splits into two fragments, releasing at the same time energy and further neutrons which activate a chain reaction. The emitted thermal energy is used to generate electricity in a conventional steam turbine process. There are several reactor concepts, which can be classified by their coolants and moderators<sup>6</sup>: Reactors using regular (light) water are Pressurized (PWR) and Boiling (BWR) Water Reactors. Pressurized Heavy Water Reactors (PHWR) can be operated with non-enriched uranium. Other reactor types are e.g. graphite moderated and cooled with gas or water. The French company Framatome and Siemens AG cooperated in developing the EPR (European Pressurized Reactor). The first commercial pilot plant of this "generation III" type will possibly be on line in 2012 in Olkiluoto/Finland (1,600 MW<sub>net</sub>; start of construction: 2005). A second plant with identical capacity is under construction in Flamanville/France since 2007. Besides there are plans for future EPR plants in Abu Dhabi, China, India, Europe, and the USA. In 2001 the "Generation IV International Forum" (GIF) was launched to "lead the collaborative efforts of the world's leading nu-

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<sup>4</sup> HVDC = high-voltage direct-current

<sup>5</sup> Intelligent grid management means for example that the transmission capacity of existing cables can be boosted by 30 to 100 % by exact temperature measurement (see [www.wind-energie.de/de/themen/windenergie-im-stromnetz/sichere-netze/erdkabel-vs-freileitung](http://www.wind-energie.de/de/themen/windenergie-im-stromnetz/sichere-netze/erdkabel-vs-freileitung)).

<sup>6</sup> Moderators are neutrons decelerating substances.

clear technology nations to develop next generation nuclear energy systems to meet the world's future energy needs.” (GIF 2009). In this forum several nations cooperate in research to develop the next generation reactor concepts (“**Generation IV**”). They claim to design safer reactor types that produce less radioactive waste with a lower proliferation risk. There are different technologies<sup>7</sup> that are expected to be suited for these criteria, but Generation IV reactors still have to prove their promises and are not expected to be on market before 2030 (Schulenberg 2004, DOE 2002).

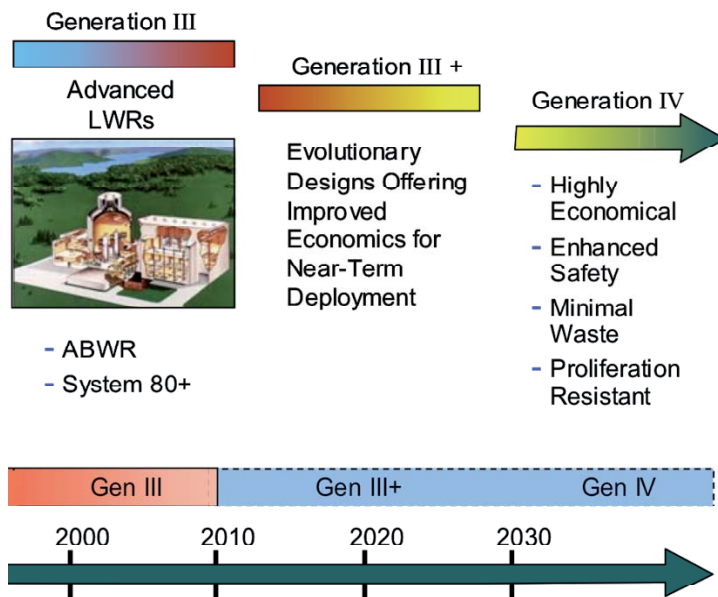


Fig. 3-1. Timescale of nuclear reactor concepts. DOE 2002.

With present consumption the global uranium resources will not last longer than 50 years and are becoming more and more expensive. Fast breeder technology could expand those resources but would amplify the risk of dangerous proliferation of plutonium. (DLR 2005)

**Solar thermal power plants** can be differentiated between concentrating (= CSP, e.g. parabolic through) and non-concentrating (e.g. solar chimney plants) systems. CSP plants can be further classified into systems focussing insolation in a point (e.g. Dish-Stirling) and in a line (e.g. parabolic through) and into distributed collectors (e.g. parabolic through) and central receiver (solar power tower) concepts.

**Parabolic through systems** are the best-established CSP technology with more than 20 years of commercial experience. By now a total capacity of about 500 MW is installed and more than 2000 MW are planned worldwide (SM 2009). Parabolic through systems consist of long, parabolic metallised collectors that are dynamically adjusted to the sun to bundle sunlight. In the focal line is a pipe filled with working fluid (thermal oil or water). This fluid is used as a heat source for the power generation system (conventional steam turbine cycle). These plants achieve efficiencies of 11-16 % (annual mean). The typical plant size is 50 to 80 MW<sub>el</sub>.

<sup>7</sup> The following next-generation technologies are under study by the GIF: Gas-Cooled Fast Reactor (GFR) / Very-High-Temperature Reactor (VHTR) / Supercritical-Water-Cooled Reactor (SCWR) / Sodium-Cooled Fast Reactor (SFR) / Lead-Cooled Fast Reactor (LFR) / Molten Salt Reactor (MSR).

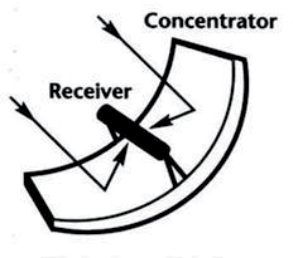


Fig. 3-2. Principle of Parabolic through systems. DLR 1995.

Systems based on fresnel lenses work similar to parabolic through systems but use several non-curved mirrors to focus the sunlight instead of parabolic collectors. Some fresnel reflector pilot plants are currently under development (e.g. FRESDEMO project in Almería/Spain). They promise lower production cost than parabolic through systems but reach lower efficiency.



Fig. 3-3. Principle of fresnel reflector systems. BdS 2009.

**Dish-Stirling-plants** focus sunlight by using a parabolic dish with a receiver in the focal point, which conducts the heat to a Stirling motor that drives a generator. The system can track the sun in two dimensions; very high concentration ratios lead to efficiencies of up to 30 %. Typical plant size is 10 to 50 kW; clusters of them can build greater modular parks. Thus this technology is well suited for distributed energy generation. Dish-Stirling-plants are technically mature but haven't proven their economic efficiency yet.

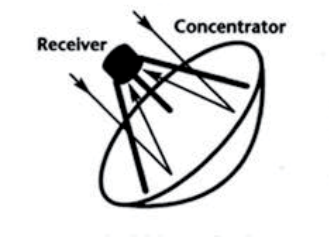


Fig. 3-4. Principle of Dish-Stirling systems. DLR 1995.

**Solar power towers** use a wide array of mirrors (heliostats) that are tracking the sun in two dimensions and concentrate the sunlight on a receiver on top of a tower. Temperatures up to 1.000 °C can be reached with this technology. These high temperatures can be used for vaporisation of a working fluid that drives a steam turbine and a generator. Other possible applications are industrial steam production or solar chemical processes (e.g. methane reforming or hydrogen production in the long term). Plants with sizes up to 11 MW<sub>el</sub> (e.g. PS10 near Seville) are in use;

bigger power stations are under construction and further research and development is going on, for example at the solar power tower in Jülich/Germany.<sup>8</sup>

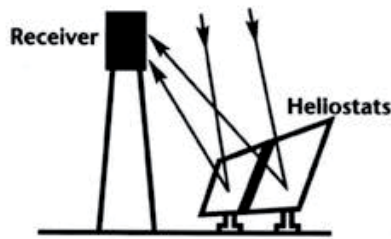


Fig. 3-5. Principle of solar power tower systems. DLR 1995.

**CSP potentials.** The international energy agency (IEA) estimates the potential for CSP as 20.000 to 40.000 MW<sub>el</sub> that can realistically be implemented until 2020. Theoretically the potentials in Morocco's solar radiation alone could meet the power requirement of the whole world market. An average direct normal insolation (DNI) of 2000 kWh/m<sup>2</sup> per year is suitable for the installation and running of a CSP plant. The „Global Market Initiative for Concentrating Solar Power (GMI)“, which is borne by national ministries and international organisations, aims at developing the capability and markets for the huge potentials of solar thermal power plants. The objective is to facilitate and expedite the building of 5000 MW of CSP worldwide over the next decade.

**CSP costs and prices.** The initial costs of solar thermal power plants are around 9 to 16 Ct/kWh (compared to 30 to 80 Ct/kWh for photovoltaic power generation). The costs are expected to decrease by half in medium-term. In 2002 the Spanish government passed a feed-in law for solar thermal power plants, guaranteeing a cost-covering compensation for 25 years. Thereby the first commercial European CSP plants have been realised in Spain.

**Solar chimney power plants.** All technologies described above require direct solar radiation. Diffuse radiation can be used in *solar chimney power plants* (also: solar updraft tower): A large area is covered by a glass roof (diameter of several kilometres). The air underneath the roof heats up and flows to a chimney placed in the middle of the roof (stack effect). There the flowing air drives wind turbines that generate electricity. This concept doesn't require cooling water and is thus applicable for regions suffering from water shortage. The technological feasibility has already been proven in the 1980's in Manzanares/Spain (50 kW<sub>el</sub> prototype), but due to high investment costs for plants on an economic scale (of about 100MW<sub>el</sub>) a commercial demonstration plant is still missing (Hennicke/Fischedick 2007).

<sup>8</sup> [www.solarturm-juelich.de/en](http://www.solarturm-juelich.de/en)

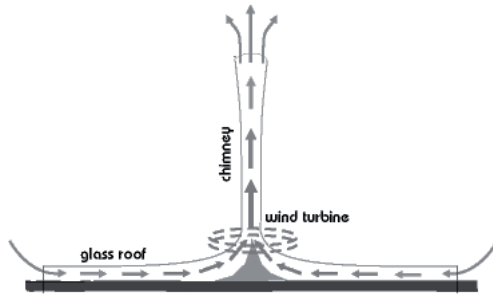


Fig. 3-6 Principle of solar chimney systems. Stirlingengines 2009.

**Wind turbines** convert kinetic energy from air movement into electric energy by using a rotor that drives a generator. The most established converters are equipped with three-blade horizontal rotors. Wind turbines can have different sizes from some kilowatt to several megawatts (Hennicke/Fischedick 2007). Today the largest commercial available plants can yield up to 6 MW<sub>el</sub>. On a suitable location this plant can deliver electricity of more than 17 GWh per year, which corresponds to the annual electricity demand of about 5000 three-persons-households in Germany.

**Geothermal energy.** There are two techniques for the utilisation of (deep) geothermal energy: The hydrothermal and the Hot Dry Rock (HDR) power plant. In *hydrothermal plants* hot water from aquiferous rock formations in geologic anomalies is used. These formations are relatively close to the surface, so this technology is cheaper to use if such formations exist. So-called *HDR plants* use water that is pressed into hot, dry (that means non-aquiferous) rock formations. There it heats up and then becomes extracted. This technology requires deep (several thousand meters) and thus expensive bore holes but is more independent from the existence of anomalies structures. Both technologies use the heated water to drive either conventional steam turbines or, if the temperature isn't high enough, organic-Rankine (ORC) or Kalina-cycle processes (for a description of technology see Supersberger 2007). The lower the temperature of the heated water, the lower is the efficiency factor of the process.



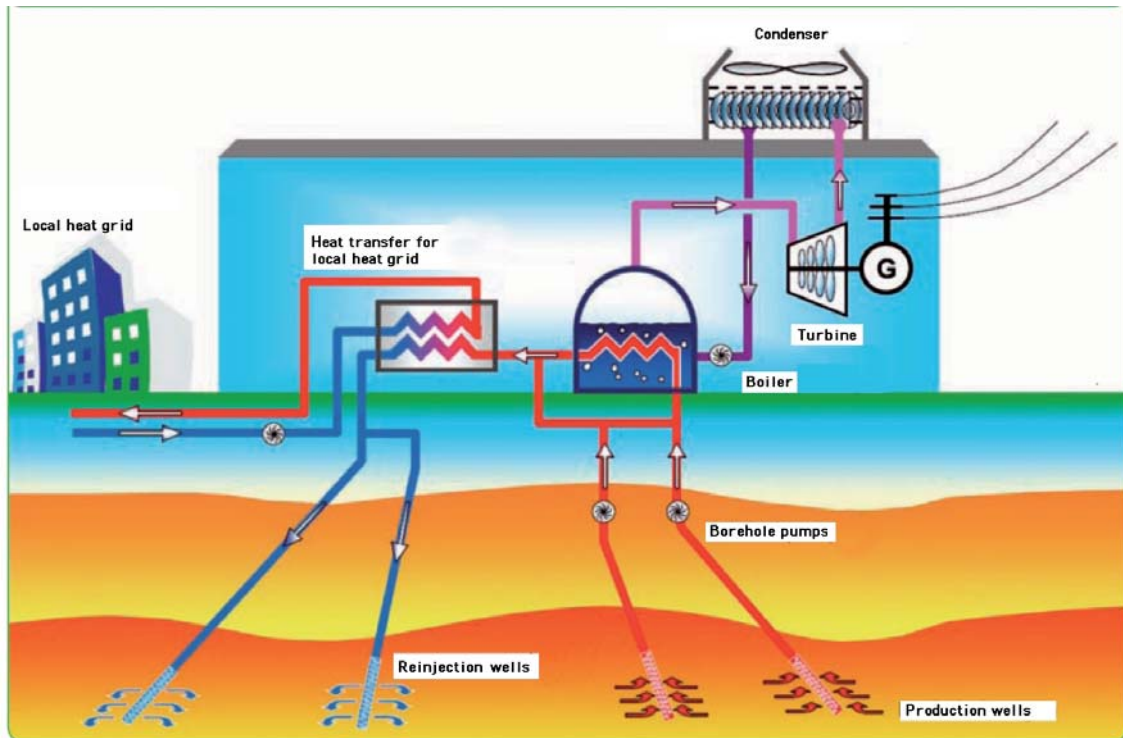


Fig. 3-7. Principle of a CHP hydrothermal system. SWM 2007.

**Ocean energy.** There are different possibilities to use ocean energy: The so called *OTEC power plant* (Ocean Thermal Energy Conversion) uses temperature differences between the ocean's by sun heated surface and cold water in about 1000 meters depth to drive a thermodynamic cycle. This technology is in a very immature state and thus not regarded in the following. More promising are ocean current power and wave power technologies: *Ocean current power plants* work similar to wind turbines (Fig. 3-8). They are anchored on the ocean's ground and driven by water current instead of air movement. First pilot plants have been installed (e.g. 1.2 MW<sub>el</sub> tidal energy converter "SeaGen" in Strangford Lough/Northern Ireland). The worldwide potential of known suitable locations is estimated over 50 GW<sub>el</sub> with an electricity production potential of more than 150 TWh/a. The technical potential probably considerably exceeds this appraisal.

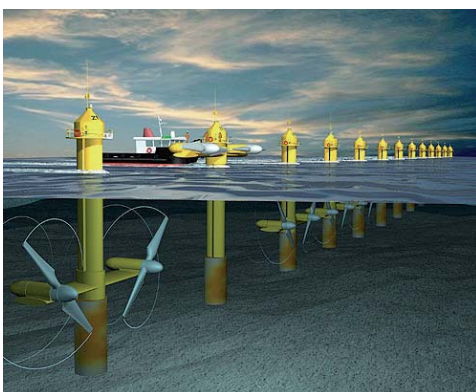


Fig. 3-8. Concept for a park of ocean current power plants with twin axial flow rotors. Marinerturbines 2009.

For the utilisation of *wave power* different technologies are suggested: One is to use the technical principle of an oscillating water column (OWC, see Fig. 3-9). The waves supersede the air in a tank. This air drives a so-called Wells-turbine<sup>9</sup> that is connected to a generator. Other technologies are for example *tapered channel plants* or the *Pelamis wave energy converter*. There are some rather small plants planned or in operation around the world, but by now wave power doesn't play a significant role. (Hennicke/Fischedick 2007)

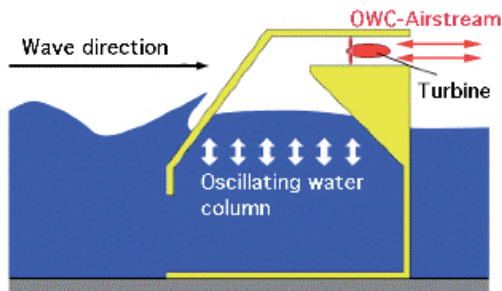


Fig. 3-9. Principle of an oscillating water column system (OWC). Graw 2004.

**Energy efficiency** means to reach the same output or service using lower energy input by an intelligent usage of energy. This requires more efficient generation, distribution and usage of energy. For a better end-use efficiency more efficient appliances are needed. A broad range of examples for measures to reduce energy consumption is given in Fig. 3-15.

### 3.3.4 Lead times

Beside economic and ecological issues the lead time for the erection of power plants is an important criterion for the assessment of different energy supply technologies. As a rule, the longer the lead time the higher the financial risks (e.g. concerning the interest of building loan or concerning contractual penalties) as well as the risks of security of energy supply and the more inflexible the system integration. “Lead time” means the time between the positive decision for a project and the commercial commissioning date. In Fig. 3-10 the lead times for some RE technologies (geothermal, solar thermal power plants and wind farms), for nuclear energy and for **energy efficiency measures** are illustrated. The latter offers the shortest time for planning and construction. Its “lead time” (or better here: time for implementation) normally is about one year, but often much faster (e.g. the replacement of an incandescent lamp against a fluorescent lamp takes only a few minutes). **Geothermal** and **solar thermal power plants** have lead times of four to five years. **Onshore wind farms** are in a similar range, but with shorter construction time. Information about **offshore wind farms** differ from at least five up to ten years with the greatest share for the planning and approval time. Because this is a very young technology, lead times should decrease in the future. The evaluation of worldwide **nuclear energy** projects (Schneider/Mez 2008) shows that with more than ten years this technology has the longest lead time of all technologies under consideration. Within this evaluation only “regular” lead times have been included, projects with time overruns of more than 20 years (e.g. some reactors under construction in Russia, Ukraine and Iran) have not been taken into account.

<sup>9</sup> A Wells-turbine is able to use rotation energy irrespective from the sense of rotation.

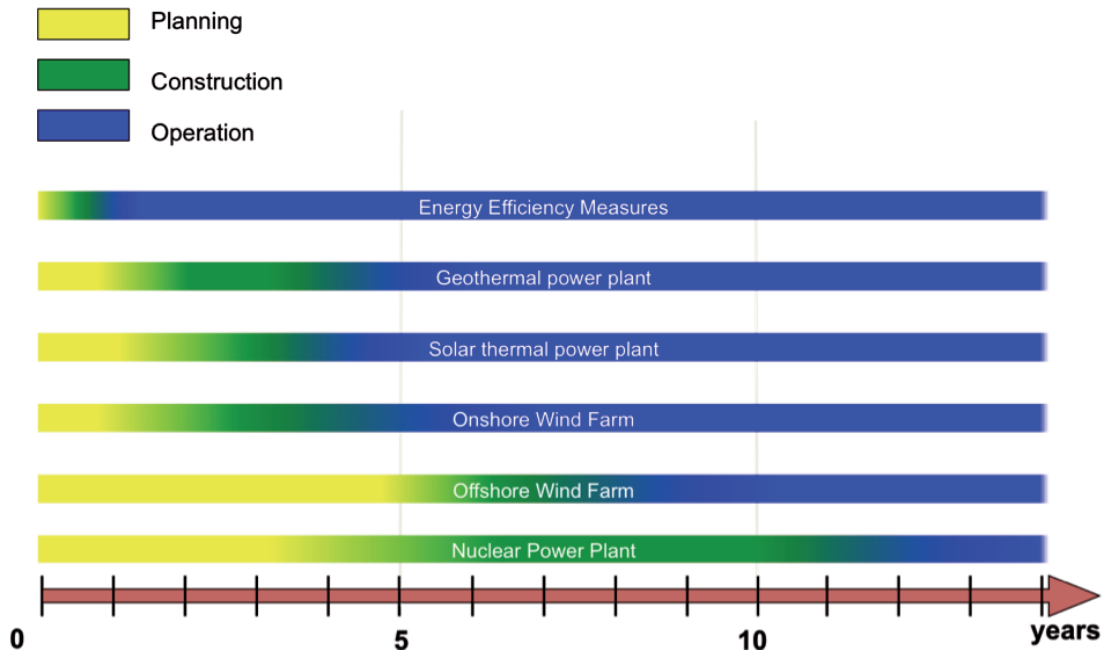


Fig. 3-10. Average time needed for planning and construction of power systems.

Sources: Geothermal: Geothermische Vereinigung - Bundesverband Geothermie e.V./ Geeste (GtV), e-Mail 28th April 2009. Solar: Solar Millenium/Erlangen, e-Mail 4th May 2009. Efficiency: Own estimations. Nuclear: Schneider/Mez 2008 (Lead-time >10 a, time for erection of plants currently under construction: 4-7 y). Wind: www.wind-energie.de/de/themen/offshore/ (lead time: 10 y) www.trouw.nl/nieuws/economie/article1697779.ece, (planning: 7 y + construction: 2 y) www.eon-uk.com/generation/howisawindfarmdeveloped.aspx (planning: 3-4 y + construction: 2-3 y)

### 3.3.5 Economic aspects

In this chapter the economic performance of the considered power generation technologies is discussed. For that purpose investment costs, electricity generation costs and cost reduction potentials are described and compared. Last but not least external costs – often a cause for distortion of competition – are examined.

#### 3.3.5.1 Costs and cost reduction potential

Fig. 3-11 gives an outlook of the **specific investment costs** for power generation technologies today and in the future. Capital investment costs for renewable energy technologies (dashed lines) are expected to remain more expensive than those for fossil fuel power stations with the exception of wind energy (cheaper than coal power stations as from approximately 2010) and photovoltaic (as from 2030). In contrast to the falling costs for other renewable energy technologies CSP plants' costs are rising up until the year 2020 due to the assumption of an increasing solar share from 25% to 90%<sup>10</sup>. The numbers are taken from the 2005 MED-CSP study and give prices in US-\$<sub>2000</sub> per kilowatt of installed capacity for new plants erected in the Mediterranean region (DLR 2005). For nuclear energy, the originally forecasted investment costs of 3200 million € (4730 million US-\$<sup>11</sup>) for the 1,600 MW<sub>net</sub> EPR in Finland are revised and esti-

<sup>10</sup> Assumptions for solar share: 2000: 25% / 2010: 45% / 2020: 90% / 2030: 95% / 2040 and 2050: 99%

<sup>11</sup> Conversion factor: 1,479 US-\$/EUR = average of 12 data from the first day of month in 2008 (source: www.oanda.com)

mated to reach 4500 million € (6655 million US-\$) by 2008 (see Tab. 3-3). Further cost increases are likely. Related to one kilowatt installed capacity these are specific investment costs of roughly 3000 to 4200 US-\$<sup>12</sup>. Both these numbers are added in Fig. 3-11 to mark a low and a mid price scenario for nuclear energy investment costs in 2008. Thus today's investment costs for nuclear energy are higher than they are for most renewable or fossil technology options considered here.

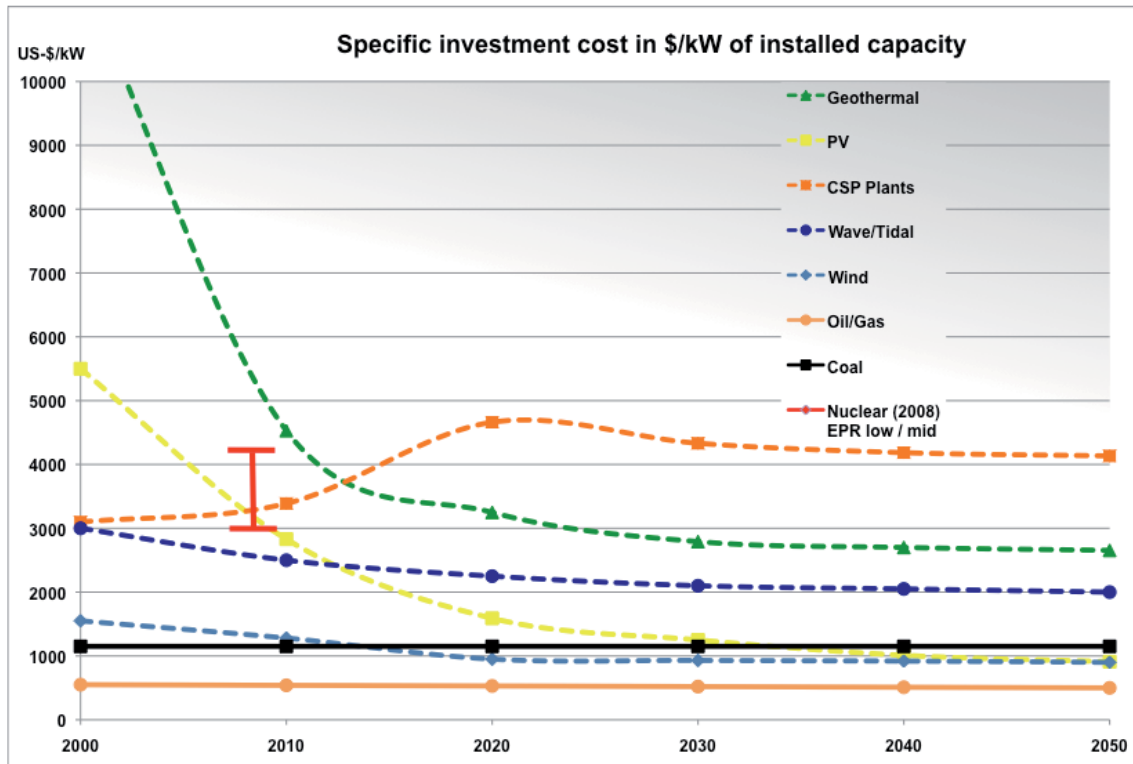


Fig. 3-11. Specific investment costs in US-\$ per kilowatt on timescale. Irrek 2008 (nuclear), DLR 2005 (others).

In the following figures historic, current and estimated future **electricity production costs** are outlined for the examined technologies: Fig. 3-12 shows the expected learning curves for renewable energy technologies (dashed lines) in contrast to the increasing electricity generation costs of fossil fuel technologies. The figure is also taken from the MED-CSP study from 2005 giving prices in US-\$<sub>2000</sub> per Megawatt hour for new plants erected in the Mediterranean region. Thus the **break-even point of renewable energy** technologies roughly can be expected between 2005 (wind vs. oil/gas) and 2035 (PV vs. coal). The bandwidth of nuclear energy costs is again supplemented from another source (Irrek 2008) for the single year 2008: The lower value (2.37 US-Ct<sub>2000</sub>/kWh) characterizes the optimistic assumptions of Prognos (2008)<sup>13</sup>, discounted

<sup>12</sup> For comparison: The U.S. reactors built between 1990 and 2000 had actual installed capital costs between 6 000 and 13 000 US-\$/kW (source: US Keystone report 2007, found in Rechsteiner 2008).

<sup>13</sup> Prognos assumes low capital costs and a very low interest of capital of only 2.6%.

down from 2007 to 2000. The mid value (5.59 US-Ct<sub>2000</sub>/kWh) includes several financial risks<sup>14</sup> and seems to be more realistic. The upper value (9.53 US-Ct<sub>2000</sub>/kWh) is additionally calculated with full internalisation of external costs for an adequate insurance against the risks of nuclear meltdown (see Fig. 3-14). Taking the mid value as realistic scenario, wind energy on suitable location today is already cheaper than nuclear energy. Presuming constant prices for nuclear energy on timescale any other of the considered RE technologies (except PV) are cheaper as from 2020.

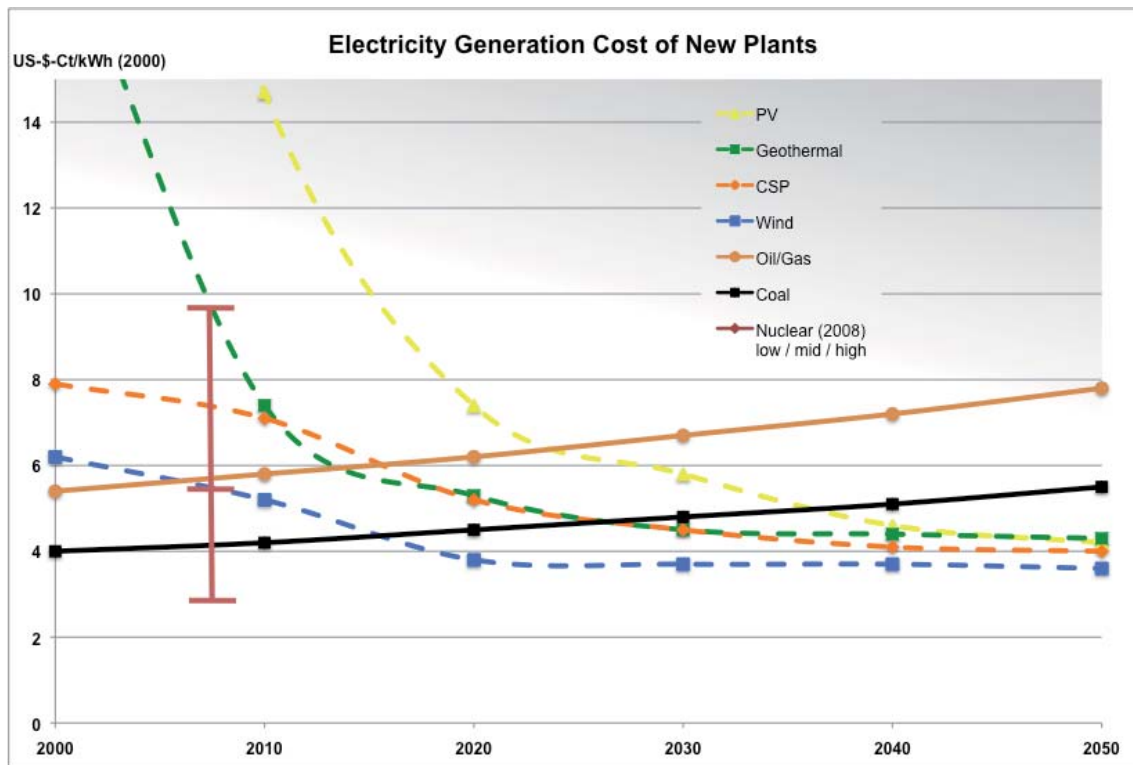


Fig. 3-12. Levelized energy cost (LEC) of new power plants for the Mediterranean Region on timescale (US-\$-Ct/kWh<sub>2000</sub>) in comparison to three nuclear power plant price scenarios for 2008. Irrek 2008 (nuclear), DLR 2005 (others). Discount rate 5% pa, in US\$<sub>2000</sub>.

In comparison to the figure above, Fig. 3-13 presents the future cost development of electricity-generating renewable technologies up to 2050 and the average of the all-renewable mix according to the present Lead Scenario 2008 for Germany (BMU 2008). The prices are in Euro-Cent<sub>2005</sub> per kilowatt-hour and the curves represent the averages of several individual technologies. This figure shows that even in Germany with its moderate wind and unfavourable solar insolation potential (compared to the Mediterranean region) average electricity generation costs from renewable energy sources of only about 6 €-Ct/kWh<sub>2005</sub> are expected in the long term.

<sup>14</sup> Three financial risks are integrated into the mid price scenario in relation to the Prognos base scenario: risk of different load (80% instead 87%), risk of different life (40a instead 60a) and risk of different interest of capital (12% instead 2.5%).

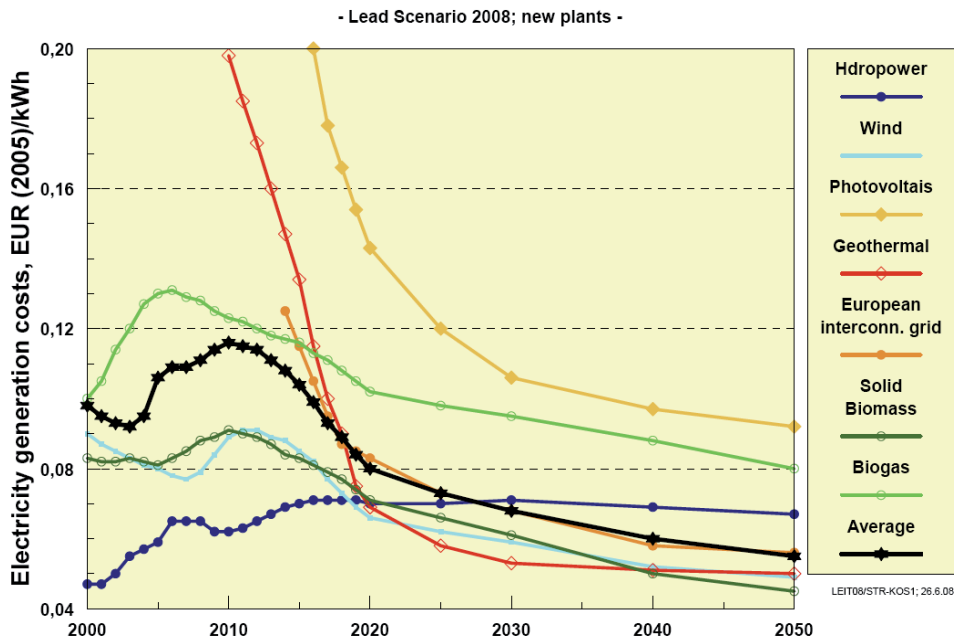


Fig. 3-13. Electricity generation cost (€-Ct/kWh<sub>2005</sub>) of new plants for Germany on timescale. Real interest rate 6% pa, in US\$<sub>2005</sub>. BMU 2008.

**Nuclear power** plant producers and operating companies tend to underestimate investment costs (see Tab. 3-3): E.g. the costs for a nuclear power plant in Tarapur / India had an overrun of 255 %. The new EPR plant in Finland (reactor unit 3 in Olkiluoto) was estimated to cost 3.2 billion €, by 2008 actual costs have risen up to 4.5 billion € (+ 41%) and will presumably continue rising.

Tab. 3-3. Overnight investment costs of nuclear power plants and their systematical underestimation. Irrek 2008.

Nuclear plant (start of building)	Original cost estimation	Actual costs	Cost escalation
75 operating US-reactors	45 billion US-\$	145 billion US-\$ (Thomas, Bradford, Froggatt, Milborrow 2007)	+324%
Tarapur III und IV, India (implementing 2006)	2 428 Rs Crores	6 200 Rs Crores (Ramana et al. 2005)	+255%
Temelin, Czech Republic (1987)	20 billion CZK (1981)	99 billion CZK (IEA 2001 for 1998)	+495%
Sizewell B, UK (1987)	1 691 million £	3 700 million £ (House of Commons 1990)	+219%
EPR OL 3 Olkiluoto, Finland (2003)	3.2 billion Euro	4.5 billion Euro up today (Alich/Höpfner 2008)	min. +41%

Due to the lack of data accessible to the public and due to uncertainties about timescales and risks it is not possible to give exact figures for true electricity generation costs for nuclear power plants. The reference costs used here (3.0 €-Ct/kWh, red column in Fig. 3-14) are based on a study of Prognos that calculated macroeconomic electricity generation costs for new nuclear power plants in Switzerland including expenses for retrofitting, decommissioning, final disposal and safety (Prognos 2008). Assuming less optimistic financial conditions (less load hours, shorter life, higher interest of capital, see risks 1 to 3 in Fig. 3-14) costs would rise up to 7.1 €-Ct/kWh (Irrek 2008). But in case of additional full internalisation of external costs (costs for adequate risk insurance), electricity generation costs for nuclear power would soar up to 12.1 €Ct/kWh.

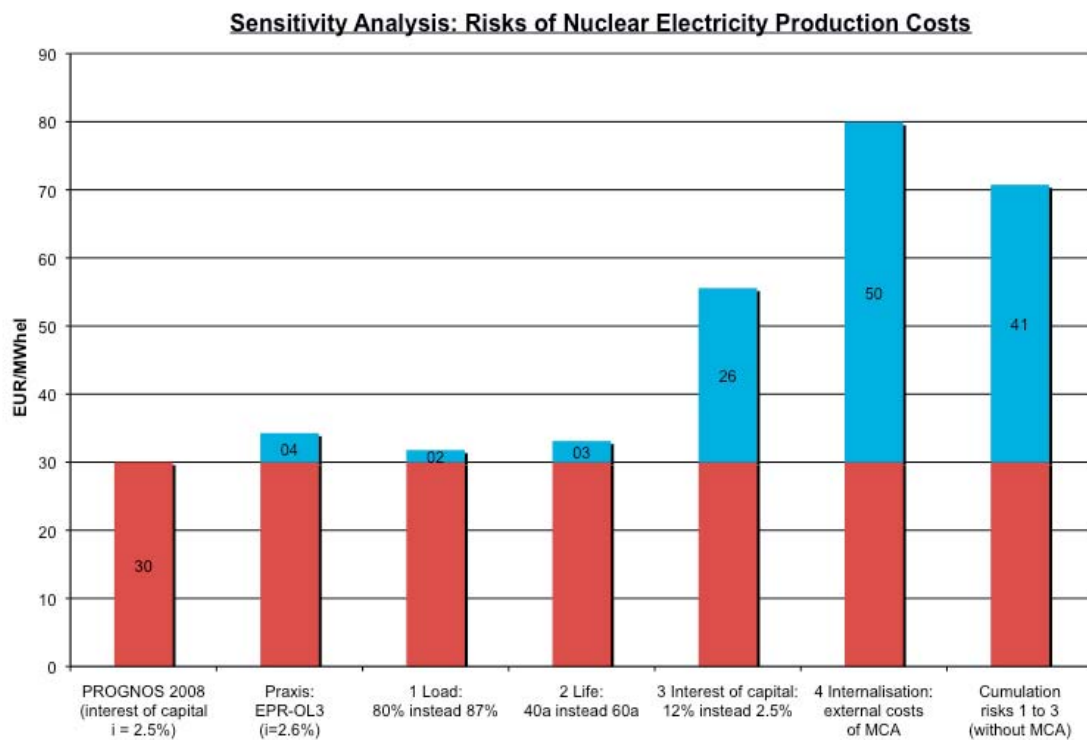


Fig. 3-14. Sensitivity analysis of different cost risks (blue) for nuclear energy (1,600 MW<sub>el</sub> EPR) additional to calculations of Prognos 2008 (red). Based on Irrek 2008.

Data base: Interest of capital = 2.5% / life = 60a / load hour = 7,600 h/a / 3,350 CHF<sub>2007</sub>/kW<sub>el</sub> / construction time = 5a / conversion factor CHF/EUR = 1.600 (5<sup>th</sup> Sep. 2008). MCA: Maximum Credible Accident. EPR-OL3: Olkiluoto Nuclear Power Plant.

Following Schneider (2000) it costs about half as much to invest in electricity savings in the industry than it would cost to build a nuclear power plant of equivalent capacity. Even though it would cost about 1.4 times more to invest in energy savings in the commercial and residential sector, globally, investment in energy efficiency measures pays back four times faster than investing in a nuclear power plant (Schneider 2000). In general the profitability of **energy efficiency** measures depends on the energy costs and the amount of savings that can be achieved by an investment (Öko-Institut 2005).

Studies demonstrate that there is a huge potential of energy savings that can be realised with negative specific net costs. Fig. 3-15 shows a cost-potential-curve for energy efficiency measures in different sectors (industry, trade and commercial, household) using the example of Germany. According to this by investing in energy efficiency measures up to 120 million tonnes of CO<sub>2</sub> per year could be avoided and - over lifetime - money could be saved at the same time (net cost ≤ 0 €-Cent/kWh). Under an ambitious climate reduction regime a further 40 million tonnes CO<sub>2</sub>/y could be mitigated for net costs of less than 6 €-Ct per kilowatt-hour for final energy. Assuming higher energy prices respectively lower investment costs for energy efficiency measures beyond that a great share of these 40 million tonnes CO<sub>2</sub>/y could additionally be mitigated without net costs.

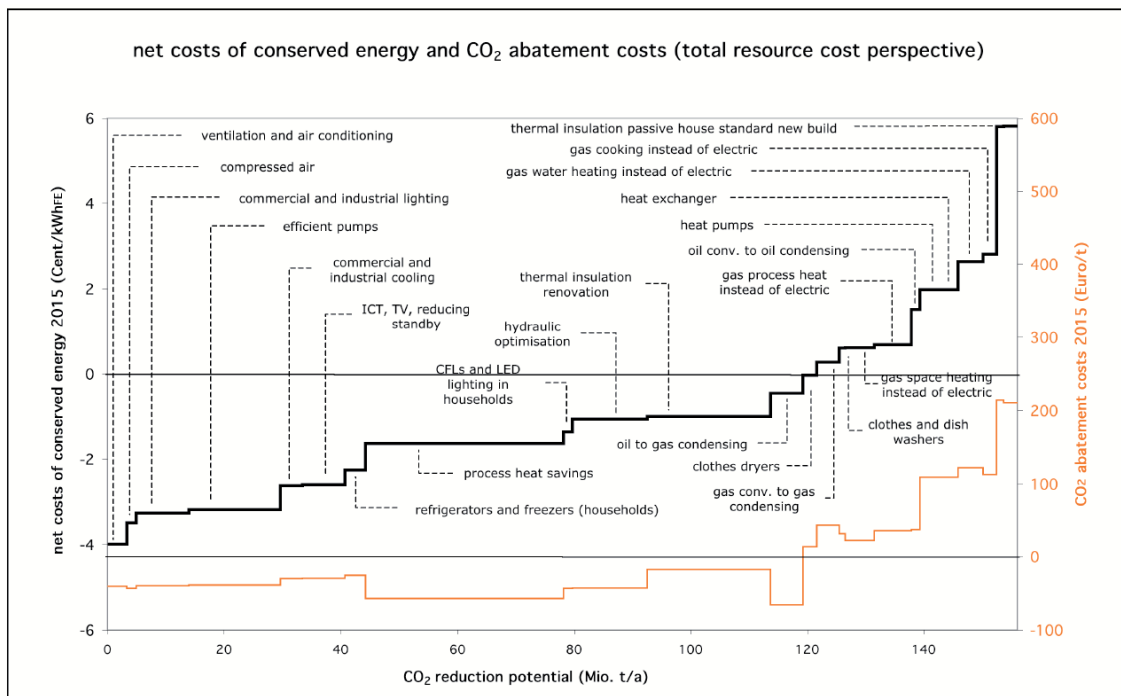


Fig. 3-15. Average net costs<sup>15</sup> for energy savings and carbon mitigation from a macroeconomic view (Germany until 2015). WI 2006.

### 3.3.5.2 Competitiveness (required subsidies)

The bulk of **renewable energy** technologies will not require long-term subsidies like fossil or nuclear energy sources do, but only an initial investment to disseminate the new renewable energy technologies on the market. In the long run, they can save national economies the expenses of energy subsidies (DLR 2005).

**Nuclear power.** Prices per kWh are largely subsidized by revenues from interest gained through back-end funds (for spent fuel, plutonium and waste management) and still – like in the case of fossil fuels – external costs and risks are covered by state respectively by citizens (see above) (Schneider 2000). In this light Fatih Birol (Chief Economist of OECD International En-

<sup>15</sup> Average net costs of conserved final energy (bold line) and CO<sub>2</sub> abatement costs (thin line) compared to the costs of measures that would have been installed in a baseline scenario, and net of avoided long-run marginal system costs of energy supply (hence net costs), from the total resource cost perspective.



ergy Agency IEA) stated “If governments do not facilitate the investment, I don’t think nuclear will fly.” (Economist 2006)

**Solar energy.** Today under favourable conditions costs for electricity generation from CSP plants that are only a few US-cents higher than those from conventional power plants can be reached, as long as the fossil fuel is not subsidised. Electricity generation cost for new plants differ from ca. 10 €-Ct/kWh to 20 €-Ct/kWh for solar only generation. When used for hybrid generation costs of less than 10 Ct can be reached (BMU 2006) .

**Wind energy.** Prices for wind turbines have decreased due to the production of large quantities, optimized production processes and efficient systems engineering. By now wind energy electricity generation costs (for plants at appropriate locations) are comparable to those of new conventional plants<sup>16</sup>.

**Geothermal energy.** *Hydrothermal* geothermal plants in regions with geothermal anomalies use hot water near the surface and hence do not require very deep and expensive boreholes. In the long term, hydrothermal energy generation leads to electricity generation costs of less than 0.03 \$/kWh (due to a high load factor) (Supersberger 2007). Commercial *HDR plants* aren’t yet on the market, but their electricity generating costs are forecasted to be in a range of about 7 to 15 €-Cents/kWh (at 8000 full-load hours per year and estimated invest costs of 2500 to 5000 Euro/kW) (BMU 2006).

**Ocean power.** Ocean power technologies are very young technologies with lack of commercial implementation. That’s why reliable cost data aren’t yet available. BINE (2004) estimates future electricity generation costs from ocean current power plants in serial production in a range between 5 and 10 €-Ct/kWh (at 1750 €/kW and 3500 h/y).

**Energy efficiency.** Subsidisation of energy leads to higher energy intensity. Thus for a broad implementation of energy efficiency measure reduced energy subsidies are essential. Most investments in energy efficiency pay back through reduced energy costs during their life cycle. Nevertheless, efficiency can be promoted by additional monetary incentives for the acquisition of efficient appliances (see also Fig. 3-15).

### 3.3.5.3 External costs

The costs described above (Fig. 3-11 - Fig. 3-13) are private costs from an investor’s point of view. They don’t include externalities for damages caused by the use of the power generation on climate system, health, crop losses etc. Although it is difficult to monetize those damages exactly, some studies have tried to do this. According to DLR/ISI (2006) conventional fossil power plants cause specific external costs in the range of 3 to 8 €-Ct/kWh<sub>el</sub> (see Fig. 3-16). This means with full internalisation of external costs electricity generation costs from fossil fuel power plants would increase by 100% to 200%. For the bulk of these externalities climate change damages as consequence of greenhouse gas (GHG) emissions are responsible. Those emissions have been weighted in DLR/ISI (2006) with 70 € per tonne CO<sub>2</sub>. External costs of renewable energy technologies are between 0.1 and 1.0 €-Ct/kWh<sub>el</sub> thus about one order of magnitude below those of fossil technologies (ca. 3 - 8 €-Ct/kWh<sub>el</sub>). That means that with full inter-

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<sup>16</sup> Reference: [www.wind-energie.de/de/themen/kosten/](http://www.wind-energie.de/de/themen/kosten/) (access on 30.03.2009)

nalisation of external costs RE technologies are compatible with conventional power stations already today. External costs of nuclear energy have not been in the focus of DLR/ISI (2006), but even an adequate risk insurance alone would lead to external costs of about 5 €-Ct/kWh<sub>el</sub> by guess (see Fig. 3-14).

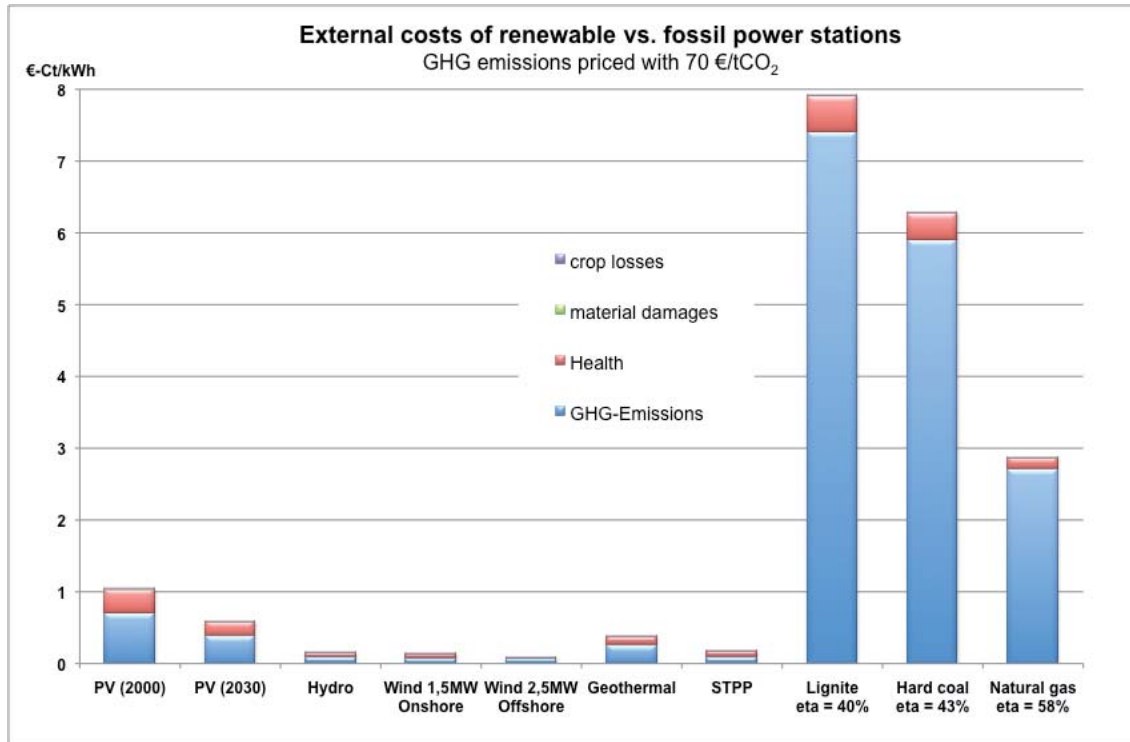


Fig. 3-16. Assessment of external costs caused by renewable and fossil power stations. DLR/ISI 2006.

As a **conclusion** due to learning effects both future capital investment and electricity generation costs of renewable energy technologies will further decrease. On the other hand costs for nuclear and fossil energy will presumably rise as a consequence of higher security standards respectively escalating fossil fuel and CO<sub>2</sub> certificate prices. Hence in a few years electricity from most renewable energy sources will most likely be cheaper than from conventional technologies. Taking into account a full internalisation of external costs they are already today compatible with fossil and nuclear power generation.

### 3.3.6 Ecological aspects

The analysis of ecological aspects consists of two different fields: direct impact on the surrounding area (including requirement of plants) and man on the one hand; and total contamination and long-term aspects during the whole life-cycle on the other hand. It is taken into account that such discrimination can in some fields create overlaps. However, in the project context this split clarifies the matter.

#### 3.3.6.1 Impact on surrounding environment and man

As the following Fig. 3-17 shows, compared to fossil fuel power technologies (here: coal steam power stations), specific CO<sub>2</sub> emissions per kWh<sub>el</sub> of every renewable energy technology and of nuclear energy are about one order of magnitude lower. But while CO<sub>2</sub> intensity for new renew-

able technologies further decreases (PV 2000: 99 g/kWh / PV 2030: 54 g/kWh / PV 2050: 3-8 g/kWh see Fig. 3-17 and Fig. 3-18), due to rising energy demand for uranium conditioning future nuclear power plants presumably will have a larger CO<sub>2</sub> footprint. Also other coal power station pollutants are a multiple of those of renewable energies<sup>17</sup>. Pollutants from nuclear LCA have been calculated neither in DLR/ISI (2006) nor in Öko-Institut (2007).

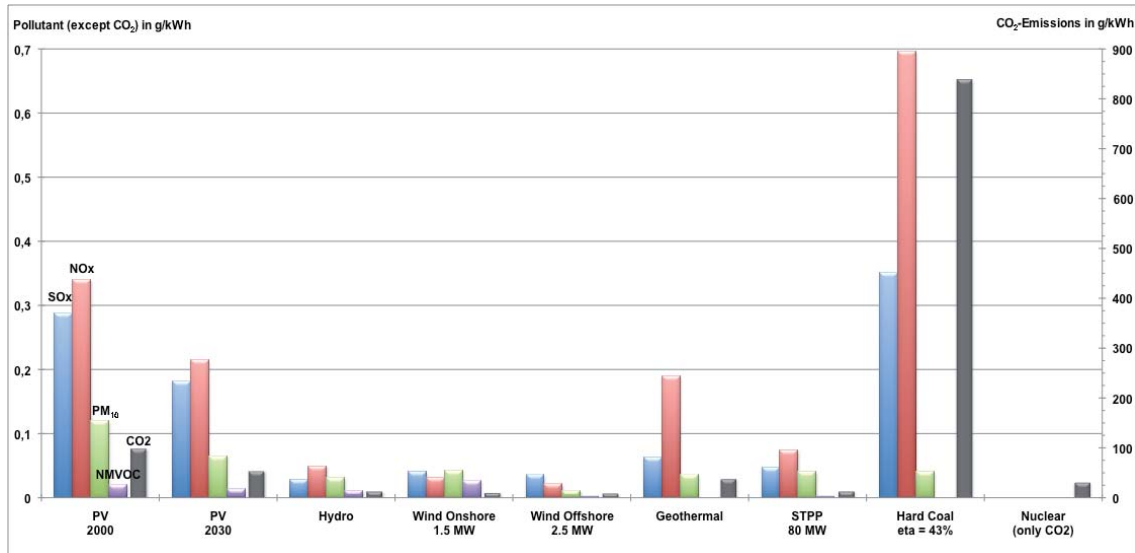


Fig. 3-17. Specific LCA emissions of pollutants (left axis) and the greenhouse gas CO<sub>2</sub> (right axis) of renewable, fossil and nuclear technologies. Öko-Institut 2007 (nuclear), DLR/ISI 2006 (others).

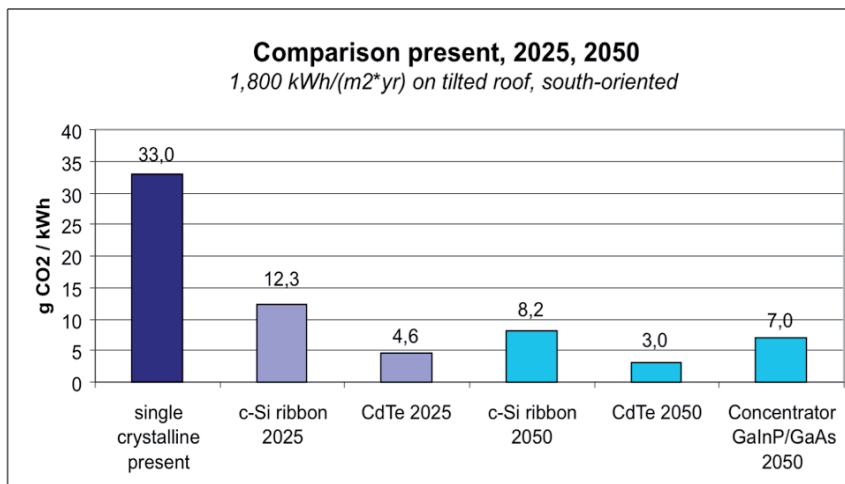


Fig. 3-18. Future PV life cycle CO<sub>2</sub> emissions. Krewitt 2009.

**Nuclear power.** Despite all security measures, electricity production from nuclear power plants always leads to inevitable radioactive emissions (at small scale) (BMU 2007). There is a risk of radiological health impacts on workers due to routine work and accidental exposure (DLR 2005).

<sup>17</sup> For renewable technologies only total dust data are available in Öko-Institut (2007) thus resulting in Fig. 3-17 to an overestimation of PM<sub>10</sub> (particulate matter) emissions for renewable energies.

**Solar energy.** Land-use intensity of CSP systems can impair ecological habitats, e.g. through shading: The large amount of land (approximately one square kilometre for every 20-60 MW) is often considered a problem because the large plants could impair ecological habitats by shading. But shading may also have positive effects, e.g. on the possibility of land use for agriculture. Considering the life cycle use of land including raw material exploitation, operation, infrastructure and disposal, solar technologies are the most area-efficient renewable electricity generating technologies (DLR 2005). Operating a CSP plant doesn't cause air pollution except when the plant is operated in hybrid mode (WI/DLR 2008, DLR 2005).

**Wind energy.** Environmental impacts from wind turbines include noise emissions, disturbances for animals (especially birds and bats) and their habitats, and detracting of the landscape. In some cases the flickering shadow is a problem, but this is largely eliminated by modern control technology. Problems that can occur with offshore wind plants are for example disruption in benthic ecosystems (when installing the turbine and laying the cables) and possible disorientation of whales through infrasound. Furthermore, offshore wind parks can have an impact on shipping routes. But they can also have a positive effect on animal populations as wind farm areas serve as nursery grounds for larvae of a multitude of marine animals.

**Geothermal energy** plants affect ecosystems on small scale through drilling and access roads (WI/DLR 2008), also thermal and chemical atmospheric, water and soil pollution can occur by well blow-outs and leakage and during drilling. Further there is a risk of sinking of land surface when the used material is not re-injected into the ground. Closed-loop systems are almost totally benign, since gases or fluids removed from the well are not exposed to the atmosphere and are usually injected back into the ground after losing their heat. Open-loop systems can generate large amounts of solid wastes as well as noxious fumes. (WI/DLR 2008, DLR 2005)

**Wave and ocean current power** plants could possibly impede animal movements (WI/DLR 2008). First environmental impact analyses on ocean current power plants showed relatively marginal impacts of the slow rotating propeller on waves, seabed, sediments, water quality and marine diversity. (BINE 2004)

**Energy efficiency.** Generally there is no ecological impact resulting from energy efficiency technologies, but depending on the technology possibly toxic materials can be applied (e.g. mercury in energy saving bulbs<sup>18</sup>). In rare cases energy efficiency measures can lead to less comfort in end-use applications.

### 3.3.6.2 Contamination during life cycle

Most **renewable energy** technologies have no emissions at all during operation. On a life cycle basis, usually emissions occur only during the production of the plants (DLR 2005).

**Nuclear power.** Radioactive waste (depleted fuel rods, radioactive steel and concrete scrap, highly radioactive liquid waste) emits radiation for several 10000 of years and decay heat. This has to be conducted securely for a very long time. Until now there exists not one safe repository

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<sup>18</sup> In spite of the usage of mercury in the production process the net balance of energy saving bulbs in comparison to conventional incandescent lamps is positive, because they save about 80% of electric energy and electric energy generation by coal power stations is loaded with atmospheric mercury emissions.

in the world (BMU 2007). Life cycle assessments predicate total emissions of 8 to 32 g CO<sub>2</sub>-equivalent per kWh<sub>el</sub>, including emissions caused by upstream chains (uranium enrichment) and power station construction (Öko-Institut 2007). Nuclear power stations operated with uranium from Russia produce more than double the amount of CO<sub>2</sub>-equivalent (65 g/kWh<sub>el</sub>) according to Öko-Institut (2007). Uranium production is very energy-intensive; the energy required for exploitation increases exponentially with decreasing uranium concentration in ores (WI 2007): Ore deposits with high uranium concentrations are running short, so future uranium must be mined from deposits with low concentration which leads to higher energy intensity and environmental impacts (Greenpeace 2006).

**Solar energy.** The heat transfer fluid (normally thermal oil) of some CSP plants can be hazardous and needs to be disposed of carefully (DLR 2005). Apart from that there are no critical components or substances correlated to CSP plants. The ecosystem on the location can be completely restored (WI/DLR 2008) .

**Wind energy.** There is no ecological impact after use of wind turbines (WI/DLR 2008). According to LCA (Life Cycle Assessment) of offshore wind plants they cause total emissions of 24 g CO<sub>2</sub>-equivalent per kWh<sub>el</sub> (Öko-Institut 2007).

**Ocean Energy.** Long-term ecological impacts of wave respectively ocean current power stations are not sufficiently known yet (WI/DLR 2008).

**Geothermal Energy.** In closed loop geothermal systems there is no contamination of the environment with deep saline water. Working fluids (organic substances or ammoniac) in thermodynamic ORC or Kalina processes have to be handled and disposed of carefully.

**Energy Efficiency.** In some cases energy efficiency measures lead to a greater material intensity. The disposal cost might be increased, e.g. due to a higher amount of isolating materials. (WI/DLR 2008)

### 3.3.7 Independence

The overall energy mix of a country may depend largely on the import of fossil fuels. In the light of increasingly scarce oil and gas resources and higher prices on the world market this may lead to higher economic vulnerability. This is also true when fuels such as oil and gas that are also finite cover the overall energy supply. As a result the dimension “independence” comprises the dependency of a country on importing energy resources and the share of domestic depletable fuels as part of the overall energy mix.

#### 3.3.7.1 Fuel import dependency

Most prominently, the discussion on foreign policy implications of energy focuses on the oil dependency of a country that may have a negative influence on its foreign policy objectives. This dependency can be expressed by economic dependency on a specific fuel such as oil (e.g. oil demand out of GDP) and the share of net imports in the respective fuel consumption. In addition, a further dimension can be included with the import vulnerability as a function of import diversity weighted by the political instability of the supplier countries. However, in recent years also increasing gas dependency was discussed in a similar way and also the dependency on coal imports due to increasing prices for coal on the world markets. Compared to these fossil fuels,

renewable energies show only a minor or even no elements of new dependencies. The technologies needed in this regard, however, may require the import of steel for wind turbines or silicon (or rare metals) for solar panels. Due to dynamic trends in this sector this may lead to temporary shortages on the supply side if the resource is not available domestically. With regard to nuclear energy, this argument holds also true, especially for the supply of uranium. Most countries depend to large parts on the import of uranium and are hence vulnerable to developments on the world markets.

### **3.3.7.2 Dependency on depletable fuels**

The dependency of a country's energy mix on depletable fuels such as oil, gas or uranium may limit economic capacities in the medium to long-term. In addition to the dimension of import dependency this may even be true if the resources are available domestically today. Only the diversity of energy sources used in the economic sector can ensure sustainable production processes.

## **3.3.8 Political stability**

Energy consumption is in different ways related to the overall stability of a country or a region. Key elements that can be distinguished are the overall infrastructural security, the potential of the energy source to reduce resource conflicts, its contribution to transnational confidence building as well as its potential military relevance.

### **3.3.8.1 Infrastructure security**

Stable energy supply is a key element of political and economic stability. Since the energy infrastructure may be the target of deliberate attacks by terrorists, the facilities and grid infrastructures are part of the discussion about critical infrastructures and how to protect them (e.g. Farrell et al 2004). Different aspects of the overall energy infrastructure can be characterized by specific vulnerabilities (Tänzler et al. 2007, Pascal 2009). Traditional infrastructures for electricity generation and transmission are often considered to be vulnerable to shocks and disruptions due to the concentrated structure of the overall system and insufficient storage capacity for emergency supply. On the other hand, a more decentralised energy supply offers the chance for a more resilient infrastructure which is less susceptible towards external shocks: In other words, deliberated attacks at the local level will only have limited impacts on the overall political and economic stability of a country or a region whereas the disruption of large-scale facilities are more relevant for the overall stability of the political system.

Hence infrastructure security, political stability and the size of generation units are linked. This proliferates to the level of energy system planning and the question of whether few large or many small units create the more fail-safe environment. In terms of required reserve capacity – an indicator for system stability – Fig. 3-19 shows that many small units are more capable to stabilise a system than a few large units.

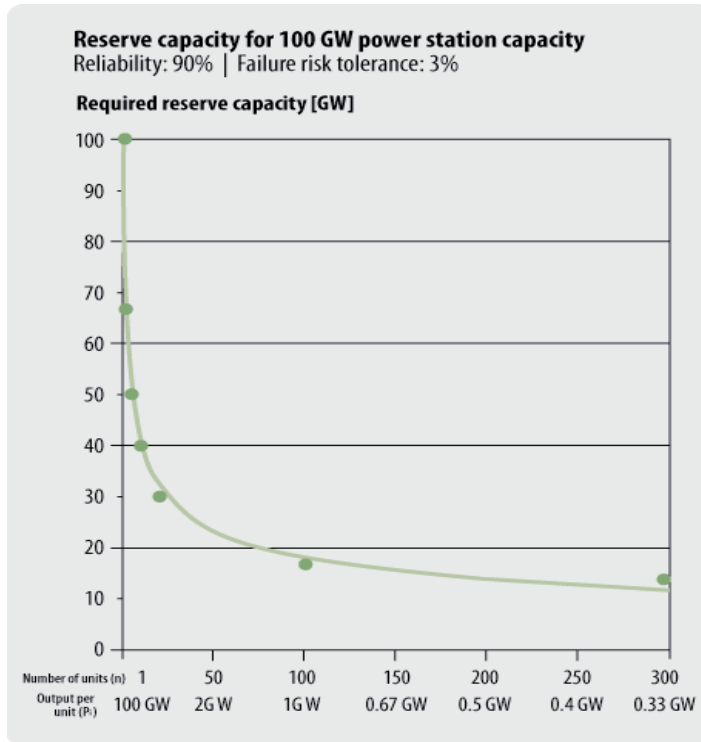


Fig. 3-19. Required reserve capacity as a function of unit output  $P_i$  (assuming identically sized units) for 100 GW generating capacity. Schüwer 1997.

**Nuclear energy.** Especially due to high investment costs to be spent in security technologies (e.g. reactor containment) new nuclear power plants are only economically feasible with high capacity<sup>19</sup>. But large, central plants need high (and thus expensive) backup power (see Fig. 3-19). Without sufficient backup power a blackout of a nuclear power plant would lead to serious energy supply problems. Typical reactor block sizes are about 200 – 1600 MW. The world's largest plant is Kashiwazaki-Kariwa (Japan), which generates 8212 MW in seven reactor blocks.

**Solar thermal power plants** are scalable from some kW to some hundred MW, so the system vulnerability could be held low by installing small and decentralised plants. If electricity should be exported from the MENA region to Europe on a large scale larger plants using collective high-power transmission lines (HVDC) would have to be built. If these transmission lines broke down all affected solar parks would be disconnected from the grid.

**Wind energy.** An electricity system becomes intrinsically more secure by the use of numerous small generators in wind farms (few MW per generator). The attractiveness as a target for terrorist attacks is low. For offshore plants there is a low risk of failure through shipping accidents (WI/DLR 2008). Large wind parks are connected to the grid by a central transmission line, which makes it a “central technology” in some regards and suffer from the same blackout risks as described above.

**Geothermal Energy.** Geothermal energy can per se only be used with small units. Therefore its vulnerability to external disturbances in terms of terrorist attacks and others is very low.

<sup>19</sup> E.g. the EPR reactor in Olkiluoto/Finland has a net output of 1,600 MW<sub>el</sub>.

**Energy Efficiency** intrinsically enhances structural stability. At the same time, the efficiency concept is in many ways not very intricate; “using less” requires only small changes in structures (however, this depends on the degree of efficiency increase).

### 3.3.8.2 Potential to reduce resource conflicts

Current trend extrapolations indicate that global energy dependencies will continue to grow throughout the world, and demand for energy is also set to rise by almost two thirds by 2030, with an average annual growth rate of around 1.7% (IEA 2008). This trend is even more striking given the high level of energy poverty in many regions of the world. One quarter of the world’s population – some 1.6 billion people – currently does not have access to electricity. As a structural factor this may heighten the potential for crises of various forms. About two thirds of the projected growth are attributable to the massive growth in economy and population in developing and newly industrialising countries. Over the medium term, this significant rise in demand for energy cannot be matched by a corresponding growth in fossil energy supply due to e.g. the peaking of oil production.

As a result, resource competition is likely to increase, which may also lead to tensions and civil unrest if no alternative energy sources are used. However, resource scarcity as such rarely results in direct violence (Homer-Dixon 1999, Bächler et al. 1996). Instead, it can become a lasting root cause of conflict, continuously eroding the resilience of societies to resolve conflictive situations in a peaceful way. In the light of this debate it is reasonable to assume that the expansion of the use of alternative energy sources can contribute to minimize the risk of resource-related conflicts and also to strengthen the resilience of societies. However, alternative ways of energy use may also depend on the supply of increasingly scarce resources such as uranium. As a result, those energy sources that show the lowest demand for additional resource input have a higher potential to increase political stability.

**Nuclear Energy.** According to the Nuclear Energy Agency the global uranium resources are sufficient to meet the projected demand of nuclear energy in the future. The amount of conventional uranium resources is estimated to equal about 5.5 million tonnes. In addition, NEA assumes that there are 10.5 million tonnes undiscovered resources (NEA 2008). However, NEA states that there are significant fluctuations in the production in some of the main supply countries such as Canada or Australia. In addition, for the current use in nuclear power plants much highly enriched uranium is taken primarily from dismantled nuclear warheads. Due to the concentration on only a few producer countries, uranium is a resource that may be subject to increased competition.

**Solar energy.** In principle, solar energy is available without limit. Shortages may occur only when it comes to the production of solar technologies. Due to dynamic trends in solar panel production in recent years there have been temporary shortages of silicon on the market. These shortages were mainly caused by the fact that not enough production facilities have been established during recent years. With silicon panels getting more expensive, however, the solar industry has moved to amorphous silicon or semiconductor materials as an alternative. The thin-film market is going to increase in the future thereby offering alternatives for companies in the solar industry. Nevertheless silicon production is predicted to increase in the years to come



since the availability of the resource, in principle, is unlimited. Alternatives to silicon-based technologies could generate shortages of several essential elements (rare metals).

**Wind energy and geothermal energy.** There are no resource shortages known that may limit the use of wind or geothermal energy. The only difficulties wind energy may face concerning supply of resources may occur in meeting dynamic demand for steel for the wind mills. However this is caused by dynamic growth trends in the sector and not by absolute scarcity of steel resources.

**Energy efficiency.** Technologies to improve energy efficiency offer the greatest possibilities to limit resource competition especially with respect to the fossil fuels oil and gas.

### **3.3.8.3 Contribution to transnational confidence building**

Joint transboundary energy projects can provide for confidence building and regional stability. From such a perspective, large-scale energy infrastructures that provide electricity for more than one country are of greater relevance than small-scale decentralised facilities. The establishment of transboundary grid infrastructure can also stabilize regional relations. Such a cooperation of countries may also be the prerequisite to cover the upfront investment costs that are needed. Such strategic cooperation can help to move the question of energy security away from a solely national focus. Regional frameworks of cooperation can provide for information sharing, dialogue facilitation and regional integration. To this end, solar thermal as well as nuclear power plants may be more appropriate than decentralised approaches and may in this concrete perspective compensate for some of the more destabilizing effects outlined above.

### **3.3.8.4 Military harmlessness**

As last element in the realm of political stability the military relevance of an energy source needs to be considered. The rationale here is to assess to what extent the respective energy source can be used to support military and strategic objectives that may also negatively impact the relationship with neighbouring or other countries. Most prominently "dual use technologies" refer to techniques that may not only be used for civil but also for military or related purposes. The very nature of nuclear technology as well as the manufacturing processes associated with it (nuclear reactors, enrichment plants) makes it impossible to ensure only the civil use option. Therefore, international assurance mechanisms are developed to ensure that activities in the nuclear fuel cycle are not used for military purposes. The question of how to balance free access to the peaceful benefits of energy against the mechanisms needed to avoid the military misuse is of no relevance for other energy resources in the focus of this analysis. This potential military capacity of nuclear energy is likely to endanger the political stability and may run against the confidence building function of energy cooperation.

### **3.3.9 Climate policy benefits**

There is a growing recognition of the linkages between climate change and energy security (Carius/Tänzler 2006; Tänzler 2008). Policies and measures that address both issues have the potential to provide significant social and economic benefits. The transformation of traditional energy systems away from fossil fuel use offers significant climate protection benefits. At the same time such measures also offer options to actively engage in international climate change

efforts. Industrialised and developing countries share a common responsibility to avoid dangerous climate change (Art. 2, UNFCCC). States are both able to contribute to respective activities and benefit from climate mitigation policies by improving the sustainable development of their societies. In addition, there are also linkages between adaptation to climate change impacts and different aspects of energy supply.

### **3.3.9.1 Reduction of GHG**

In general, different kinds of renewable energies, increased energy efficiency and also the use of nuclear energy can – compared to the use of fossil fuels – contribute to the reduction of GHG emissions. To assess the specific contribution of each of the options, country-specific framework conditions need to be taken into account. In general, GHG intensity together with sector-specific performance indicators and the respective potentials for the various renewable and non-renewable energies can help to identify the most promising GHG reduction options. However, the availability of these alternative energy choices does very much depend on the economic and ecological costs as already analysed above.

### **3.3.9.2 CDM eligibility**

A current key approach to support climate protection efforts on a global level is the Clean Development Mechanism (CDM) which is the major option for developing countries under the Kyoto Protocol to take an active role in mitigating climate change. Through the joint projects a market is created that provides significant volumes of emission reductions. In May 2009, more than 4000 CDM projects were under validation and registration. In 2007, 551 million tonnes of carbon dioxide equivalents to about 7.5 billion US\$ were managed under the CDM. The average price of a Certified Emission Reduction (CER) was between €10 and €17 (the former amount is paid upfront, the latter on delivery). Hence, the CDM offers, in principal, vast opportunities to engage in international climate change efforts and to support processes towards a transformation of the energy system. There is some reason to believe that as part of the post-2012 framework of global climate policy a sectoral CDM will be the result of the reform of the current CDM structure. Respective projects should have the potential for larger sustainable development benefits and an additional transfer of financial and technological resources. However, with respect to the current project portfolio and plans up to 2012, the following overall relevance of different energy technologies can be summarized as follows.

**Nuclear Energy.** Nuclear energy was excluded by the conference of the parties (COP) as an option to meet the obligation under Art. 3.1 of the Kyoto Protocol back in 2001. Accordingly, it is not regarded as a climate policy benefit from the perspective of the international climate community.

**Solar energy and geothermal energy.** Until June 2009 only a minor share of the CDM projects in the pipeline (28 projects, 1% of the overall number) is focused on the joint implementation of solar energy projects (UNEP Risoe 2009). Most of these projects are small-scale (photovoltaic, solar water heating, solar cooking). Even less geothermal projects are implemented under the CDM (15 projects).

**Wind energy.** Wind energy projects account for a share of 16% of all CDM projects as of June 2009. More than 700 projects are in the pipeline. About one third of the wind energy projects are small-scale (with an overall regional focus on India).

**Biomass and biogas.** CDM projects increasing the use of biomass account for a significant share of 15% of the overall CDM portfolio whereas biogas projects account for 6%. In sum, 645 and 283 projects are currently in the CDM pipeline. A major part of the biomass projects are based on the use of agricultural residues and of bagasse power.

**Energy efficiency.** Through the CDM instrument a number of energy efficiency measures, both on the supply and the demand side, can be supported. Whereas supply side projects account for 10% of the overall project portfolio, 4% can be attributed to demand side projects.

### **3.3.9.3 The linkages between adaptation and energy**

The overall structure of the energy system has several implications when it comes to challenges of adaptation to climate change impacts. As the IPCC outlined in its Fourth Assessment Report the impacts of extreme events on energy supply can be significant (IPCC 2007). In addition to potential damages to gas and oil pipelines caused by permafrost melt especially the changes in water levels for hydro power projects are of importance for many regions throughout the world. Changes in rainfall patterns as well as glacier melting (e.g. in the Andes and in the Himalaya) will clearly impact hydro power capacities in the years to come. Generally, a decentralized energy system is likely to be more robust in coping with such extreme events. A further aspect is that energy is needed to implement some sort of adaptation process. In order to tackle the problem of water scarcity, e.g., some countries have already started to desalinate sea water as an adaptation strategy which, however, demands large amounts of energy.

**Nuclear Energy:** Nuclear power generation has been vulnerable to shortages of cooling water due to heat-waves resulting in high ambient temperatures, like those in the EU in 2003 and 2006, when nuclear power plants had to reduce capacity due to cooling water scarcity and cooling water streams getting too warm (HA 2003, Spiegel 2003). This problem is expected to intensify with the rise in these climate-related events. This may also limit the capacity of nuclear power to be used as a source for desalination.

**Solar energy:** Large scale concentrating solar thermal power is an option for regions with vast solar potential. This energy generating option will hardly be affected negatively by climate change impacts. In addition, the waste heat could be used to desalinate seawater.

**Biomass:** If land is used for planting energy crops this may affect water availability, food supply and forestry cover. As a result, the ability of communities to adapt to the impacts of climate change such as a reduced food supply can be further degraded.

**Small scale PV installations or wind energy facilities** can be negatively affected by climate change impacts such as flooding or storms. However, due to the decentralised character of these facilities the impacts may be limited to single facilities that may be destroyed or damaged. The overall energy system based on small scale installations will not automatically be severely affected.

### 3.4 Results and conclusion

The aspects discussed above are summarised in Tab. 3-4. It can be said that centralised supply options have generally stronger negative effects on the criteria set. As decentralised technologies are “newer” than centralised ones, they bear greater cost reduction potential and will lead to the reduction of overall energy system costs in the future. Decentralised technologies are also less vulnerable. These are just two aspects that need to be taken into consideration when it comes to large-scale utilisation of renewable energies, e.g. via offshore wind farms.

Tab. 3-4. Summary: Effects of different technology options on a set of criteria.

	Nuclear power	Renewables (small and large)	Energy efficiency
<b>Ecosystem stability</b>			
“Harmlessness” of total life-cycle on environment and humans: including production processes and disposal	Very low: large impact, mainly during ore production. Disposal unsolved.	High	Very high
“Harmlessness” of technology on direct environment/ surrounding area and on humans (local effects during operation)	Possibly increased risk of cancer in vicinity of nuclear plants	Depending on technology. In general high to very high	Very high
<b>Micro- and macro-economic benefits</b>			
Job potential and potential for technology R&D for national development (technology multiplication effects)	Low	High	High
Affordable energy supply I: cost reduction potential in mid to long term	No cost reduction potential. Total costs usually higher than planned (e.g. in Finland): cost-relevant delays, strong dependence on discount rates, etc.	Medium to high cost reduction potentials	High cost reduction potentials
Affordable energy supply II: redundancy of subsidies	Direct or hidden subsidies for nuclear power plants worldwide	Currently subsidised	Prod. of techn.: no subsidies. High prices pay back soon
<b>Independence</b>			
Independence from depletable fuels (geological perspective)	Strong dependence, resources concentrated in few countries	Globally very high, nationally/locally sometimes restricted (potentials)	Very high independence
Reducing national dependence on imported fuels (political perspective)	Most countries with nuclear power depend on imports	High	Very high
<b>Technical integratability into existing and growing systems</b>			
Flexibility of operation mode (possibility to make system more flexible)	Zero	Depending on technology	Depending on load curve of saved energy
Rapid temporal availability of technology: short length of planning and build-up period	Very long planning and build-up periods	Large scale: medium/low temporal availability. Small	Very quick implementation possible

		scale: very short	
Constancy/permanence of generation	High (base load only)	High with load management	No negative influence
Possibility to integrate technology into the existing grid	High in large systems	Depending on technology, combination of technologies and shares of RE	Very high
Technological status: market readiness of technology	Ready. Some reactor concepts need high R&D support	Depending on technology	Ready
<b>Political stability</b>			
Potential to reduce conflicts over resources	Low	High. Large hydro: Low reduction potential	Very high potential
Contribution to transnational confidence building	Depending on country		
Infrastructural security (local level): resilience towards shocks (terrorism etc.)	Low: due to import dependence on producers, transport chains. Technical and human failure. Sabotage, terrorist attacks	High, but depending on plant sizes. Import dependence low, possibly dep. on plant producers	High resilience towards shocks
Military harmlessness	Low: dual-use possible	Very harmless	Very harmless
<b>Climate policy benefits</b>			
CDM eligibility	No	Yes	Yes
Adaptation facilitation: Contribution to reduction of water scarcity (including desalination)	No contribution, very high amounts of cooling water needed. Possibly contribution to reduction of scarcity via desalination	Depending on technology	High
Reduction of GHG			

## 4 System Analysis of Algeria

### 4.1 Production and availability of energy resources

#### 4.1.1 Crude oil and natural gas production and reserves

Algeria is an OPEC member with relatively few **crude oil reserves**. BP and OPEC agree with data in the range of 12.3 gigabarrels, which represent 1.3 % of OPEC's total reserves. This share partly contrasted by Algeria's crude oil production share: Producing 1.37 mbpd Algeria contributes well above 4 % to OPEC's total crude oil output (OPEC 2008). According to BP Algeria's total oil production (including crude oil plus condensates and other oil types) amounted to 2.0 mbpd in 2007 (share of total OPEC production: 6 %).

Conclusion I: Algeria is an OPEC member with small oil reserves.

Algeria consumes only a small share of the domestic production (see Fig. 4-1). Refined products demand stood at 0.27 mbpd. The rest was exported either as crude oil (1.25 mbpd) or as refined products (0.45 mbpd).<sup>20</sup>

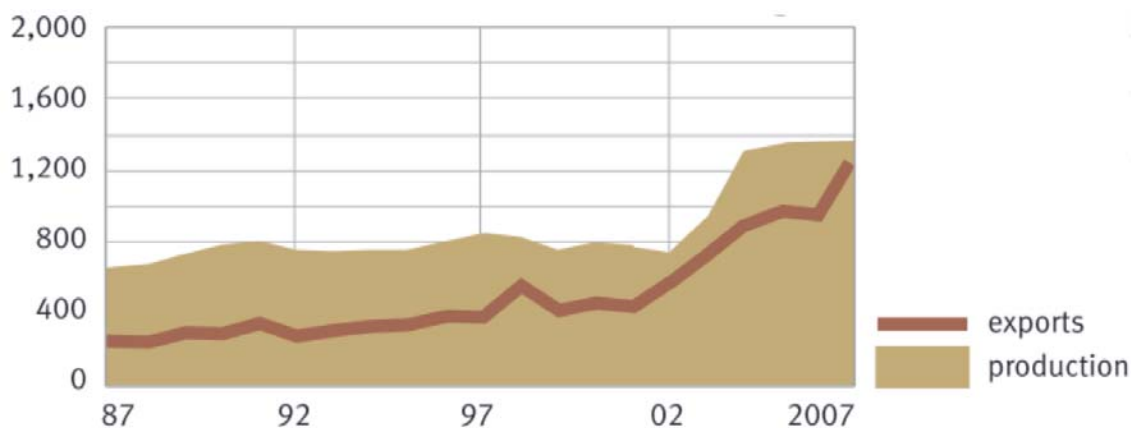


Fig. 4-1. Conventional crude oil production, exports and domestic consumption of DZA. OPEC 2008.

Conclusion II: Algeria is a so-called low-absorber OPEC member, as only a small share of its domestic production is consumed domestically.

Exports of crude oil are rather diversified with North America, Western Europe and Asia taking different shares of the export portfolio (Tab. 4-1).

<sup>20</sup> These OPEC data sum up to a total oil production of  $1.25 + 0.45 + 0.27$  mbpd = 1,97 mbpd. This result is identical to BP's statistics. This allows the statement that about 0.6 mbpd of oil types other than conventional crude (mainly condensates in Algeria) are produced.

Tab. 4-1. Crude oil exports from DZA. OPEC 2008.

<b>Algeria</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>
<b>North America</b>	<b>263.9</b>	<b>354.3</b>	<b>390.4</b>	<b>509.6</b>	<b>738.9</b>
Canada	123.2	127.1	122.1	149.6	166.0
United States	140.6	227.2	268.3	360.1	572.9
<b>Latin America</b>	<b>65.2</b>	<b>85.4</b>	<b>100.6</b>	<b>40.8</b>	<b>48.5</b>
Eastern Europe	0.7	–	2.7	1.0	–
<b>Western Europe</b>	<b>383.4</b>	<b>399.5</b>	<b>435.1</b>	<b>289.9</b>	<b>374.3</b>
Belgium	4.7	–	0.3	0.1	45.2
France	133.6	141.4	15.4	68.1	36.6
Germany	31.3	14.8	55.5	46.9	49.9
Italy	110.8	78.2	62.1	68.0	30.0
Netherlands	5.0	5.0	20.3	1.9	31.1
Spain	32.0	53.6	56.3	68.7	68.1
United Kingdom	33.7	32.6	38.1	32.2	43.4
<b>Middle East</b>	<b>–</b>	<b>8.6</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>Africa</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>–</b>
<b>Asia and Pacific</b>	<b>28.0</b>	<b>45.4</b>	<b>41.5</b>	<b>20.9</b>	<b>37.8</b>
<b>Unspecified</b>	<b>–</b>	<b>–</b>	<b>–</b>	<b>85.1</b>	<b>54.1</b>
<b>Total world</b>	<b>741.0</b>	<b>893.2</b>	<b>970.3</b>	<b>947.2</b>	<b>1,253.5</b>

Algeria is the third largest natural gas supplier to the European Union. Seen from an OPEC perspective, DZA is a major gas producer, contributing more than 15 % to OPEC gas production (marketed production). This stands in strong contrast to the share of natural gas reserves, which are only 5 % of OPEC's total (4.5 trillion m<sup>3</sup> vs. 91 tn m<sup>3</sup>). Domestic demand was roughly 26 bn m<sup>3</sup> in 2007 (OPEC 2008), the remainder was exported via pipeline or as LNG to Spain and Italy.

#### 4.1.2 Coal and uranium sources

Coal reserves are negligible in Algeria from a global point of view, and even put into national perspective domestic endowment is small (0.01 %, BGR 2007). This is valid for coal resources as well.

Algeria has no uranium ore reserves, total uranium resources are estimated 20 kt by the Nuclear Energy Agency (NEA 2008). The International Atomic Energy Agency estimates Reasonably Assured Resources<sup>21</sup> to 52000 tons uranium (IAEA 2008).

#### 4.1.3 Renewables potentials

The German Aerospace Center DLR conducted three in-depth studies presenting the renewable energy potentials of North Africa and the Persian Gulf region. These data were mainly calculated from satellite imaging. Tab. 4-2 summarises wind, solar, geothermal and biomass potentials for electricity generation. Especially solar thermal potentials are concentrating on large-scale generation units (solar thermal power plants that require large flat areas). Additionally

<sup>21</sup> Reasonably Assured uranium Resources refers to uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities that could be recovered within the given production cost ranges with currently proven mining and processing technology can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of project characteristics. Reasonably Assured Resources at prevailing market prices are commonly defined as "Reserves". See UNECE (2004).

there are potentials for the use of solar radiation on small scale, which could mainly cover de-centralised heat demand.

Tab. 4-2. Economic electricity supply side potential of renewable energies in Algeria, TWh/a. DLR 2005.

Algeria	CSP	Wind-power	PV	Hydro-power	Geothermal	Biomass	Power production 2005
Economic potential	168,972	35	13.9	0.5	4.7	12.1	35 TWh
Performance indicators	DNI: 2700 kWh/m <sup>2</sup> /a	1,789 full load hours per year (FLH)	Horizontal irradiance: 1970 kWh/m <sup>2</sup> /a	Full load hours per year: 1000	Temperature at 5000 m depth: 213°C	FLH: 3500	

CSP: from direct normal insolation (DNI) and CSP site mapping taking sites with DNI > 2000 kWh/m<sup>2</sup>/a as economic. Wind: wind speed and site mapping, sites with yield > 14 GWh/y and from literature. PV: general growth rates used for calculation. Hydropower: from literature. Geothermal: depth 5000 m, > 180°C taken as economic. Biomass: agricultural and municipal waste, solid biomass.

Algeria’s *Ministry of Energy and Mines* (MoEM) had renewable energy potentials evaluated on its own territories and states that “the biggest potential in Algeria is solar” (MoEM 2007). Especially in the Sahara region the potential is very high (see Tab. 4-3).

Tab. 4-3. Data on solar irradiation in Algeria. MoEM 2007.

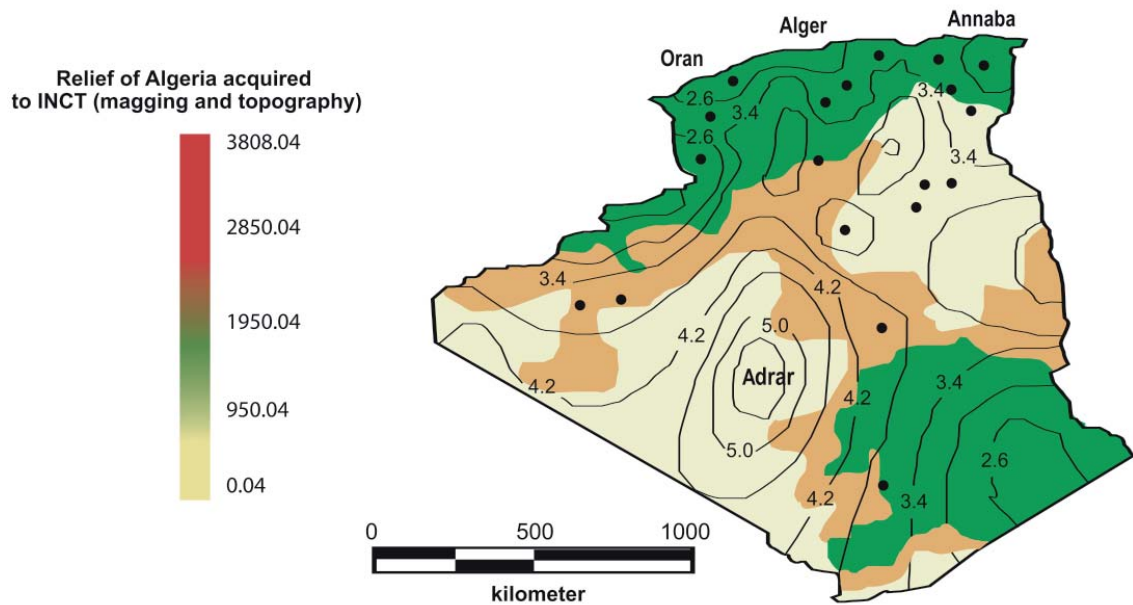
Region	Coastal	Highlands	Sahara
Country area	4	10	86
Average sun hours per year	2650	3000	3500
Average energy received, kWh/m <sup>2</sup> /a	1700	1900	2650

World Energy Council published different data, but they stay in the same range: Annual average insolation is rated at 2000 hours with the high plateaus receiving about 3900 hours. This gives average solar energy of 2400 kWh/m<sup>2</sup>/a (WEC 2007).

The *Center for the Development of Renewable Energies* (CDER) surveyed different types of renewable energies. Data are gathered in the Guidelines to Renewable Energies report by the Ministry of Energy and Mines (MoEM 2007). National wind energy potential onshore is rated as being low, although the Algerian coastline measures 1200 km (MoEM 2007). However, according to an analysis comparing wind data from 75 locations in Algeria published already in 2000, there are a number of promising sites for wind power. They are located in the region of Adrar in the south, Oran in the northwest, the region extending from Meghress to Biskra in the east and the region extending from El Kheiter to Tiaret in the west (Hamane/Khellaf 2000).

For wind map see Fig. 4-2. Offshore data were not available.





**Medium speed plot at 10 m of the ground**

Fig. 4-2. Wind map of Algeria showing only low onshore potential. CDER, taken from MoEM 2007.

Geothermal energy utilisation has to be strongly differentiated. With a multitude of hot springs, Algeria has large potential for low-temperature geothermal applications. In terms of power production geothermal potential is in the range of 700 MW (MoEM 2007).

General data on plant and animal stock are available but were not used to calculate feasible biomass potential. Hydropower potential was not evaluated either.

Conclusion on renewable energy potentials: Solar irradiation is available in amounts that exceed energy demand by several orders of magnitude, whereas other renewable potentials are rather limited.

**4.2 Domestic energy demand: History and present**

Algeria’s total primary energy supply (TPES) is dominated by natural gas and crude oil (see Fig. 4-3). In 2005, natural gas covered about 66% (22.9 Mtoe) of the national TPES; crude oil and petroleum-based products (excluding exported petroleum products) represented approximately 32% (11 Mtoe). Despite significant quantitative renewable potentials, especially arising from high sunshine levels, the share of energy from renewable sources in the Algerian energy balance merely was 0.4% (0.1 Mtoe). Of this percentage, hydroenergy contributed 0.1% (48 Ktoe) and combustible renewables and waste about 0.3% (76 ktoe) (IEA 2007).

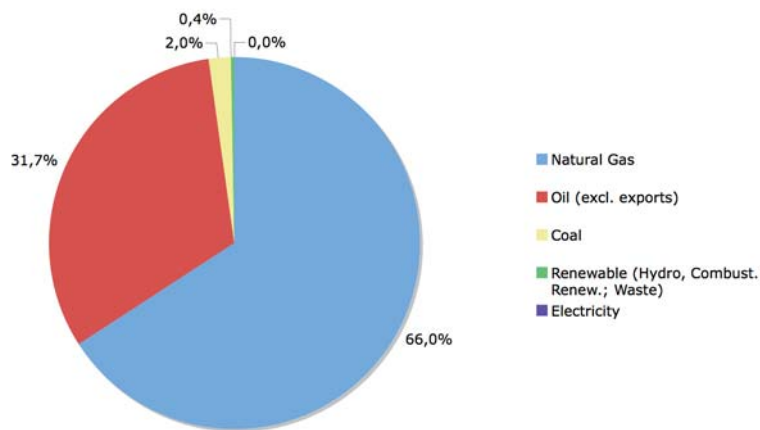


Fig. 4-3. Algerian total primary energy supply, 2005. IEA 2005.

Algerian power production reached nearly 35 TWh in 2005 and is almost exclusively based on natural gas. Oil-fired power plants (2-3%) and hydropower (less than 1%) made marginal contributions (IEA 2009). Implemented renewable energy projects for power generation include (UNEP 2007):

- Installation of 500 kW photovoltaic (PV) power generating capacity for the electrification of 16 isolated villages
- Construction of a 150 MW integrated solar combined cycle (ISCC) hybrid CSP of which is fuelled with solar energy (30 MW) and natural gas (120 MW)
- Installation of 10 MW wind power capacity

In addition to renewable energy technologies for power generation, 1000 m<sup>2</sup> of solar collectors for water heating were installed in various parts of the country.

### 4.3 Energy intensity and energy efficiency potentials

Total primary energy demand in Algeria amounted to 33 Mtoe in 2003 (IEA 2005). Between 1990 and 2003, demand increased by approximately 2.5% per year. Until 2030, the International Energy Agency expects primary energy demand to grow at a similar pace, reaching 43 Mtoe in 2010 and 70 Mtoe in 2030 (IEA 2005, see Fig. 4-4). The Algerian Agency for Promotion and Rationalisation of the Use of Energy (APRUE) expects that national energy consumption will increase by 81% between 2003 and 2020 or an annual growth rate of about 3.5% in case of a “laissez-faire” scenario. The demand for electricity will be particularly high due to accelerating urbanisation, an increasing standard of living and a significant development of the service sector (Rafik 2006).

The development of Algerian primary energy intensity is widely in line with the national GDP. In 2006, it was estimated at 0.14-0.18 koe/\$ 95 at purchasing power parities (WEC 2008a). Between 1990 and 2006, only slight reductions of energy intensity, in the range of 0.3-0.4%, were achieved. Contrary, at world level, the amount of energy used per unit GDP decreased by 1.6% per year on average (WEC 2008a).

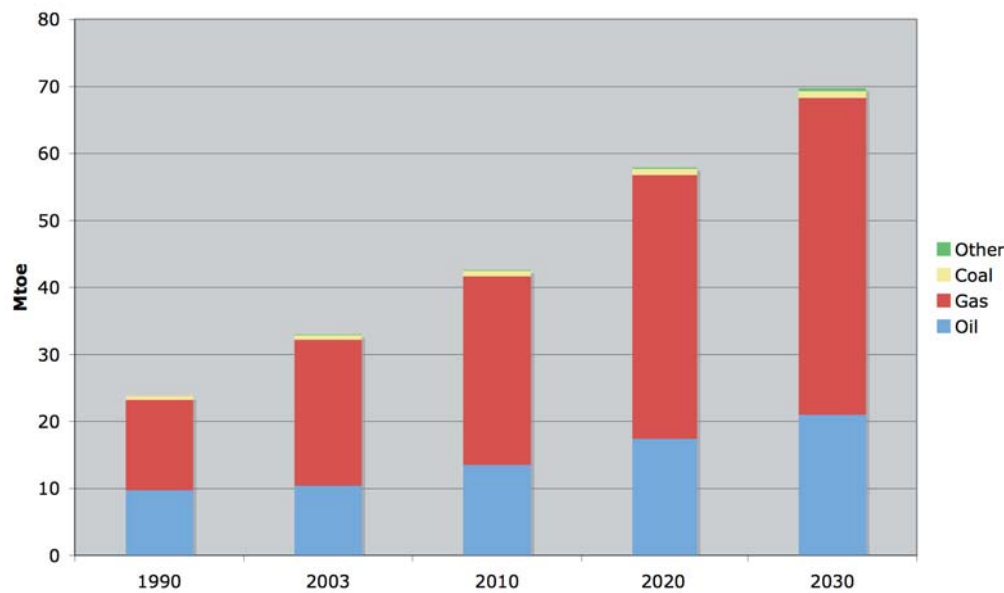


Fig. 4-4. Algerian Total Primary Energy Demand, 1990-2030. IEA 2005.

The rather minor reductions of Algeria's energy intensity are mainly due to an expansion of the export-oriented and highly carbon-intensive hydrocarbon sector (IEA 2005). Furthermore, the efficiency of energy conversion is very low compared to standards in industrialised countries. For example, generating efficiency of the Algerian power sector was below 30% in 2006, whereas the world average was 34%. In the European Union, average power generating efficiency even reached 40% (WEC 2008a). Consequently, there is a lot of leeway for energy efficiency improvements on the supply side.

However, in most emerging countries and regions, the demand side implies the highest potential for reducing energy intensity. Several studies have shown that Algeria's residential and service sector constitute the highest potential for energy efficiency improvements. In the Algiers area, the annual energy consumption of housing is 632 MJ/m<sup>2</sup> with heating constituting the largest share (46%), followed by cooking (22%), hot water (13%) and other electric appliances (19%) (Rafik 2006)

There is significant leeway to reduce residential energy consumption in Algeria, e.g. by substituting traditional fuels with modern and more efficient fuels (WEC 2008a) and by using more efficient electrical appliances. For example, in 2002, the Algerian market for refrigerators was dominated by models, which would be classified under the categories C, B and G in the European labelling system (see Fig. 4-5). High-efficiency models represented only a minor share of the total (Bouzeriba et al 2002).

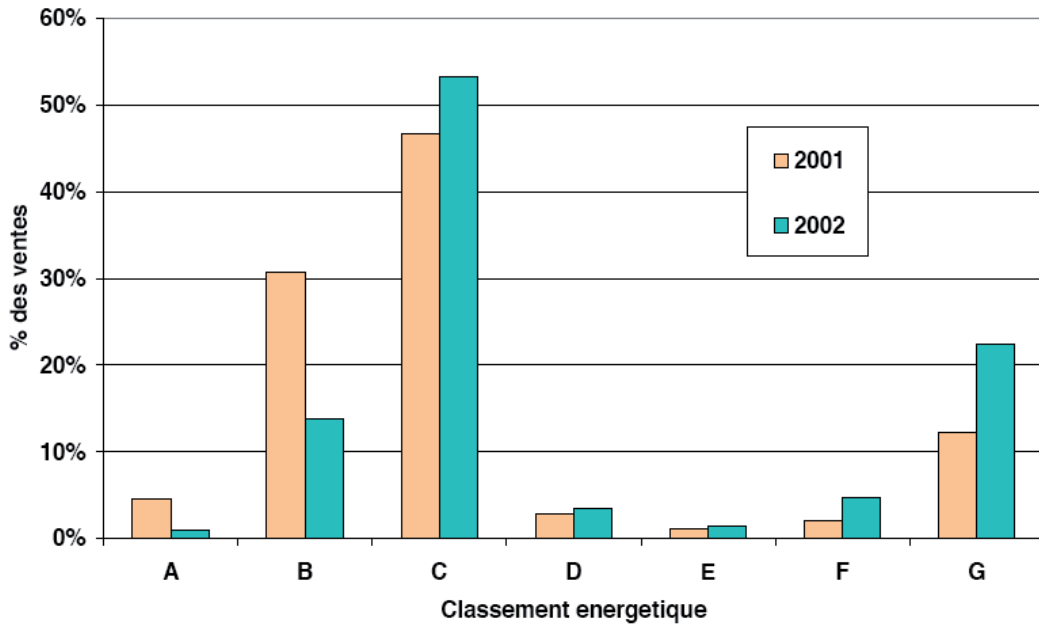


Fig. 4-5. Percentage of Sales of Refrigerators and Freezers in Algeria in 2001 and 2002 by Energy Label Class According to the European Labelling System. Bouzeriba et al 2002.

Tab. 4-4 confirms the impression that the Algerian market for energy efficient products in the residential sector is at an early stage of development. It lists products related to energy efficiency and indicates the degree of maturity of the market for each product.

Tab. 4-4. Maturity of markets for energy efficiency products in Algeria’s residential sector. Rafik 2006.

Product <i>Level of maturity: (1) new; (5) mature</i>	Building type	
	New	Existing
Double glazing	2	1
Roof insulation (cork polystyrene)	2	2
Wall insulation (polystyrene)	1	1
Insulation (mineral wool)	1	1
Efficient lighting	1	1
Efficient energy equipment	1	1
Photovoltaic systems	1	1
Solar water heater	1	1

## 4.4 Energy policy in DZA

### 4.4.1 Nuclear energy policy<sup>22</sup>

Nuclear policy has been practiced on Algerian territory before the inception of the independent Algerian state: on February 13, 1960, France began to conduct a series of nuclear weapons test in the desert hamlets of Reggane and In Ecker. France's last nuclear test was conducted on February 16, 1966.

With its considerable civil nuclear research activity and some uranium deposits, Algeria currently owns one of the most advanced nuclear energy complexes in the MENA region. Algeria's nuclear energy research is mainly conducted by two institutions, the Centre des Sciences et de la Technologie Nucléaire (created in 1976) and four regional centres under the auspices of the Commissariat pour l'Energie Atomique (COMENA); an agency created in 1996 that itself reports to the Presidential Palace directly.

Algeria is a member of the IAEA since 1963. The government studied the possibility of nuclear power generation since 1974. A full-fledged nuclear energy programme that was mainly designed to save its own fossil fuel reserves for export into the world market was consecutively launched in 1981. Since the late 1980s, its programme consists of four facilities on two sites: the Nur (Arabic: "light") research reactor and a fuel-fabrication plant at the Draria nuclear complex 20km east of Algiers. Notably, the former 1MWt light-water reactor that went critical in 1989 has not been a turnkey operation. The Algerian government made sure that numerous Algerian engineers were involved in the project run by an Argentinean firm thus guaranteeing a considerable knowledge and technology transfer towards the Algerian national nuclear programme itself.

The second major nuclear site of the country is the Es Salam (Arabic "Peace") research reactor in Ain Oussera 140 km south of Algiers. The 15 MWt heavy-water reactor that had been built by a Chinese contractor on the grounds of an Algerian-Chinese nuclear cooperation treaty from the 1980s is owned by the Ministry of Science Higher and Education. It went critical in 1992. Further, the Ain Oussera site hosts numerous other nuclear research facilities, e.g. an isotope-production plant, a hot-cell laboratory etc. Even though the Algerian government ratified the Non-Proliferation Protocol in 1991 and agreed on IAEA-control of these facilities following international pressure in the early 1990s, critics continue to view Algeria's nuclear activity as a danger for nuclear proliferation in the region. It seems, however, more likely that the country's elites do not have a direct interest in developing a nuclear weapon itself but rather to possess the potential for a nuclear weapons production in order to safeguard its regional position and as an icon of national prestige towards its own population.

In the recent past, Algeria has taken new steps towards a larger nuclear energy option. In his opening address to the 2007 African Union (AU) conference on nuclear energy President Bouteflika strongly supported Iran's plans for a civil use of nuclear energy accusing the incum-

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<sup>22</sup> This chapter is informed by the highly valuable publication IISS (2008), Nuclear Programmes in the Middle East. In the shadow of Iran, 107-112.

bent nuclear regime of structural unfairness and denial of support of the nuclear option for emerging powers (IISS 2008). More substantially, the government attempts to position itself as the key (North) African nuclear energy force; a desire also mirrored by its permanent hosting of the African Union's (AU) Energy Commission in Algiers<sup>23</sup>. On the national level, COMENA announced heightened efforts in nuclear energy while the country's Minister of Energy and Mining, Chakib Khelil, confirmed the launch of a major nuclear energy scheme for his country in 2006. Regarding international technological cooperation, Algeria seems to opt for a multiplicity of options. Next to its December 2007 cooperative nuclear energy framework agreement with former colonizing power France, it entertains nuclear research and business relations with South Korea, Iran, Russia and the United States while an interest in exchange with its AU partners South Africa and Egypt has been expressed (ARB 2008, Pinkston 2006, Reuters 2007).

Summing up the security concerns, even though it is unlikely that Algeria in fact seeks to develop nuclear arms, this potential demonstrably exists in the Ain Oussera complex: Pakistan, running a nuclear reactor of the same type, has developed weapon-grade plutonium from it. It can be regarded as definite, however, that Algeria will attempt to develop nuclear electricity generation for the domestic (and potentially foreign) market.

#### **4.4.2 Renewable energy policy**

The Algerian government has clearly expressed its political will to further increase the share of renewable energy in power generation. According to the Minister of Energy and Mines, the government recognises the „beneficial effects of these (renewable) energies on the economic development of our country“ (Khelil 2004). The government has adopted an ambitious target for the development of renewable energy in the power sector. Until 2015, renewable energies (and co-generation) shall provide 6% of the country's power mix (MoEM 2007). The implementation of large-sale hybrid projects based on domestic natural gas and solar energy is a key element of Algeria's renewable energy strategy. Hybrid plants shall not only contribute to Algerian electricity supply but also export electricity to Europe. Under the global market initiative, Algeria envisages to install 1000 MW of hybrid power capacities (Khelil 2004).

In order to achieve its targets, the government has established a framework of policies and programmes for the promotion and development of renewable energies. The following section provides an overview of the Algerian legislative framework for renewable energy.

*Law on Electricity and Gas Distribution, February 2002; Decree on the Diversification of Power Generating Costs (“Décret exécutif aux coûts de diversification de la production d'électricité“), March 2004*

The Law on Electricity and Gas Distribution regulates the liberalisation of the Algerian power sector and includes the objective to produce energy in an environmentally benign way. It provides incentives for the generation of power from renewable energy sources and its integration into the power network. Among the incentives mentioned in the law are preferential power tariffs as well as premiums and tax reductions to induce the deployment of renewable energy technologies.

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23 « Un nouvel essor pour le nucléaire en Algérie », La Nouvelle République, 8.3.2005.

In March 2004, the outlined incentives were specified through a Decree on the Diversification of Power Generating Costs, which introduced feed-in tariffs for power from renewable sources. Renewable energies covered by the decree include hydropower, wind power, geothermal power, solar power and electricity from waste utilisation. As the Algerian government considers the combined utilisation of solar energy and natural gas the most efficient way to make use of renewable energy (Khelil 2004), the decree creates specific feed-in tariffs for ISCC power plants.

The feed-in tariffs are based on the regular rates for electricity, which are set by the Electricity and Gas Regulatory Commission (CREG). Feed-in tariffs for ISCC plants differ by the share of solar energy fed to the plant (see Tab. 4-5). In November 2008, Algerian electricity rates for residential use ranged from 0.023-0.054 €/kWh. Compared to other countries in the Middle East and North Africa, Algeria's electricity rates are rather low. For example, Morocco's electricity rates for residential use in the same month were 0.081-0.130 €/kWh (GTZ 2008). The low level of Algerian electricity prices can be partly explained by the fact that the country's power demand is nearly fully covered with domestic natural gas, which is supplied by a state-owned company. It is furthermore likely that electricity rates are affected by subsidies although no data on the amount of subsidies are available. Shortly after Algeria's independence, energy subsidies were motivated by the new leadership's aim to ensure affordable energy in order to launch the process of industrialisation of the country and to contribute to a better social life. However, the current Algerian government intends to gradually adjust national energy tariffs to real prices (Zidane 2006).

Tab. 4-5. Feed-In Tariffs for ISCC Power Plants in Algeria. MoEM 2004.

Share of Solar Energy	Feed-In Tariffs (% of Normal Electricity Rate)
0-5%	0%
5-10%	100%
10-15%	140%
15-20%	160%
20-25%	180%
25%+	200%

In ISCC systems, solar energy supplements a gas-fired combined cycle process and reduces the required fossil fuel. As mentioned in section 2.3.5, the realisation of a 150 MW<sub>e</sub> ISCC plant is among Algeria's most important renewable energy projects. The plant is currently under construction and will be located at Hassi-R'mel - Algeria's largest gas field. 30 MW of its power generating capacity will be produced from solar troughs. Abengoa, an international company, which operates renewable energy plants, and New Energy Algeria (NEAL) will operate the plant. Sonatrach will purchase the produced energy. NEAL was formed in 2002 as a joint venture of Sonatrach (45% of shares) and Sonelgaz (45% of shares) - two state corporations - and SIM (10% of shares), which is a private Algerian company (U.S.-Algeria Business Council 2006). Sonatrach is Algeria's leading gas company and Sonelgaz dominates the national power sector. NEAL's task is to foster the development of energy from solar (solar thermal plants and photovoltaic installations), wind, and biomass. This target shall be achieved by identifying and

realising projects related to renewable energies, elaborating and implementing development strategies and organising industrial and commercial activities (Ainouche 2006).

The generation of electricity based on 100% renewable energy is induced by source-specific feed-in tariffs. Wind power receives the highest premium, up to 300% of the regular electricity rate. Tab. 4-6 lists the feed-in tariffs for renewables by energy source. Besides power generation from renewable sources, the decree includes feed-in tariffs for power from co-generation units.

Tab. 4-6. Feed-In Tariffs for 100% Renewable-Based Electricity in Algeria. MoEM 2004.

Source of Energy	Feed-In Tariffs (% of Normal Electricity Rate)
Wind	300%
Solar	300%
Waste	200%
Hydro	100%

*Law on Renewable Energy (“Loi relative à la promotion des énergies renouvelables dans le cadre du développement durable“), August 2004*

The law establishes a National Programme for the Promotion of Renewable Energy, which shall last until 2020. The programme includes a multi-annual evaluation of the use of renewable energies compared to fossil fuels and introduces several measures to inform and educate the public about renewable energy. It is integrated into a framework for sustainable development and land-use planning and comprises mechanisms for the economic assessment of energy technologies. These mechanisms encompass, among others, environmental criteria. Furthermore, the law establishes a certification system for power generating sources and installs a legal setting for green certificates, certified emission reductions and research and development initiatives (UNEP 2007).

The described legislative framework suggests that Algeria’s renewable energy policy is very advanced compared to other developing countries. The government has translated international examples of best practice (e.g. the German feed-in law for power from renewable energy sources) into the Algerian policy framework in order to promote power generation based on renewable energy. However, so far, the implementation of the adopted regulations is inadequate, which is why it remains to be seen if the regulations can significantly increase the share of renewable energies in Algeria’s energy supply.

#### **4.4.3 Other relevant policies: Energy efficiency**

*Energy Efficiency Law (“Loi relative à la Maîtrise de l’Energie“), July 1999*

Besides improvements of energy efficiency (see sect. 4.3), the regulation shall foster the development of renewable energies. Sources of renewable energy covered by this legislation include solar energy, geothermal energy, biomass, hydropower, and wind power. Renewable energies shall contribute to the law’s aim to preserve non-renewable energy sources and protect the environment. It shall promote the development and commercialisation of new energy technologies



and, by doing so, enhance national energy security. Renewable energy projects are covered by a newly established National Energy Management Fund, which finances projects on renewable energy and energy efficiency and functions as a catalyst for actions and programmes. Renewable energy projects within the fund focus on tertiary and residential sectors (MoEM 2007).

Low efficiency rates in energy production and consumption indicate that there is substantial scope for improving Algeria's energy efficiency. By doing so, the country's domestic demand of natural gas could be reduced, making additional volumes of gas available for exports. The Algerian government seems to recognise the necessity of reducing energy demand and has established a policy framework to improve energy efficiency. In the following, the most important cornerstones of the Algerian energy efficiency policy setting are briefly discussed. Tab. 4-7 presents an overview of existing policies. As mentioned above, in 1999, the government adopted an Energy Efficiency Law ("*Loi relative à la Maîtrise de l'Energie*"), which defines a framework for the reduction and management of energy demand. The law declares energy efficiency to be an activity of public interest and encompasses the following components:

- Establishment of a national energy agency for energy efficiency;
- Introduction of energy efficiency standards;
- Introduction of a national programme for energy efficiency;
- Establishment of a national energy management fund;
- Mandatory labelling of every new or used electric appliance to be sold on the national territory;
- Monitoring of energy efficiency;
- Introduction of mandatory energy audits;
- Support of R&D activities for energy efficiency improvements;
- Incentives for energy efficiency improvements;
- Measures to improve public awareness of the necessity to reduce energy consumption.

Tab. 4-7. Overview of Algerian energy efficiency policies. WEC 2008b.

Measure	Details/Requirements/Targets
Establishment of a National Energy Efficiency Agency	APRUE (Algerian Agency for the Promotion and Rationalisation of Energy Use); budget (2005): \$ 0.83 mill., 47 employees
National Programme for Energy Efficiency, 2006-2010	2006-2010: 1 Mtoe saving, 2006-2010: 2 million tonnes CO <sub>2</sub> savings
Energy efficiency standards for new buildings and dwellings	30-40% savings
Energy efficiency standards and labels for household electrical appliances	Under development
Mandatory energy audits	Tertiary sector: Consumers concerned: > 500 toe

	Industry: Consumers concerned: > 2000 toe Transport: Consumers >1000 toe
Energy efficiency incentives for passenger transport	Motor fuels tax for gasoline and diesel distinguishes different energy classes
National Energy Efficiency Fund	"Fonds National de Maîtrise de l'Energie" <i>National Energy Management Fund</i> Budget (2005): \$ 34 mill.

The National Programme for Energy Efficiency aims to achieve energy savings of 1 Mtoe in the period from 2006-2010 and mitigate 2 million tonnes of CO<sub>2</sub>. One of the first actions of the programme was the distribution of a million low consumption lamps (LCL). This operation shall result in the reduction of approximately 7% of household energy consumption (Zidane 2006). The programme is sponsored by the National Energy Management Fund ("*Fonds National de Maîtrise de l'Energie*"), which also supports renewable energy technologies. In 2005, the Fund's budget totalled \$ 34 million (WEC 2008b), with taxes on energy consumption, specific subsidies and incomes from fees being the most important sources of funding. Projects of the fund are overseen by APRUE.

Policies outlined in the Energy Efficiency Law and the National Programme for Energy Efficiency are specified in executive decrees. The decrees are implemented by the Algerian National Agency for the Promotion and Rationalisation of Energy Use (APRUE), which has a budget of approximately \$ 830000 (2005) and employs 47 people (WEC 2008b).

Energy efficiency standards for new buildings and dwellings as well as standards for household electrical appliances and mandatory audits are prominent steps to comply with the goals of the Algerian energy efficiency programme. Energy demand of new dwellings and buildings is required to be reduced by 30-40%. The set of standards includes technical standards of insulation window tightness, isolation quality of materials as well as heating and cooling devices. However, during five years, which correspond to a transition period, the application of the codes will not be compulsory for individual houses (Zidane 2006).

The described building codes are supplemented by two national codes called DTR. They were developed by the National Centre of Integrated Research in Buildings under authority of the Housing Ministry and approved in 1997 or 1998 respectively. The first code, titled "Thermal control in residential buildings – Calculation rules of heat losses", defines the calculation methods of heat losses under winter conditions and the standards the building envelopes have to comply with. The second standard defines the calculation rules of heat gains in buildings for cooling purposes. However, so far, the implementation of both codes is poor and contributes to a low development of insulation in Algeria's construction industry (Rafik 2006).

Efficiency of electrical appliances for households shall be covered by a new labelling scheme. A draft executive decree has specified certain issues of a future labelling scheme, such as the control of energy efficiency and rules for imported appliances, both new and used ones. The draft decree also determines that the energy performance requirements for household appliances will

be set by government orders and that the label system shall include categories comparable to those of existing label systems (e.g. to the European system) (Bouzeriba et al 2002).

In 2005, a decree defined three sectors – industry, services and transport – which are obligated to conduct mandatory energy audits. The threshold for participation is fixed at a minimum energy demand of 2000 toe for industrial companies, 500 toe for tertiary sector companies and 1000 toe for transport companies. In order to facilitate the enforcement of audits, the system is framed by accompanying measures, such as the development of a databank with benchmarking data and training of auditors. Nevertheless, the audit process seems to advance slowly and information on the outcome of audits is hardly available (WEC 2008c).

Besides the aforementioned efficiency standards and the audit system, energy efficiency improvements in the transport sector are pursued through a motor fuels taxation scheme, which distinguishes different energy efficiency classes (WEC 2008b). Nonetheless, the Algerian fuel pricing system does not create incentives for energy savings, since the purchase of gasoline and diesel is heavily subsidised. As a result, Algerian motor fuel prices are very low in comparison to international standards (see Fig. 4-6) and even most other African countries (GTZ 2007). In November 2006, Algerian retail prices of gasoline and diesel were \$-Ct. 19/litre and \$-Ct 32/litre respectively, whereas European retail fuel prices were near (diesel) or beyond (gasoline) \$-Ct. 120/litre (GTZ 2007). Therefore, it may be concluded that measures aiming at energy efficiency improvements in the transport sector are, at least partly, offset by subsidised retail prices for motor fuels.

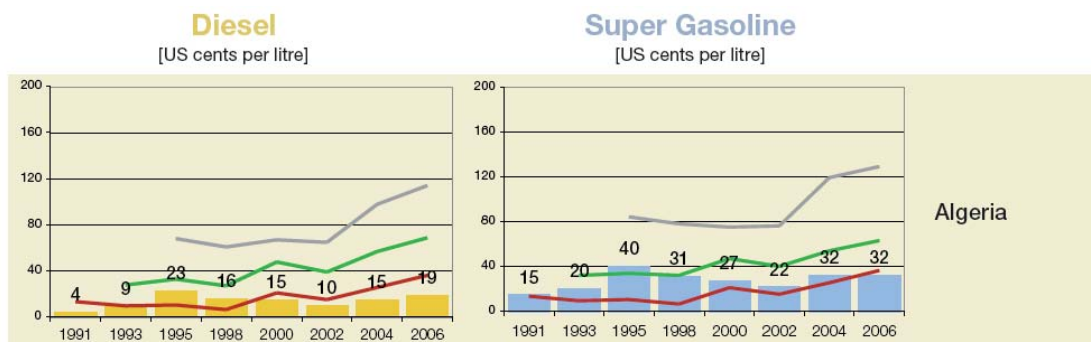


Fig. 4-6. Fuel Retail Prices in Algeria, 1991-2006. GTZ 2007.

Grey benchmark line: Retail fuel prices of Luxembourg = Orientation level in European Union; green benchmark line: Retail fuel prices in the United States; red benchmark line: crude oil prices on world market („Brent“ at Rotterdam).

## 4.5 Future development of the Algerian energy system

This section describes possible development paths of the Algerian energy system in terms of crude oil production, natural gas production and capacity demand for electricity generation. These scenarios set a frame for the analysis of the total energy system in terms of the criteria defined in sections 2.

### 4.5.1 Crude oil production and consumption scenarios

According to different sources of Association for the Study of Peak Oil and Gas (ASPO 2005-2009) crude oil production will reach its maximum in many countries, the same holds true for

Algeria. In combination with up-to-date data on production an early peak oil was modelled including production on a plateau and subsequent decline at one % per year (beginning in 2011). This has to be seen as “not so good case development” / “bad case” in contrast to optimistic statements on production dynamics. Rationale for this is that 1) production profile of Algeria shows a flat phase in previous years despite the fact that global demand was very high, oil prices the like; 2) Such a “bad case” assumption pays tribute to the fact that mid- and long-term system planning and decision making should include *precautionary principle* aspects: If there are insecurities in the data base, there should always be safe-guarding measures in case that resources can’t be produced as optimistically as assumed.

This production profile sets the frame for crude oil supply. On demand side two scenarios were modelled: High Consumption and Low Consumption.

**Assumption for High Consumption.** Consumption of crude oil (i.e. crude oil products) increases from 2008-2020 by 5 % annually. This is a medium value of the data from 2001 to 2007. From 2021 consumption was set to increase by 3 % per year. This overall trend shows a typical behaviour of countries: Consumption increases slow down during economic development. In High Consumption Algeria becomes a net importer of crude oil shortly after 2050 (see Fig. 4-7 on this trend).

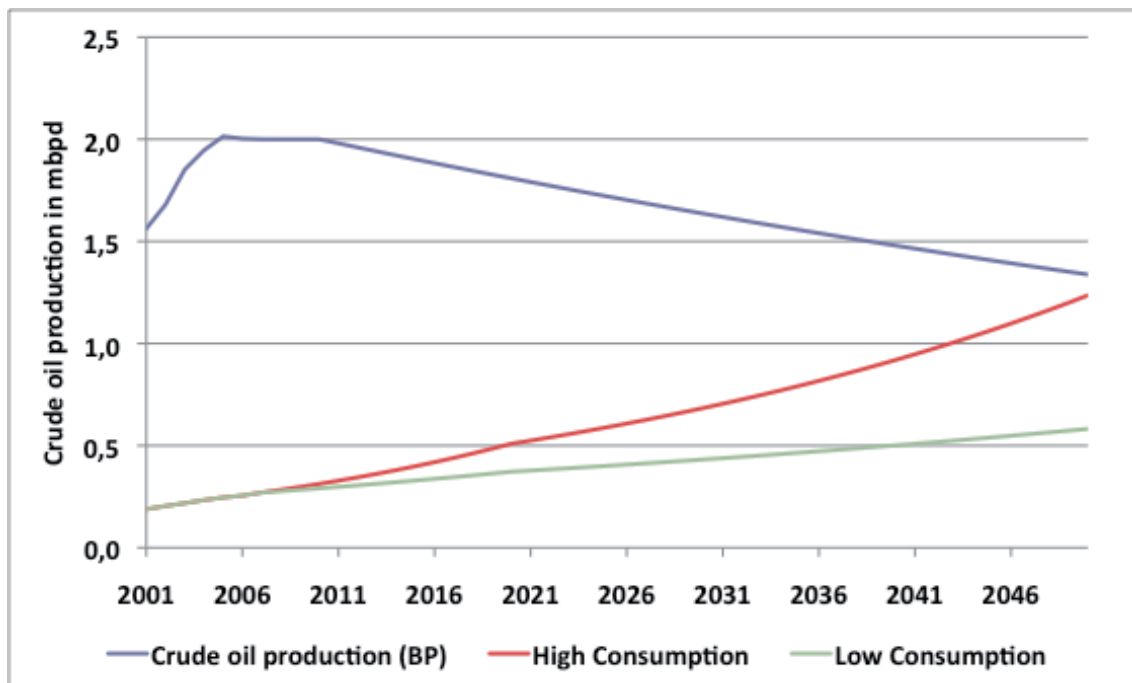


Fig. 4-7. Crude oil production and consumption, scenario High Consumption and Low Consumption, Algeria. Own calculations.

**Assumption for Low Consumption.** Consumption grows half as quick as in High Consumption: by 2.5 % annually from 2008 to 2020 and by 1.5 % from 2021 onwards. In this scenario Algeria will be able to retain its status as crude oil exporter for many decades to come.

#### 4.5.2 Natural gas production and consumption

Long-term scenarios for natural gas production pose a great challenge in terms of assumptions, as there are only few data available and the dynamics of gas production depend on a multitude of different factors. However, some basic assumptions were made to give a broad description of possible development paths.

**Assumptions for natural gas production.** Production in Algeria can be increased significantly in the coming years but after a production plateau it will decrease quickly (usually much quicker than crude oil production). Currently Algeria exports the major part of its production. If consumption increases comparably to historic data, Algeria will lose its status as natural gas exporter in 2036 (assuming consumption increase: 5% pa from 2008 to 2020, 2.5% pa from 2021 onwards). Higher levels of energy efficiency in the Algerian economy (increase of consumption: 2.5% pa from 2008 to 2020, 1% pa from 2021 onwards) will shift this date about ten years. For a display of these developments see Fig. 4-8.

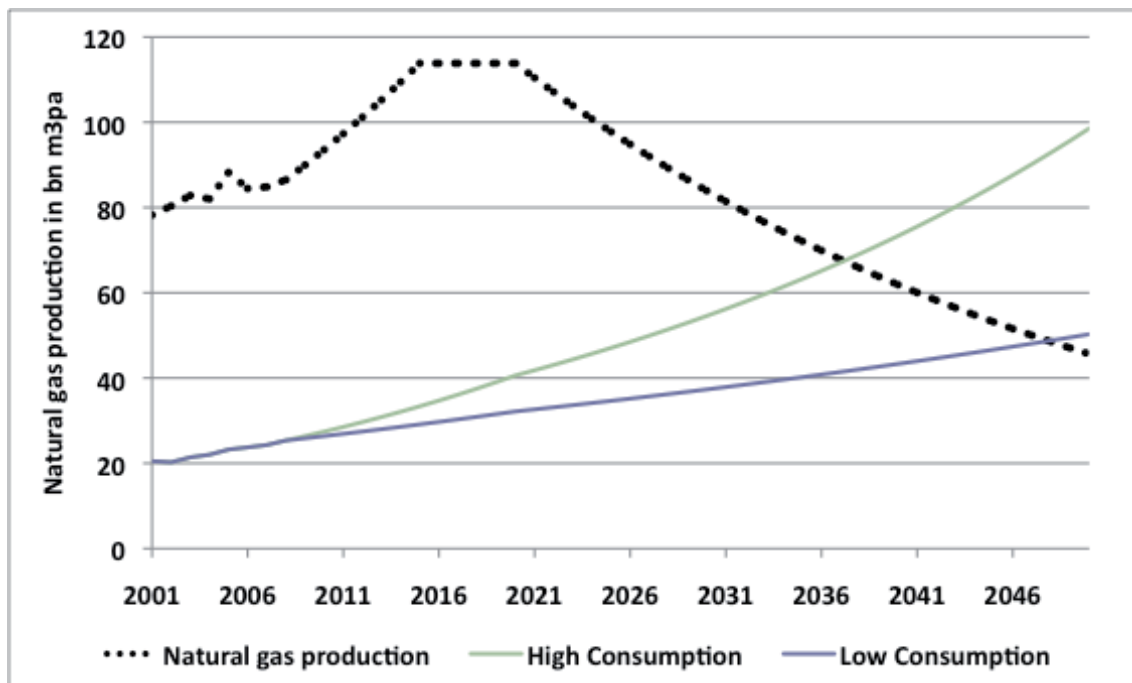


Fig. 4-8. Possible natural gas production and two scenarios of Algerian consumption. Own calculations.

#### 4.5.3 Power Demand Scenarios for DZA

Data were modelled according to different development options published by CREG (2006), in which electricity consumption was translated into demand for power generation capacity. For the discussion of integration of different power plant types (renewable or nuclear) the absolute size of generation capacity allows the best conclusions. CREG gives two different development paths for the years 2006 to 2015 as high and average growth (French “fort” and “moyen”). With forecasts ending in 2015, own growth assumptions were modelled for the time frame 2016 to 2030.

**Scenario High Capacity.** According to CREG power generation capacity can increase between 2006 and 2015 from well above 6 GW to 11 GW, assuming annual growth of 6.4 %. In scenario High Capacity this growth trend was extrapolated to 2030, resulting in total power generation capacity of 27.9 GW (see Tab. 4-8 and Fig. 4-9). This growth trend is in the same range as the scenario of DLR 2009, which calculates Algerian electricity consumption by 2030 in the order of 145 TWh/a (DLR 2009).

Tab. 4-8. Scenarios High Capacity and Low Capacity for the Algerian power sector. Own calculations.

MW	2006	2010	2020	2030
High capacity	6300	8074	15015	27922
Low capacity	6300	7585	11638	17228

**Scenario Low Capacity.** The lower growth path of CREG describes the basis for a more compact electricity system in Algeria. Generation capacity increases to 9.5 GW by 2015, annual growth of 4.75 %. From 2016 to 2030 own calculations were added describing a more efficient growth path. For this time period growth was modelled at 4 % per year, resulting in 17.2 GW generation capacity.

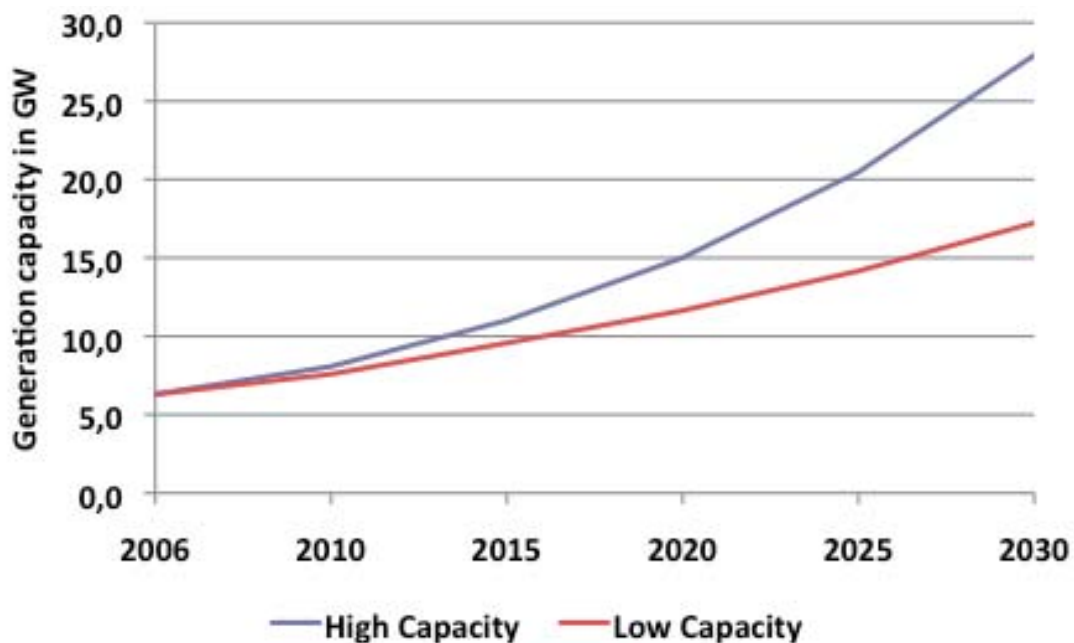


Fig. 4-9. Scenarios High Capacity and Low Capacity for the Algerian power sector. Own calculations.

## 4.6 Assessment of technologies in the Algerian context

### 4.6.1 Ecosystem stability of technologies and implications for Algeria

#### 4.6.1.1 “Harmlessness” of total life-cycle on environment and humans

**Nuclear energy.** Algeria owns uranium ore deposits, however, according to NEA (2008), these are resources, not reserves, that are very intensive and expensive to be produced. These re-

sources could possibly be sufficient to fuel very few nuclear power plants. If Algeria decided to start mining, the environmental burden would be very high. Final disposal of waste would be another source of environmental damages. Rating: Low harmlessness of the total life-cycle.

**Renewable energies.** In Algeria mainly wind and solar irradiation will be utilised. Life-cycle impacts of wind turbines and large-scale solar power plants on environment and humans are very low. They resemble the impacts of other industrial processes that can be made environmentally sound via legislative measures. Material and resources can be recycled to minimise environmental impact. This is the case for small-scale applications as well.

Large hydropower plants have high negative environmental impacts, i.e. they are not harmless. Small hydropower is not an energy option with large potential in Algeria and is therefore omitted in the analysis.

Rating: Solar and wind power: High harmlessness. Large hydropower: Low harmlessness.

**Energy efficiency.** Energy-efficient appliances are harmless in terms of environmental impacts of their life-cycle. As they reduce total energy demand, they help to reduce environmental impact of energy consumption. Rating: High harmlessness.

#### **4.6.1.2 “Harmlessness” of technology on direct environment/ surrounding area and on humans during operation**

**Nuclear power.** The impacts of plants on direct surrounding environment and humans in Algeria will probably not be higher than in industrialised countries. However, security hazards would probably be higher due to lacking experience in operation of such power plants. Rating: Medium to low harmlessness.

**Renewable energies.** Direct environment is affected only to a small extent; Algeria has plenty of land area available for the installation of plants. Sealing of areas is low in wind and solar energy utilisation. However, some ecosystems are affected during building and operation of large-scale plants. Small power generation systems (small-scale photovoltaics) have no negative effect, hence they are very harmless to the environment and for humans. Large hydropower plants have severe direct effects on environment and on humans (microclimate changes etc.). Rating: Solar and wind power: High harmlessness. Large hydropower: Low harmlessness.

**Energy efficiency.** Efficient appliances do not affect the environment and humans more than less efficient ones. They directly reduce the impact of energy consumption on environment. Rating: High harmlessness.

Total rating of criterion “ecosystem stability of technologies and implications for Algeria”:

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: Low.

Energy efficiency: High.

## **4.6.2 Micro- and macroeconomic benefits of technologies and implications for Algeria**

### **4.6.2.1 Job potential and potential for technology R&D for national development (technology multiplication effects)**

**Nuclear power.** Nuclear power plants are in comparison to other energy options not job intensive. Operation of plants requires few but very highly qualified technicians due to the very high degree of automation and scale effects. Currently Algeria does not have significant R&D expertise in nuclear technology and it is very ambitious to establish such expertise. Even in countries that are experienced in nuclear power plant operation and R&D, the technological know-how is in the hands of only few think tanks and clusters. It is therefore not probable that Algeria will be able to establish a nuclear technology branch with considerable job effects. Rating: Low job potential.

**Renewable energies.** Small-scale renewable energy technologies are very job intensive during operation due to maintenance and other services. They bear the potential for many jobs that can be accomplished by unskilled persons. This is valid for small-scale photovoltaic systems as well as for single wind turbines. Large-scale solar power plants are not highly job intensive (in this respect they range between nuclear power and small-scale renewables applications). Large hydropower plants are comparable to nuclear power plants. On- and offshore wind farms are more job intensive than solar power plants. Rating: Small-scale technologies: High job potential. Wind turbines: Medium to high potential. Solar large-scale: Medium job potential. Large hydro: Low job potential.

**Energy efficiency.** Production of energy efficient appliances is not more job intensive than the production of less efficient ones. But as these technologies are equivalent to each other in terms of complexity, it would be possible to create domestic industries that – with international instruments like technology transfer – could become job machines in the mid term. This is transferable to Algeria only to some extent: The Algerian industry is mainly based on very few very large companies (mainly state-owned) and on very many very small enterprises (with less than 10 staff). Medium-sized companies are rare in Algeria. Therefore new industry branches would probably develop slower than in other countries or would only have medium overall job effects. The situation is different for energy services, where considerable job potential exists in Algeria as well, but this strongly depends on institutional framework. Rating: Medium job potential.

### **4.6.2.2 Affordable energy supply I: cost reduction potential in mid to long term**

**Nuclear power.** The Algerian situation is comparable to the situation worldwide. Some nuclear power plant concepts are mature without cost reduction potentials. New plant concepts like the EPR theoretically bear cost reduction potentials, however, as is evident in Finland currently, costs are increasing very fast during the construction phase. It therefore has to be doubted that nuclear power concepts will ever have decreasing cost or learning curves; for a listing of cost projections and realised costs of nuclear power plants compare p. 35. Nuclear power plants are in this respect a factor of insecurity for economic planning. Rating: Low cost reduction potential.



**Renewable energies.** Solar power technologies bear cost reduction potentials: solar thermal power plants (parabolic troughs) are technologically rather mature but costs can be reduced by economies of scale. This is comparable to photovoltaics; however, there is a large variety of PV technologies, and a sorting-out will happen in the coming years. This is particularly important for Algeria, as Algeria is the country in the Maghreb with the most favourable conditions for solar power in terms of available area, institutional frame (policy, institutions etc.) and accomplished first steps. Currently CSP power plants are in discussion on high political level, the first plant is in the construction phase. Wind power is a mature technology; cost reduction potentials are low. However, in offshore wind power cost reduction potentials are larger. The situation in Algeria is comparable to the global situation.

Rating: Solar power technologies: Medium to high cost reduction potentials. Wind power: Low to medium cost reduction potential.

**Energy efficiency.** High cost reduction potentials for energy efficient appliances exist in Algeria. On broader scale energy efficiency potentials can be tapped at low costs. Rating: High cost reduction potential.

#### **4.6.2.3 Affordable energy supply II: redundancy of subsidies**

Final energy prices are subsidised in Algeria. It is assumed that in mid- to long-run the Algerian government will abolish direct subsidies of final energy carriers and allow for undistorted competition in the electricity sector. It is further assumed that electricity generation costs will reflect the total costs without hidden subsidies (externalisation etc.). The question is: will technologies still have to be subsidised in such a system to be affordable?

**Nuclear power.** The Algerian situation is comparable to the global situation. Nuclear power is only economic because of massive hidden subsidies in the form of e.g. insurance exemptions and massive externalisation of costs. So if Algeria decides to use nuclear power, it would only be possible with subsidisation on large scale. Rating: Low redundancy of subsidies.

**Renewable energies.** Large hydropower plants can be operated in market conditions, i.e. without subsidisation. Solar electricity technologies have to be subsidised in Algeria (as in other countries). However, insolation conditions are very favourable which shifts the time frames of necessary subsidisation (as known from Western European countries): Subsidies will only be necessary in short-term perspective. In the medium to long term Algeria will be able to integrate solar power plants and wind turbines into its energy system without subsidies.

Rating: Large hydropower: High redundancy of subsidies. Solar and wind power: Medium redundancy of subsidies.

**Energy efficiency.** As price levels are low in Algeria, energy efficiency appliances are rather expensive and therefore need subsidisation in the short to medium term. However, in a system free of energy subsidies, payback time will decrease soon. Rating: medium to high redundancy of subsidies.

Total rating of criterion “micro- and macroeconomic benefits of technologies and implications for Algeria”:

Nuclear energy: Low.

Solar and wind power, large-scale: Medium.

Solar and wind power, small-scale: Medium.

Large hydropower: Low.

Energy efficiency: Medium.

### 4.6.3 Technical integratability to existing and growing energy system

Between 2010 and 2020 a growing capacity demand for electricity of 6.9 GW in the High scenario (respectively 4.1 GW in the Low scenario) is expected for Algeria (see Fig. 4-9 and Tab. 4-8). This corresponds to a growth rate of 86% (53% in the Low scenario) within ten years. Assuming that realistically only one nuclear power plant with an assumed capacity of 1.0 GW could be erected within this period, 1.0 GW or 7% (9% in the Low scenario) would origin from nuclear electricity in 2020 (see Fig. 4-10).

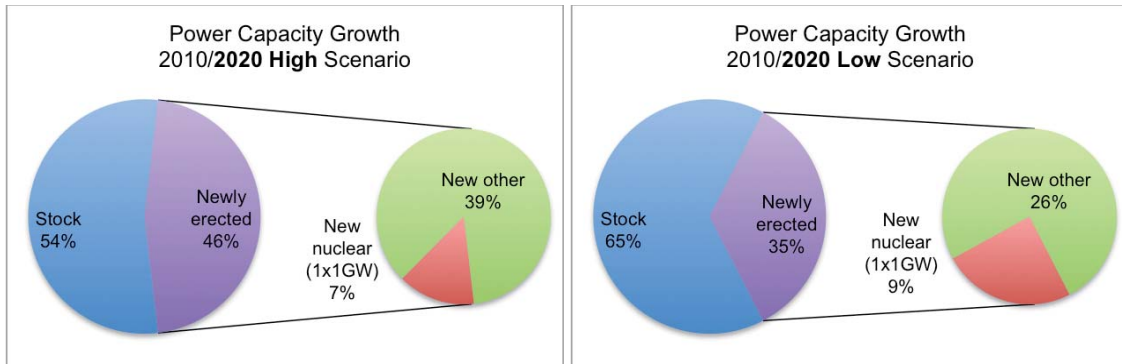


Fig. 4-10. Shares of newly erected power plants in Algeria with one new nuclear power plant of 1.0 GW capacity for the scenarios High and Low Capacity within 2010 and 2020. Own calculations.

Until 2030 even 19.8 GW (9.6 GW) of new capacity must be erected according to the High (respectively Low) scenario. This means a factor of 2.5 (1.3 in the Low scenario) compared to the power plant stock in 2010. Assuming an implementation of two 1.0 GW nuclear power plants, the nuclear share would result in 7% (12% in the Low scenario) in 2030 (Fig. 4-11).

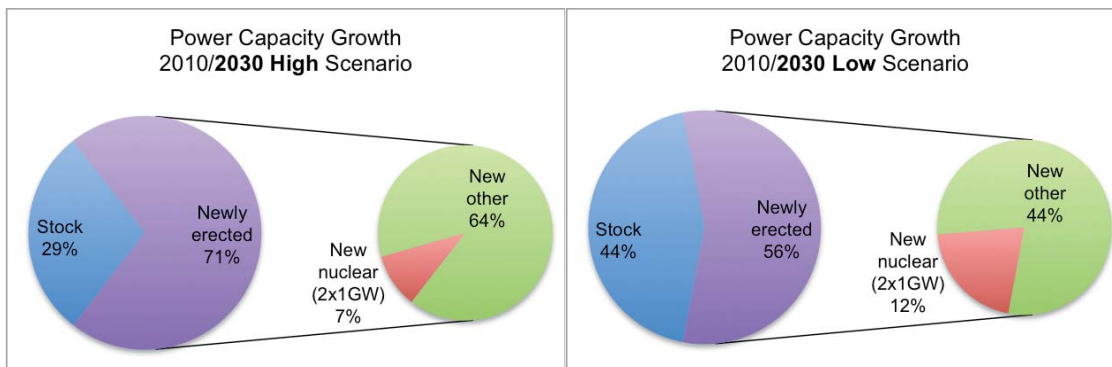


Fig. 4-11. Shares of newly erected power plants in Algeria with two new nuclear power plants of 1.0 GW capacity for the scenarios High and Low Capacity between 2010 and 2030. Own calculations.

### Integration of larger nuclear power plants

The plant size of 1.0 GW was chosen because according to (Prognos 2009, p. 18) the average size of the global nuclear power plant stock is about 900 MW, while the sum of planned and suggested new installations would have an average installed gross capacity of 1.060 GW until 2020 respectively 0.980 GW until 2030 (Prognos 2009, p. 33). Principally also smaller units could be realised technically. But due to economies of scale (e.g. for expensive safety containment) smaller units probably cannot deliver electricity at competitive prices. For this reason some marketable available reactor types like the “EPR” even have considerable greater capacity in the range of 1.6 GW. To cover this possible case of larger capacity, Fig. 4-12 and Fig. 4-13 show the development for 1.6 GW power units: one unit by 2020 and a further unit by 2030. Integrating such units would pose further challenges on integration into existing small electricity grids, as their relative sizes (up to 19% related to the total net capacity) would be significantly larger.

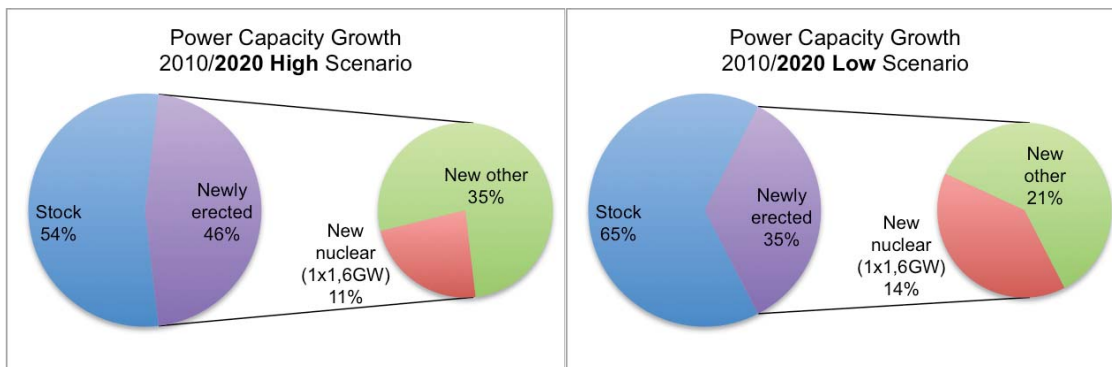


Fig. 4-12. Shares of newly erected power plants in Algeria with one new nuclear power plant of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2020. Own calculations.

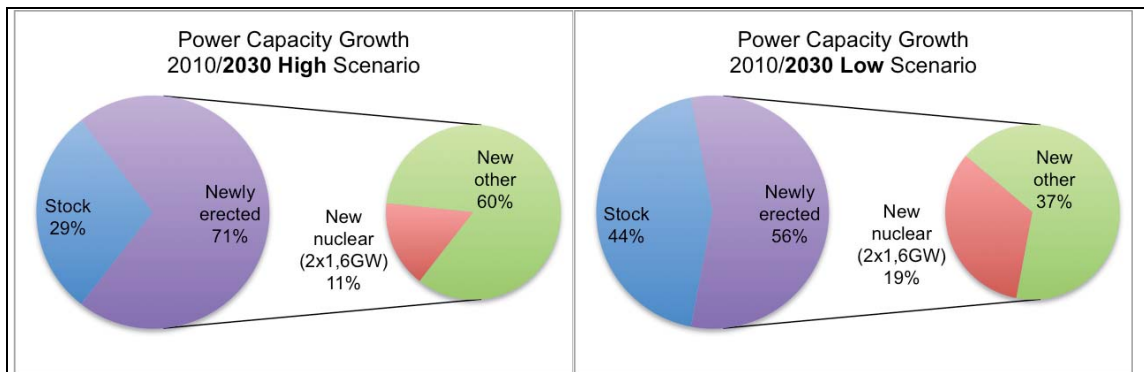


Fig. 4-13. Shares of newly erected power plants in Algeria with one respectively two new nuclear power plants of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2030. Own calculations.

#### 4.6.3.1 Flexibility of operation mode

**Nuclear power.** Due to technical (slow reacting system) and economical (high investment costs) restrictions nuclear power plants are only suitable for base load capacity. With regard to the relatively high shares of 7% to 12% (11% to 19% in the 1.6 GW scenario respectively) in total generation capacity in 2020/2030 already the establishment of one or two nuclear power plants in Algeria would possibly cause conflicts with the integration of high shares of new renewable energies with fluctuating feed in (especially electricity from wind turbines and from PV plants). Rating: Very low flexibility.

**Renewable energy.** Renewable energies have different characteristics regarding flexibility of operation mode: While wind turbines and PV generators – if electricity is not stored – only can be shut down partially or totally, many other renewable sources like biomass, geothermal and hydro energy but especially also CSP plants with thermal storage or gas co-firing can deliver constant and/or flexible power. As CSP with its enormous economic potential of ca. 169000 TWh/a in Algeria in gas hybrid mode is a key element of Algeria's renewable energy policy, flexibility in operation mode will be very high. Rating: CSP, hydro and geothermal power: Very high flexibility. Wind power and PV: low flexibility

**Energy efficiency.** Energy efficiency measures lower the need for electrical capacity (in GW) and consumption (in GWh), e.g. savings by energy-saving lamps. So-called “load management systems” on the other side cut load peaks. Thus the first doesn't influence the system's flexibility of operation mode while the second improves its flexibility. Rating: strong contribution to flexibility of the overall system.

#### 4.6.3.2 Temporal availability of technology

**Nuclear power.** The average lead-time for planning, approval and construction of nuclear power plants takes more than 10 years (Schneider/Mez 2008). Taking this experience into account, the chosen scenario with an establishment of maximal one single nuclear power plant until 2020 and another one until 2030 seems to be realistic. Constructing several (three or more) plants in Algeria in the short or even in the mid term presumably will fail due to lacking con-

struction capacity in the nuclear power sector on the one hand and due to the very high financial needs on the other hand. Rating: Very low temporal availability.

**Renewable energy.** While only few nuclear power constructors exist worldwide the supplier market of most renewable technologies (e.g. PV, wind onshore, biomass) is a more decentralized and fast growing one. This diminishes the risk of (temporal) bottlenecks for production and erection of power systems. Apart from big offshore wind parks with lead times up to 10 years, renewable energy technologies in general are temporally available within less than five years (solar thermal power plants or geothermal plants) and even often in considerably shorter periods (e.g. PV < 1 year depending on size and net integration). Rating: Medium to high temporal availability.

**Energy efficiency.** Energy efficiency measures are principally available and applicable immediately, but due to an immature market for energy efficient products in Algeria sometimes special efficiency technology has to be imported from abroad. Rating: Very high temporal availability.

#### 4.6.3.3 Constancy/permanence of generation

**Nuclear power.** As mentioned above nuclear energy is predestined for base load operation and permanent electricity generation. But if large shares of Algeria's power production originated from centralised nuclear power plants (see scenarios in Fig. 4-10 and Fig. 4-11 *with only one respectively two single plants*) this could lead to serious problems of supply security: If such a power plant has to reduce capacity – predictably for maintenance or abruptly due to system failure – a severe lack of capacity will be the consequence. Rating: Medium constancy of generation.

**Renewable energy.** Algeria's main strategy among the renewable energy technologies is to develop large-scale CSP power plants with natural gas co-firing (ISCC<sup>24</sup>). In contrast to PV or wind plants this hybrid system offers a very high constancy of generation and security of power supply as well, independent of weather conditions, daytime or season. Similar permanency in power generation could be reached by adding solar thermal storages to CSP plants instead of gas co-firing. Maintenance of plants can be done in cascades (not all plants at the same time), which allows high permanence of overall system operation. Rating for constancy of generation: ISCC/CSP with thermal storage, geothermal: High. Hydro and wind power (offshore): Medium. Wind (onshore), PV: Low.

**Energy efficiency.** Implemented energy efficiency measures are generally available permanently. Normally they have no direct effect on the constancy of power generation. Rating: No negative impact on constancy of generation.

#### 4.6.3.4 Possibility to integrate technology into the existing grid

**Nuclear power.** Nearly doubling the power capacity in Algeria within ten years is a very ambitious task in itself. But integrating 1.0 GW centralised nuclear power into a today's 8.1 GW respectively a 2020's network of 15 GW may be technically difficult. Even though big units profit from economies of scale their integration into Algeria's small power grid would cause extra

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<sup>24</sup> ISCC: Integrated solar combined cycle

costs to keep ready redundancy for the sake of security of supply: The required reserve capacity has to be higher for a centralised system than for decentralised ones (see Fig. 3-19). Furthermore it has to be fundamentally clarified if the grid's performance on the envisaged plant location in Algeria is high enough to take up such high capacity (of 1 Gigawatt) in one single supply point. Rating: Very low possibility for grid integration.

**Renewable energy.** Taking into account the inflexible operation mode of nuclear power plants it would be technically but also economically difficult to integrate high shares of renewable energies in the future, especially those with fluctuating feeding. Costly investments into big centralised power plants like nuclear plants would lock this inconvenient situation for many decades. Rating for possibility for grid integration: Medium (low nuclear shares) to low (high nuclear shares).

**Energy efficiency.** Energy efficiency measures are easily capable of being integrated to the existing grid. Moreover they would release the power grid or would offer the chance for a slower growth of power net capacity for Algeria. Not only new renewable power plants, but also energy efficient local CHP plants would suffer from centralised nuclear energy structures (see above). Rating: Very high possibility for grid integration.

#### 4.6.3.5 Technological status (market readiness of technology)

**Nuclear power.** Nuclear power plants are principally market-ready since several decades. New types of the so-called "third" (like the EPR<sup>25</sup>) or "forth generation" (only design studies at present) still have to prove their technical, economical and security performance in practice. Rating: Very high market readiness.

**Renewable energy.** The most important RE technology for Algeria – solar thermal power plants – has been available and marketable for several decades: First plants have been erected in 1980<sup>th</sup> in Cramer Junction / California and still are operating. Also other RE sources that could be used in Algeria (wind power, PV, hydropower, geothermal energy, biomass; see Tab. 4-2) have reached market maturity. Rating: Very high market readiness.

**Energy efficiency.** Energy efficiency products and measurements are mature and marketable available in a great variety. Rating: Very high market readiness.

Total rating of criterion "technical integratability to existing and growing energy system":

Nuclear energy: Low.

Solar and wind power, large-scale: Medium.

Solar and wind power, small-scale: Medium.

Large hydropower: Medium.

Energy efficiency: High.

<sup>25</sup> The first commercial pilot plant of the "generation III" type will possibly be on line in 2012 in Olkiluoto/Finland (1,600 MWnet; start of construction: 2005).

## 4.6.4 Contribution to political stability and implications for Algeria

### 4.6.4.1 Potential to reduce conflicts over resources

**Nuclear power.** Estimates on Algeria's uranium resources are difficult. As the 2008 report "uranium 2007: Resources, Production and Demand" states, Algeria did not report any information on uranium production, requirements, stocks and prices (OECD NEA, IAEA 2008). Its Reasonably Assured Resources<sup>26</sup> add up to 52000 tons uranium (ibid.). Some sources indicate that Algeria purchased 150 tons of uranium concentrate from Niger in 1984 (see González/Larraya 1998). Just recently, the Algerian Ministry of Energy and Mines issued a tender for uranium prospecting in eight different sites in the Wilaya of Tamanrasset (the tender also encloses exploration and prospecting of gold in other sites) (MoEM 2007). This current development suggests that the country may want to decrease its dependency on external supply of fissile material. Indeed, this could potentially limit the risk of conflicts over uranium. Rating: medium potential to reduce conflicts over resources.

**Renewable energy.** As for solar energy, shortages of technological components like solar panels may come up as the expansion of solar capacities throughout the world increases. There is some interest in Algeria in building own production sites for solar technology, however the country is currently lacking the technical expertise and capacities to produce solar technology of sufficient quality (Reyes, 24.06.2009). It is therefore rather likely that the main technical components for solar technology will continue to be imported from other countries such as India. This principally increases the vulnerability of Algerian solar energy plans to shortages in the supply of e.g. solar panels. However, due to new technological developments in this area such shortages are most likely to be only temporarily. Other renewable energies such as wind energy, geothermal energy and biomass have a very low potential to spur any conflict over resources needed to produce energy with such facilities in Algeria. Rating: High potential to reduce conflicts over resources.

**Energy efficiency.** Technologies to improve energy efficiency offer the greatest possibilities to limit resource competition especially with respect to the fossil fuels oil and gas. High cost reduction potentials for energy efficient appliances exist in Algeria. Rating: very high potential to reduce conflicts over resources.

### 4.6.4.2 Military harmlessness

**Nuclear power.** The Algerian government emphasizes its intention of the peaceful use of nuclear energy. It joined the Nuclear Non-Proliferation Treaty and signed a nuclear cooperation accord with the United States in 2007 (The New York Times, 10.06.2007). Algeria traditionally cooperates with China and Argentina for its nuclear program, as well as with Russia and a wide range of other countries, including Egypt. Yet, there are also critical voices concerned about the military potential of the Algerian nuclear program (ISN 2007). Indeed, in case that the nuclear

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<sup>26</sup> Reasonably Assured uranium Resources refers to uranium that occurs in known mineral deposits of delineated size, grade and configuration such that the quantities that could be recovered within the given production cost ranges with currently proven mining and processing technology, can be specified. Estimates of tonnage and grade are based on specific sample data and measurements of the deposits and on knowledge of project characteristics. Reasonably Assured Resources at prevailing market prices are commonly defined as "Reserves". See UNECE (2004).

arms build-up in the region gains momentum, the possibility of Algeria developing nuclear weapons cannot be excluded. Algeria so far has shown no ambitions for building up domestic enrichment facilities or producing nuclear weapons. Nevertheless, the risk of proliferation of fissile material in the region cannot be neglected. Rating: very low military harmfulness despite the declared intention for peaceful use.

**Renewable energy.** In contrast to nuclear power, renewable energy's potential for military use is low and few contentious issues are attached to it. Rating: very high level of military harmfulness.

**Energy efficiency.** There is no relation between increasing energy efficiency and military and strategic objectives, which may negatively impact the relationship with neighbouring or other countries. Rating: very high level of military harmfulness.

#### **4.6.4.3 Contribution to transnational confidence building**

As part of expanding the Algerian transmission network length, one focus is to significantly improve the connections with neighbouring countries Morocco and Tunisia. The goal is the evolution of an Inter-Maghreb interconnection that can in a second step be expanded to also including a Euro-Maghreb interconnection (Hassina 2009).

**Nuclear power.** The establishment of an Inter-Maghreb interconnection can contribute to closer cooperation between the neighbouring states. To this end, nuclear power can, in principle, serve as one source to provide the electricity needed. However, since the possibility of Algeria developing nuclear weapons cannot be excluded, nuclear power can also counter such confidence-building approaches and create mistrust in the neighbouring states as well as in the international community. Rating: medium contribution to transnational confidence building.

**Renewable energy.** The establishment of an Inter-Maghreb interconnection offers new prospects for an expanded use of renewable energy to meet the increase in demand. Indeed, especially solar energy has large potential for further economic growth and energy integration of the region and for strengthening the political and economic ties with Europe. The latest example for this is the planned DESERTEC initiative. Cooperation in the field of renewable energy is thus also envisaged within the European Neighbourhood Policy and the Union for the Mediterranean (Mediterranean Solar Plan). Rating: Very high contribution to transnational confidence building.

**Energy efficiency.** There is no direct linkage between energy efficiency measures and transnational confidence building. Indirectly however, regional energy cooperation frameworks can help to improve the overall efficiency performance in the grid, e.g. through information sharing, dialogue facilitation and regional integration. Rating: medium contribution to transnational confidence building.

#### **4.6.4.4 Infrastructural security**

Large, centralized installations of power plants are more vulnerable to natural disasters or sabotage.

**Nuclear power.** From this perspective, the set up of a nuclear power plant in Algeria may have negative impacts on the overall resilience of the Algerian energy infrastructure. As for nuclear



power plants, two experimental nuclear plants exist in Draria and another one in Ain Oussera, near Djelfa about 300 kms from Algiers. Especially the plant in Draria is characterized by a close proximity to a densely populated area, because it is located in the suburbs of Algiers. On the one hand, this would ensure a short transmission route to the energy consumers in the city. On the other hand, the impact on the close-by population could be severe in case of sabotage or accidents in the nuclear power plant. Rating: low infrastructural security.

**Renewable energy.** The situation differs among renewable energies applications. There are plans to set up a regional energy grid and to export electricity to Europe in the long-term demand large-scale plants using collective high-power transmission lines (HVDC), which have yet to be built. If these transmission lines broke down, all affected solar parks would be disconnected from the grid. However, compared to nuclear power plants the components of these facilities are easier to replace and to reinstall and the damages through sabotages are very limited and will not affect public health significantly. In addition, system vulnerability could be held low by installing small and decentralized plants and also by expanding wind energy generation. Rating: medium to high infrastructural security.

**Energy efficiency.** Energy efficiency is enhancing stability of energy infrastructures intrinsically. Rating: high infrastructural security.

Total rating of criterion “contribution to political stability and implications for Algeria”:

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: Medium.

Energy efficiency: High.

## 4.6.5 Independence of technologies and implications for Algeria

### 4.6.5.1 Independence from depletable fuels (geological perspective)

**Nuclear power.** Nuclear fuel resources are limited, and according to various studies depletion symptoms could become visible on global scale soon (NEA 2007). Algeria is no exception in this respect. Rating: No independence from depletable fuels.

**Renewable energies.** All renewable energies are independent from depletable fossil fuels. The question here is whether renewable energy potentials are limited, whether they can be “depleted”, hence be used to their maximum potential and in which order of magnitude this will be in terms of contribution to energy supply.

Hydropower potential is limited in Algeria. Wind power is an option in some regions, and if the potential of 35 TWh/a were utilised (DLR 2005), this would make a considerable contribution to electricity supply in the future. Solar potential can be rated as “unlimited”, as solar resources exceed possible power demand by a factor of 1000. Geothermal resources are limited but could

contribute at least a small share to electricity production (about 5 TWh/a (DLR 2005), which is in the range of 700 MW installed capacity mentioned by MoEM (2007)).

Each unit of renewable energy used in Algeria will spare fossil fuels, namely oil and gas. Hence renewable energies can contribute to keeping levels of fossil fuel exports high. Taken into consideration that Algeria could become a net importer of crude oil and natural gas in about 30 years, renewables are an option for keeping Algeria's trade balance positive in future decades.

Rating: All renewable energies: High independence.

**Energy efficiency.** Low energy consumption via energy efficient appliances and energy saving are one key element for curbing dependence on depletable fuels. Production of appliances is largely independent from depletable fuels. Increasing energy efficiency in the Algerian energy system will have positive effects on the range of Algeria's fossil fuels and its status as exporter of oil and gas. Rating: very high independence from depletable fuels.

#### **4.6.5.2 Reducing national dependence on imported fuels (political perspective)**

**Nuclear power.** Algeria could possibly be able to produce uranium ore domestically for at least some years. Rating: Medium independence from imported fuels.

**Renewable energies.** Algeria could use its national renewable energy potentials and would not have to import fuels in long-term perspective (see section 4.5, p. 67). Rating: All renewable energy carriers reduce dependence on imported fuels.

**Energy efficiency.** Low energy consumption is a key to reduce dependence on imported fuels. In the case of Algeria the other direction is more important: Making its energy system more efficient will set fossil fuels free from domestic consumption and increase export potentials for oil and gas. Hence Algeria would be able to remain an energy exporter for many decades to come in an energy efficient system (see scenario calculations above). Rating: very high independence from imported fuels.

Total rating of criterion "independence of technologies and implications for Algeria":

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: High.

Energy efficiency: High.

### **4.6.6 Climate policy benefits of technologies and implications for Algeria**

#### **4.6.6.1 CDM eligibility**

Algeria established a DNA in 2003. There is high CDM potential in the oil and gas sectors as well as in the renewable energy sector and with regard to energy efficiency (Amous, Abdel-Aziz 2009). Since especially gas flaring projects and energy efficiency related CDM projects

are well established globally there is great potential for Algerian engagement. Solar energy projects, which might be of special interests for Algeria currently, account for only a minor share of the overall projects. In order to use CDM as a lever for sustainable energy use however, Algerian efforts need to be intensified: There are no CDM projects in Algeria currently, neither registered projects nor in the pipeline. Yet, Chatham House reported in 2005 that Algeria prepares several CDM projects (Chatham House 2005). A CDM capacity building pilot project has been developed up to the Project Design Document (PDD) stage in 2004 (Allouani 2005, Djumena 2005). It deals with gas flaring from Ohanet oil field and is supposed to save 5.7 million tCO<sub>2</sub>. Gas flaring from oil fields seems to be the project type receiving most attention so far. Algeria acceded to the Global Gas Flaring reduction (GGFR) Partnership and the Algerian energy supplier SONATRACH agreed to finance gas flaring projects. Besides, since 2006 Algeria is a member of the UNEP project CD4CDM (BMU 2009). In the realm of this program, a national workshop on developing renewable energy through CDM took place outlining the potentials for such projects in Algeria (UNEP 2009a).

**Nuclear power.** Nuclear energy is excluded as a CDM option. Rating: very low CDM eligibility.

**Renewable energy.** The situation differs among renewable energies applications. The overall CDM eligibility can be considered as very high but requires first-hand experiment with the CDM procedures in Algeria which has so far not been gained. Rating: high CDM eligibility.

**Energy efficiency.** In the light of the overall potential for energy efficiency CDM eligibility could be considered as very high but, again, requires first-hand experiment with the CDM procedures in Algeria which has so far not been gained. Rating: high CDM eligibility.

#### 4.6.6.2 Adaptation facilitation

**Nuclear power.** As one effect of climate change, Algeria expects rising energy consumption due to the increasing need for cooling systems on the industrial as well as on the residential level (Republique Algerienne Democratique et Populaire 2001). Consumption peaks during the summers are likely to increase, particularly during heat waves. Nuclear power offers high potentials with regard to electricity production for cooling etc. as well. Yet, it is more vulnerable to shortages of water because of its reliance on coolant. Therefore it may contribute less to a sound adaptation strategy. Ranking: low potential to facilitate adaptation.

**Renewable energy.** Especially solar energy has a significant potential to facilitate Algeria's adaptation to climate change. Large-scale solar power plants can produce electricity for cooling and be used for desalination. Besides they may deliver electricity for pumping water into the water-scarce South of Algeria. Potentials for wind power are rated as being lower than solar energy. Besides, in some of the locations more suitable for wind power plants, rising temperatures due to climate change may cause technical problems making the implementation of wind power plants less favourable. Temperatures in the central area of Algeria where higher wind velocities exist may rise up to 50°C (Merzouk, 23.06.2009). These high temperatures may cause overheating in the wind turbines and damage the facility. Ranking: high to very high potential to facilitate adaptation.

**Energy efficiency.** Energy efficiency is enhancing stability of energy infrastructures intrinsically and is, hence, reducing the overall vulnerability of the energy infrastructure to climate extremes. Rating: high to very high potential to facilitate adaptation.

#### 4.6.6.3 Reduction of GHG

In 2006, more than 99 % of Algeria's electricity were produced using natural gas or oil (IEA 2006). As the Initial National Communication to the UNFCCC of Algeria shows (Republique Algerienne Democratique et Populaire 2001), nearly 39 % of greenhouse gas emissions were produced by the energy industries in 1994. More recent data is not published yet but is likely to be available soon since the Second National Communication has been under preparation since 2006. It can be expected that the share of the energy industry has remained stable or even risen due to increased energy demand over the last decade.

**Nuclear power.** In the light of the high GHG emissions caused by the current Algerian energy mix, the use of nuclear power can, in principle, contribute to GHG reductions. However, the economical and ecological costs linked to nuclear power also need to be taken into account. Rating: high potential to reduce GHG.

**Renewable energy.** Against the backdrop of the currently large share of fossil fuels in Algeria's energy mix, renewable energies may contribute significantly to a reduction of greenhouse gases in the energy production. There are estimates of a ten % renewable energy share in the national energy mix by 2025 (Derradji 27.06.2009), indicating a tremendous potential for GHG mitigation. Ranking: high to very high potential to reduce GHG.

**Energy efficiency.** Low energy consumption via energy efficient appliances and energy saving are among the most cost-effective GHG reduction measures and the Algerian energy system offers a number of entry points to implement such measures. Ranking: very high potential to reduce GHG.

Total rating of criterion "climate policy benefits of technologies and implications for Algeria":

Nuclear energy: Medium.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: Medium.

Energy efficiency: High.

#### 4.6.7 Web diagrams for technology options

**Utilisation of nuclear energy** would have severe effects on the Algerian energy system. Despite strong growth of generation capacity in the coming decades its absolute size will remain rather small compared to usual sizes of nuclear power plants: Assuming high growth, generation capacity will stand at 15 GW, whereas nuclear power plant sizes are in the range of 1.6 GW. One single generation unit would require very high reserve capacity and would make the system

inflexible. In the case of an unforeseen shut-down wide-reaching blackouts would be the consequence. Choosing a smaller power plant size would have other negative effects instead: generation and investment costs would increase due to lost economies of scale.

The absolute size of the Algerian electricity system is one reason why **nuclear power and energy efficiency are mutually exclusive**: in an energy-efficient system generation capacity would be less than 15 GW by 2020 (about 11.6 GW according to the scenario), and hence the relative size of one single nuclear power plant in comparison to total generation capacity would be even larger which would worsen the power balance.

**Domestic small uranium ore deposits** encourage the development of nuclear power. As these deposits are of medium to low quality (currently rated as resources instead of reserves), environmental burden of mining and processing would be high. Final disposal of nuclear waste is currently not discussed in Algeria but would pose a major problem in the future. If Algeria on the other side would import nuclear fuel, it would become an energy importer.

Algeria is **lacking nuclear power infrastructures** in terms of R&D, component suppliers and O&M. As a consequence a very large share of the full operation cycle of plants would be in the hands of foreign companies and would be likely to remain there in the coming decades. Job potential is therefore very low. The only positive aspect of nuclear power in the Algerian context is GHG mitigation.

As nuclear power has many adverse effects to positive criteria, the area nuclear power covers in the web diagram is very small, see Fig. 4-14.

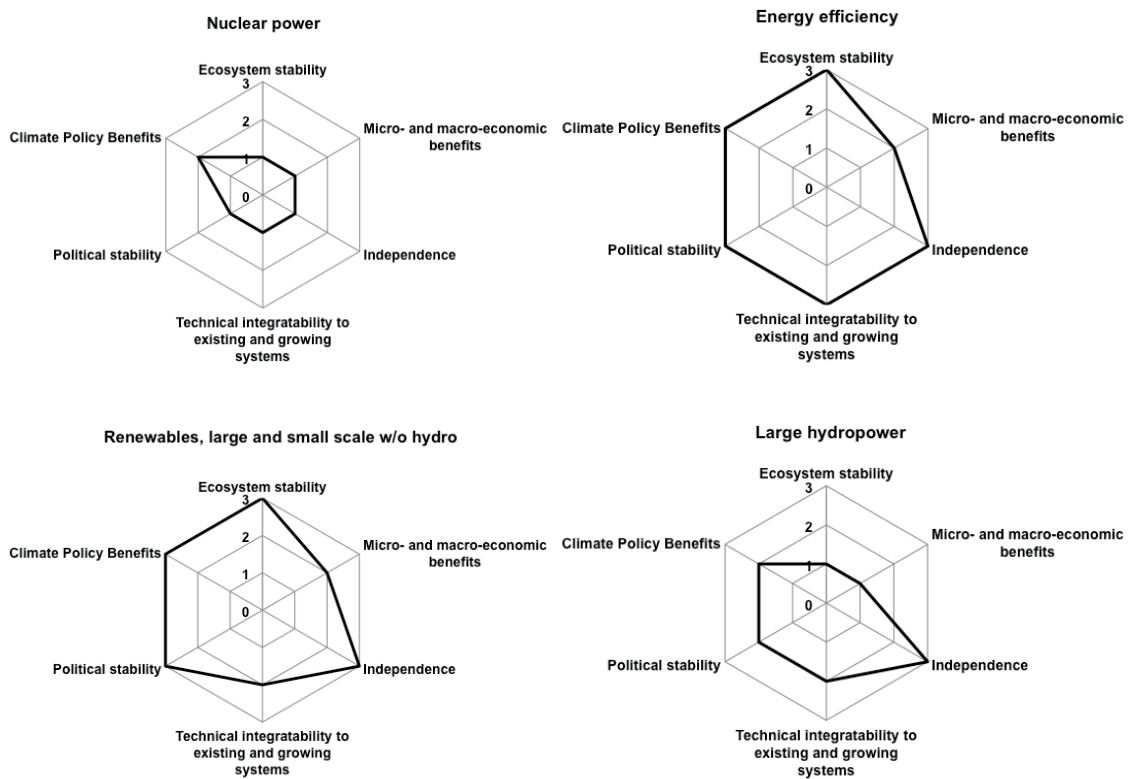


Fig. 4-14. Web diagrams of Algerian energy options. 1: Low impact, 2: Medium impact, 3: High impact on criterion.

**Energy efficiency** is an option for Algeria to enter a sustainable development path. As Fig. 4-14 shows, efficiency covers the largest area in the web diagrams, pointing to the most positive ratings. However, job potential is probably not very high in Algeria, at least in short to medium perspective, as industry structures are missing to build up an industry branch producing energy-efficient appliances.

The **lack of appropriate industry structures** can also become an obstacle for the creation of a domestic renewables industry. Therefore job potential of renewables was rated medium. Integration of wind power could become difficult due to the size of the Algerian electricity system. In this respect solar thermal power plants that can store energy or can be operated in hybrid mode with natural gas have advantages. Large hydropower is a negligible side-option in Algeria due to low potential.

## 4.7 Algeria's energy profile and prospects for future development

Algeria's energy supply is currently highly dependent on fossil fuels with natural gas accounting for nearly 100 % of electricity production. Algeria exports most of its natural gas and is the third largest supplier to the EU. Yet, it is foreseeable that Algeria will lose its status as natural gas exporter in the mid-2030s if domestic consumption increases and no alternative energy solutions are implemented on a larger scale. Increased energy efficiency measures may delay this development by about ten years since there is a substantial scope for improving Algeria's energy efficiency. Related policies are outlined in the Energy Efficiency Law and the National Programme for Energy Efficiency.

Nonetheless, the mentioned scenario implies serious problems for Algeria, which is fiscally highly dependent on fossil fuel exports. A new approach to domestic energy supply is therefore necessary. Plans exist to expand the use of renewable and nuclear energy. Today, they play a rather marginal role for domestic electricity generation.

In the Algerian context the introduction of nuclear power and renewable energies and the utilisation of energy efficiency potentials will have different consequences on the overall system development.

Regarding **nuclear energy**, it can be stated that

- Algeria might be able to **mine uranium ore**, but would have to establish enrichment facilities etc. Mining of ore would cause high environmental impacts, disposal of waste as well. It remains to be seen whether Algeria will be able to handle this or if it would rather import fuels.
- Currently **Algeria lacks infrastructures for the nuclear energy cycle**, which would make it even more difficult to establish a program not completely dependent on foreign expertise.
- The Algerian **energy system is probably too small for nuclear power**: Nuclear energy is projected to contribute about 10 % to domestic electricity production by 2020 with probably only one reactor/plant. Integration of a large generation unit is technically complex in an

electricity system as in Algeria and requires very large reserve capacities, as power plants have regular maintenance cycles. Unforeseen shut-downs would cause blackouts.

- By **enlarging the electricity system** (i.e. the grid) via international connections to its neighbouring North African countries, this situation could change
- There exists **little evidence for a military use** of nuclear power in Algeria. The country joined the Nuclear Non-Proliferation Treaty and signed a nuclear cooperation accord with the United States in 2007.

As for **renewable energies**, the following conclusions can be made:

- It is projected by the Algerian Ministry of Energy and Mines that by 2015 six % of the **national energy mix** will be contributed by renewable energies and co-generation. To reach this, the Algerian government has established a **framework of policies and programs**. Yet, more efforts need to be done to implement policies effectively, create favourable conditions for investment and to ensure reliable feed-in-tariffs.
- There is wind energy potential in Algeria, however, policy makers are concentrating very strongly on solar thermal power plants. It remains to be discussed how this could be changed.
- The **small size of the Algerian energy system** has various implications for renewable energies: a) **Solar power is most suitable** for a large-scale application as it can be combined with natural gas feed. b) Integration of the **intermittent source wind energy** could become a difficult task depending on the total capacity of wind power installed and the total growth of the Algerian electricity system.
- Making a **North African electricity grid** work would bear opportunities for renewable energies: in such a large system intermittent energy sources could be integrated better, Algeria could deliver electricity to other countries, even to Europe.
- Algeria is in favour of the **DESERTEC** initiative, yet it wishes for a more appreciated role as a partner (Derradji 2009).
- Key element of Algeria's renewable energy strategy is the implementation of large-scale hybrid projects based on domestic natural gas and solar energy (Khelil 2004).
- **Job potential** is high in the renewables industries: in technology production and in operation and maintenance the like. However, the Algerian industry infrastructures are not yet organised to allow the establishment of according companies in a time period.
- Currently, renewable energies play a minor role regarding the application of **CDM**. Yet, if capacities and efforts are increased in the future, especially solar energy could have a significant CDM potential.

Implications of increased **energy efficiency** are:

- The Algerian energy system bears very **large efficiency potentials** that could be utilised at low costs. They could be also used under the CDM.

- Energy efficiency strategies (e.g. energy services) and appliances bear high job potential. However, in Algeria it could be **difficult to establish an energy efficiency industry**, as the basic industrial structures are unsuitable yet.

#### **System integration of nuclear power, renewable energies and energy efficiency**

- Depending on the absolute amount of intermittent renewables capacity installed it could become impossible to introduce both renewables and nuclear power as the Algerian electricity system is small compared to absolute sizes of nuclear power plants.
- An energy-efficient energy system runs counter to the introduction of nuclear power, because the Algerian electricity system is very small. In an energy system that is more efficient total generation capacity would be lower and would make it even more difficult to integrate large nuclear power units.

#### **International climate and energy governance**

Awareness of climate change and correlations with energy production and consumption patterns is currently not fully developed in Algeria. Yet, it can be concluded that there is a noticeable shift to renewable energies and GHG reduction also influencing the overall position of Algeria within the evolving system of international climate and energy governance. In his introductory remarks at the 4th International OPEC Seminar in Vienna, 18-19 May 2009, Algeria's Minister of Energy and Mines, Chakib Khelil, stated that the promotion of renewable energy has to be the clear target and environmental issues need to be addressed (Khelil 2009). He encouraged the development and application of CCS technologies to ensure a more environmental friendly use of fossil fuels. In January 2009, the country also joined the International Renewable Energy Agency (IRENA) as a founding member. Although it was not involved in the process of negotiating the formation of IRENA, it fully committed to encourage the organization during the founding conference (Algerian Delegation 2009).

Several factors contribute to Algeria's engagement to foster renewable energies and to reduce GHG emissions. These are increasing population, high unemployment, low diversification of the domestic industrial sector as well as the country's high vulnerability regarding climate change impacts. It also needs to be taken into account that there is a range of attractive opportunities offered by the international climate change regime, such as the Clean Development Mechanism (CDM). This strongly implies a further commitment of Algeria to move away from a fossil fuel-based energy supply. Incentives from domestic as well as international actors could foster a privileged treatment of renewable energies.



## 5 System Analysis of Islamic Republic of Iran

### 5.1 Production and availability of energy resources

#### 5.1.1 Crude oil and natural gas production and reserves, energy exports

Data are excerpted from the Annual Statistical Bulletin of OPEC (OPEC 2008) unless indicated differently.

Iran is an OPEC member with large **crude oil reserves**. BP and OPEC mostly agree with data in the range of 130 gigabarrels that represent 15 % of OPEC's total reserves. According to BP Iran produced 4.4 mbpd in 2007, whereas OPEC states produced 4.0 mbpd. This results in a possible production of non-conventional oil of 0.4 mbpd. This is due to liquids production from gas fields (condensates). The amount of domestic consumption is about 40 % (1.6 mbpd) of total production, the rest is exported (see Fig. 5-1). Iran's production share in total OPEC production is about 15 %, resembling its share in total reserves.

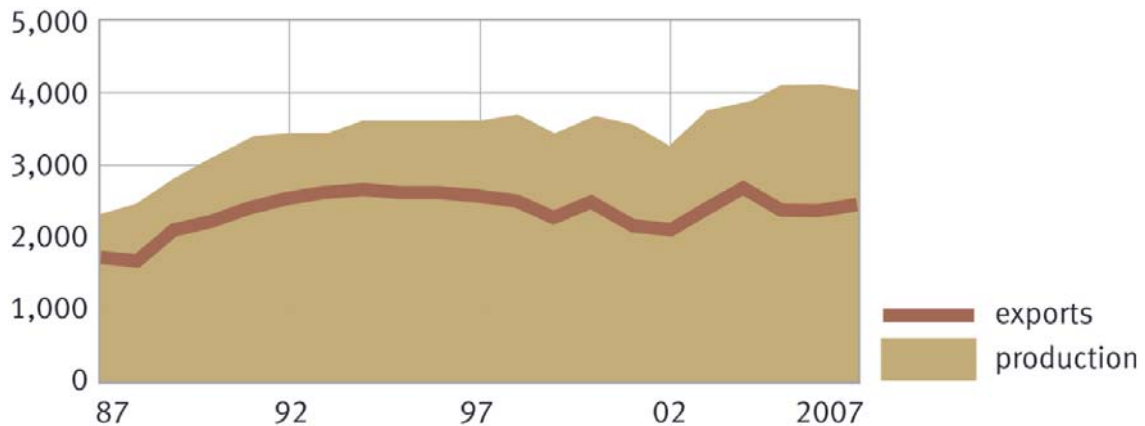


Fig. 5-1. Crude oil production, exports and domestic consumption of IRN. OPEC 2008.

Conclusion: Iran is an OPEC member with large oil reserves. It is further a so-called low-absorber OPEC member, as a large share of its domestic production is consumed domestically.

Within OPEC, Iran is a major gas producer: marketed production stood at 112 bn m<sup>3</sup> in 2007 (BP 2008), total production (marketed production plus flaring plus injection into oil wells plus losses) at 174 bn m<sup>3</sup> (OPEC 2008). With total OPEC production at roughly 900 bn m<sup>3</sup>, Iran's production share was about 20 %. This is in contrast to the share of natural gas reserves of 30 % of OPEC's total reserves: Iran holds about 28 trillion m<sup>3</sup> of natural gas.

Iran is currently a net importer of natural gas. Turkmenistan imports natural gas to the Tehran region (7 bn m<sup>3</sup> in 2007). Turkey receives natural gas 6 bn m<sup>3</sup> in 2007), but in strongly varying amounts, as Iran wasn't able to deliver reliably due to varying imports from Turkmenistan. Gas is also exported to Aserbaidshchan to small amounts. Iran plans to export natural gas in large quantities as LNG in the near future. There are also detailed plans on the so-called *peace pipeline* from Iran to India passing through Pakistan (the pipeline is also called IPI-pipeline).

Official OPEC statistics are incomplete (see Tab. 5-1). Total exports are indicated, but it is not possible to get the whole picture.

Tab. 5-1. Crude oil exports from Iran. OPEC 2008.

IR Iran	2003	2004	2005	2006	2007
<b>North America</b>	-	-	-	-	-
Canada	-	-	-	-	-
United States	-	-	-	-	-
<b>Latin America</b>	52.5	58.8	-	-	2.3
<b>Eastern Europe</b>	124.9	139.9	-	-	-
<b>Western Europe</b>	708.8	794.0	1,061.2	871.7	847.4
France	111.4	124.8	210.7	205.6	132.2
Germany	0.5	0.5	14.6	5.0	8.4
Italy	202.2	226.5	293.8	291.8	192.4
Netherlands	46.4	52.0	42.3	12.5	-
United Kingdom	-	-	-	-	-
<b>Middle East</b>	26.5	29.7	211.7	-	-
<b>Africa</b>	166.4	186.3	-	149.2	148.1
<b>Asia and Pacific</b>	1,202.6	1,347.0	1,121.6	1,350.6	1,469.1
Australia	1.4	1.6	-	-	-
Japan	652.2	730.5	822.1	684.3	450.4
<b>Unspecified</b>	114.6	128.4	-	5.7	-
<b>Total world</b>	<b>2,396.3</b>	<b>2,684.1</b>	<b>2,394.5</b>	<b>2,377.2</b>	<b>2,466.8</b>

Notes: Corresponds to a fiscal year ending March 20.

The data set does not allow a complete picture of exports, as many details are missing. Example: exports to Western Europe are listed with 847 mb in 2007, but exports to listed countries sum up to only 333.0 mb.

### 5.1.2 Coal and uranium sources

Iran holds some small amounts of uranium ore in the range of 18000 t. However, these are not reserves, but resources that are currently not worthwhile to mine. Up to now Iran does not have any experience with uranium mining. Hard coal reserves stand at 420 million tons, resources at 45000 Mt. This would allow coal mining to some extent. In 2007 about 2 Mt were produced. Lignite (soft coal) is not found on Iranian territory (BGR 2008).

### 5.1.3 Renewables potentials

Iran has various sources of renewable energies that could be tapped for supply. A first overview is given in Tab. 5-2 regarding electricity supply. For heat supply, solar energy could be tapped as main source.

Tab. 5-2. Economic electricity supply side potential of renewable energies in Iran, TWh/a. DLR 2005.

TWh/a	CSP	Wind power	PV	Hydropower	Geothermal	Biomass	Power production Iran 2003
Economic potential	20000	8.0	16.0	48.0	11.3	23.7	155 TWh
Performance indicators	DNI: 2200 kWh/m <sup>2</sup> /a	1176 full load hours per year (FLH)	Global horizontal irradiance: 2010 kWh/m <sup>2</sup> /a	Full load hours per year: 1,351	Temperature at 5000 m depth: 295°C	FLH: 3500	

CSP: from direct normal insolation (DNI) and CSP site mapping taking sites with DNI > 2000 kWh/m<sup>2</sup>/a as economic. Wind: wind speed and site mapping, sites with yield > 14 GWh/y. PV: general growth rates used for calculation. Hydro-

power: from literature. Geothermal: depth 5000 m, > 180°C taken as economic. Biomass: agricultural and municipal waste, solid biomass.

**Wind power.** Wind energy potential estimates cover a broad bandwidth. The German Aerospace Center generated a wind map with satellite imaging, showing only a small wind power potential of 8 TWh/a. Worldbank lists 6500 MW of total capacity, SUNA derived a potential of 12000-16000 MW potential (CEERS et al 2006). Assuming 2000 full load hours, the latter estimate leads to a potential generation of 32 TWh/a of electricity. The forthcoming wind atlas will provide more detailed data. In Khusistan a German company made province-wide measurements, but the data were not published. According to experts involved in province wide measurements there are some exceptionally good wind power sites in N-E-Iran (Hagenkort 2004, Kipke 2004).

DLR (2005) lists a biomass potential of 24 TWh/a electricity, but this figure includes municipal waste (Table 2.5).

**Geothermal.** Geothermal primary energy data are pretty well investigated in Iran, but there is a lack of knowledge on economic and technical potentials. Behnam Talebi, who was leader of the geothermal program at SUNA in 2004, made a rough estimation of the country-wide geothermal electricity potential: 5000 – 6000 MWel. As geothermal energy can be used for base load on 24/7 basis, full load hours (flh) are high. Assuming 7500 flh, about 37 – 45 TWh/a electricity could be produced. As geothermal hot spots are far from inhabited areas, heat could not be used. Therefore only the electrical option remains for geothermal energy utilisation.

As Fig. 5-2 shows, there are 14 geothermally promising regions in Iran. They can be divided in three categories (Talebi 2004, Fotouhi 1994):

- Category 1: Sabalan/Meshkin-Shahr. Explored in detail, here the first geothermal power plant is being built. Potential is investigated in-depth, temperatures are well known.
- Category 2: Khoy-Maku, Sahand, Damavand. These regions were identified as potential geothermal sites already in the 1970s. They are explored pretty well and there are detailed estimations on energy contents.
- Category 3: Takab, Ramsar, Isfahan, Khur, Ferdows, Nayband, Bushehr, Lar, Bandar Abbas, Taftan-Bazman. They are identified as potential geoth. regions, but still need detailed assessment.

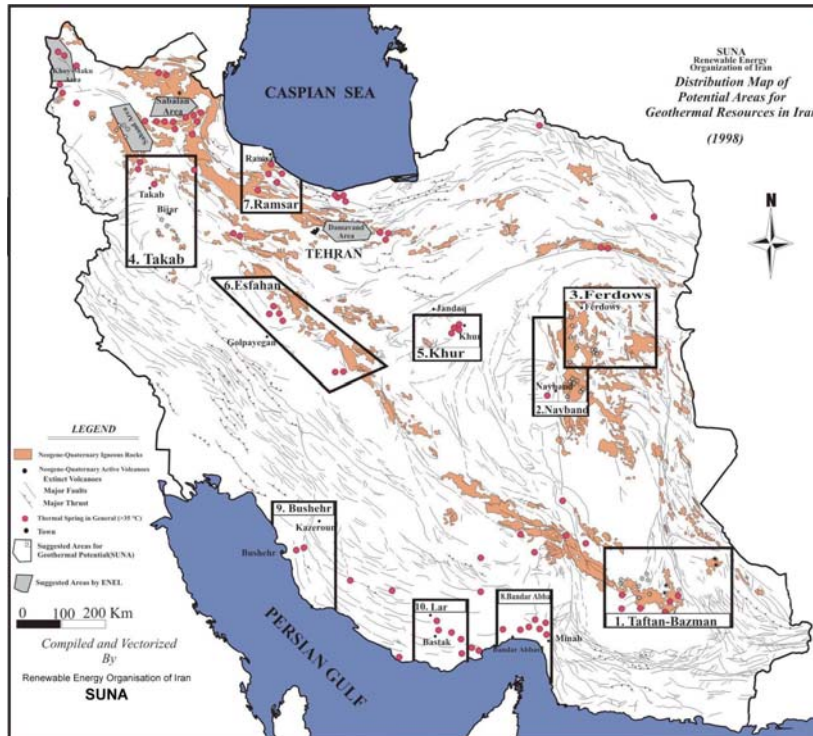


Fig. 5-2. Geothermal Resources in Iran. SUNA 1998.

**Solar irradiation.** Solar irradiation is very high in Iran. DLR (2005) assessed a direct normal irradiance of 2200 kWh/m<sup>2</sup>/a. Total economic potential for the use of concentrating solar power plants (CSP) is calculated by DLR via satellite imaging. In the economic potential data the relevant topographic aspects are included: areas that are covered already, water surfaces, high inclinations (mountains etc.) and other problematic areas are excluded. This gives a hint on the total area that could be used for the erection of other solar power solutions as well, e. g. photovoltaics. However, utilisable surfaces are so large that they will not be a limiting factor for solar energy utilisation.

Samimi (1994) conducted a country-wide analysis of irradiation and states that on 80 % of Iranian territory solar irradiation would be between 1640 and 1970 kWh/m<sup>2</sup>/a, highest values are reached in the Central-Iranian region. Detailed measurements were made by Geyer (1997), showing high solar intensities for some selected sites. He presents a maximum direct normal insolation in Shiraz of about 2580 kWh/m<sup>2</sup>/a. Data for Yazd are of particular interest, as tender documents for a solar thermal power plant were prepared there (see Fig. 5-3). According to Geyer (1997) solar insolation in Yazd is in the range of 2100 kWh/m<sup>2</sup>/a.

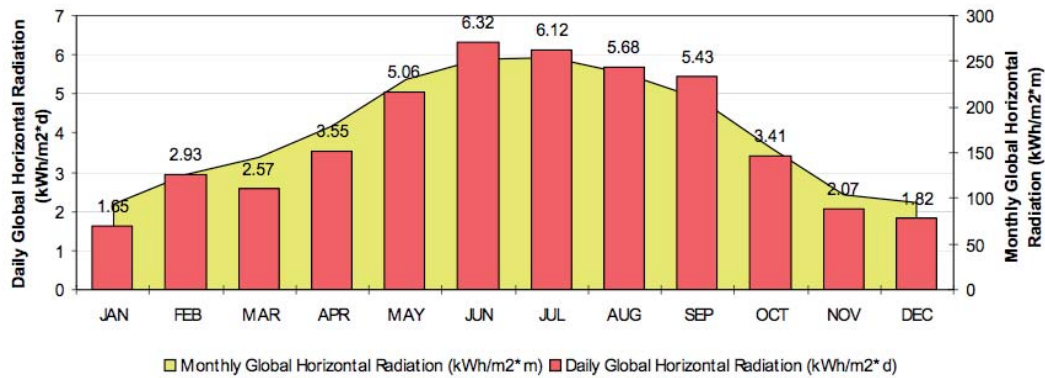


Fig. 5-3. Example of a Detailed Solar Irradiation Measurement: City of Yazd. Geyer 1997.

**Hydropower.** Hydropower is used to a small extent in Iran (less than 10 TWh/a), but there are plans to increase hydropower contribution to the electricity mix. World Energy Council (WEC) and DLR estimate Iran’s hydropower potential to be 48 TWh/a (DLR 2005, WEC 2001).

## 5.2 Energy intensity and energy efficiency potentials

Energy is used very inefficiently in Iran compared to other Non-OPEC countries (see Fig. 5-4).

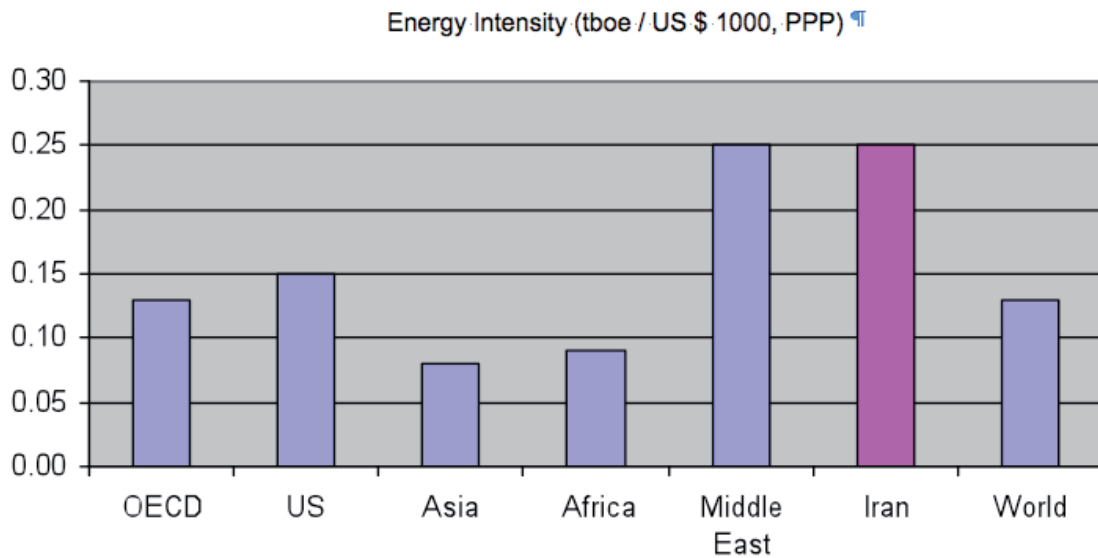


Fig. 5-4. Iran’s energy intensity in comparison to economic and regional aggregates, in purchase power parity. IEA et al. 2009.

This is also valid for other OPEC members (see Tab. 5-3). One example clarifies this: currently car-fuel efficiency is above 14 litres per 100 km in Iran, a value about twice as high as in European industrialised countries (IEA et al. 2009, Supersberger 2007).

Tab. 5-3. Energy intensity of Iran in comparison to several other OPEC members. From Supersberger 2007.

in toe/1000 US\$	TPED/GDP
IRN	1.13
DZA	0.54
ARE	0.50
Angola	0.83
Iraq	1.48
Qatar	0.74
Kuwait	0.57
Libya	0.46
Nigeria	2.01
Saudi-Arabia	0.64
Venezuela	0.53
World	0.32

Depending on the time frame for implementation there are large cost-effective saving potentials in energy consumption. Supersberger (2007) stated that between 2001 and 2050 in the transportation sector and in heat consumption efficiency increases of 75 % were possible, in the power sector about 50 % on generation side and 60 % on consumption side. IEA et al. (2009) assumed in mid-term from 2005 to 2030 efficiency gains that are in a comparable proportion (with respect to the shorter time frame). These efficiency potentials in Iran indicate that in the coming decades there will be no barriers for efficiency increases that come from the side of technical restrictions.

### 5.3 Domestic energy demand: History and present

The energy sector is facing two major problems: 1) increasing domestic demand, 2) limited potential to further increase production of crude oil. Additional problems that accelerate the deterioration of the energy supply situation are energy subsidies and lacking incentives to use energy efficiently, combined with the absence of sustainable long-term and environmental policies.

Energy demand in Iran is rising steadily (see Fig. 5-5). Consumption growth of about five % annually is comparable to GDP growth, in some years demand grew even faster. In former decades crude oil contributed more than 50 % to total energy supply. This situation changed, from 2004 on natural gas became the dominating energy carrier, due to three reasons:

- Crude oil generates larger export revenues than gas currently can (Iran does not have infrastructures for large-scale gas exports at the moment)
- Natural gas causes less environmental problems than crude oil products do
- Natural gas production can be increased strongly in the coming decades

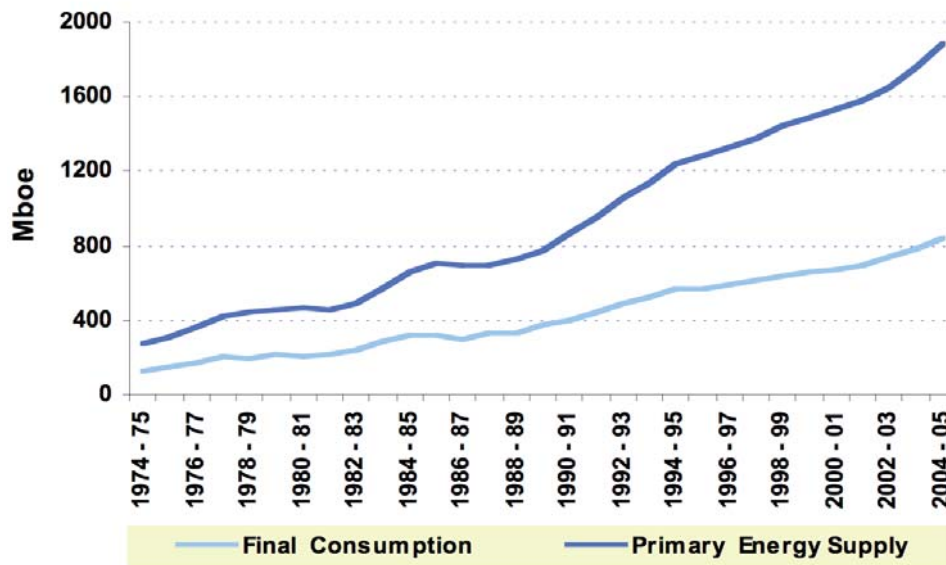


Fig. 5-5. Energy production (Primary Energy Supply) and final energy consumption in Iran, million barrels of oil equivalents. MoE 2007.

Producing more than 4 mbpd, Iran is currently one of the largest crude oil producers and exporters of the world. About 40 % are consumed domestically. Conventional crude oil production remained on a constant level in the last few years, production of unconventional oil increased steadily in the same time period. Without bringing new production wells online, crude oil production in Iran would fall at a rate of about 5 % per year. To increase total production (e.g. by 2 %), decreasing production from old wells has to be replaced (5 %) plus the additional net production increase (which then sums up to 7 % production increase). Therefore Iran is under considerable stress to modernise its production equipment.

Independent from these concrete problems of “everyday oil production” Iran is facing a far more lasting challenge: Inevitably oil production will reach its maximum, the so-called peak oil. This peak could also take the shape of a more or less pronounced plateau. However, production will decrease. There is a dispute on the possible date of peak. An overview is given in Supersberger (2007). For the analysis the peak date of 2010 was chosen, as several hints point to such an early rather than a late peak. This production path is displayed in Fig. 5-6.

## 5.4 Energy policy in Iran

The Iranian government started an ambitious substitution strategy in the 1990s, steadily replacing crude oil products by natural gas. Hence 2004 was the first year in which more natural gas than oil products was consumed (MoE 2008). This strategy was implemented via the 5-Year Development Plans that gather policy and economic goals of the Iranian government.

Oil products are mainly substituted by natural gas for heat generation (industry and households) and for electricity production, whereas the transportation sector is not experiencing these substitution efforts: currently consumption of oil products – gasoline and diesel – increases by about eight to ten % per year. Lacking refinery capacity made Iran one of the major oil products im-

porters of the region: one third of fuels consumed daily (about 60 – 70 million litres) has to be imported.

**Energy subsidies.** Soaring energy consumption is triggered partly by the very high level of energy subsidisation. Subsidies reached a size of about 15 to 20 % of total GDP, which is strongly depending on the method of subsidy calculation. Subsidies are indeed perceived as a problem and danger for the Iranian economy, but abolishment of subsidies seems politically inappropriate for the current government. The government has in fact raised energy prices in the last 15 years, but real energy prices decreased, as inflation rate exceeded price increases. All attempts to raise real energy prices in Iran failed so far.

Subsidies are most prominent in gasoline consumption, which contributes one third to total energy subsidies. Gasoline is sold at around 10 cents per liter, which is about one fifth to one fourth of international prices and below production costs.

In June 2007, a gasoline rationing system was introduced to stop the rapidly growing consumption. In this system each private passenger car can receive 30 liters of gasoline per month at a fixed price of 1000 rials (about US 11 cents) per liter. The rationing scheme did not have any significant effect on domestic consumption (due to various dodges), but it reduced the amount of gasoline smuggling to neighbouring countries.

**Electrification of rural areas** by investing in new transmission lines and by keeping the electricity price very low was one major policy project of the post-revolution era. The policy that started in the 1980's has led many rural areas to be connected to the national electricity grid and changed energy consumption and living conditions in those areas. This policy is proliferated by encouraging rural people to substitute oil products by electricity (IEA et al. 2009).

**Set-up of energy organisations.** The Iranian energy ministry established two organisations for energy efficiency/saving and renewable energies: Iran Energy Efficiency Organisation (SABA) in 1994 and Iran Renewable Energy Organisation (SUNA) in 1995. These two institutes conducted various projects on wind, solar, and geothermal energy resources but their activities are small-scale compared to Iran's problems in securing energy supply. The oil ministry established the Iran Fuel Conservation Organisation (IFCO) in 2000 to study and invest in energy efficiency in different sectors. IFCO audited manufacturing industries and elaborated recommendations for energy conservation.

#### **5.4.1 Nuclear energy policy**

There are only very few official statements on Iran's ambitions to use nuclear power. It is also difficult to find other reliable data. One reason is that nuclear plans were delayed several times. A good example is the nuclear power plant in Bushehr: after start of operation has been postponed from year to year, it has been scheduled for 2010. By 2020 nuclear power is supposed to stand at 6 to 7 GW generation capacity (IEA et al. 2009). However, it is very doubtful that such ambitious plans can be realised. While embargos and Iran's political behaviour made it a "pariah" among the international community, economic relations are getting increasingly difficult.



### **5.4.2 Renewable energies policy**

The Iranian government introduced a renewable electricity feed-in tariff in 2008/2009 for all renewable energy sources. SUNA (Iran's renewable energies agency) makes contracts with investors on power purchase. Power producers will get a tariff of 12.65 US-cents per kWh for 20 years (including adjustment for inflation). The government will accomplish the connection to the grid (probably via TAVANIR, Iran's national power company) (Atabi 2009). As the feed-in tariff has been introduced quite recently, there is no information available on its success yet.

### **5.4.3 Energy efficiency policy**

*Note 11* was introduced by the national efficiency organisation SABA and the Iranian Fuel Conservation Organisation IFCO (SABA 2005, in CEERS et al. 2006): „The only fiscal policy that has been proven successful is Note 11. Under Note 11 scheme, any industry that receives loan from any bank with any interest rate for the purpose of implementation of energy efficiency measures will be entitled to receive the amount of interest soon after completing the project. In other words, industries would receive a loan of 3 to 5 years payback from bank with a certain interest rate; but they usually receive the total amount of interest usually within 6 months. Thus such grant would mean a kind of capital for industries.“ (CEERS et al. 2006, S. 2-21). However, Note 11 was merely a small-scale program that didn't have a successor.

According to the World Energy Council there are four energy service companies, whereas SABA mentions 24. Their business actions are restricted to auditing. They don't invest in energy services (CEERS et al. 2006, WEC 2004).

## **5.5 Future development of the Iranian energy system**

This section describes possible development paths of the Iranian energy system in terms of crude oil production, natural gas production and capacity demand for electricity generation. These scenarios set a frame for the analysis of the total energy system in terms of the criteria defined in sections 2.

### **5.5.1 Production of crude oil and increasing demand**

Taking realistic oil and gas production curves into consideration (including a peak production of crude oil in the year 2010 and a subsequent decline (ASPO 2003)), Iran will lose its status as a net energy exporting country before 2040 in a Business as Usual development. The point at which consumption and production reach the same value represents the so-called “(crude oil/natural gas) equivalence point”. Fig. 5-6 shows this development for crude oil production and consumption. That trend is similar for natural gas with one major exception: owning the world's second largest gas reserves, production can be increased considerably in the next years. However, natural gas consumption is growing faster than gross domestic product due to substitution of oil products by natural gas (see above). Retaining these consumption structures Iran will become a large net importer of natural gas before 2040.

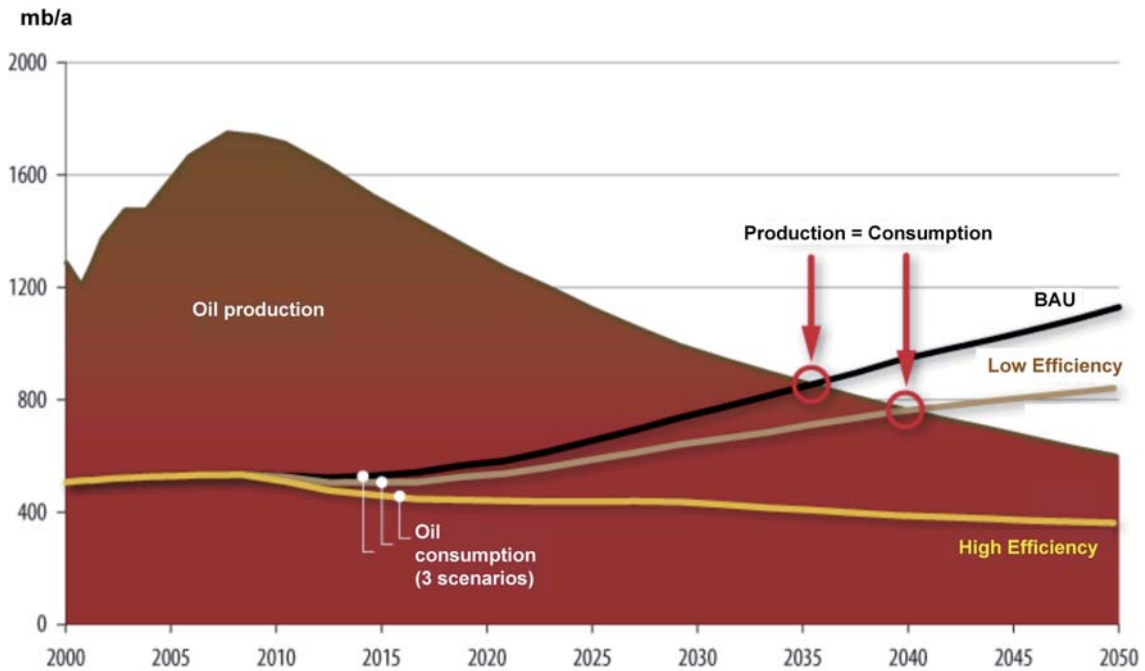


Fig. 5-6. Crude oil production and Iranian crude oil demand according to different scenarios. Supersberger 2007.

Scenarios BAU (Business as Usual) and High Efficiency are used as high and low demand scenarios. (Scenario Low Efficiency represents a middle path in the original study.) The equivalence point locates the year in which production and consumption reach the same size, which will be 2036 in BAU scenario. mb/a: million barrels per year.

Decades before this equivalence point Iran will experience more severe consequences of high consumption and sinking production of fossil fuels: export revenues will decrease. This has to be seen in the light of the strong dependence of the Iranian state on export revenues: about 80 % of the government’s budget derives from these revenues and about 90 % of total exports are crude oil currently.

### 5.5.2 Natural gas production and consumption

Long-term scenarios for natural gas production are usually very difficult to model, but in the case of Iran detailed work has been done in previous years: In accordance with Supersberger (2009) basic assumptions were made to give a description of possible development paths.

**Assumptions for natural gas production.** Production in Iran can be increased very strongly in the coming decades, as the country is just at the beginning of its “natural gas history”. Production peak will be reached in between 2020 and 2040 (plateau) with subsequent decline.

Iran is currently a net importer of natural gas but will become a net exporter for about 30 years in a high consumption scenario. By 2040 it will eventually become a net importer again. In scenario Low Consumption Iran will remain net exporter until long after 2050. For comparison of production and consumption scenarios see Fig. 5-7.

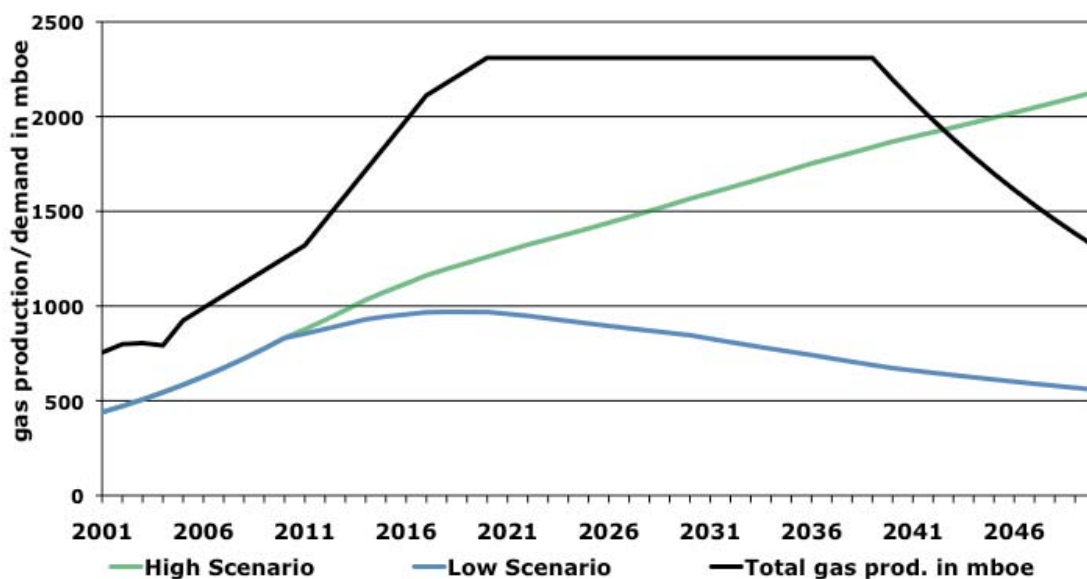


Fig. 5-7. Possible natural gas production and two scenarios of consumption of Iran. Supersberger 2007.

### 5.5.3 Power demand scenarios for Iran

Currently the major part of the Iranian electricity and heat production is contributed by natural gas. Hydropower contributes only little to the electricity sector, but Iranian energy system planning targets a bigger role for hydropower in the future. So-called “new” renewable energies don’t play a role in energy system planning.

The Wuppertal Institute conducted intensive scenario work on the Iranian energy system. Two scenarios were chosen to represent high and low growth paths (Supersberger 2007). They describe identical developments up to the year 2010. In 2011 the paths deviate: Scenario Low Capacity assumes efficiency increases throughout the whole energy system, on supply as well as demand side, whereas High Capacity follows a more traditional path of low efficiency gains.

**Scenario High Capacity.** Generation capacity increases from 2005 to 2010 by about 5 % annually. From 2011 to 2030 the increase slows down, as in the scenario the assumption was made that due to further economic development of the country the accompanying energy system will increase in efficiency (as can be seen in the historic development of industrialised countries) to about 3 to 4 % (see Tab. 5-4 and Fig. 5-8). This results in an increase in total capacity of nearly 100 % from 2005 to 2030.

Tab. 5-4. Scenarios High Capacity and Low Capacity for the Iranian power sector. Supersberger 2007.

	2005	2010	2020	2030
High Capacity	36.0	46.3	59.5	71.0
Low Capacity	36.0	46.3	52.0	48.0

**Scenario Low Capacity.** In scenario Low Capacity electricity demand grows much slower from 2011 on. Accordingly generation capacity grows at slower pace than in scenario High Capacity. In 2030 total electricity generation capacity stands at 48 GW.

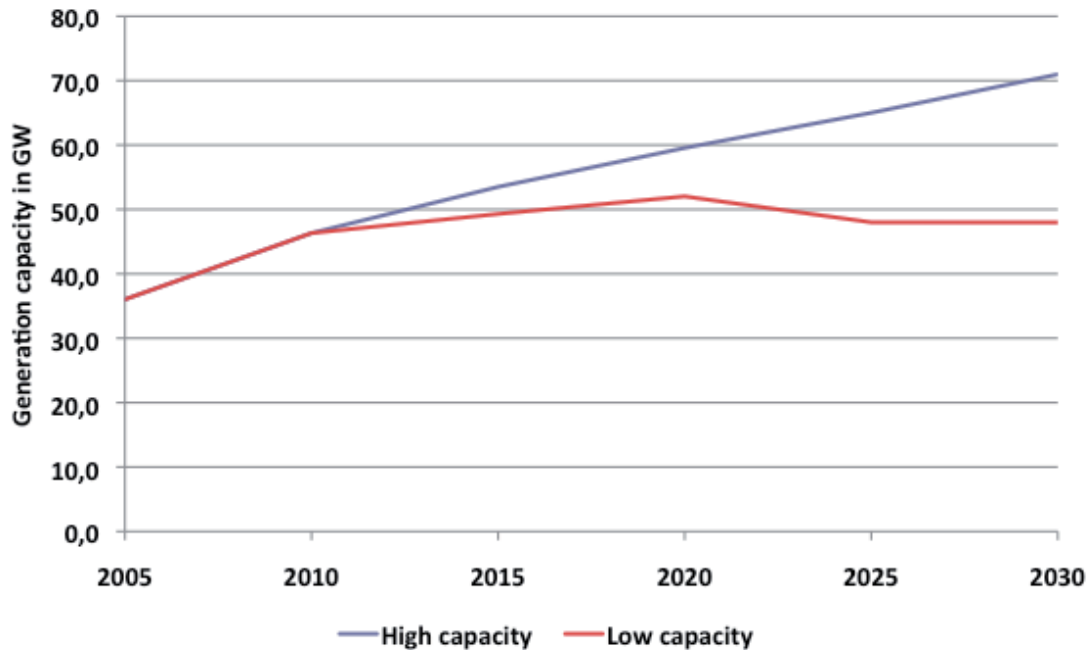


Fig. 5-8. Scenarios High Capacity and Low Capacity for the Iranian power sector. Supersberger 2007.

## 5.6 Assessment of technologies in the Iranian context

### 5.6.1 Ecosystem stability of technologies and implications for Iran

#### 5.6.1.1 “Harmlessness” of total life-cycle on environment and humans

**Nuclear energy.** Iran does own uranium ore, however, mining would be very costly and extensive. Therefore the environmental burden on this stage of the life cycle would be high. There are no statements on the open question regarding disposal of nuclear waste, but there is no reason to assume that disposal of waste could be done outside of Iranian territory, so environmental burdens would be fully within Iran. Rating: Low harmlessness of the life-cycle.

**Renewable energies.** In Iran the full range of renewables (except biomass) can be utilised. Life-cycle impacts of wind turbines and large-scale solar power plants on environment and humans are low. Their impacts resemble the impacts of other industrial processes that can be made environmentally sound via legislative measures. Materials and resources can be recycled to minimise environmental impact. This is the case for small-scale applications as well. Geothermal power generation has low negative environmental impacts.

Large hydropower plants of which Iran operates several have highly negative environmental impacts, i.e. they are not harmless. A further increase of hydropower in Iran would require the utilisation of valuable fresh water sources and could therefore create problems for ecosystems and human water cycles (e.g. via agriculture).

Rating: Solar, geothermal and wind power: High harmlessness. Large hydropower: Low harmlessness.

**Energy efficiency.** Energy-efficient appliances are harmless in terms of environmental impacts of their life-cycle. They reduce total energy demand and thus help to reduce environmental impacts of energy consumption. Their production is not more harming to the environment and to humans than are less efficient technologies. Rating: High harmlessness.

#### **5.6.1.2 “Harmlessness” of technology on direct environment / surrounding area and on humans during operation**

**Nuclear power.** The impacts of power plants during operation on direct surrounding environment and on humans will probably not be higher than in industrialised countries. However, it might occur that security hazards are higher due to lacking experience in operation of such power plants. Rating: Medium to low harmlessness.

**Renewable energies.** The environment is affected only to a small extent in the case of solar, wind and geothermal plants, as sealing of areas is low. However, some ecosystems are affected during building and operation of large-scale plants, and due to shading (mainly in the case of solar power plants (CSP and PV) desert and other arid ecosystems could be affected. Small power generation systems (small-scale photovoltaics) have no negative effect, hence they are very harmless to the environment. As geothermally active regions are very far from inhabited areas, impacts on humans would be low as well. The same is true for wind and solar energy plants that could be built away from larger population centres. Large hydropower plants have severe direct effects on the environment and on humans (alteration and extinction of ecosystems etc.).

Rating: Solar, geothermal and wind power: High harmlessness. Large hydropower: Low harmlessness.

**Energy efficiency.** The use of efficient appliances directly reduces the impact of energy consumption on environment. During their operation/life time they do not affect humans and the environment more than do less efficient appliances. Rating: High harmlessness.

Total rating of criterion “ecosystem stability of technologies and implications for Iran”:

Nuclear energy: Low.

Solar, geothermal and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: Low.

Energy efficiency: High.

## **5.6.2 Micro- and macroeconomic benefits of technologies and implications for Iran**

### **5.6.2.1 Job potential and potential for technology R&D for national development (technology multiplication effects)**

**Nuclear power.** Nuclear power plants are – compared to other energy options – not job intensive. Operation of plants requires few but very highly qualified technicians due to very high degree of automation and scale effects. Iran built up R&D expertise in nuclear technology and it is very ambitious in fostering its R&D capabilities.

Even in countries that are experienced in nuclear power plant operation and R&D the technology know-how is in the hands of only some few think tanks and clusters. Iran will probably not be able to cover the full fuel cycle on the one hand (let alone the international community would accept Iran to do so) and to produce and build power plants itself. Hence a large part of all jobs that are related to the life cycle of nuclear power plants would therefore not be situated in Iran but abroad. Rating: Low job potential.

**Renewable energies.** Small-scale renewable energy technologies are due to maintenance and other services during operation very job-intensive. They bear the potential for many jobs that can be accomplished by unskilled persons. This is valid for small-scale photovoltaic systems as well as for single wind turbines. Large-scale solar power plants are less job-intensive during operation. Large hydropower plants are comparable to nuclear power plants in terms of job potentials. On- and offshore wind farms are more job-intensive than solar power plants. Facing the high unemployment rate in Iran the operation of renewable energy technologies could be one pillar to create jobs.

Technology research and development potential is high in Iran, as the education system (universities, technical schools etc.) can be considered as good. There are various development centres that already work on renewable energies.

Iran could in mid-term perspective create domestic industries specialised on the production of the whole range of renewable energy technologies. This is due to the facts that

- Iran's economy is comprised of a large share of small and medium enterprises (SME)
- the engineering and manufacturing sector is well established and
- there are already some few companies that are active in the renewables technology sector.

Rating: Small-scale: High job potential. Wind turbines: High potential. Solar large-scale: High job potential. Large hydro: Low job potential.

**Energy efficiency.** Production of energy-efficient appliances is not more job-intensive than the production of less efficient ones. But as these technologies are equivalent to each other in terms of complexity, it would be possible to introduce such technology production to domestic industries that could become job engines in the mid term. This approach is transferable to Iran (on the structure of the Iranian industry sector see above). Being the largest economy in the region, Iran

has a strong position in terms of potential to export technologies and appliances to Arab neighbours.

Energy services bear high job potentials, and in Iran there are already several energy service companies working. However, job potential in this branch only exists if energy subsidies are reduced and higher prices create incentives for efficient use. Rating: Medium to high job potential.

#### **5.6.2.2 Affordable energy supply I: cost reduction potential in mid to long term**

**Nuclear power.** The Iranian situation is comparable to the situation worldwide. Some nuclear power plant concepts are mature and don't offer cost reduction potentials. New plant concepts like the EPR theoretically bear cost reduction potentials, however, as it can currently be seen in Finland, costs are increasing very fast during the construction phase. It has therefore to be doubted that nuclear power concepts will ever have decreasing cost or learning curves; for a list of cost projections and realised costs of nuclear power plants compare p. 35. Nuclear power plants are a factor of insecurity for economic planning in this respect. The nuclear power plant currently in construction near the city of Bushehr is probably much more expensive than scheduled in initial cost planning, and as the start of operation has been delayed several times, costs further increase. Rating: Low or no cost reduction potential in Iran.

**Renewable energies.** Solar power technologies bear global cost reduction potential: solar thermal power plants (parabolic troughs) have rather mature technology but costs can be reduced by economies of scale. This is comparable to photovoltaics. However, there is a large variety of PV technologies, and a sorting-out will happen in the coming years. Costs for PV technologies are expected to decrease drastically.

Wind power is a mature technology; cost reduction potentials are low. However, in offshore wind power cost reduction potentials are larger. The situation in Iran is comparable to the global situation. Geothermal electricity generation bears very high cost reduction potential, and together with the large natural potential this could be a trigger for more geothermal energy utilisation in Iran.

Rating: Solar power technologies: Medium to high cost reduction potentials. Wind power: Low to medium cost reduction potential. Geothermal: Very high cost reduction potential.

**Energy efficiency.** In Iran there are high cost reduction potentials for energy-efficient appliances. On broader scale energy efficiency potentials can be tapped at low costs. Rating: High cost reduction potential.

#### **5.6.2.3 Affordable energy supply II: redundancy of subsidies**

Final energy prices are very strongly subsidised in Iran. It is assumed that in mid- to long-run the Iranian government will abolish direct final energy subsidies and allow for undistorted competition in the electricity sector. It is further assumed that electricity generation costs will reflect the total costs without *hidden* subsidies (externalisation etc.). The question then is: Will technologies still have to be subsidised to be able to contribute to supply?

**Nuclear power.** The Iranian situation is comparable to the global situation. Nuclear power is economically viable because of massive hidden subsidies in the form of externalisation of costs

(costs of disposal etc.). Starting at the level of mining and upgrading high costs of health effects and environmental damages will have to be compensated for. Insurance for possible damages during operation of plants would be another major cost factor. Disposal of nuclear waste would generate additional costs. Hence if Iran introduced nuclear power to its energy system, this would only be possible with subsidisation on all levels of the fuel cycle. Other technologies would be very less cost-intensive. Rating: Very low redundancy of subsidies.

**Renewable energies.** Large hydropower plants can be operated at market conditions, i.e. without subsidisation. Good capacity utilisation assumed, hydropower is the cheapest base-load generation technology. Solar electricity technologies would have to be subsidised in Iran (as in other countries) in the coming few years. However, as insolation conditions are favourable, costs can be reduced significantly. In the medium to long term Iran will be able to operate solar power plants and wind turbines without subsidies.

Rating: Large hydropower: High redundancy of subsidies. Solar and wind power: Medium redundancy of subsidies.

**Energy efficiency.** Energy-efficient appliances need subsidisation in the short term. However, in a system free of energy subsidies, payback time would decrease rapidly. Rating: high redundancy of subsidies.

Total rating of criterion “micro- and macroeconomic benefits of technologies and implications for Iran”:

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale, and geothermal: Medium.

Large hydropower: Medium.

Energy efficiency: High.

### 5.6.3 Technical integratability into the existing and growing energy system

Between 2010 and 2020 a growing electricity capacity demand of 13.2 GW in the High scenario (respectively 5.7 GW in the Low scenario) is expected for Iran (see Fig. 5-8 and Tab. 5-4). This corresponds to a growth of 29% (12% in the Low scenario) within ten years. For the sake of comparability we assume that – like in Algeria – realistically only one nuclear power plant of an installed capacity of 1.0 GW can be erected within this period. Consequently 1.0 GW or 1.7% (1.9% in the Low scenario) will origin from nuclear electricity in 2020 (see Fig. 5-9).



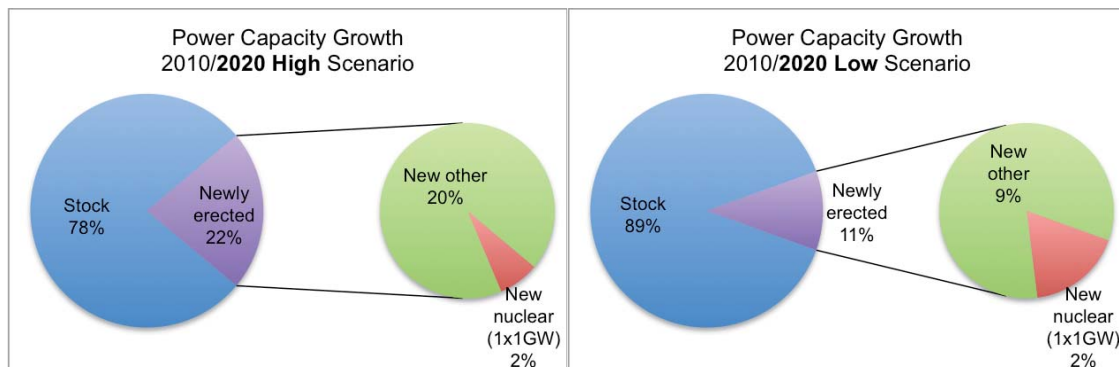


Fig. 5-9. Shares of newly erected power plants in Iran with one new nuclear power plant of 1.0 GW capacity for the scenarios High and Low Capacity within 2010 and 2020. Own calculations.

By 2030 24.7 GW according to the High scenario (1.7 GW according to the Low scenario) of new capacity must be erected. This means a capacity growth of more than 50% compared to the power plant stock in 2010. Meanwhile in the Low scenario only a slight increase of 4% would be necessary. Again assuming an implementation of a further 1.0 GW nuclear power plant in the next decade, the nuclear share would result in 2.8% in 2030. For the Low scenario a further 1.0 GW unit would lead to over-capacities, because only further 0.7 GW would be needed. If a 0.7 GW nuclear power plant would be erected in the period between 2020 and 2030, the total of the 3.5% new installed capacity would origin from nuclear energy (see Fig. 5-10, right side).

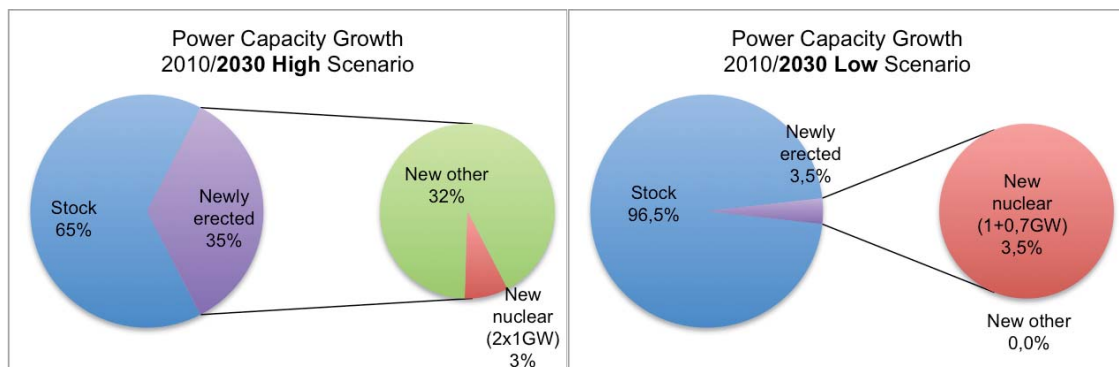


Fig. 5-10. Shares of newly erected power plants in Iran with two new nuclear power plants of 1.0 GW capacity for scenarios High and Low Capacity between 2010 and 2030 (second plant in Low Sc.: 0.7 GW). Own calculations.

#### Integration of larger nuclear power plants

The plant size of 1.0 GW was chosen because according to (Prognos 2009, p. 18) the average size of the global nuclear power plant stock is about 900 MW, while the sum of planned and suggested new installations would have an average installed gross capacity of 1.060 GW until 2020 respectively 0.980 GW until 2030 (Prognos 2009, p. 33). Principally also smaller units could be realised technically. But due to economies of scale (e.g. for expensive safety containment) smaller units probably cannot deliver electricity at competitive prices. For this reason some marketable available reactor types like the “EPR” even have considerable greater capacity in the range of 1.6 GW. To cover this possible case of larger capacity, Fig. 5-11 and Fig. 5-12 show the development for 1.6 GW power units: one unit by 2020 and – in the High scenario – a

further unit by 2030. In the Low scenario no further unit can be erected, because the additional capacity demand is only 0.1 GW and consequently too low for a nuclear power plant.

Integrating such units would pose further challenges on integration into existing small electricity grids, as their relative sizes would be significantly larger.

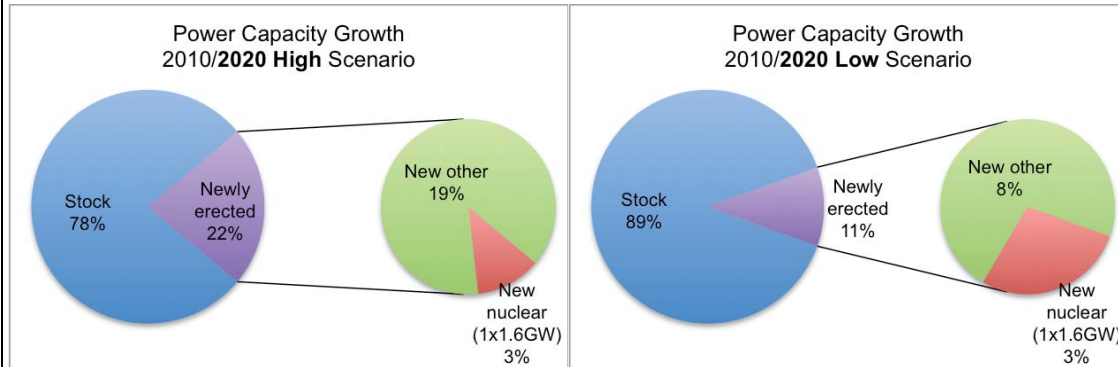


Fig. 5-11. Shares of newly erected power plants in Iran with one new nuclear power plant of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2020. Own calculations.

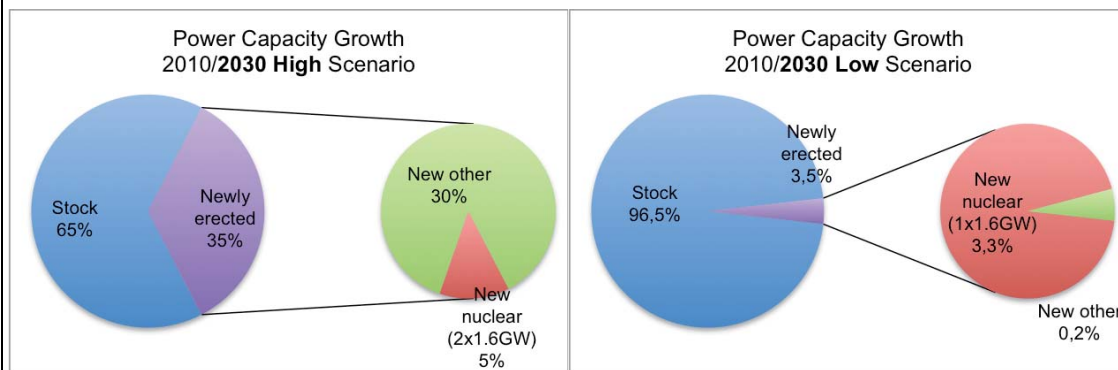


Fig. 5-12. Shares of newly erected power plants in Iran with one new nuclear power plant of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2030. Own calculations.

### 5.6.3.1 Flexibility of operation mode

**Nuclear power.** Due to technical (slow reacting system) and economic (high investment costs) restrictions nuclear power plants are only suitable for base load capacity. With regard to the relatively low shares of 1.7% (1.9% in the Low Scenario) in 2020 the establishment of *only one* single nuclear power plant in Iran would presumably cause fewer conflicts for the integration of new renewable energies with fluctuating feed in (especially electricity from wind turbines and from PV plants). Nevertheless: Due to the principal lack of flexibility of nuclear power the establishment of *several* centralised power plants would likely hamper the development of RE and EE strategies as well (see also the point below “grid integration”). Rating: Very low flexibility.

**Renewable energy.** As described above renewable energy technologies have different characteristics regarding flexibility of operation mode. CSP plants with an economic potential of ca. 20 000 TWh/a could play an important role in Iran’s future power sector. Assembled with thermal storage or gas co-firing they can deliver constant as well as flexible power. Further im-

portant RE sources in Iran like hydropower (48 TWh/a) and geothermal energy (11 TWh/a) are also flexible in power control. Wind power and PV are lacking flexibility of operation. Rating: CSP, hydro and geothermal power: High flexibility. Wind power and PV: Low flexibility.

**Energy efficiency.** Energy efficiency measures can either simply lower the need for electricity capacity (in GW) and consumption (in GWh), e.g. savings by using energy saving lamps. So-called “load management systems” only cut the load peaks. Thus the first doesn’t influence the systems flexibility of operation mode while the second improves it. There are large-cost-effective saving potentials in Iran. Yet more concrete predications aren’t possible at the moment. Rating: strong contribution to flexibility of the overall system.

### 5.6.3.2 Temporal availability of technology

**Nuclear power.** The average lead-time for planning, approval and construction of nuclear power plants is more than 10 years (Schneider/Mez 2008). The Iranian Bushehr power plant (915 MW<sub>net</sub>) even has been under construction more than 30 years (since May 1975). Constructing several (three or more) plants in Iran in the short or even in the mid term possibly could fail due to lacking construction capacity in the nuclear power sector on the one hand and due to the very high financial needs on the other hand. Rating: Very low temporal availability.

**Renewable energy.** While only few nuclear power constructors exist worldwide, the supplier market for most renewable technologies (e.g. PV, wind onshore) is decentralized and rapidly growing. This reduces the risk of (temporal) bottlenecks for production and installation of power systems. Apart from large offshore wind parks with lead times up to 10 years, renewable energy technologies in general are available within less than five years (solar thermal power plants or geothermal plants) and even often in considerably shorter periods (e.g. PV < 1 year depending on size and net integration). Rating: Medium to high temporal availability.

**Energy efficiency.** In principle, energy efficiency measures and products are immediately available and applicable. But due to an immature domestic market for energy-efficient products in Iran appropriate efficiency technology still has to be imported from abroad. Rating: Very high temporal availability.

### 5.6.3.3 Constancy/permanence of generation

**Nuclear power.** As mentioned above nuclear energy is predestined for base load operation and permanent electricity generation. Only if very large shares of the Iranian power production originated from centralised nuclear power plants problems of security of supply could arise as a consequence of predictable (maintenance work) or abrupt (accident) shut-downs. However, the Iranian electricity system is large and could therefore compensate shut-downs. Rating: High constancy of generation.

**Renewable energy.** Iran’s most favourable renewable energy technology is the large-scale CSP plant (economic potential of 20 000 TWh/a). In contrast to PV or wind plants CSP plants in hybrid mode offer a very high constancy of generation and security of power supply, independent of weather conditions, daytime or season. Hybrid mode means to add solar thermal storages or natural gas co-firing units (ISCC<sup>27</sup>) to the solar plant to guarantee permanency in power genera-

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<sup>27</sup> ISCC: integrated solar combined cycle

tion. Rating: ISCC / CSP with thermal storage, geothermal power: Very high constancy. Hydro and wind power (offshore): Medium. Wind (onshore), PV: Very low constancy.

**Energy efficiency.** Once implemented energy efficiency measures generally are permanently available. Normally they have no direct effect on the constancy of power generation. Rating: No negative impact on constancy of generation.

#### 5.6.3.4 Possibility to integrate technology into the existing grid

**Nuclear power.** In general the integration of few large centralised units<sup>28</sup> (especially large scale nuclear power plants) plus the integration of many small systems with fluctuating feed-in<sup>29</sup> (like wind and PV) into a power grid causes extra costs to maintain security of supply. But the development of (fluctuating) wind power *without boosting the grid* shouldn't cause any problems for Iran's grid in the area of about up to 3 GW in 2020<sup>30</sup>. *With grid extension* and/or with the development of additional storage capacities it should be possible to integrate more than 10 GW of new wind turbines into the Iranian network. But especially in the Low scenario, which describes a possible future efficiency path, it will be difficult to integrate new renewable energy technologies in combination with nuclear energy at all: Until 2020 the nuclear share of 18% of all newly built plants would possibly not hamper RE, but by 2030 with a nuclear share of 100% RE would have nearly vanished (Fig. 5-12). These calculations show that a nuclear expansion path doesn't fit to an ambitious RE and EE strategy. Furthermore it has to be fundamentally clarified if the grid's performance on the envisaged plant locations in Iran is high enough to take up such high capacity (of one GW) in one single supply point. Rating: Low to medium possibility for grid integration.

**Renewable energy.** Taking into account the inflexible operation mode of nuclear power plants it would be technically but also economically difficult to integrate high shares of renewable energies in the future, especially those with fluctuating feeding (see above). Costly investments into big centralised power plants like nuclear plants would predetermine this inconvenient situation for many decades. Rating for possibility of grid integration: Large scale: High (without nuclear power) to medium (low nuclear shares) to low (high nuclear shares).

**Energy efficiency.** Energy efficiency measures are easily integratable into the existing grid. Also they would release the power grid respectively would offer Iran the chance of a slower growth of power plant and power net capacity (see efficiency path). Not only new renewable power plants but also energy-efficient local CHP plants would suffer from centralised nuclear energy structures (see above). Rating: Very high possibility for grid integration.

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<sup>28</sup> The required reserve capacity has to be higher for a centralised system than for decentralised ones.

<sup>29</sup> Relevant for Iran with a regional capacity of several Gigawatt in total.

<sup>30</sup> 3 GW corresponds to 5% of Iran's expected power capacity in 2020. For comparison: In Germany there are 23.9 GW wind power, nearly 20% of the total power plant fleet capacity, which have been installed by 2008 with an electricity production of 40400 GWh/a (= 6,6% of Germany's total power consumption). (Source: AGEE Stat, June 2009

[www.erneuerbare-energien.de/files/pdfs/allgemein/application/mspowerpoint/ee\\_in\\_deutschland\\_graf\\_tab\\_2008.ppt](http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/mspowerpoint/ee_in_deutschland_graf_tab_2008.ppt)).

### 5.6.3.5 Technological status (market readiness of technology)

**Nuclear power.** In principle, nuclear power plants have been market ready for several decades. New types of the so-called “third” (like the EPR<sup>31</sup>) or “fourth generation” (only design studies at present) still have to prove their technical, economical and security performance in practice. Rating: High market readiness.

**Renewable energy.** The most important RE technology for Iran – solar thermal power plants – has been available on the market for several decades: First plants have been erected in the 1980s in Cramer Junction / California and are still operating. Also other RE sources that could be used in Iran (wind power, PV, hydropower, geothermal energy, biomass; see Tab. 5-2) have reached market maturity. Rating: Very high market readiness.

**Energy efficiency.** Energy efficiency products and measurements are mature and available on the market in a great variety. Rating: Very high market readiness.

Total rating of criterion “technical integratability into the existing and growing energy system”:

Nuclear energy: Medium.

Solar, geothermal and wind power, large-scale: High.

Solar and wind power, small-scale: Medium.

Large hydropower: High.

Energy efficiency: High.

## 5.6.4 Contribution to political stability and implications for Iran

### 5.6.4.1 Potential to reduce conflicts over resources

**Nuclear power.** In the mid 1970s, Iran imported 600 tons of yellow cake uranium from South Africa. Assessments vary, to which extent this amount has been used up. Iran is running uranium mines throughout the country, but the quality of the extracted material is unknown (ISIS 2009). Combined with the ongoing embargo towards Iran it is likely that Iran will not be able to meet its future demand of fissile material on its own. Therefore, Iran could try to find suppliers in defiance of the UN sanctions. Rating: Low potential to reduce conflicts over resources.

**Renewable energies.** Potentials for conflicts over resources used in the production of solar panels have been outlined before and also hold true for Iran. However, alternatives in the realm of solar panel production have gained more and more relevance recently. The largest part of Iran’s electricity is still produced using fossil fuels (IEA 2006). Renewable energies such as solar, geothermal and biomass might as well contribute significantly to the production of energy. If their potentials were used, they could substitute fossil fuels and further reduce Iran’s dependency on oil and gas to meeting the growing domestic energy demand. In addition, increasing re-

<sup>31</sup> The first commercial pilot plant of the “generation III” type will possibly be on line in 2012 in Olkiluoto/Finland (1600 MWnet; start of construction: 2005).

renewable energy capacities in Iran have large potentials to reduce conflicts over resources domestically as well as internationally as nascent capacities could be exported to the world market and create further revenues for Iran. This results in larger amounts of fossil fuels on the world market with two consequences. First, other countries depending on energy imports and with minor renewable energy capacities can use such resources. The global potential of energy-related resource conflicts will be reduced when Iran expands the use of its renewable energy capacities at the expense of fossil fuels. Second, one needs to consider that the continuing use of fossil fuel resources would make it more difficult to avoid the dangerous climate change and security implications of such a development (WBGU 2007; Carius et al 2008). The wide application of renewable energies is also a counter measure for such a scenario.

The case of hydropower is different though. Hydropower is already used but only to a small extent and it is likely to be expanded in the future. Yet, plans existing to develop the upper arms of the Tigris River in the border region of Iran already lead to tensions with neighbouring Iraq. Iraq's water supply will be severely affected by dams built on the Iranian side of the border (Pearce 2009). There is no agreement in place safeguarding the interests of both countries in the Tigris. Besides, talks between Iran and Iraq led to no concrete outcomes in the past. The issue is complicated by strong domestic considerations of Iran: The border region is characterized by ethnical and religious heterogeneity. Therefore, the government's plans for constructing dams are linked with internal security issues.<sup>32</sup> Rating: Hydropower has only a low potential, other renewables have a high potential to reduce conflicts over resources.

**Energy efficiency.** Technologies to improve energy efficiency offer the greatest possibilities to limit resource competition especially with respect to the fossil fuels oil and gas. High cost reduction potentials for energy efficient appliances exist in Iran. Rating: Very high potential to reduce conflicts over resources.

#### **5.6.4.2 Military harmlessness**

**Nuclear power.** Iran's nuclear energy program is widely perceived as a jigsaw piece for the development of nuclear weapons. Especially enrichment and processing of nuclear fuel could add to Iran having command over the nuclear fuel cycle, which is a key technology for the production of nuclear weapons. Iran has repeatedly emphasized its right of using nuclear energy peacefully to meet its increasing energy demand. Thus, its nuclear energy program has raised concerns throughout its neighbouring countries as well as within the international community. Iran ratified the Nuclear Nonproliferation Treaty in 1970. It allowed the IAEA inspections of its nuclear facilities since 1992. In 2005, the IAEA revealed Iran's noncompliance with its Nuclear Nonproliferation Treaty (NPT) safeguards agreement and reported to the U.N. Security Council early in 2006. Thereupon, the Council demanded Iran to suspend its enrichment program and imposed sanctions given the continuing defiance of the NPT. In its February 2009 report to the IAEA Board of Governors, the Director General, Mohamed El Baradei, pointed out that there "remain a number of outstanding issues which give rise to concerns, and which need to be clarified, to exclude the existence of possible military dimensions to Iran's nuclear programme"

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<sup>32</sup> Interview with UNEP expert, conducted on 13 August 2009 via telephone.

(IAEA 2009). Rating: Very low military harmlessness despite the declared intention for peaceful use.

**Renewable energies.** In contrast to nuclear power, renewable energy's potential for military use is low and few contentious issues are attached to it. Rating: Very high level of military harmlessness.

**Energy efficiency.** There is no relation between increasing energy efficiency and military and strategic objectives that may negatively impact the relationship with neighbouring or other countries. Rating: Very high level of military harmlessness.

#### **5.6.4.3 Contribution to transnational confidence building**

**Nuclear power.** As outlined above, Iran's nuclear energy program has raised concerns throughout its neighbouring countries and needs to be considered as a contra-productive approach to provide for regional integration and stability. There is little known about Iran's intention to use the electricity generated by nuclear power plants as pillar for a transnational energy grid. Such benefits for neighbouring countries could, at least theoretically, contribute to closer cooperation and confidence building. Rating: Low contribution to transnational confidence building.

**Renewable energies.** Exploiting the potential of renewable energy in Iran could foster transnational confidence building in two ways: First, it could lower the need for nuclear energy to meet the domestic energy demand. This could ease the international tensions attached to the Iranian nuclear energy program. Second, enhancement of Iran's renewable energy capacities opens a wide range of possibilities for technical cooperation between Iran and other states. This could foster international relations and build up trust.

Yet, especially hydropower generation could exacerbate tensions with Iran's neighbour Iraq. Plans exist to develop the upper arms of the Tigris River in the border region of Iran. It is very likely that Iraq's water supply will be severely affected by dams on the Iranian side of the border. The situation is complicated by lacking agreements between the riparian states and Iran's domestic interest in developing water management schemes in the border area. Rating: High contribution to transnational confidence building apart from hydropower expansion (low contribution).

**Energy efficiency.** There is no direct linkage between energy efficiency measures and transnational confidence building. Indirectly however, regional frameworks of energy cooperation can provide assistance how to improve the overall efficiency performance in the grid, e.g. through information sharing, dialogue facilitation and regional integration. Rating: Medium contribution to transnational confidence building.

#### **5.6.4.4 Infrastructural security (local level)**

**Nuclear power.** As for Iran's nuclear power program, many speculations have been going on in the past years regarding Israel attacking Iran's nuclear facilities. Since they are located in various spots throughout the country and often built deep underground, some experts doubt the success of an Israeli attack on Iran's nuclear program. Thus, this is not the only challenge to the infrastructural security of Iran's nuclear power plants. As mentioned above, Iran's access to fissile fuel is limited. It cannot be excluded that it might not be able to supply its nuclear power plants

with sufficient amounts of fissile material, setting the reliability of energy production by nuclear power plants at risk. Rating: Low infrastructural security.

**Renewable energies.** The mere size of the country and the different spots suitable for the generation of renewable energies suggest a rather decentralized energy system, which is less vulnerable to shocks. Rating: High infrastructural security.

**Energy efficiency.** Measures to improve energy efficiency help enhancing stability of energy infrastructures intrinsically. Rating: High infrastructural security.

Total rating of criterion “contribution to political stability and implications for Iran”:

Nuclear energy: Low.

Solar, geothermal and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: Medium.

Energy efficiency: High.

## 5.6.5 Independence of technologies and implications for Iran

### 5.6.5.1 Independence from depletable fuels (geological perspective)

**Nuclear power.** Nuclear fuel resources are limited and according to various studies depletion symptoms could soon become visible on global scale (NEA 2007). Iran has own uranium resources, but they are limited, hence Iran is no exception in this respect. Rating: No independence from depletable fuels.

**Renewable energies.** All renewable energies are independent from depletable fossil fuels. The question is, whether renewables potentials are limited, whether they can be “depleted”, hence be used to their maximum potential and which order of magnitude this will be in terms of contribution to national energy supply.

Hydropower potential is just below 50 TWh/a in Iran (see section 5.1.3). It could therefore contribute a significant share to overall electricity supply. Wind power is another option in some regions. Solar potential can be rated as “unlimited”, as solar resources exceed possible Iranian power demand by a factor between 50 and 100. Geothermal resources are limited but could contribute a small share to base-load electricity production (about 5000 MW installed capacity (see above)).

Rating: Large hydropower: Medium independence. Solar power technologies: Very high independence. Wind power: Medium independence. Geothermal power: Medium independence.

**Energy efficiency.** Low energy consumption via energy efficient appliances and energy saving are one key element for curbing dependence on depletable fuels. By using energy more efficiently the range of domestic fossil fuel resources could be extended significantly. Rating: Very high independence from depletable fuels.



### 5.6.5.2 Reducing national dependence on imported fuels (political perspective)

**Nuclear power.** Iran could operate about one to two nuclear power plants with domestic fuels. If the country intended to build more reactors, fuels would have to be imported in the medium to long term. Rating: Low to medium independence from imported fuels.

**Renewable energies.** Each unit of renewable energy used in Iran will spare fossil fuels, namely oil and gas. Hence renewable energies could contribute to keeping levels of fossil fuel exports high. This is particularly relevant for natural gas supply: currently being a net gas importer, Iran could become a net exporter, but only for about three decades, assuming that demand will increase strongly (for these dynamics compare subsection 5.5.2). By sparing natural gas in the future by building renewable powered plants, Iran could generate positive effects in terms of prolonged export capacities. Rating: All renewable energy carriers would reduce dependence on imported fuels.

**Energy efficiency.** Low energy consumption is a key strategy to reduce dependence on imported fuels. For Iran, efficiency would allow the country to keep its status as a net exporter of energy for more decades, as currently energy consumption is increasing so quick that Iran would become a net crude oil importer by 2036. Depending on the degree of efficiency this date could be shifted significantly into the future. This is particularly important in the oil products sector, as Iran is one of the world's largest oil products importers – despite its status as crude oil exporter. Rating: Very high independence from imported fuels.

Total rating of criterion “independence of technologies and implications for Iran”:

Nuclear energy: Low.

Solar, geothermal and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Large hydropower: High.

Energy efficiency: High.

## 5.6.6 Climate policy benefits of technologies and implications for Iran

### 5.6.6.1 CDM eligibility

Iran signed the UNFCCC in 1992 and ratified the convention in 1996. In 2005, it joined the Kyoto protocol. Subsequently, in 2006 Iran established a Designated National Authority (DNA). Estimates suggest that Iran's CDM potential is very high in the areas of renewable energy, energy efficiency, wastes as well as the power, oil and gas sectors. Yet, current CDM activity is still relatively low (Amous 2009). According to a study conducted in 2004, the limited private sector hinders the development of CDM projects (Jan et al. 2004). This is due to the fact that capital for investing in CDM projects is mainly concentrated in the hands of state-owned energy companies that have little incentives to invest in CDM. Besides, Iran lacks the project experience although considerable research capacities dealing with climate change adaption and mitigation exist (Ibid.).

Not surprisingly, no CDM projects have been registered so far (UNEP 2009b). However, there are three projects in the pipeline, two of them at validation stage and one requesting registration. The latter includes the capture of gas flared at offshore oil fields within the crediting period of 2009-2016 and is supported by Norway. The two activities at validation stage are about landfill gas and an efficient gas power plant (UNEP 2009b). Furthermore, there are four projects at the PIN/PDD issuing stage announced on the DNA's website. The PINs were already launched in 2004 (Iran's Climate Change Office 2009). According to estimates, Iran has a very high CDM potential in the areas renewable energy, energy efficiency, wastes, as well as in the power, oil and gas sectors whereas current CDM activity is still relatively low (Amous 2009).

**Nuclear power.** Nuclear energy is excluded as a CDM option. Rating: Very low CDM eligibility.

**Renewable energies.** The overall CDM eligibility can be considered as very high but requires first-hand experiment with the CDM procedures in Iran, which has so far not been gained. Rating: High CDM eligibility.

**Energy efficiency.** In Iran, the overall potential for energy efficiency and the comprehensive experience with the mechanism especially in the field of CDM eligibility could be considered as very high but, again, requires first-hand experiment with the CDM procedures in Iran which has so far not been gained. Rating: High CDM eligibility.

#### 5.6.6.2 Adaptation facilitation

**Nuclear power.** Nuclear power plants will be less favourable in terms of climate change adaptation, as they are dependent on coolant and could be negatively affected by decreasing precipitation and water levels of rivers. Ranking: Low potential to facilitate adaptation.

**Renewable energies.** According to Iran's Initial National Communication to the UNFCCC, most hydropower plants will be located in Southern Iran (Islamic Republic of Iran 2003, p. 93). Due to climate change, rainfall patterns will most likely change and the occurrence of droughts increase. This will have an adverse effect on the water supply for hydropower plants leading to a reduction in electricity production (ibid.). Hydropower may therefore be less favourable in terms of climate change adaptation. Heavy increases in temperature could also adversely affect electricity production by wind power turbines. This underlines the necessity of careful and provisional selection of sites for such plants. Solar power seems most likely to contribute to climate change adaptation. Ranking: High (solar) and low (hydropower) potential to facilitate adaptation.

**Energy efficiency.** Energy efficiency is enhancing stability of energy infrastructures intrinsically and is, hence, reducing the overall vulnerability of the energy infrastructure to climate extremes. Rating: High to very high potential to facilitate adaptation.

#### 5.6.6.3 Reduction of GHG

In 2003, Iran submitted its Initial National Communication to the UNFCCC. As part of the Communication, the enclosed GHG inventory showed that 84 % of Iran's GHG emissions were contributed by the country's energy production (Islamic Republic of Iran 2003). The data provided in the report dated back to 1994, yet, it is very likely that energy production still emits the

largest share of Iran’s GHG, although industry and transportation sector have grown significantly over the last decade.

**Nuclear power.** In the light of the high global warming potential of the Iranian energy mix, the use of nuclear power can, in principle, contribute to GHG reductions. However, the economical and ecological costs linked to nuclear power need also to be taken into account. Rating: High potential to reduce GHG.

**Renewable energies.** Replacing the use of oil and gas for energy production by renewable energies could contribute to lowering GHG substantially. Ranking: High potential to reduce GHG.

**Energy efficiency.** Especially energy efficiency measures in the energy production section can yield a number of benefits: Apart from substantial GHG reductions, e.g. more energy will be available for export. Ranking: Very high potential to reduce GHG.

Total rating of criterion “climate policy benefits of technologies and implications for Iran”:

Nuclear energy: Medium.

Solar, geothermal and wind power, large-scale: High.

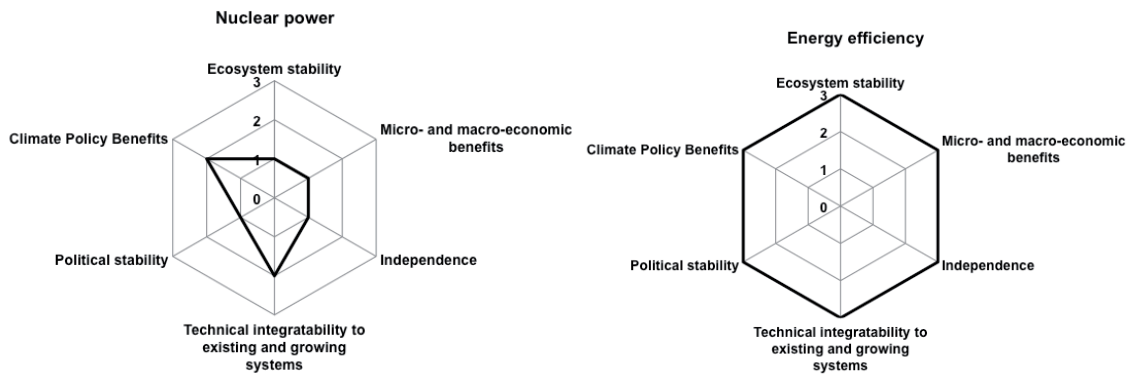
Solar and wind power, small-scale: High.

Large hydropower: Medium.

Energy efficiency: High.

### 5.6.7 Web diagrams of the Iranian technology situation

Iran operates some **uranium ore mines**, posing great burden on environment, human health and safety. As deposits are small, Iran would sooner or later have to import nuclear fuels completely, hence giving control of supply out of its own hands. Job potential of the nuclear power branch is small in Iran, and costs of plants are high. As the Iranian electricity system is large and growing steadily, **nuclear plants could be introduced without major systemic problems**, assumed that grid expansion will keep pace with overall growth. In the Iranian context nuclear power shows the smallest area in all web diagrams; compare Fig. 5-13.



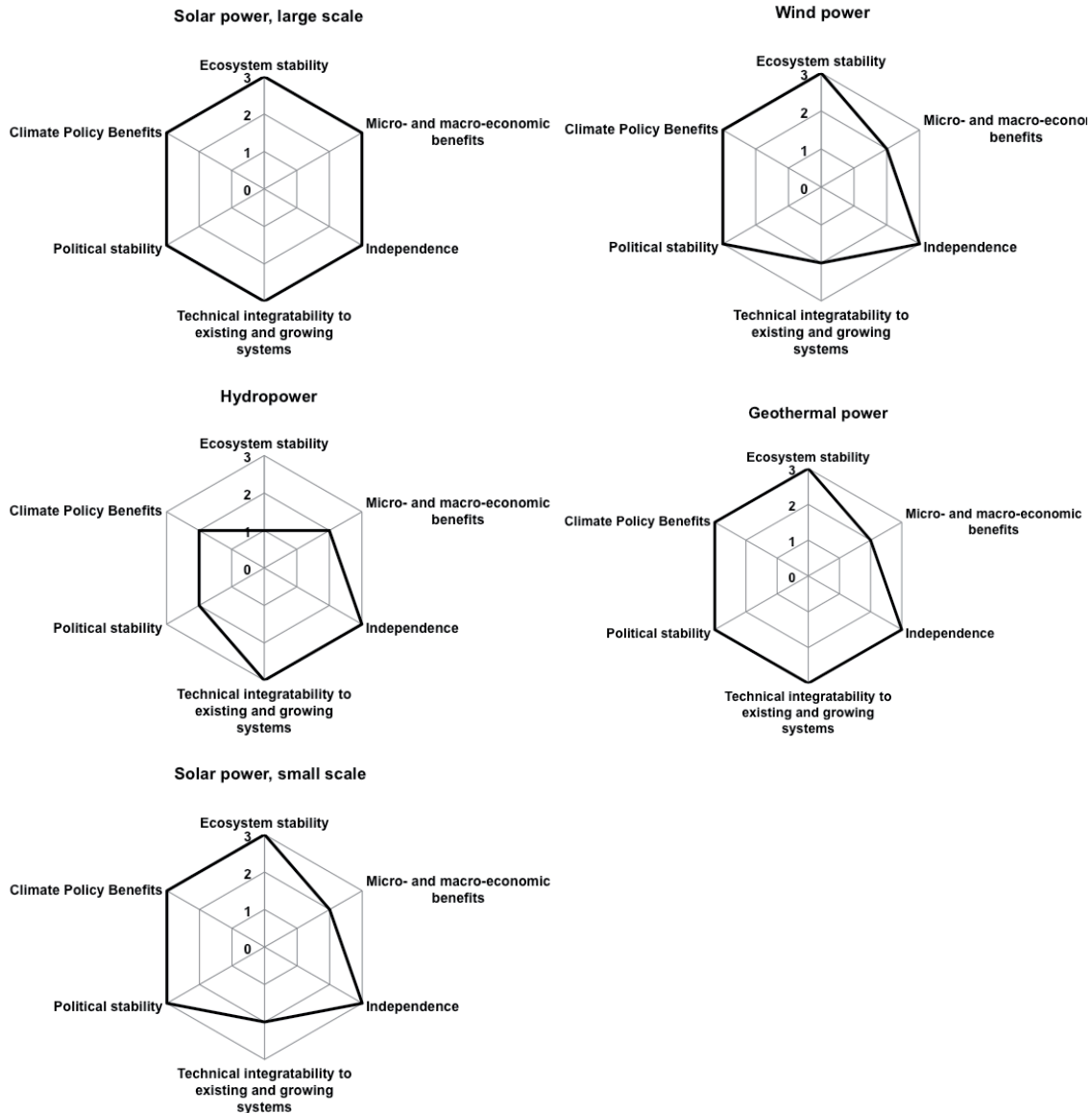


Fig. 5-13. Web diagrams for Iran. 1: Low impact, 2: Medium impact, 3: High impact on criterion.

Energy efficiency and large-scale solar power plants have maximum areas in the web diagrams, pointing to the most positive ratings. This is a consequence of the rather **well developed industrial and energy systemic structures**: many small and medium sized companies exist that could act as component suppliers for renewable technologies and/or produce energy-efficient appliances. The creation of such industries – eventually producing wind turbines and solar thermal power plants domestically – can be accomplished in medium term perspective.

As is the case with nuclear power, due to the large size of the electricity system, renewable energy technologies could be integrated soon and to large shares. This is true even in a more efficient system.

Iran has considerable geothermal power potential. This valuable base load option has various positive effects on the criteria that were analysed (Fig. 5-13).

## 5.7 Iran's energy profile and prospects for future development

Iran is a country with very large crude oil and gas reserves. It consumes 40 % of its oil production domestically and is currently a net importer of natural gas. It also imports refined oil products especially for the transportation sector. Energy demand is rising steadily in Iran, partly due to the high level of energy subsidisation. Subsidies are perceived as problem for the Iranian economy, but abolishment seems politically not appropriate. If current high consumption paths on the fossil fuel side persist, Iran will become a net importer of crude oil and natural gas as well by the mid-2030s.

Iran is actively developing a nuclear power program, which is under heavy international criticism due to security concerns. There is an embargo prohibiting the supply of components and fissile fuel to Iran. The country is running uranium mines throughout the country, but the quality of the extracted material is unknown (ISIS 2009). Taking this into account, a reliable nuclear power production seems to be at risk for a number of reasons. The following additional remarks can be made:

- It is very **unlikely that Iran will be able to build and operate 6 to 7 GW of nuclear generation capacity by 2020**, as intended by the government. As current developments show, nuclear plant constructions are delayed in Iran, and therefore it is difficult to reliably plan the integration of nuclear power.
- Iran could use **own uranium resources**, but they are scarce and would not allow fuelling more than one plant during full operation life.
- Integration of nuclear generation capacity would be possible probably without major technical difficulties.
- Nuclear power bears considerable potential for conflicts.

As Iran is relying heavily on fossil fuel exports and as domestic energy demand is projected to increase, the switch to renewable fuels and implementation of energy efficiency measures is advisable. Regarding renewable energies it can be stated that:

- **Potentials for renewable energies are large**, especially solar and geothermal power. There is significant wind power potential as well, e.g. located in N-E Iran. Geothermal potentials are located far from inhabited areas, hence usage for electricity production is more likely than for heat supply. Hydropower is currently used to limited extent. Plans for developing hydropower in the South as well as at the tributaries to the Tigris exist. Yet, while the latter may trigger conflicts with neighbouring Iran, hydropower plants in the South may be more vulnerable to climate change.
- Iran's electricity system is large, **renewable energy technologies could be integrated without major technical problems**, set the case that grid infrastructures get modernised as scheduled.
- The Iranian government introduced a renewable electricity feed-in tariff in 2008/2009 for all renewable energy sources. But investors were not attracted yet. Conditions in Iran are cur-

rently not favourable for renewable energies under the CDM. Yet, if the private sector gained more importance in the future, these potentials could be used.

- **Job potential in Iran is high** for renewable energy technologies and maintenance and operation of plants, and due to the existing industrial infrastructures these potentials could be tapped.
- If renewable energies provided a reliable and cost efficient alternative to Iran's nuclear power plans, they could contribute significantly to easing the tensions related to Iran's nuclear ambitions.

The situation of energy efficiency allows the following conclusions:

- There is large potential for applying energy efficiency measures in Iran. An Iranian Energy Efficiency Organisation (IEEO - SABA) has been established.
- Already in 2036 Iran could become a net importer of crude oil. Even with only slight efficiency enhancements this date could be shifted considerably into the future; dynamics in the natural gas sector are comparable.
- Iran had some energy efficiency initiatives running in the past.
- **Energy services** could be established in Iran as a business branch, but before this could be realised, energy subsidies would have to be abolished.
- **Energy efficiency bears large job potential.** Industry infrastructures in Iran are suitable for the creation of energy efficiency branches

### **International energy and climate governance**

Iran shares the fear of many other OPEC countries regarding adverse effects of the international climate change regime on its economy. Yet, the countries climate and its domestic basis for water and food supply will be severely affected by rising temperatures. This may have contributed to Iran's growing engagement for renewable energies aside from its rising energy demand and its fiscal dependency on fossil fuel exports. Iran – as a country struggling with unemployment and an economy without diversification – has also recognized the benefits attached to it, such as making use of CDM, positive effects on job creation and encouraging the development of a private sector. Iran has also been a founding member of the International Renewable Energy Agency (IRENA).

## 6 System Analysis of the United Arab Emirates, ARE

### 6.1 Production and availability of energy resources

#### 6.1.1 Crude oil and natural gas production and reserves

The United Arab Emirates is an OPEC member with large **crude oil reserves**. BP and OPEC agree at 97.8 gigabarrels that represent ten % of OPEC's total reserves. This close match means that BP and OPEC use the same data source or that BP used data from OPEC. The ARE's production share stood at 8 % of OPEC's total production (in OPEC's statistics: 2.53 mbpd of 32.08 mbpd, in BP's statistics 2.92 mbpd of 35.20 mbpd) (BP 2008, OPEC 2008).

Domestic consumption is low compared to production: In 2007 a mere 0.22 mbpd of refined products were consumed. Export share of production is thus above 90 % (see Fig. 6-1).

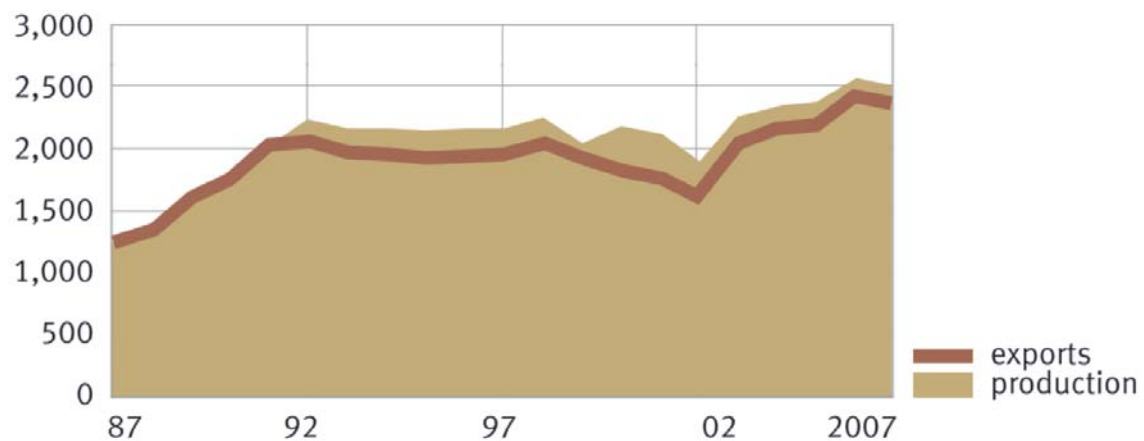


Fig. 6-1. Crude oil production, exports and domestic consumption of the ARE. OPEC 2008.

Conclusion: The ARE is an OPEC member with large oil reserves and low domestic absorption.

The ARE increased their natural gas production continuously over the last decades. In 2007 gross production reached 74.6 bn m<sup>3</sup>, of which 50 bn m<sup>3</sup> were marketed production. The share of flaring is negligible in the ARE, re-injection made about 18 bn m<sup>3</sup>, shrinkage (losses) 5.7 bn m<sup>3</sup> (OPEC 2008). The ARE's share in OPEC total share is below ten %.

#### 6.1.2 Export of energy

The major part of crude oil exports is shipped to Asia (> 90 %), mainly to Japan (70 %). For the structure of the Emirati crude oil shipping see Tab. 6-1.

Tab. 6-1. Crude oil exports from the ARE. OPEC 2008.

<b>United Arab Emirates</b>	2003	2004	2005	2006	2007
<b>North America</b>	<b>7.0</b>	<b>5.0</b>	<b>9.0</b>	<b>6.6</b>	<b>12.3</b>
United States	7.0	4.7	9.0	6.1	4.2
<b>Latin America</b>	-	-	-	-	-
<b>Eastern Europe</b>	-	-	-	-	-
<b>Western Europe</b>	-	-	<b>5.0</b>	<b>28.2</b>	<b>20.3</b>
France	-	-	2.6	24.4	17.6
Germany	-	-	-	-	-
Italy	-	-	-	-	-
Netherlands	-	-	-	-	-
United Kingdom	-	-	1.8	3.7	2.7
<b>Middle East</b>	-	-	-	-	-
<b>Africa</b>	<b>28.0</b>	<b>30.0</b>	<b>41.0</b>	<b>34.4</b>	<b>33.2</b>
<b>Asia and Pacific</b>	<b>2,013.0</b>	<b>2,137.0</b>	<b>2,140.0</b>	<b>2,351.1</b>	<b>2,276.9</b>
Japan	1,224.0	1,047.7	1,508.2	1,626.8	1,575.4
<b>Unspecified</b>	-	-	-	-	-
<b>Total world</b>	<b>2,048.0</b>	<b>2,172.0</b>	<b>2,195.0</b>	<b>2,420.3</b>	<b>2,342.7</b>

### 6.1.3 Coal and uranium sources

The ARE do not own significant coal or uranium reserves.

### 6.1.4 Renewables potentials

There are significant potentials for the use of renewable energies. According to satellite measurements solar irradiation is very high in the ARE (see Tab. 6-2). UNEP conducted wind velocity measurements to specify suitable wind power areas. However, these data could not be assessed by the project team.

Tab. 6-2. Economic electricity supply side potential of renewable energies in United Arab Emirates, TWh/a. Brackets: technical potential. DLR 2005, IEA 2008.

TWh/a	CSP	PV	Power generation ARE 2006
Economic potential	1988	3.0	62 TWh
Performance indicators	DNI: 2200 kWh/m <sup>2</sup> /a	Global horizontal irradiance: 2120 kWh/m <sup>2</sup> /a	

Windpower, geothermal and hydropower: no data available. Biomass: negligible. CSP: from direct normal irradiation (DNI) and CSP site mapping taking sites with DNI > 2000 kWh/m<sup>2</sup>/a as economic.

## 6.2 Domestic energy demand system: history and present

The ARE's economy and energy demand grew at a very high pace in the past. In phases of high oil prices the emirates' governments set up investment funds that were fuelled by additional oil revenues. Energy demand per capita is among the highest in the world. The reasons are mainly very energy intensive infrastructures (large distances within cities, strong demand for desalination combined with waste of fresh water, and others), high consumption of cars and poor insulation of buildings.



Absolute electricity demand grew by 8 to 10 % per year in the last decade. The main fuel in the electricity sector is natural gas, which is partly imported from Qatar. The strong growth in primary energy consumption mainly derives from an increasing natural gas demand due to a rising electricity demand. However, crude oil products consumption in the transport sector is rising at high pace as well. Renewable energies are absent in the ARE's energy system so far.

As domestic demand takes only about ten % of total crude oil production, there is no specific concern about a possible conflict between rising domestic consumption and decreasing exports (or decreasing foreign currency earnings due to oil exports). Natural gas imports from Qatar are the size of 2 bn m<sup>3</sup> annually and are satisfying a small share of the ARE's natural gas demand (BP 2009).

Energy is subsidised in the ARE. Electricity prices are varying within the ARE: Emirate nationals pay subsidised prices, whereas foreigners pay much higher rates. Gasoline costs about 45 US-cent per litre in 2008, diesel about 62 US-cent per litre (gtz 2009). These prices are below the retail prices in the United States of America.<sup>33</sup>

### **6.3 Energy intensity and energy efficiency potentials**

According to IEA, per capita energy intensity in the ARE is about 2.5 times as high (above 10 toe/capita) as in Germany (4.2 toe/capita), energy intensity per GDP the like (ca. 0.4 toe/1000US\$<sub>2000</sub> vs. 0.17 toe/1000US\$<sub>2000</sub>) (IEA 2008)<sup>34</sup>. For comparison: World average is 1.8 toe/capita and 0.3 toe/1000US\$<sub>2000</sub>. Income per capita in the ARE was 26800 US\$<sub>2000</sub>/capita, in Germany 24400 US\$<sub>2000</sub>/capita in 2007 (own calculations using IEA 2008), world average was 5800 US\$<sub>2000</sub>/capita. The ARE are an industrialised country according to economic parameters. However, speaking in these terms, the ARE would be a very inefficiently working industrialised country. Reducing energy intensity to the level of Germany's intensity (as example of a medium-efficient industrialised country), the ARE's energy consumption would about halve.

### **6.4 Energy policy in the ARE**

Energy policy is mainly in the responsibility of single emirates. However, the national Ministry of Energy is covering nation-wide aspects. Abu Dhabi as most powerful emirate takes kind of a leading role in many aspects. Energy systemic aspects have to be discussed within this dual structure.

In the ARE active energy policy in the form of fostering certain energy carriers was absent in former decades, apart from the introduction of natural gas to replace crude oil products in domestic consumption. However, the perceived necessity to diversify supply sources created the need for some kind of energy system planning. This was also fostered by the implementation of a GCC-wide electricity grid, which will be finalised in 2010 (Al-Asaad/Ebrahim 2007/2008).

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<sup>33</sup> Quote GTZ: "Retail price of Gasoline is above the price for crude oil on the world market and below the price level of the United States. Note: The fuel prices of the United States are average cost-covering retail prices incl. industry margin, VAT and incl. approx. 10 US cents for the 2 road funds (federal and state). This fuel price may be considered as the international minimum benchmark for a non-subsidised road transport policy." (gtz 2009)

<sup>34</sup> As mentioned before, data by the IEA on ARE have to be treated with care due to low reliability.

The most important motivations for the introduction of nuclear energy and renewable energies into the ARE's energy system are: Supply diversification in the light of a possible natural gas shortage with ever growing energy demand on the one hand and the maintenance of high crude oil export levels on the other hand. The aspect of cheap electricity supply to foster economic growth might be another motivation. According to the Ministry of Energy, the "heavy future reliance on liquids would entail extremely high economic costs as well as a significant degradation in the environmental performance of the ARE's electricity sector" (MoE 2008, p. 1).

Coal is perceived very differently than nuclear fuels. The quoted report characterises the coal option as bearing "thorny issues related to security of supply" (MoE 2008, p. 3).

The only data set that could be obtained from ARE sources that can be interpreted as background data for energy system planning up to 2020 is the development of the ARE's electricity generation capacity increasing by 9 % per year (MoE 2008). This path (Fig. 6-2) is assuming a more or less constant high growth of electricity generation capacity at around 9 % per year.



Fig. 6-2. Possible development of the ARE's power generation capacity with "roughly 9% from 2007 onward". Quote and original graph taken from MoE 2008.

There is no detailed energy system planning available yet. But a strongly diversified energy mix was proposed by Khalid Al Awadi, energy expert at Emarat: In 2020 the ARE electricity mix could consist of 30 % nuclear energy, 15 % coal and 5 % renewables, the rest (50 %) being contributed by natural gas (GulfNews 2008). Assuming that total capacity could reach ca. 41 GW, this would translate to 12 GW nuclear, 6 GW coal and 2 GW renewables generation capacity. These data stand in contrast to official announcements and plans.

Abdullah Al Mutawa, director of the Ministry of Energy's electricity department, pointed out the three pillars of the ARE's future electricity system: nuclear power, renewable energies and

the GCC grid (ArabianBusiness 2008). Renewable energies are believed to be able to contribute to supply “5-7% of the UAE’s peak electricity demand by 2020”. This is the only statement on the possible role of renewable energy carriers on national scale.

Nuclear energy ambitions are twofold in the ARE: They exist on national and on GCC scale. The IAEA conducted a pre-feasibility study for the GCC in the context of a common GCC electricity grid (finalised in November 2007). In a subsequent step the IAEA assists the GCC in preparing an in-depth feasibility study covering topics of technology selection, economic aspects and others. One of the most relevant questions for GCC-wide nuclear power utilisation is the site selection for future plants: They could be located either in one country (creating one centralised nuclear electricity generation centre) or in each member country. This is a question of great concern, as most GCC members are interested in operating plants on their own territory.

The ARE’s national plans partly thwart GCC’s common ambitions. The ARE are pushing nuclear energy forward ambitiously and could be the first country in the Middle East (apart from Iran) to operate nuclear reactors. Frame conditions are favourable, as the ARE have financial means not only to build reactors, but also to acquire foreign expertise for the full infrastructure. With the first reactor coming on-grid in 2017 as earliest date, the ARE are expected to open international tender procedures on such a project. Currently the ARE do not have any domestic expertise in nuclear matters, but ties with the USA, Great Britain, France and Japan try to compensate this lack.

According to the World Nuclear Association the ARE plans to build 20 GWe of nuclear generation capacity with 14 plants in total “with nearly one quarter of this operating by 2020” (World Nuclear Association 2008). However, these data were not found in official publications and can be doubted. Most sources mention three nuclear power plants that are projected to supply electricity by 2020 without giving information on the time frame beyond 2020.

There is no nuclear energy law drafted yet, but a nuclear energy office has been established. The Nuclear Energy Program Implementation Organization has set up the Emirates Nuclear Energy Corporation ENEC. ENEC is acting as evaluation and implementation body for the ARE’s nuclear power plans and is funded with 100 million US\$ (WEA 2008).

The ARE government has signed various memoranda with other countries’ governments. Great Britain, USA and France are currently the dominating actors in this respect. The ARE signed full bilateral accords with France and the USA. In January 2009 the ARE signed a memorandum of understanding with Japan (Business 2009, IISS 2009).

Despite these accords and memoranda, the final decision to actually start construction – which can be interpreted as the first no-return-landmark – has not been passed yet. In spring 2008 the ARE cabinet approved the mentioned policy statement on nuclear energy. However, this statement contains the phrase “should the UAE proceed with the development of a peaceful nuclear energy program...” (MoE 2008, p. 7) which hints to the possibility to abandon nuclear power if in future frame conditions should change.

### **6.4.1 Nuclear and renewable energy policies, and energy efficiency policy**

On ARE level there are no concise statements on quantitative targets for renewable energies. Several emirates however started initiatives and phrased basic strategies to foster renewables.

*Abu Dhabi.* The government of Abu Dhabi committed itself to the target of 7 % renewable generation capacity by 2020. Projecting total generation capacity at around 20 GW by 2020, this translates to 1.5 GW. As load hours are lower in such plants than in conventional ones, contribution to electricity production would be significantly lower.

1.5 GW of capacity could be contributed by six concentrating solar power plants at a size of 250 MW each. This is what is currently envisaged by the Masdar Initiative, but not yet published officially. Currently one solar power plant is in the construction phase, about 120 km south of Abu Dhabi city.

The Masdar Initiative, a multi-billion dollar fund to establish the ARE as a leading player in the renewable energy branch globally, combines different strategies: Masdar City is the 22 bn US\$ commitment to build a new city for 50000 inhabitants that is completely supplied with carbon-neutral energy. Masdar Institute, planned by the Massachusetts Institute of Technology (USA), will focus on research and development and will establish a high-level education programme for students world-wide on university level. Masdar Invest currently invests into companies worldwide, e. g. in WinWinD, a Finnish wind turbine producer, and is also building own production facilities, e. g. in Germany (Masdar PV). Other branches of the Masdar Initiative specialize in carbon trading and other branches.

*Dubai.* The government adopted a sustainable development policy (“Dubai Strategic Plan 2015”) covering all aspects of society. In the energy branch green building standards and water and energy conservation and management as well as green power generation are relevant aspects. A newly formed “Renewable Energy Division” will set up plans and instruments (Raouf 2008). As building standard the so-called LEED, Leadership in Energy and Environmental Design, was introduced. Rising energy tariffs will increase energy prices significantly for foreigners. This approach is supposed to lead to a more environmentally aware use of energy (Dubai 2008). The world’s first renewable-energy-powered skyscraper (so-called BUtj Al Taqa, Energy Tower) will be completed in Dubai in 2009.

A study for a 1 bn \$ wind power farm has been conducted in Dubai. Its goal is to shift 10% of Dubai’s energy supply to wind energy. However, this information could not be cross-checked. Implemented projects are: solar cooling of an apartment complex and the utilisation of solar energy to operate a hot water system in a hotel.

*Fujairah.* In Fujairah Free Zone a solar-cell production line has been established. The emirate further plans to introduce 200 MW of wind power to its grid through several wind farms (Raouf 2008).

Currently there are no policies towards the enhancement of energy efficiency on national scale. Dubai introduced the LEED standard, see above.

## 6.5 Future development of the ARE energy system

This section describes possible development paths of the Emirates' energy system in terms of crude oil production, natural gas production and capacity demand for electricity generation. These scenarios set a frame for the analysis of the total energy system in terms of the criteria defined in section 2.

### 6.5.1 Crude oil production and consumption scenarios

Crude oil production in the United Arab Emirates will eventually reach its peak. This peak was assumed to occur in 2010 with a subsequent decline of 1 % per year. This can be seen as “bad case” development in contrast to optimistic statements on production dynamics. Rationale for this is 1) production profile of the ARE shows a slight upwards trend, but production is getting increasingly difficult. 2) A “bad case” pays tribute to the fact that mid- and long-term system planning and decision making should include *precautionary principle* aspects: if there are insecurities in the data base, there should be safe-guarding measures in case that resources can't be produced as optimistically as assumed. This production profile sets the frame for crude oil supply. On demand side two scenarios were modelled: High Consumption and Low Consumption.

**Assumption for High Consumption.** Consumption of crude oil (i.e. crude oil products) increases from 2008-2020 by 6 % annually. This is a rough average value of the data from 2001 to 2007. From 2021 consumption was set to increase by 4 % per year. This overall trend is typical: consumption increases slow down during economic development. However, the ARE's energy consumption is growing at a very high level and so this typical behaviour was shifted to reflect this. Despite strong consumption growth in scenario High Consumption the ARE will not become a net importer of crude oil before 2060 (see Fig. 6-3 on this trend).

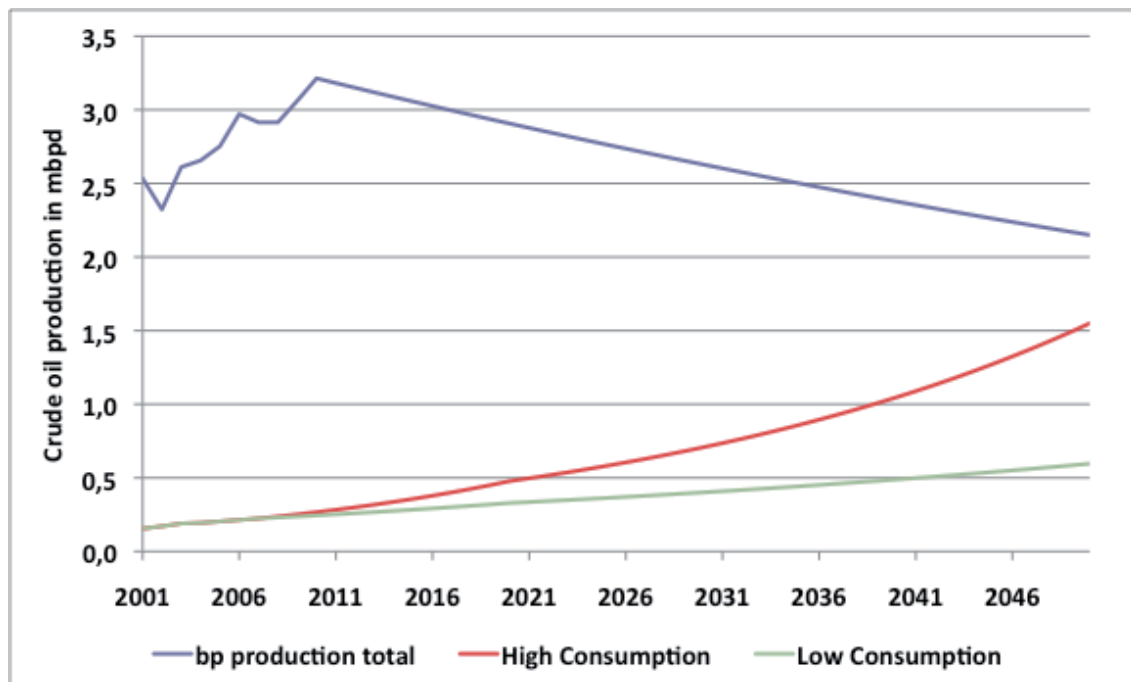


Fig. 6-3. Crude oil production and consumption, scenario High Consumption and Low Consumption, United Arab Emirates. Own calculations.

**Assumption for Low Consumption.** Consumption grows half as quick as in High Consumption: by 3 % annually from 2008 to 2020 and by 2 % from 2021 onwards. In this scenario The ARE will be able to retain its status as crude oil exporter for very much longer than in scenario High Consumption.

### 6.5.2 Natural gas production and consumption

Long-term scenarios for natural gas production pose a great challenge in terms of assumptions, as there are only few data available and the dynamics of gas production depend on a multitude of different factors. However, some basic assumptions were made to give a broad description of possible development paths.

**Assumptions for natural gas production.** Production in the ARE currently is at maximum due to difficulties in geologic formations. Beginning in 2011 production will decrease by 1 % per year. Soaring demand made the ARE become a net importer of natural gas from Qatar (via the Dolphin pipeline). From 2006 to 2008 consumption increased by about 30 % (BP 2009).

Consumption has been modelled in the High Consumption scenario to increase by 5 % annually (average between 2001 and 2006) between 2009 and 2020, decreasing to 2.5 % per year afterwards. In scenario Low Consumption increase is 2.5 % and 1 % respectively.

In these scenarios, the ARE will always remain a net importer of natural gas. For clarification of these trends see Fig. 6-4.

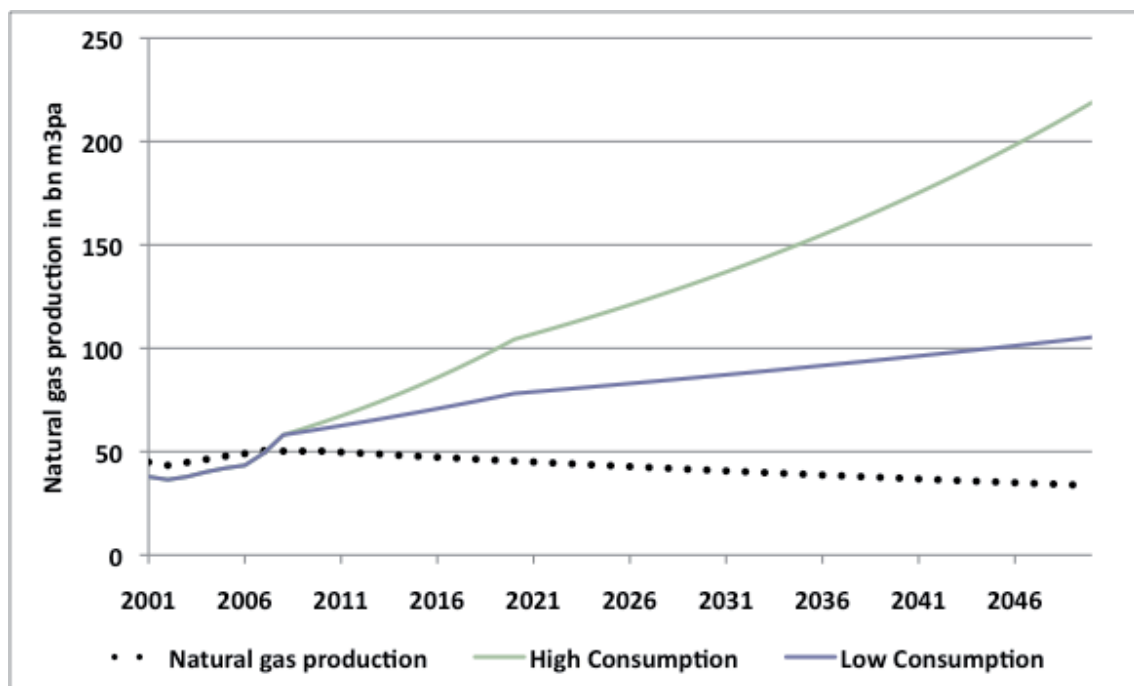


Fig. 6-4. Possible natural gas production and two scenarios of consumption of the United Arab Emirates. Own calculations.

### 6.5.3 Power Demand Scenarios for the ARE

The ARE's Ministry of Energy published a forecast for the Emirates' electricity generation demand up to 2020 (MoE 2008). Annual growth of total generation capacity is above 9 %, resulting in an almost quadrupled demand from 2006 to 2020.

**Scenario High Capacity.** The forecast of MoE (see above) was set as high growth path of the electricity system. The period from 2021 to 2030 was subsequently modelled applying own assumptions: After the phase with extremely high growth up to 2020 demand for new power generation capacity decreases but remains on a high level with 5 % per year, resulting in a total power capacity of 66.5 GW (see Tab. 6-3 and Fig. 6-5). This represents a six-fold increase within 24 years (2006 – 2030).

Tab. 6-3. Scenarios High Capacity and Low Capacity for the Algerian power sector. Own calculations.

	2006	2010	2020	2030
High capacity	11.7	21.5	40.9	66.5
Low capacity	11.7	14.8	26.5	35.7

**Scenario Low Capacity.** Scenario Low Capacity was modelled independently from the official forecast: Deviating from the very strong increase in generation capacity, Scenario Low Capacity implicitly assumes some efficiency efforts to curb consumption growth, reflecting an annual capacity increase of still 6 %. After 2020 increase slows down to 3 % per year. Total generation capacity stands at 35.7 GW in 2030.

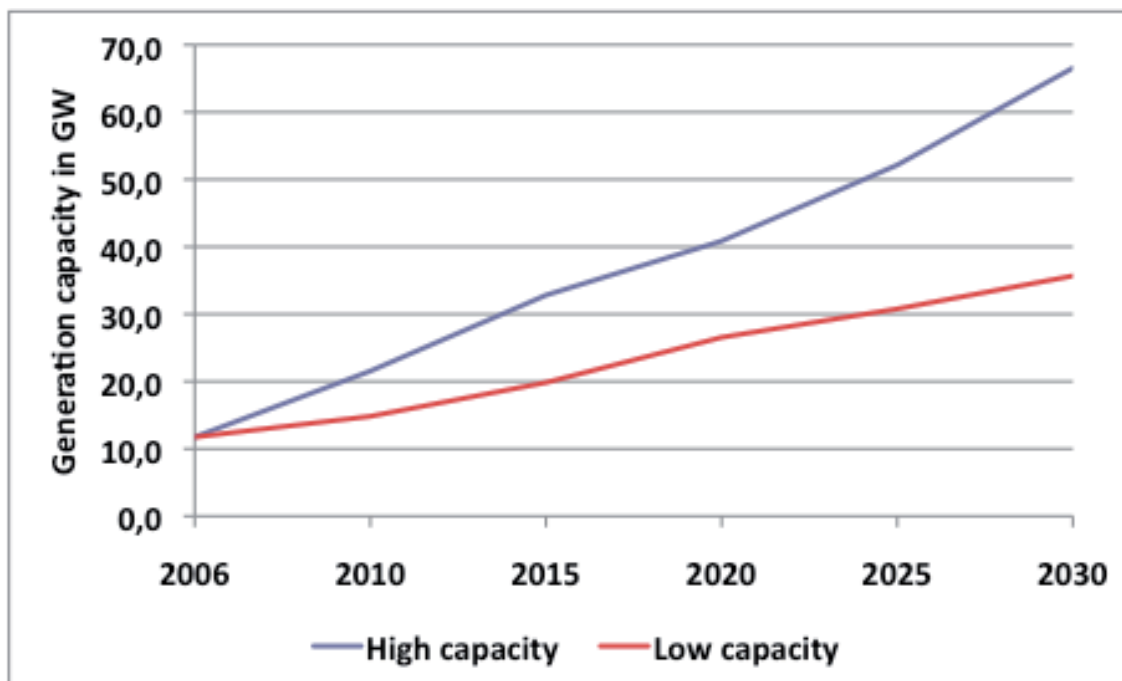


Fig. 6-5. Scenarios High Capacity and Low Capacity for the ARE's power sector. MoE 2008 and own calculations.

## 6.6 Assessment of technologies in the Emirates' context

### 6.6.1 Ecosystem stability of technologies and implications for the ARE

#### 6.6.1.1 "Harmlessness" of total life-cycle on environment and humans

**Nuclear energy.** The Arab Emirates does not own uranium ore, it would have to import nuclear fuels. Further it stated that it intends to return depleted nuclear fuel rods to the supplier. Using such a scheme means maximum externalisation of environmental burdens of the nuclear life-cycle. Seen from the ARE's perspective: There would be no environmental burdens before and after the use of fuel in power plants. Rating: High harmlessness of the life-cycle.

**Renewable energies.** In the ARE solar and wind energy can be utilised. Life-cycle impacts of wind turbines and large-scale solar power plants on environment and humans are very low. Their impacts resemble the impacts of other industrial processes that can be made environmentally sound via legislative measures. Materials and resources can be recycled to minimise environmental impacts. This is the case for small scale applications as well. Rating: Solar and wind power: High harmlessness.

**Energy efficiency.** Energy efficient appliances are harmless in terms of environmental impacts of their life-cycle. They reduce total energy demand and thus help to reduce environmental impacts of energy consumption. Their production is not more harming to the environment and to humans than less efficient technologies are. Rating: High harmlessness.

#### 6.6.1.2 "Harmlessness" of technology on direct environment / surrounding area and on humans during operation

**Nuclear power.** The impacts of power plants during operation on direct surrounding environment and on humans will probably not be higher in the Emirates than in industrialised countries. However, it might occur that security hazards are higher due to lacking experience in operation of such power plants. Rating: Medium to low harmlessness.

**Renewable energies.** Solar power plants and wind turbines affect the environment only to a small extent, as sealing of areas is low. However, some ecosystems are affected during building and operation of large-scale plants, and due to shading (CSP and PV) desert ecosystems could be affected. Small power generation systems (small-scale photovoltaics) have no negative effect; hence they are harmless for the environment and for humans. Rating: Solar and wind power: High harmlessness.

**Energy efficiency.** Efficient appliances directly reduce the impact of energy consumption on the environment. During their operation they do not affect humans and the environment more than less efficient appliances do. Rating: High harmlessness.



Total rating of criterion “ecosystem stability of technologies and implications for the United Arab Emirates”:

Nuclear energy: High.

Solar and wind power, large-scale: High

Solar and wind power, small-scale: High.

Energy efficiency: High.

## 6.6.2 Micro- and macroeconomic benefits of technologies and implications for the ARE

### 6.6.2.1 Job potential and potential for technology R&D for national development (technology multiplication effects)

**Nuclear power.** Nuclear power plants are – compared to other energy options – not job intensive. Operation of plants requires few but very highly qualified technicians due to the high degree of automation and scale effects. The ARE has not built up R&D expertise in nuclear technology yet. Even in countries that are experienced in nuclear power plant operation and R&D the technology know-how is in the hands of only a few think tanks and clusters.

The Arab Emirates will probably not produce parts and build own nuclear power plants domestically. This is inhibited partly by the lacking industrial infrastructures. A very large part of all jobs that are related to the nuclear power industry would therefore not be situated in ARE but abroad. Rating: Low to no job potential.

**Renewable energies.** Small-scale renewable energy technologies are very job intensive during operation due to maintenance and other services. They bear the potential for many jobs that can be accomplished by unskilled persons. This is valid for small-scale photovoltaic systems as well as for single wind turbines. Large-scale solar power plants are not job intensive during operation. On- and offshore wind farms are more job intensive than solar power plants. In mid to long term perspective the Emirates could create domestic industries specialised on the production of technologies. In the recent past promising attempts were made to foster the creation of such industries. The same holds true for education and training infrastructures. The Masdar initiative intends to build a complete research and development infrastructure on ARE territory, and together with participations in companies worldwide such a renewable energy cluster could initiate positive job and capacity building effects. Currently technology research and development potential is medium in ARE, as the education system (universities, technical schools etc.) can be considered as good but not as deeply structured than e.g. in Western European countries. In the mid to long term there is potential for more R&D activities.

Rating: Small-scale renewable technologies: Medium to high job potential. Wind turbines and large-scale solar: Medium to high job and R&D potential.

**Energy efficiency.** Production of energy efficient appliances is not more job intensive than the production of less efficient ones. But the ARE are not technology or appliances producers yet, so it would be an ambitious task to settle foreign or create new companies in this branch. Therefore job potential is considered to be low to medium in the ARE. Rating: Low to medium job potential.

#### **6.6.2.2 Affordable energy supply I: cost reduction potential in mid to long term**

**Nuclear power.** The situation in the Arab Emirates is comparable to the situation worldwide. Some nuclear power plant concepts are mature and don't offer cost reduction potentials. New plant concepts like the EPR theoretically bear cost reduction potentials; however, as is evidenced in Finland currently, costs are increasing very fast during the construction phase. It has therefore to be doubted that nuclear power concepts will ever have decreasing cost or learning curves; for a list of cost projections and realised costs of nuclear power plants compare p. 35. Nuclear power plants are in this respect a factor of insecurity for economic planning. Rating: Low or no cost reduction potential.

**Renewable energies.** Solar power technologies bear cost reduction potential globally: Solar thermal power plants (parabolic troughs) are technologically rather mature, nevertheless costs can be reduced by economies of scale. This is comparable to photovoltaics. Wind power is a mature technology, cost reduction potentials are low. However, in offshore wind power cost reduction potentials are larger. Rating: Solar power technologies: Medium to high cost reduction potentials. Wind power: Low to medium cost reduction potential.

**Energy efficiency.** There are high cost reduction potentials for energy efficient appliances. On a broader scale energy efficiency potentials can be tapped in the ARE at low cost. Rating: High cost reduction potential.

#### **6.6.2.3 Affordable energy supply II: redundancy of subsidies**

Final energy prices are subsidised in the ARE, where natives pay lower prices than foreigners. No electricity generation technology can compete with such distorted market prices. The only possibility for independent power producers to enter the market is making arrangements over power purchases with authorities. It is assumed here that in mid- to long-run the Emirates' government will abolish energy subsidies. It is further assumed that electricity generation costs will reflect the total costs without *hidden* subsidies (externalisation etc.). The question is: Could technologies compete in such a non-subsidised system or would they be unable to deliver electricity at affordable prices?

**Nuclear power.** The situation in the ARE is comparable to the global situation. Nuclear power is economically viable because of hidden subsidies in the form of e.g. externalisation of costs. The ARE would not have external or other costs on the stages of mining and upgrading of ore and on the stage of disposal of waste. Nevertheless nuclear power would probably be exempted from insurances, hence be subsidised. Rating: Low redundancy of subsidies.

**Renewable energies.** Solar electricity technologies would have to be subsidised in the Arab Emirates (as in other countries) in the following few years. However, as insolation conditions are favourable, costs can be reduced significantly. Hence subsidies will only be necessary in short term perspective. There is also potential for wind power utilisation, but at much lower lev-

els. In the medium to long term the ARE will be able to operate solar power plants and wind turbines without subsidies in a market environment. Rating: Solar and wind power: Medium redundancy of subsidies.

**Energy efficiency.** High energy efficiency potentials can be tapped in the United Arab Emirates. Assuming a market environment without distorted energy prices, energy efficient appliances have short payback rates. Therefore these appliances would only have to be subsidised (“incentivised”) in an initial short period. Rating: High redundancy of subsidies.

Total rating of criterion “micro- and macroeconomic benefits of technologies and implications for the United Arab Emirates”

Nuclear energy: Low.

Solar and wind power, large-scale: Medium.

Solar and wind power, small-scale: Medium.

Energy efficiency: Medium.

### 6.6.3 Technical integratability into existing and growing energy system

Between 2010 and 2020 for the ARE a growing electricity capacity demand of 19.4 GW in the High scenario (respectively 11.7 GW in the Low scenario) is expected (see Tab. 6-3 and Fig. 6-5). This corresponds to a growth of 90% (79% in the Low scenario) within ten years. For the sake of comparability we assume that only one nuclear power plant with 1 GW installed capacity could be erected within this period. Consequently 1.0 GW or 2.4% (3.8% in the Low scenario) would origin from nuclear electricity in 2020 (see Fig. 6-6).

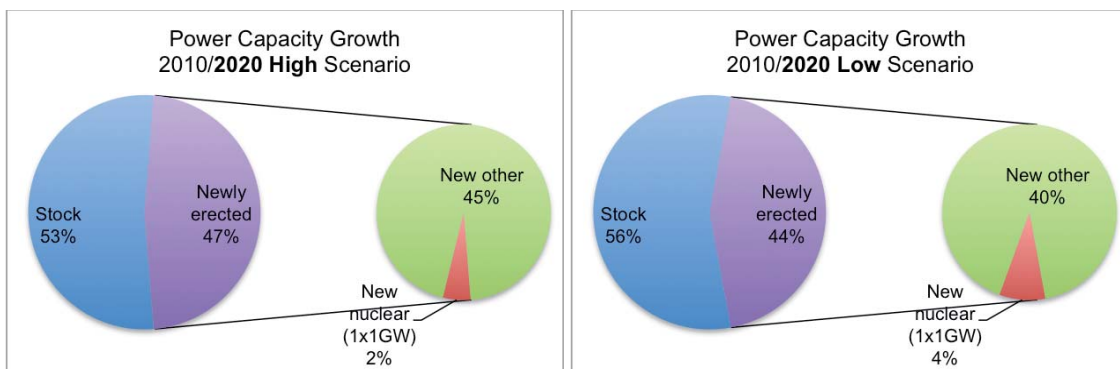


Fig. 6-6. Shares of newly erected power plants in the ARE with one new nuclear power plant of 1.0 GW capacity for the scenarios High and Low Capacity between 2010 and 2020. Own calculations.

Until 2030 even 45.1 GW (20.9 GW) of new capacity must be erected according to the High (respectively Low) scenario. This means a factor of 2.1 (1.4 in the Low scenario) compared to the power plant stock in 2010. Again assuming an implementation of a further 1.0 GW nuclear power plant, the nuclear share would result in 3.0% (5.6% in the Low scenario) in 2030 (Fig. 6-7).

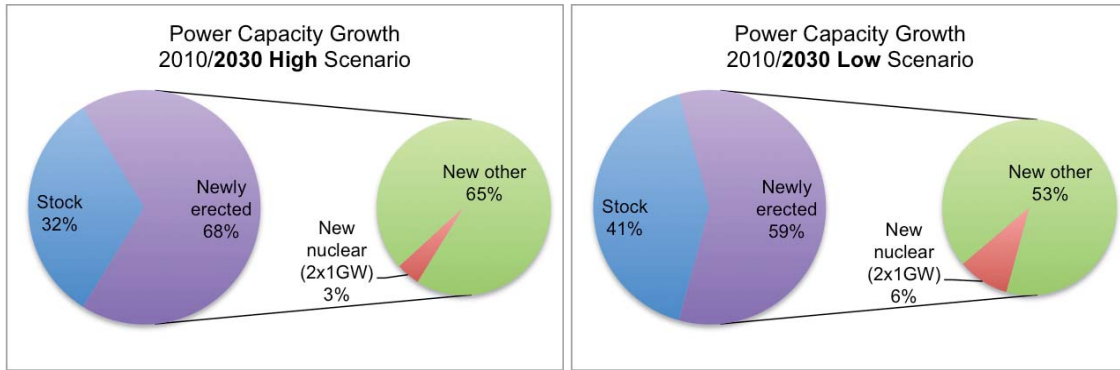


Fig. 6-7. Shares of newly erected power plants in the ARE with two new nuclear power plants of 1.0 GW capacity for the scenarios High and Low Capacity within 2010 and 2030. Own calculations.

### Integration of larger nuclear power plants

The plant size of 1.0 GW was chosen because according to (Prognos 2009, p. 18) the average size of the global nuclear power plant stock is about 900 MW, while the sum of planned and suggested new installations would have an average installed gross capacity of 1.060 GW til 2020 respectively 0.980 GW until 2030 (Prognos 2009, p. 33). Principally also smaller units could be realised technically. But due to economies of scale (e.g. for expensive safety containment) smaller units probably cannot deliver electricity at competitive prices. For this reason some marketable available reactor types like the “EPR” even have considerable greater capacity in the range of 1.6 GW. To cover this possible case of larger capacity, Fig. 6-8 and Fig. 6-9 show the development for 1.6 GW power units: one unit by 2020 and a further unit by 2030. Integrating such units would pose further challenges on integration into existing small electricity grids, as their relative sizes would be significantly larger.

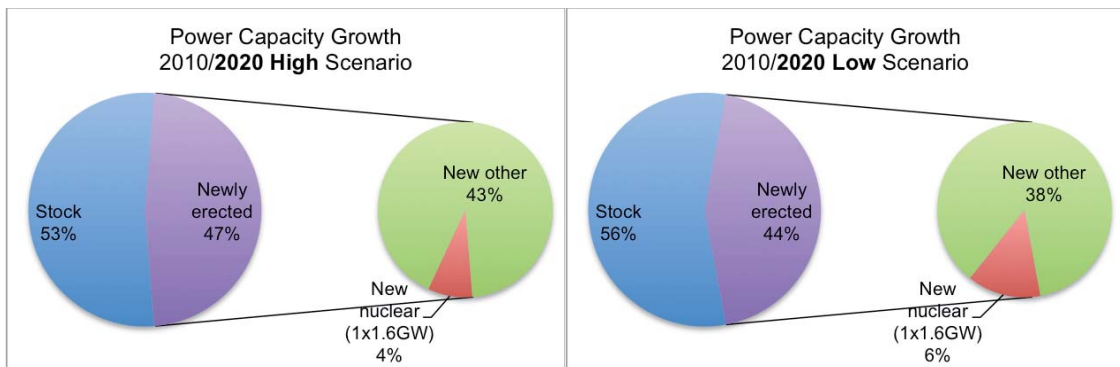


Fig. 6-8. Shares of newly erected power plants in ARE with one new nuclear power plant of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2020. Own calculations.

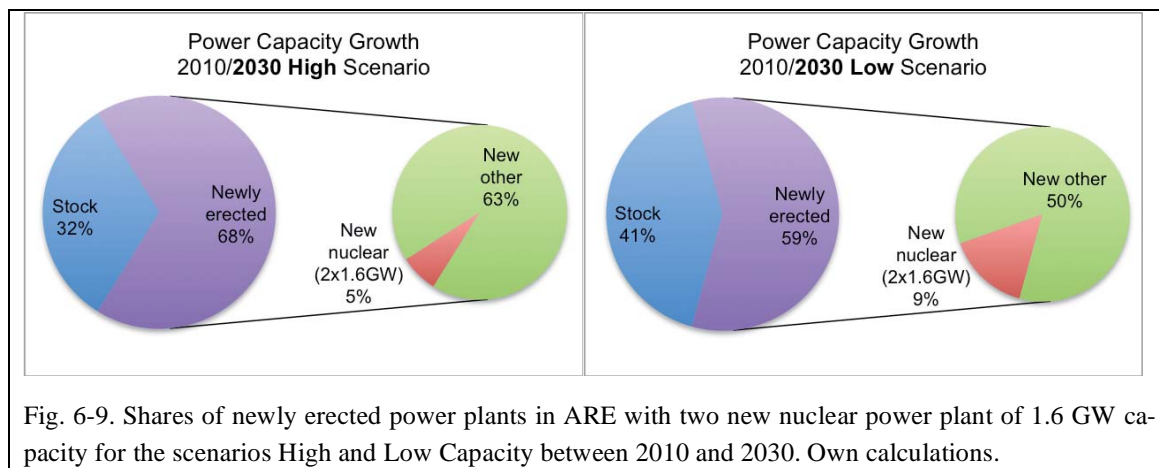


Fig. 6-9. Shares of newly erected power plants in ARE with two new nuclear power plant of 1.6 GW capacity for the scenarios High and Low Capacity between 2010 and 2030. Own calculations.

### 6.6.3.1 Flexibility of operation mode

**Nuclear power.** Due to technical (slow reacting system) and economical (high investment costs) restrictions nuclear power plants are only suitable for base load capacity. With regard to the relatively low shares of 2% (4% in the Low scenario) in total generation capacity in 2020, the establishment of *only one* single nuclear power plant in the ARE would presumably hardly cause conflicts with the integration of new renewable energies with fluctuating feed in (especially electricity from wind turbines and from PV plants). Nevertheless due to the general lack of flexibility of nuclear power the establishment of *several* centralised power plants would very likely hamper the development of RE and EE strategies as well (see also the point below “grid integration”). Rating: Low flexibility.

**Renewable energy.** Renewable energies have different characteristics regarding flexibility of operation mode: While wind turbines and PV generators – if electricity is not stored – only can be shut down partially or totally, many other renewable sources like biomass, geothermal energy, (sometimes) water energy but especially also CSP plants with thermal storage or gas co-firing can deliver constant and/or flexible power. As CSP with its enormous economic potential of ca. 2 000 TWh/a in the ARE is in the focus of the ARE’s renewable energy policy (e.g. in the Masdar Initiative), flexibility in operation mode could be guaranteed if those solar plants were equipped with thermal storage or a gas co-firing backup system. Rating: CSP: High flexibility. Wind, PV: Low flexibility.

**Energy efficiency.** Energy efficiency measures lower the need for electricity capacity (in GW) and consumption (in GWh), e.g. savings by energy saving lamps. So called “load management systems” in contrast cut load peaks. Thus the first doesn’t influence the system’s flexibility of operation mode while the second improves its flexibility. Rating: Strong contribution to flexibility of the overall system.

### 6.6.3.2 Temporal availability of technology

**Nuclear power.** The average lead-time for planning, approval and construction of nuclear power plants is more than 10 years (Schneider/Mez 2008). Taking this experience into account the chosen scenario with an establishment of maximal one single nuclear power plant until 2020 and another one until 2030 seems to be realistic. Constructing several (three or more) plants in ARE in the short or even in the mid term presumably has to fail due to lacking construction ca-

capacity in the nuclear power sector on the one hand and due to the very high financial needs on the other hand. Rating: Very low temporal availability.

**Renewable energy.** While there are very few nuclear power constructors worldwide, the supplier market for most renewable technologies (e.g. PV, wind onshore, biomass) is more decentralized and rapidly growing. This diminishes the risk of (temporal) bottlenecks for production and erection of power systems. Apart from big offshore wind parks with lead times up to 10 years, renewable energy technologies in general are available within less than five years (solar thermal power plants or geothermal plants) and even often in considerably shorter periods (e.g. PV < 1 year depending on size and net integration). Rating: Medium to high temporal availability.

**Energy efficiency.** In principle, energy efficiency measures are immediately available and applicable, but due to an obviously small demand for energy efficient products (respectively life styles) in the ARE sometimes special efficiency technology will have to be imported from abroad. First approaches for setting standards for efficient buildings in single cities (like the LEED standard in Dubai) could give impulses for domestic capacity building in this market segment. Rating: Very high temporal availability.

#### **6.6.3.3 Constancy/permanence of generation**

**Nuclear power.** As mentioned above nuclear energy is predestined for base load operation and permanent electricity generation. Only if large shares of the ARE's power production originated from centralised nuclear power plants, serious supply security risks could be the consequence: If several power plants had to shut down due to maintenance or abruptly due to accidents etc. a considerable lack of capacity would be the consequence. Rating: Medium to high constancy of generation.

**Renewable energy.** The ARE's main known potential among the renewable energy technologies lies in the field of solar thermal power. In contrast to PV or wind plants CSP power plants combined with natural gas co-firing (ISCC<sup>35</sup>) or a thermal storage offer a very high constancy of generation and security of power supply as well, independent from weather conditions, daytime or season. Rating: ISCC / CSP with thermal storage: Very high. Wind (offshore): Medium. Wind (onshore), PV: Very low.

**Energy efficiency.** Once implemented energy efficiency measures are permanently available in general. They usually don't have a direct effect on the constancy of power generation. Rating: No negative impact on constancy of generation.

#### **6.6.3.4 Possibility to integrate technology into the existing grid**

**Nuclear power.** Nearly doubling the power capacity (21.5 GW in 2010 to 40.9 GW in 2020) in the ARE within ten years is a very ambitious task. In general the integration of few big centralised systems (especially large scale nuclear power plants) as well as the integration of a multitude of systems with fluctuating feed in (like wind and PV) into a power grid causes extra costs to keep ready redundancy for the sake of security of supply. The required reserve capacity has to be higher for centralised systems than for decentralised ones. Adding only one single nuclear

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<sup>35</sup> ISCC: integrated solar combined cycle

power plant (of 1.0 GW) within this period should not be problematic with regard to the ARE's net integration, because the share of nuclear energy in total would only amount to 2.4% in the High scenario (3.8% in the Low scenario). Relating to the new plants the share would be 5.2% (8.5% in the Low scenario), in this case enough space would remain for feeding in of renewable energy sources. But it has to be assessed whether grid performance on the envisaged plant location in the ARE is high enough to take up such high capacity (of one Gigawatt) in one single supply point. Rating: Medium possibility for grid integration.

**Renewable energy.** Taking into account the inflexible operation mode of nuclear power plants, it would be technically but also economically difficult to integrate high shares of renewable energies in the future, especially those with fluctuating feeding. Costly investments into big centralised power plants like nuclear plants would determine this inconvenient situation for many decades. The development of (fluctuating) wind power *without boosting the grid* shouldn't cause problems for the ARE's grid in the region of up to about 2 GW by 2020<sup>36</sup>. *With grid extension* and/or with the development of additional storage capacities more than 8 GW of new wind turbines should be integratable into the ARE network. The integration of CSP plants can be done modular, e.g. in units in a range of 10 to 250 MW. Generally it can be stated that a strong nuclear expansion path does not go well with an ambitious RE and EE strategy. Rating for possibility for grid integration: High to medium (low nuclear shares) to low (high nuclear shares).

**Energy efficiency.** Energy efficiency measures are easily integratable into the existing grid. Moreover they would release the power grid respectively would offer the chance for the ARE for a slower growth of power plant and power net capacity. Not only new renewable power plants, also energy-efficient local CHP plants would suffer from centralised nuclear energy structures (see above). Rating: Very high possibility for grid integration.

#### 6.6.3.5 Technological status (market readiness of technology)

**Nuclear power.** Nuclear power plants have in principle been market ready for several decades. New types of the so-called "third" (like the EPR<sup>37</sup>) or "fourth generation" (only design studies at present) still have to prove their technical, economical and security performance in practice. Rating: High market readiness.

**Renewable energy.** The most important RE technology for ARE – solar thermal power plants – has been available on the market for several decades: First plants have been erected in 1980s in Cramer Junction/California and are still operating. Also other RE sources that could be used in the ARE (especially wind power and PV, see Tab. 6-2) have reached market maturity. Rating: Very high market readiness.

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<sup>36</sup> 2 GW corresponds to 5% of ARE's expected power capacity in 2020. For comparison: In Germany 23.9 GW wind power, nearly 20% of the total power plant fleet capacity, have been installed up to 2008 with an electricity production of 40400 GWh/a (= 6.6% of Germany's total power consumption). (Source: AGEE Stat, June 2009 [www.erneuerbare-energien.de/files/pdfs/allgemein/application/mspowerpoint/ee\\_in\\_deutschland\\_graf\\_tab\\_2008.ppt](http://www.erneuerbare-energien.de/files/pdfs/allgemein/application/mspowerpoint/ee_in_deutschland_graf_tab_2008.ppt)).

<sup>37</sup> The first commercial pilot plant of the "Generation III" type will possibly be on line in 2012 in Olkiluoto/Finland (1600 MWnet; start of construction: 2005).

**Energy efficiency.** Energy efficiency products and measurements are mature and available in a great variety on the market. Rating: Very high market readiness.

Total rating of criterion “technical integratability to existing and growing energy system”:

Nuclear energy: Medium.

Solar power, large-scale: High.

Wind power, large-scale: Medium.

Solar and wind power, small-scale: Medium.

Energy efficiency: High.

## 6.6.4 Contribution to political stability and implications for the ARE

### 6.6.4.1 Potential to reduce conflicts over resources

**Nuclear power.** Due to its abundant oil and gas resources, the ARE are not in danger of failing to meet their rising domestic energy demand in the future. Yet, satisfying the growing energy demand partially with nuclear energy will allow it to keep high export rates of fossil fuels. In principle, this can help to mitigate conflict potentials over increasingly scarce oil and gas resources in other countries in the future. However, the potential of nuclear power to reduce conflicts over resources may be limited since it could be a cause of increasing resource scarcity given that the ARE will be dependent on imports of fissile material for its nuclear energy program. The IAEA has published a report predicting that uranium resources will consistently meet the growing demand up to 2025 (IAEA, OECD 2006). Besides, the ARE have made major commitments to the proposed LEU fuel bank and could benefit from its implementation (IAEA 2008). Nonetheless, it cannot be excluded that the ARE might be vulnerable to future shortages in nuclear fuel supply. Rating: Low potential to reduce conflicts over resources.

**Renewable energies.** Expanding the use of renewable energies will allow the ARE to keep high export rates of fossil fuels. In addition, increasing renewable energy capacities in the ARE has a large potential to reduce conflicts over resources internationally as nascent capacities could be exported to the world market and create further revenues for the ARE. This results in larger amounts of fossil fuels on the world market with two consequences. First, such resources can be used by other countries depending on energy imports and with minor renewable energy capacities. Hence, the global potential of energy-related resource conflicts will be reduced when the ARE expand the use of its renewable energy capacities. Second, one needs to consider that the use of these fossil fuel resources will make it more difficult to avoid dangerous climate change and security implications of such a development (WBGU 2007; Carius et al 2008). Rating: Renewables such as solar and wind have a high potential to reduce conflicts over resources.

**Energy efficiency.** Technologies to improve energy efficiency offer the greatest chances to limit resource competition especially with respect to the fossil fuels oil and gas. There are high cost reduction potentials for energy efficient appliances in the ARE. Rating: Very high potential to reduce conflicts over resources.



#### 6.6.4.2 Military harmlessness

**Nuclear power.** In 2006, the Secretary-General of the GCC announced efforts for a joint nuclear research program (Arab News; 27.07.2009). Besides, the United States and the UAE government negotiated a memorandum of understanding and a proposed bilateral agreement on peaceful nuclear cooperation pursuant to Section 123 of the Atomic Energy Act (AEA) of 1954. The proposed agreement was signed by the US early 2009 and is currently submitted to the Congress (Blanchard&Kerr 2009).<sup>38</sup>The agreement includes several provisions to ensure the peaceful nature of the ARE's nuclear program, e.g. the ARE committed to refrain from enrichment and reprocessing of uranium or other nuclear fuel. This provision will very likely be stipulated in a national nuclear law that is currently drafted. Besides, the ARE are a party of the Nuclear Nonproliferation Treaty (NPT). Therefore, any future ARE nuclear facilities would be subject to IAEA safeguards. In a 2008 policy statement, the ARE also pointed out that its nuclear energy programme would rely on light-water reactors. Among nuclear proliferation experts, this reactor type is very much considered to be the most proliferation-resistant (ibid.). However, despite the ARE's commitment to a peaceful use of nuclear energy and the measures taken to secure this intention, it cannot be excluded that nuclear material will be illegally proliferated to Iran or other countries. Rating: Very low military harmlessness.

**Renewable energies.** In contrast to nuclear power, renewable energy's potential for military use is low and few contentious issues are attached to it. Rating: Very high level of military harmlessness.

**Energy efficiency.** There is no relation between increasing energy efficiency and military and strategic objectives which may negatively impact the relationship with neighbouring or other countries. Rating: Very high level of military harmlessness.

#### 6.6.4.3 Contribution to transnational confidence building

**Nuclear power.** The GCC power grid is already linking Saudi Arabia, Bahrain, Kuwait and Qatar and is supposed to include Oman and the ARE by 2011 (GCC Supreme Council 2006). Nuclear energy could be fed into the grid and has, hence, some potential to support transnational confidence building. However, the establishment of nuclear energy-related infrastructures as such is likely to be a source of mistrust given the military potential outlined above. Rating: Low contribution to transnational confidence building.

**Renewable energies.** Renewable energies have large potentials to promote transnational confidence building. They could be fed into the GCC power grid mentioned above. In addition, the ARE's engagement in renewable energy, its Masdar Initiative and especially hosting the headquarters of the International Renewable Energy Agency (IRENA) provides a multitude of options for transnational cooperation. A further expansion of its activities is very likely. Rating: Medium contribution to transnational confidence building.

**Energy efficiency.** There is no direct linkage between energy efficiency measures and transnational confidence building. Indirectly however, regional frameworks of energy cooperation can

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<sup>38</sup> For further information view the related website maintained by the UAE embassy in Washington: <http://www.usuae123.com/index.php> (11.08.2009).

provide assistance how to improve the overall efficiency performance in the grid, e.g. through information sharing, dialogue facilitation and regional integration. Rating: Medium contribution to transnational confidence building.

#### 6.6.4.4 Infrastructural security

The expansion of the GCC power grid will offer some prospects to build up a resilient electricity grid. Due to the fact that different electricity sources are envisaged to contribute to the grid, a more resilient infrastructure can be established that is also less vulnerable towards sabotage or extreme weather events. However, in general, centralized installations of power plants are more vulnerable to natural disasters or sabotage.

**Nuclear power.** The set up of a nuclear power plant in the ARE is likely to have negative impacts on the overall resilience of the national energy infrastructure. Nuclear facilities on the limited geographical area will automatically be located close to the population which could have significant consequences in case of sabotage or accidents in the nuclear power plant. Rating: Low infrastructural security.

**Renewable energies.** The situation is different for the construction of solar power plants. Their components are easier to replace and to reinstall and the damages through sabotages are very limited and will not significantly affect public health. Rating: Medium infrastructural security

**Energy efficiency.** Measures to improve energy efficiency intrinsically help enhancing stability of energy infrastructures. Rating: High infrastructural security.

Total rating of criterion “contribution to political stability and implications for ARE”:

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Energy efficiency: High.

### 6.6.5 Independence of technologies and implications for the ARE

#### 6.6.5.1 Independence from depletable fuels (geological perspective)

**Nuclear power.** Nuclear fuel resources are limited, and according to various studies depletion symptoms could soon become visible on global scale (NEA 2007). Being in a global competition for nuclear fuel, the ARE would be affected by such depletion tendencies as well as other nuclear power users. Rating: No independence from depletable fuels.

**Renewable energies.** Renewable energies are independent from depletable fossil fuels. The question here is whether renewables potentials are limited, whether they can be “depleted”, hence be used to their maximum potential and which order of magnitude this will be in terms of contribution to national energy supply. Wind power potential is limited in the ARE. Solar power is available in “unlimited” quantities, as solar resources exceed the ARE’s possible power demand by a factor of about 50. Rating: Solar power technologies: Very high independence.

**Energy efficiency.** Low energy consumption via energy efficient appliances and energy saving is one key element for curbing dependence on depletable fuels. By using energy more efficiently the range of domestic fossil fuel resources could be extended significantly. Rating: Very high independence from depletable fuels.

#### **6.6.5.2 Reducing national dependence on imported fuels (political perspective)**

**Nuclear power.** The United Arab Emirates would hand over a part of their energy independence to someone else by introducing nuclear power, as fuels would have to be imported from the very beginning of nuclear power utilisation. Nuclear power would be able to temper the import situation of natural gas, but the ARE would not make any net progress in regaining energy independence. Rating: No independence from imported fuels.

**Renewable energies.** Utilisation of renewable energies in the ARE can spare crude oil and particularly natural gas. In the case of crude oil the situation is less severe compared to natural gas. The Emirates are currently consuming about ten % of domestic oil production and will remain an oil exporter for very long. Seen from this point of view there is no immediate necessity to use alternatives: The system of highly intense fossil fuel consumption could proliferate for some more decades without making the ARE a net oil importer. Natural gas has to be imported as the ARE can't increase production. However renewable energies could contribute to keeping the amount of natural gas imports at a lower level. Rating: High potential to reduce dependence on imported fuels.

**Energy efficiency.** Low energy consumption is a key strategy to reduce dependence on imported fuels. Energy efficiency would allow the ARE to significantly reduce the high degree of natural gas imports from Qatar. Rating: High independence from imported fuels.

Total rating of criterion "independence of technologies and implications for the ARE":

Nuclear energy: Low.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High

Energy efficiency: High.

### **6.6.6 Climate policy benefits of technologies and implications for the ARE**

#### **6.6.6.1 CDM eligibility**

The Environment Agency Abu Dhabi acts as the United Arab Emirates' DNA (UNFCCC 2009). CDM potentials in the areas solar energy, energy efficiency and the power, oil and gas sectors are considered as high (Amous 2009). There are some activities in order to use the potential: So far 13 CDM projects at different stages of the process can be identified in the ARE (UNEP Risoe 2009b, UNFCCC 2009). Two of them have already been registered, one being a small-scale solar power plant and the other one a landfill gas to energy project with the UK as involved project party.

**Nuclear power.** Nuclear energy is excluded as a CDM option. Rating: Very low CDM eligibility.

**Renewable energies.** The overall CDM eligibility can be considered as very high and, in contrast to the situation in Iran and Algeria there have already been activities in the ARE to use the CDM. A large-scale solar thermal power plant project passed the validation process and approved methodology. It is currently requesting registration. It comprehends the installation of 624 solar collector assemblies building up a capacity of 100 MW. Over a crediting period of seven years (2011-2018) the project will approximately lead to more than a million tCO<sub>2</sub>e in emissions reductions. The start of construction is scheduled for summer 2009 (Abu Dhabi Future Energy Company 2006). The project is the only large-scale solar power CDM project within the UNFCCC pipeline so far (UNFCCC 2009). Rating: Very high CDM eligibility.

**Energy efficiency.** The CDM eligibility could be considered as very high and first-hand experience with the CDM procedures in the ARE has already been gained. Ten projects still remain at validation stage. They cover gas flaring, wastes, energy efficiency and natural gas projects. Rating: Very high CDM eligibility.

#### **6.6.6.2 Adaptation facilitation**

As outlined in the Initial National Communication, the ARE are concerned about two types of vulnerability regarding its energy infrastructure and resources: Electric power production, desalination and the oil and gas infrastructures are integral to meeting the needs of population and the industries of the country. They are vulnerable to a variety of stresses imposed by a changing climate. In addition, the ARE also considers itself economically vulnerable to the impact of response measures that industrial countries adopt to reduce their emissions as outlined in the Kyoto Protocol. According to the communication, both types of vulnerability pose serious issues related to the country's industrial productivity and economic development as a whole.

**Nuclear power.** Nuclear power plants heavily depend on water resources for cooling and are therefore less favourable in terms of climate change adaptation. They could be affected negatively by decreasing precipitation and water levels of rivers. Ranking: Low potential to facilitate adaptation.

**Renewable energies.** Heavy increases in temperature could adversely affect electricity production by wind power turbines. This underlines the necessity of careful and provisional selection of sites for such plants. Solar power seems most likely to contribute to climate change adaptation. Ranking: High potential for solar power to facilitate adaptation; medium potential for wind power to facilitate adaptation.

**Energy efficiency.** Energy efficiency enhances stability of energy infrastructures intrinsically and hence reduces the overall vulnerability of the energy infrastructure to climate extremes. Rating: High to very high potential to facilitate adaptation.

#### **6.6.6.3 Reduction of GHG**

As renewable energy is predicted to make up for five to seven % of the national energy mix by 2020, its impact on the reduction of GHG is rather low compared to nuclear energy. Nuclear power plants are supposed to produce 30 % of the ARE's energy demand by 2020. Besides it is

rather likely that a consequent fuel switch towards natural gas will reduce the ARE's GHG emissions significantly.

**Nuclear power.** In the light of the high global warming potential of the Iranian energy mix, the use of nuclear power can, in principle, contribute to GHG reductions. Nevertheless the economic and ecological costs linked to nuclear power need also to be taken into account. Rating: High potential to reduce GHG.

**Renewable energies.** Replacing oil and gas for energy production by renewables could substantially contribute to lowering GHG emissions. Ranking: High potential to reduce GHG.

**Energy efficiency.** Energy efficiency measures in the energy production sector can yield a number of benefits: Apart from substantial GHG reductions, e.g. more energy will be available for export. Ranking: Very high potential to reduce GHG.

Total rating of criterion "climate policy benefits of technologies and implications for the ARE":

Nuclear energy: Medium.

Solar and wind power, large-scale: High.

Solar and wind power, small-scale: High.

Energy efficiency: High.

### 6.6.7 Web diagrams of the Emirates' technology situation

The United Arab Emirates doesn't have any uranium ore deposits on its own territory but nevertheless intends to operate nuclear power plants in the near future. The Emirates' government guaranteed **maximum transparency of the fuel cycle** by favouring a kind of leasing scheme for fuel rods: The ARE committed itself to importing rods for plant operation and to exporting rods immediately after depletion. This strategy shows two adverse effects: 1) The ARE **minimises the environmental burden of the fuel cycle** on their own territory – externalising it to other countries. Ecosystem stability is therefore very high for nuclear power (compare Fig. 6-10). 2) **The ARE becomes an energy importer** from the very beginning of nuclear power plant operation which leads the country further into the trap of dependence on depletable fuels.

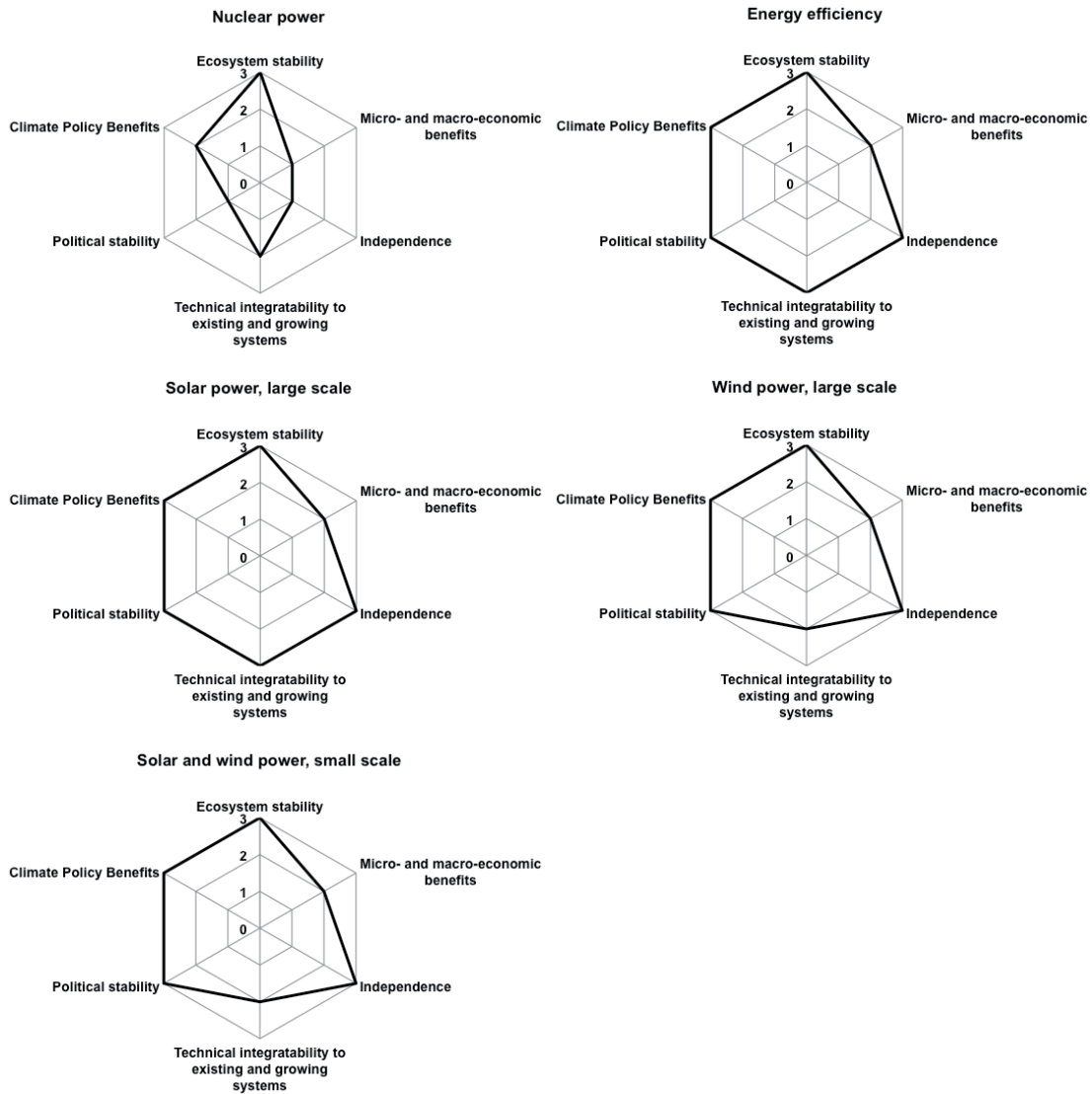


Fig. 6-10. Web diagrams of the ARE. 1: Low impact, 2: Medium impact, 3: High impact on criterion.

**Energy efficient appliances and strategies** to curb demand growth could be introduced, however, being an importer of natural gas is not perceived as a problem. From the side of crude oil depletion **the ARE don't have any incentives to curb consumption yet.** Establishing an industry for energy efficient appliances and technologies is limited, as industrial structures are not suitable for small- and medium-sized enterprises in manufacturing branches. The situation for renewable energies is comparable: Medium job potential in medium-term perspective.

## 6.7 The ARE's energy profile and prospects for future development

The ARE have very large oil and large natural gas resources. It exports 90 % of its oil production and currently satisfies most of its domestic natural gas demand. The ARE's per capita energy demand ranks among the highest in the world and is still increasing. Yet, due to abundant resources, no specific concerns rise about a possible conflict between increasing domestic consumption and lower earnings from decreasing oil exports.

The United Arab Emirates has managed to diversify its economy in the past years and pushed for fuel switch towards natural gas in electricity generation. Energy issues lie within the responsibility of single emirates. However, the national Ministry of Energy is covering nation-wide aspects and Abu Dhabi as most powerful emirate takes a leading role in many aspects.

The ARE are in favour of civil use of nuclear power and may become the first Arab country in the Middle East to operate plants. Regarding nuclear energy, the following remarks can be made:

- The ARE plan to build 20 GWe of nuclear generation capacity with 14 plants in total with nearly one quarter operating by 2020 (World Nuclear Association 2008). The **first reactor may go on-grid in 2017**. Frame conditions are favourable due to the large financial means of the ARE and cooperation with the USA, Britain, France and Japan to compensate its lacking domestic nuclear expertise. However, the **time schedule seems overambitious**.
- Nuclear energy is projected to contribute 30 % to the ARE's energy mix by 2020 in the most optimistic path. This would make the ARE's grid inflexible to varying demand.
- It is likely that the ARE's nuclear power plants will significantly contribute to the GCC-wide electricity grid.
- The ARE would fully **externalise environmental burden and human health risks of the nuclear fuel cycle** to foreign countries by importing fuel rods and exporting depleted rods (leasing scheme).

To summarize facts regarding renewable energy:

- Significant solar potential exists. Other renewable sources would not be able to play a major role. Respective technologies could be integrated into the grid without major technical difficulties.
- Renewable energies may contribute five to seven % of the ARE's electricity production by 2020: e.g. the government of Abu Dhabi committed itself to the target of 7 % renewable generation capacity by 2020.
- To establish the ARE as a leading player in the renewable energy branch globally, it has introduced the Masdar Initiative, a multi-billion dollar fund.
- Job potentials in the renewable energy branch exist.
- **The ARE are already very active in the field of CDM**. This engagement is likely to expand as renewable energy potentials are further exploited in the future.
- Electricity from renewable energy power plants could be fed into the GCC-wide power grid.

Currently, renewable energies don't play a role, but plans for further development exist. Just recently, the ARE gained the seat of the interim headquarter of IRENA. It can be expected that this special position will enhance the ARE's renewable energy commitments and may also influence its role within OPEC, where it plays a vital role since it is one of the few members that could increase its production at any time due to spare capacities (yet, in the past, the ARE were hesitant to play an active role and mainly went along with Saudi positions).

Vast energy efficiency potentials could be tapped throughout the ARE's energy system. However, there is low interest as fossil fuels are abundant and importing gas from Qatar is not perceived as a problem. Further aspects of energy efficiency are:

- Lacking industrial infrastructures make it difficult to establish an industry branch specialised in the production of energy efficient appliances. However, it does not seem likely that the ARE are interested in such a branch at all.
- Dubai introduced efficiency building standards, but on a very low level. Therefore effects will remain small.

### **Trade-offs**

There is a trade-off between nuclear power and energy efficiency: The more efficient the electricity system gets, the more difficulties arise with integrating large nuclear generation units. However, as the ARE are connected to the GCC electricity grid, such a trade-off is obsolete.

Indications are strong that the ARE will make nuclear energy its main pillar for future energy supply. Renewable energies will contribute to the national energy mix as well. Yet, with a 7 % capacity share compared to a prospected 30 % electricity production from nuclear energy, renewable energies will play a minor role. It remains to be observed how nuclear power plans work out and which options the ARE will choose if nuclear power fails to fulfil expectations.



## **7 Conclusions: Comparison of Algeria, Iran and UAE, and generalisation**

Detailed discussion of criteria in country-specific context can be found in previous sections, the task of section 7 is to outline the major differences of Algeria, Iran and the United Arab Emirates.

### **7.1 Selected aspects of system analysis**

The analysis of the economic and energy systems of DZA, IRN and the ARE in the context of their OPEC membership shows that due to structural differences there cannot be one single answer to the future integration of different energy options. The country studies show that there are obstacles for the integration of nuclear power, renewable energies and energy efficiency that have not been accounted for in the general discussion yet.

The following aspects will be discussed briefly:

- different situations of confidence building through nuclear power
- infrastructural challenges for economic integration of renewable energy and efficiency technologies, job potentials
- need to expand electricity grids beyond national borders
- role of energy subsidies in dissemination of efficiency measures and renewable energies

#### **7.1.1 Transnational confidence building: Emirates contrasting Iran**

The United Arab Emirates chose a strategy of transparency for their nuclear fuel cycle. This has to be seen in the context of Iran's "cat and mouse game" with the International Atomic Energy Agency and Western countries in previous years. In this respect the ARE can indeed use nuclear power as a measure of international confidence building and acted as a role model for how to set up a civil nuclear energy program. Its integration into the GCC adds a further facet to this strategy. Iran on the contrary will still have to fight with deep mistrust even if it decided to reveal all its nuclear activities. These two examples show that nuclear power and confidence building are not necessarily mutually excluding in countries in the Middle East.

#### **7.1.2 Industrial infrastructures in different country settings**

The Iranian economy could benefit from renewable energies and from energy efficiency almost immediately due to its industry infrastructures. In DZA and the ARE the setting is different. Both economies lack suitable infrastructures to respond quickly to incentive schemes. Short- to medium-term job potentials are therefore limited domestically. This would require a large share of foreign suppliers and even plant operators. Despite lacking structures the ARE are investing heavily in renewable energies.

### **7.1.3 Expansion of grids for integration of renewables and nuclear power**

Algeria and the Arab Emirates are similar in terms of grid size and options for expanding beyond national borders. The ARE are a member of the GCC and part of the GCC-wide electricity grid which will be fully operated by 2010/11. Algeria could become member of a North African or at least a Maghreb electricity grid with the option to connect to the very large European grid structure.

Grid integration is an enlargement of structures. Increasing the system facilitates the integration of different energy options: Intermittent generation from renewable energies can be integrated more easily. This is an opportunity for renewable energies to gain larger shares in national supply. However, the same holds true for nuclear power: If grids were too small for nuclear integration, a transnational grid could provide the necessary size to make nuclear power a viable option.

### **7.1.4 Energy subsidies as major obstacles for development**

Energy is subsidised in all analysed countries. The reduction of subsidies does not seem to be a viable option currently. Subsidies make energy saving measures *on individual level* economically senseless. Without creating a real market regime – abolishing direct subsidies on consumer level, internalising external costs of supply etc. – investment behaviour will critically depend on either incentive schemes (i.e. kind of a subsidy) or direct negotiations between investor (plant operator) and the state. It remains to be discussed whether such an environment can sustain long-term growth of renewable energies.

## **7.2 Open questions, further need for scientific research**

System analysis showed that different economic, infrastructural and resource settings have different consequences on the development of energy systems. Even among OPEC members (united through their status as crude oil exporters) the settings and consequences vary strongly. In this light the following questions are still open and should be investigated scientifically:

- Which role will the expansion of electricity grids play for the integration of renewable energies?

North Africa is of special interest due to the perspective of connecting Maghreb and Mashreq to the European grid. This will also have considerable influence on the establishment of the Mediterranean Solar Plan.

Regarding the GCC grid:

- Which consequences will investments of these countries in renewables plus integration into their own grid have on the global situation of renewable energy technologies (in terms of cost development etc.)?

Further questions of relevance:

- How could economies and energy systems of e.g. Morocco, Tunisia, Egypt and Libya react to the integration of renewable energies and energy efficiency?

- Which policies need to be developed for the North African and the Persian Gulf region to overcome the barriers revealed in this project? How strong do policies have to be adjusted to specific country settings and which elements are of general validity?
- How can the Solar Plan and the DESERTEC concept be implemented (in the light of lacking industrial infrastructures), meeting the targets of sustainable development and co-operation?
- Which strategies in the context of EU-GCC cooperation are appropriate to foster the development of renewables in the GCC?

Consequences for Non-OPEC countries of the regions:

- Which consequences could the introduction of renewable energies and energy efficiency have in countries that are importing oil and natural gas?
- Which industrial and other structures exist in these countries and could they be made compatible for renewables and efficiency?

Some countries are concentrating their efforts very strongly on only one renewable energy source, although other sources could be utilised as well. In this context strategies should be developed to foster a broad bandwidth of available renewable sources and energy efficiency potentials. Such integrated strategies are among the major challenges for sustainable development of energy systems, especially in North African and Middle Eastern countries.

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