The role of coal in the energy mix of MENA countries and alternative pathways

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List of abbreviations

AER .... Authority of Electricity Regulation
BAU .... Business as usual
BOO .... Build-own-operate
BOT .... Build-operate-transfer
CAPEX .... Capital expenditures
CCGT .... Combined-cycle gas turbine
CSP .... Concentrated solar power
CSS .... Carbon capture and storage
DEWA .... Dubai Electricity and Water Authority
DNI .... Direct normal irradiation
DRE .... Dispatchable renewable energy
DSCE .... Dubai Supreme Council of Energy
EEAA .... Egyptian Environmental Affairs Agency
EEHC .... Egyptian Electricity Holding Company
EIA .... Energy Information Administration
EOR .... Enhanced oil recovery
ERA .... Electricity Regulatory Authority
FEWA .... Federal Electricity and Water Authority
FLH .... Full load hours
GAMS .... General Algebraic Modelling System
GDP .... Gross domestic product
GHG .... Greenhouse gas
GHI .... Global horizontal irradiation
GIZ .... Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
HSBC .... Hongkong and Shanghai Banking Corporation
INDC .... Intended Nationally Determined Contribution
IPCC .... Intergovernmental Panel on Climate Change
IPP .... Independent power producer
ISFU .... Implementation Support and Follow-up Unit
JCPOA .... Joint Comprehensive Plan of Action
LCoE .... Levelised cost of electricity
LNG .... Liquefied natural gas
MEMR .... Ministry of Energy and Mineral Resources (Jordan)
MENA .... Middle East and North Africa
MILP .... Mixed integer linear programming
MIS .... Main Interconnected System
NDC .... Nationally Determined Contribution
NEEAP .... National Energy Efficiency Action Plan (Egypt)
NEPCO .... National Electric Power Company (Jordan)
NEPE .... National Environmental Policy for the Energy Sector (Oman)
NPV .... Net present value
NRDC .... Natural Resources Defense Council
O&M .... Operating and maintenance costs
OCGT .... Open-cycle gas turbine
ONEE .... Office National de l'Électricité et de l'Eau
OPEC .... Organization of the Petroleum Exporting Countries
OPEX .... Operational expenditures
OPWP .... Oman Power and Water Procurement Company
PPA .... Power purchase agreements
PV .... Photovoltaic
R&D .... Research and development
RAK .... Ras al-Khaimah (power plant in the UAE)
RCREEE .... Regional Center for Renewable Energy and Energy Efficiency
RE .... Renewable energy
RfQ .... Request for qualification
SEZ .... Special economic zone
SEZAD .... Special Economic Zone Authority Duqm (Oman)
TPES .... Total primary energy supply
TSO .... Transmission system operator
UAE .... United Arab Emirates
VRE .... Variable renewable energy
WACC .... Weighted average cost of capital

Executive summary

With the ratification of the Paris Agreement, countries have committed to limiting global warming to well below 2°C and to pursuing efforts to keep global warming below 1.5°C. The 2018 IPCC Special Report on 1.5°C clarified that this goal will require a phase-out of emissions from the power sector before the middle of the century, including the halting of investments in unabated coal power by 2030 and the phasing-out of electricity generation from coal by 2050. Despite this, more than 209 GW of unabated coal-fired power plants with life spans of several decades are under construction globally and over 443 GW are at a planning stage. This future coal capacity represents a major threat to the achievement of the global climate targets set in the Paris Agreement.

Even though the bulk of the planned new coal capacity would be located in China, India, Indonesia, Turkey and Viet Nam, significant announcements for new coal-fired capacities have been made in the **Middle East and North Africa** (MENA) region, and it is this region that is the focus of this report. Most countries in the MENA region – and thus the region itself – are characterised by an abundance of oil and gas resources, but also excellent solar and wind resources. It is only Iran that has large coal resources. The MENA region is witnessing steeply rising energy demand due to its growing population, economic development and increasing standard of living. At the same time, available domestic fossil fuel resources are declining because of both decreasing reserves and the fact that large shares of available gas and oil resources are bound up in long-term export contracts. Security of supply concerns are therefore high on the agenda of national energy priorities.

Study overview: Coal expansion plans and alternative pathways in the MENA region

This study provides a thorough analysis of the status quo, plans and motivations for coal-fired power generation in six MENA countries: **Morocco, Egypt, Jordan, the United Arab Emirates (UAE), Oman and Iran**. To explore current and future coal-fired generation and the drivers for the development of coal in these countries, experts and stakeholders were interviewed and public documents analysed. For each country, existing plants and plans for coal as well as emission limits were assessed, providing a much-needed **fact base for the discussion on the future of coal** in MENA power systems. In addition, various scenarios were modelled for a synthetic country in the MENA region using Navigant's **capacity expansion optimisation model, PowerFys-Invest**. The scenarios illustrate the impact of coal on emissions and the overall electricity system and analyse the effects of introducing a carbon price, factoring in externalities or setting renewable energy (RE) targets. Based on this analysis, recommendations for policy-makers are provided to facilitate the choice of alternatives to coal in a sustainable, affordable and secure energy system in line with the requirements of the Paris Agreement.

Status quo, expansion plans and motivations for coal in the MENA region

With the exception of Morocco, coal has so far played only a marginal role in the energy mix of most MENA countries. Nevertheless, all countries in this report (except Iran) have defined targets for expanding their coal capacity over the next two or three decades, although these plans are put into question in several countries due to current overcapacities and the economic competitiveness of other energy sources. Table 1 below shows a summary of the status quo, plans and motivations for coal in the focus countries of this report.

Table 1. Overview of status quo and plans for coal in selected MENA countries including coal's share of total primary energy supply (TPES)

	Morocco	Egypt	Jordan	UAE	Oman	Iran
Current role of coal in the energy system	22.9% of TPES (2015); 54.7% of electricity generation (2016)	0.4% of TPES (2015); not present in electricity mix (2017)	2% of TPES (2015); not present in electricity mix (2017)	2.3% of TPES (2015); not present in electricity mix (2017)	Not present in energy/electricity mix (2017)	0.5% of TPES (2015); not present in electricity mix (2016); proven coal reserves of 1.15 billion tons
Coal development plans	Further addition of 1,320 MW of coal-fired capacity through Nador plant foreseen but currently on hold	Addition of 16,800 MW of capacity from coal by 2030 according to energy strategy, but hold on all planned coal-fired power plants announced by government in November 2019	5% of energy mix from coal by 2025; 30 MW in operation, no further concrete plans	12% of energy mix from 'clean coal' by 2050; 2.4 GW of coal capacity under construction, additional 1.2 GW considered	Addition of up to 3,000 MW of coal by 2030; 1,200-MW plant announced but potentially to be replaced by thermal solar power station	No targets defined; 650-MW coal power plant officially under construction, but project appears halted
Motivations for coal according to interviews	Ease of supply; cost; system adequacy; security of supply	Industry interest (secure supply); increasing demand; diversion of gas to industries (petrochemicals, fertilisers)	Lack of indigenous fossil fuel resources; secure supply for energy-intensive industry	Diversification of the energy mix; very high standards for security of supply	Diversification of the energy mix; opportunity cost of gas (more in-country value by diverting it to industry)	Diversification of the energy mix; availability of coal; obstacles to investment in renewables due to sanctions
Caveats to the development of coal	Interest to develop gas; reduced pool of lenders willing to finance coal; local opposition to new coal power plants; successful renewables programme	Uncertainty regarding the overall amount of capacity to be added due to gas-fired plants coming online; re-evaluation of renewable energy targets	Advances in the supply from natural gas and renewables make expansion of coal less likely	Renewable energy strategies; uncertainty regarding demand forecasts; land availability (depending on Emirate)	Further coal development may be restricted by land availability (remote locations)	High demand in the metallurgic industry for coal as a raw material; slow progress in the construction of above-mentioned coal plant
Coal development plans in light of the Paris Agreement	Unabated coal-fired plants to be commissioned in the 2020s, as planned in all countries in this study in more or less significant and concrete terms, are incompatible with the requirements of the Paris Agreement (note that coal combined with carbon capture and storage [CCS] is not economical in the MENA, as the modelling in this report shows). Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector – i.e. coal-fired power plants without CSS need to be completely phased out by the middle of the century on a global scale (Climate Analytics, 2016). All plants coming online in the next decade would have a life span that extends well into and beyond the middle of the century. Apart from Morocco, whose Nationally Determined Contributions (NDCs) are deemed sufficient by Climate Action Tracker (although they do not consider the country's coal plans), the energy policies of all the other countries addressed in this study would put the world on a trajectory of well above 2°C warming.					
Energy sector structure	State-owned Office National de l'Électricité et de l'Eau Portable (ONEE) is supplier and transmission grid operator. Private and municipal distribution companies. Independent Power Producers (IPPs) exist.	Joint-stock state-owned Egypt Electricity Holding Company (EEHC) responsible for transmission, distribution and generation. Plans to open market to private suppliers from 2021. IPPs exist.	Jordan's state-owned National Electric Power Company (NEPCO) is responsible for transmission, bulk supply, and operation. Three privatised distribution companies operate under concession (JEPCO, EDCO, IDECO). IPPs exist.	Main utilities owned by Emirates are DEWA (Dubai), EWEC (Abu Dhabi) and SEWA (Sharjah). FEWA, responsible for the Northern Emirates, is to be integrated into EWEC. Joint ventures/IPPs exist, majority shares for public utilities.	Nama Group joint-stock state-owned company holding is responsible for transmission, distribution and generation. Privatisation programme launched in late 2018. IPPs exist. Spot wholesale market currently being introduced.	Tavanir is the state-owned and operated generation, distribution and transmission holding company. Wholesale power market, and privatisation process ongoing for shares of generation.

The arguments in favour of coal deployment in the MENA region, and that were commonly put forward in the interviews, are: the aim to diversify the energy supply and 'free up' gas reserves for exports or local industry; the perceived need for coal as 'baseload capacity'; concerns regarding the reliability and security of energy supply, particularly for energy-intensive industries; and the perceived cost-competitiveness of coal.

While these concerns are substantial, the use of coal has **tremendous negative effects** on public health, local air quality and the climate due to the extremely high emissions it causes. Public opposition to coal plants reflects these harmful effects. These **externalities** of coal need to be considered when comparing different generation sources. Estimates by the Regional Center for Renewable Energy and Energy Efficiency (RCREEE) show that the price of coal-based electricity would **more than double** in most MENA countries if external costs were added to the average costs of electricity. Modelling results in this report also demonstrate that **coal is no longer cost-competitive** if even minimal values for external costs are considered.

Coal-fired power plants are **not needed** to ensure an **affordable, secure and sustainable energy supply** in the MENA region. Quite the contrary, the region has excellent preconditions for alternative energy pathways with very high shares of renewable energies for electricity supply. These drivers include: the outstanding cost-competitiveness of renewables due to excellent resource availability in the region (especially solar, but also wind in Egypt, Jordan and Morocco); countries' own commitments under the Paris Agreement to reduce greenhouse gas (GHG) emissions; and the contribution that renewables make to energy independence. Finally, additional impetus for a switch to power systems heavily based on renewables comes from the investment community, including multilateral banks, which are increasingly seeing coal-power investments as too risky. Risk for investors stems not only from delays and public opposition to coal-fired power plants, but also from the global debate on the introduction of CO_2 prices to internalise the external costs of coal with regard to emissions.

Overview of the scenarios modelled in the study

Several electricity supply scenarios for **2020–50** were modelled based on a **least-cost capacity expansion** optimisation approach for a synthetic yet representative power system of the MENA region. The results of this analysis must be interpreted in light of the **cost assumptions for renewable energy technologies** in this study, which are deliberately rather **conservative,** and the fact that resource availabilities may vary from country to country (e.g. Morocco and Egypt have excellent wind sites).

Figure 1 and Figure 2 below display the results of the four main scenarios calculated in this study.

- **Scenario 1** represents the **reference scenario** as it reflects the current situation in many countries of the MENA region. Renewable energy (RE) targets are set, but the addition of coal-fired power plants is allowed as an option for meeting the strongly increasing electricity demand.
- **Scenario 2** has no RE targets and allows coal.
- **Scenario 3** has RE targets and does not allow coal.
- **Scenario 4** has no RE targets and does not allow coal.

In addition to these four main scenarios, several **sensitivities** were calculated, including:

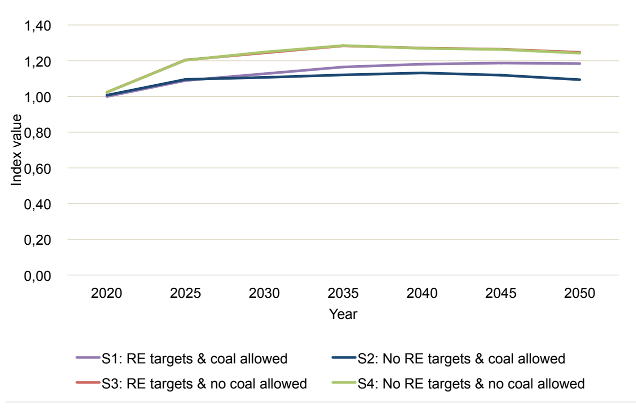
- the impact of different financing conditions (weighted average cost of capital or WACC);
- the introduction of a CO_2 price either in 2025 or 2035 with perfect or limited foresight;
- the consideration of the external costs of power generation technologies, such as impacts on public health, the environment and local air quality.

Modelling results: high-RE scenarios offer clear benefits

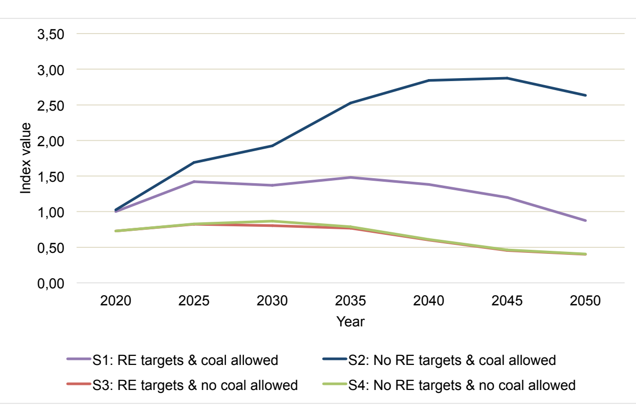
Figure1 below shows that, for power systems in the MENA region, a transition towards high shares of renewable energies (>80% in 2050) is the **least-cost option** when investments in coal power plants are not allowed, even if external costs are neglected. This is indicated in the results of Scenario 4 where, despite the fact that no renewable energy targets are applied, the least-cost capacity expansion optimisation leads to a renewable energy share of 84% in 2050 due to excellent resource availability and decreasing costs (see also Figure 2).

Figure 1. Key assumptions and results of the four main scenarios when externalities and CO_2 prices are not considered. Scenario 1 is the reference scenario for system costs and emissions (=100%). When externalities are considered, the no-coal scenarios 3 and 4 offer tremendous emissions reduction potential and are cheaper (see Figure 4).

Electricy supply costs



CO_2 emissions from electricity generation



Scenario key figures

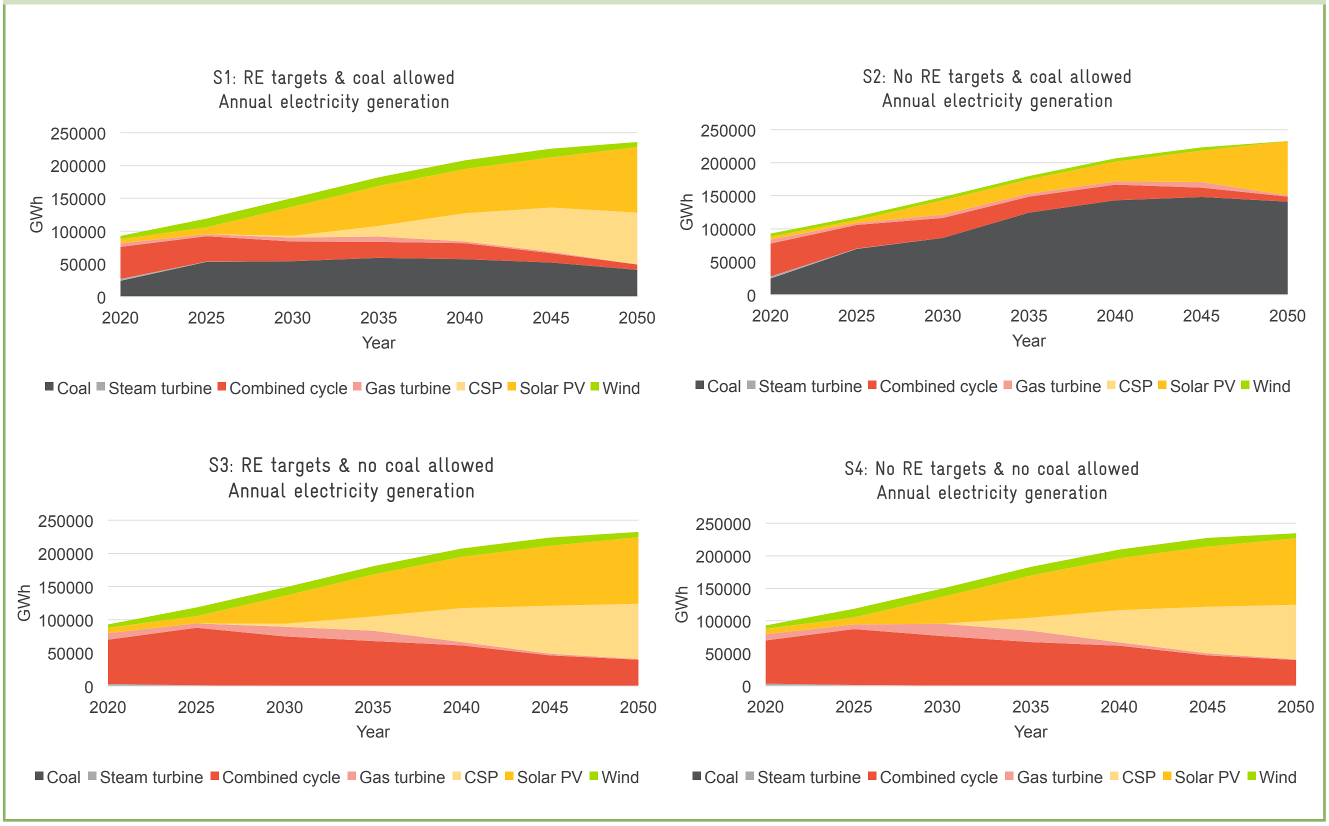
	Scenario 1: RE targets & coal allowed	Scenario 2: No RE targets & coal allowed	Scenario 3: RE targets & no coal allowed	Scenario 4: No RE targets & no coal allowed
Scenario assumption				
Renewable energy target in 2050	80% of final electricity demand	No target	80% of final electricity demand	No target
Coal allowed in power sector	Yes	Yes	No	No
CO_2 prices or external costs considered	No	No	No	No
Scenario results				
Total system costs 2020–50	100%	95%	107%	107%
Total CO_2 emissions 2020–50	100%	178%	52%	54%
Renewable energy share in 2050	81%	36%	83%	84%
CO_2 emissions in 2050	100%	301%	46%	46%
Coal share in 2050	18%	61%	0%	0%

Scenarios 3 and 4, which do not use coal, are only marginally more expensive over the whole course of the modelled period until 2050 than systems with a significant coal expansion (Scenarios 1 and 2). When externalities such as public health impacts, environmental impacts and the cost of lower air quality are considered – even to a very small extent – the scenarios without coal (3 and 4) become **less expensive** than those with coal (1 and 2; see Figure 1). In addition, zero-coal power systems have a significantly **lower implementation risk** compared to scenarios with significant coal expansion. Strong public resistance to coal plants because of air pollution and water constraints exists and is likely to grow. Scenarios 3 and 4 achieve large reductions in emissions, which would significantly enhance the MENA countries' ability to deliver on their Paris Agreement commitments and would lead to **additional benefits** in terms of health, the environment and the flexibility of power systems.

In the MENA region, a power system based on high shares of variable renewable energy (solar photovoltaic [PV] and wind power) and dispatchable renewable energy technologies (mainly concentrated solar power [CSP]), smartly combined with flexible gas-fired power plants and storage systems, can **ensure security of supply** and a reliable electricity supply at almost the same costs as a system dominated by coal power plants – or even at significantly lower costs when externalities are considered.

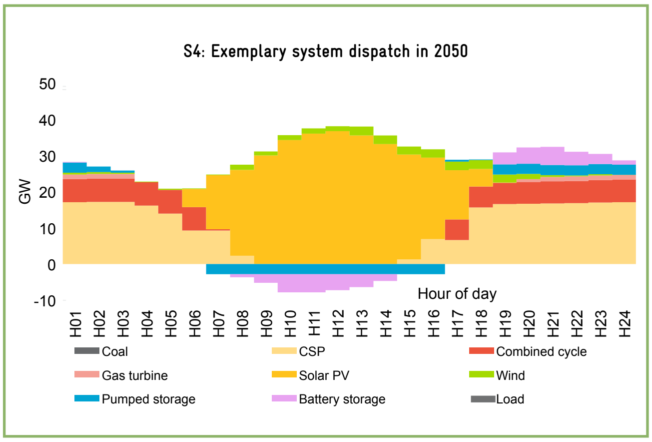
Figure 2. Annual electricity generation by technology over the 2020–50 period for the four calculated main scenarios according to the least-cost capacity expansion optimisation approach and not including CO_2 price and externalities. The low deployment of wind power is based on the assumption that wind power sites with excellent resource availability (2,800 full load hours) are very limited in the representative MENA country. In reality, several MENA countries (Egypt, Jordan and Morocco) have excellent wind capacities.

Annual electricity generation



As shown in Figure 3 (right), dispatchable CSP with thermal energy storage, flexible gas-fired power plants, and energy storage systems are valuable options for the transition towards a very high share of renewable energy in the electricity supply and can balance out low-cost electricity generation from PV and wind power as **well as actual system** load. Such a well-balanced system creates **significantly less CO_2 emissions and offers a considerably higher security of supply** due to the diversification of supply sources compared to a system dominated by coal.

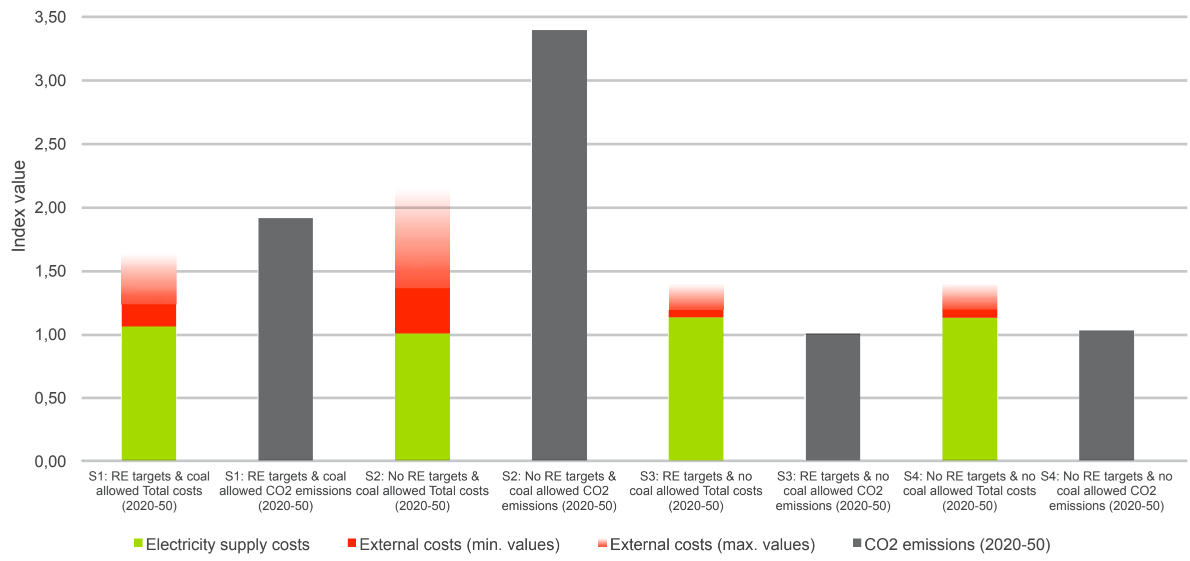
Figure 3. Exemplary daily system dispatch in 2050 under Scenario 4. Combining PV with dispatchable CSP allows for 24-hour baseload electricity production from solar resources.



As shown in Figure 4 below, if one considers even minimal costs for externalities (e.g. the impacts of emissions from coal-fired generation on public health, local air quality, water and soils), the scenarios without coal (3 and 4) immediately become less expensive than those where coal is allowed (1 and 2). The externality-cost data used for this sensitivity analysis are derived from research conducted by RCREEE in Europe. Given the vulnerabilities of the MENA region to water stress and climate change, externalities might be even higher in these countries.

following page shows the levelised cost of electricity (LCoE) as a function of full load hours (FLH) in order to provide an understanding of the cost assumptions applied within the capacity expansion optimisation. LCoE values are calculated from the technology-specific input parameters of the optimisation model – i.e. investment costs, operation and maintenance costs, fuel prices, WACC, efficiency, lifetime, and resource availability for renewable energy technologies.

Figure 4. Comparison of total costs (electricity supply costs + external costs) and CO_2 emissions of the representative MENA power system over the 2020–50 timeframe for the four main scenarios of this study. Even minimal consideration of externalities shows that scenarios without coal are significantly cheaper, while offering at least the same security of electricity supply.



Further sensitivity analyses show that where even only a moderate **CO_2 price** of 45 USD/t is assumed to be introduced around the year 2035, the lower utilisation of coal-fired power plants would lead to significant risks of stranded investments for investors. If CO_2 prices were introduced earlier, around 2025, or at higher levels, investments in coal power plants would become almost entirely unattractive.

Cost assumptions for the various technologies used in the study

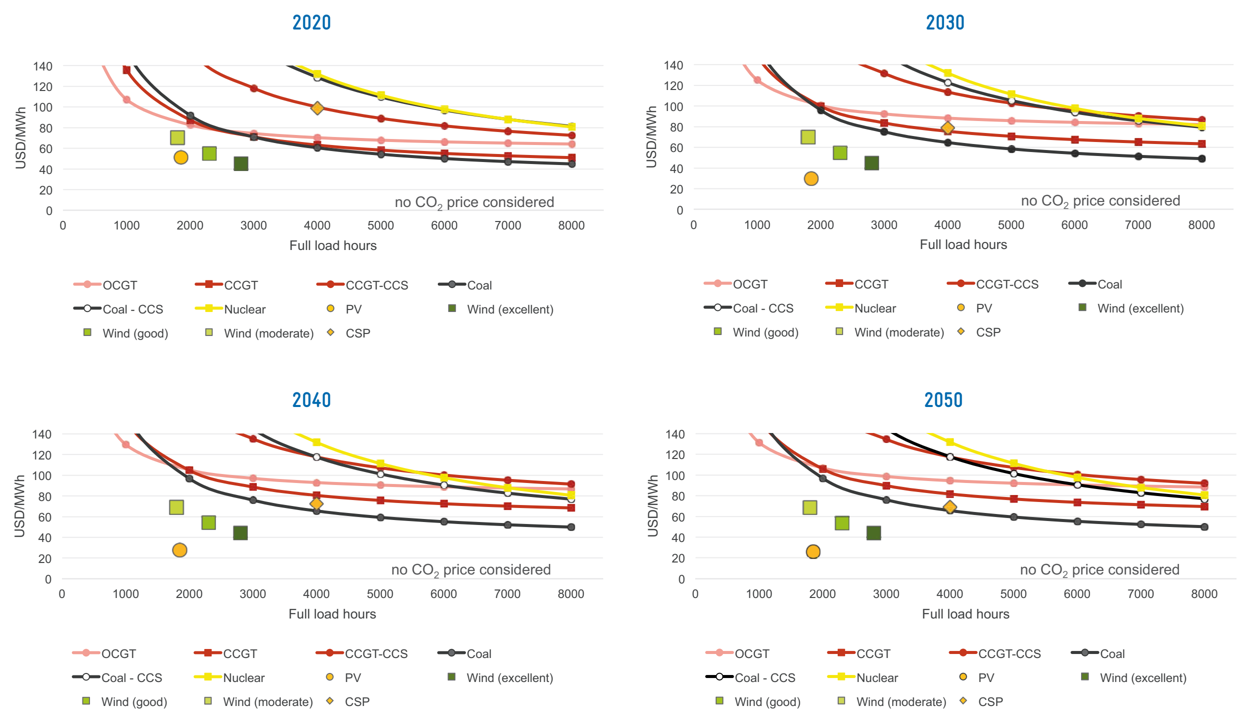
Our optimisation model identifies the least-cost expansion and power generation schedule required to meet future electricity demand while respecting several constraints on the system (e.g. defined renewable energy targets) and the technology level (e.g. maximum available potential) and considering techno-economic assumptions for various investment options. Figure 5 on the

As can be observed, the LCoE of coal- and gas-fired power generation technologies is relatively stable over the planning time frame in the absence of a CO_2 price. The LCoE of PV decreases significantly over the planning time frame from approximately 50 USD/MWh in 2020 to 25 USD/MWh in 2050. A relatively strong reduction in the LCoE is also assumed for CSP, with the LCoE dropping from about 100 USD/MWh in 2020 to around 70 USD/MWh in 2050. From 2030 on, CSP is cost-competitive with combined-cycle gas turbine (CCGT) power plants and can provide similar system services through the incorporation of thermal energy storage and back-up burners – i.e. dispatchable (flexible) firm capacity and operating reserve to balance the intermittent generation of PV and wind power. In contrast to the solar power technologies, no significant cost reduction for wind power is assumed, hence the LCoE of wind power remains stable at between 45 and 70 USD/MWh over the time frame considered.

The **techno-economic assumptions for conventional power generation** technologies are mainly based on the International Energy Agency's World Energy Outlook (New Policies Scenario). For coal, these are in line with recently signed power purchase agreements (PPAs) of 50–80 USD/MWh in the MENA region. For **renewable energy technologies** (wind power, PV and CSP), assumptions are based on data provided by various sources including the IEA, IRENA, BloombergNEF and others.

The **assumptions for renewable energy technologies** in this study are rather conservative and the assumed full load hours in the synthetic country represent an average rather than an upper limit for the MENA region. This becomes obvious when comparing these assumptions with recent PPA results in the MENA region, which comprise significantly lower prices (PV ranging between 24 and 76 USD/MWh, wind between 25 and 81 USD/MWh and CSP between 73 and 140 USD/MWh). However, it is also important to underline that beneficial framework conditions such as freely available land and free grid connections have brought down PPA results in certain cases in the MENA region and cannot therefore be taken as a standard assumption for a representative country. Full details of the assumptions for the various generation and storage technologies considered in this study can be found in Appendix 3.

Figure 5. Comparison of the LCoE of different investment options in 2020, 2030, 2040 and 2050 as a function of full load hours. Values are calculated based on the techno-economic parameters of the various investment options used within capacity expansion optimisation. Ultra-supercritical technology is used as the reference technology for coal power plants.



Note that technology specific full load hours of dispatchable technologies are not pre-defined as input for the capacity expansion model but optimized over the entire planning time frame within simultaneuos capacity expansion and dispatch optimization

Today, electricity generation from PV and wind power (at excellent sites) is already **competitive against the marginal generation costs of gas-fired power plants**, and it can be expected that the generation costs of these variable renewable energy (VRE) technologies will decrease much further in future. PV and wind power should therefore be used as '**fossil fuel savers**' as much as possible.

Due to the very limited potential of other dispatchable renewable energy technologies such as reservoir hydropower or electricity generation from biomass in the MENA region, **CSP has a key role** to play in enabling high shares (>50%) of renewable energy in the overall electricity supply of the MENA region. By using thermal energy storage with a typical capacity of 4–12 full load hours and a fossil-fuel- or bio-fuel-fired back-up burner, CSP not only can produce large quantities of electricity from solar resources (3,500–7,000 full load hours) but also can provide firm and flexible generation capacity to support VRE integration. To achieve further cost reductions in this technology, **stable investment conditions and political support** are needed. Results from recent auctions for CSP, such as those held in Dubai, show the effectiveness of such an approach and have already led to a significant drop in PPA tariffs for this technology. In addition, the development of cost-competitive short- and long-term energy storage solutions such as batteries and power-to-X technologies as well as improvements in demand-side management, energy efficiency and sector coupling in transport, industry and buildings will enable a successful transition towards a sustainable energy supply in the MENA region.

Policy recommendations: make use of the current window of opportunity, and consider the true cost of energy sources

The current need for new electricity generation capacity and the decreasing costs of renewable energy technologies have opened up a window of opportunity for sustainable energy pathways. To mitigate investment risks and make use of this window of opportunity, decision-makers should consider the following recommendations:

- **Take advantage of the declining costs for renewables and consider the externalities of coal-fired generation in decision-making**: The MENA region is uniquely positioned to benefit from the already low and declining costs of renewable energy technologies and to lead the way. When assessing the cost of different energy options, externalities should be considered when comparing options. These externalities include pollution, public health threats and import dependence, which are described in this report and reflected in the estimates of externality costs. Finally, there are many options available for bringing down the cost of non-coal energy systems even further, such as tapping into the grants and preferential funding available from multilateral banks and funds like the Green Climate Fund (GCF). For example, a combination of more than USD 150 million in grants and loans from the GCF and funding from the European Bank for Reconstruction and Development (EBRD) has helped to reduce the price of renewable energy bids in Egypt by more than half to about 30 USD/MWh.

- **Develop long-term energy strategies that mitigate investor risk**: The global move towards decarbonisation is well underway and creates a substantial risk of stranded investments for investors in coal-fired power generation. The introduction of CO_2 prices in different forms can lead to a significantly lower utilisation of coal-fired generation. Viable long-term alternatives exist, based on a combination of flexible natural gas plants, variable and dispatchable renewables, and energy storage.

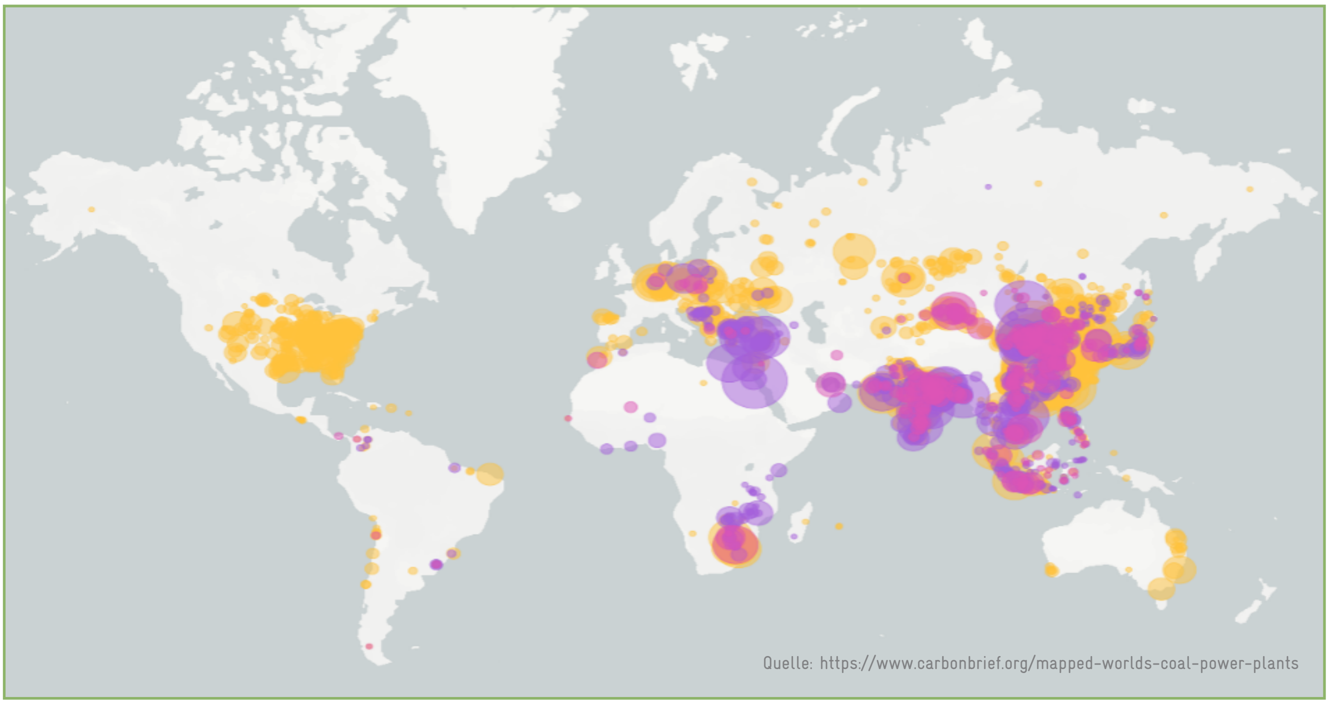
- **Build flexible power systems that can accommodate renewables in the most efficient way**: The growing energy demand in MENA countries requires investments in electricity systems. These should be made with a view to enhancing flexibility on both the generation and the demand side through sector coupling and through grid expansion to accommodate VRE in a cost-efficient manner. Flexible power systems will increase the reliability of supply and make energy systems ready for future challenges.

Our report shows that zero-coal power systems achieve the energy goals of security of supply, sustainability and affordability, while enabling MENA countries to deliver on their Paris Agreement commitments. The region's unparalleled renewable energy sources and the vast emission reduction potential of scenarios with high shares of renewables should prompt decision-makers to consider the true cost of energy sources and their externalities, promote alternatives to coal and, in so doing, ensure that the MENA region remains an energy leader in the future.

1 Introduction[1]

Even though investments in renewable energy are hitting record highs and prices for solar and wind are declining, the global energy transition remains nascent while fossil-based generation continues to expand, putting the achievement of the Paris Agreement targets at risk. More than 209 GW of coal-fired power plants are under construction and over 443 GW are at a planning stage around the world, as shown in Figure 6 below. Even though construction has begun for only about two thirds of the coal-fired power plants planned since 2010, the expansion of coal-fired power generation is the major threat to global climate protection efforts and to the successful implementation of the Paris Agreement.

Figure 6. Global coal-fired power plants in operation (yellow), under construction (pink) and planned (purple) Source: Carbon Brief (2017)



The bulk of the planned new coal capacity is in China, India, Indonesia, Turkey and Viet Nam. However, the MENA region – which, along with six of its countries (Morocco, Egypt, Jordan, the UAE, Oman and Iran), is the focus of this report – has also seen increasing announcements for new coal-fired capacities. Although some of these announcements have been put into question by recent policy decisions, the risk of significant coal-fired power additions in the face of growing demand remains. The coal-fired capacities considered in the MENA region will likely undermine the achievement of (I)NDCs. With the exception of the Moroccan NDC, the (I)NDCs of the countries studied in this report are already insufficient to reach the Paris Agreement goals and are thus likely to 'close the door on ambitious climate change mitigation targets' (Edenhofer et al., 2018) – even Morocco's more ambitious NDC does not factor in that country's coal plans. According to the IPCC, holding global temperature increase below 2°C and making best efforts to keep it below 1.5°C by 2100 requires a rapid decarbonisation of the global power sector, with zero carbon emissions needing to be reached globally by around 2050. Even with no new construction of coal-fired power plants, emissions from the existing coal-fired power generation in 2030 would still be 150% higher than the level consistent with scenarios that limit warming to below 2°C above preindustrial levels (middle of the range) (van Breevoort et al., 2015). It is therefore even more important to understand the motivations for coal-fired power generation being considered in the MENA region, where renewable energy sources are abundant and can offer reliable alternative pathways.

1 *Acknowledgements: This study benefited from valuable contributions from Mohamed Salheen, Dr Dalia Sakr, Dr Shadia El-Shishini, Behzad Aghababazadeh, Malek Kabariti, Dr Ayoub Abo Dayyeh, Tayeb Amegroud, Ashraf Kraidy, Taher Diab, and eight other experts in the region. Further, we are grateful for the valuable feedback by Philipp Litz (Agora Energiewende), Paola Parra and Dr Bill Hage (Climate Analytics), and Dr Tobias Bischof-Niemz (ENERTRAG AG).*

This study aims to close an existing gap in the literature on the status quo and plans for coal-fired power generation capacity in the MENA region, focusing on Morocco, Egypt, Jordan, the UAE, Oman and Iran. Most countries in the region – and thus the region itself – are characterised by large oil and gas resources, but also by abundant solar and wind resources. Significant coal reserves are only present in Iran. The MENA region is witnessing steeply rising energy demand due to a growing population, economic development and rising standards of living, and major shifts in MENA countries' energy landscapes can be observed. For example, the fossil fuel resources available to them are declining because of both decreasing reserves and the fact that large shares of countries' available gas and oil resources are bound up in long-term export contracts. This is true of, for instance, the United Arab Emirates (UAE), which has recently become a net importer of gas.

Coal has traditionally played a minor role in the region, but concerns about energy security, diversification of energy supply and rising energy demand have brought it on to the agenda. At the same time, several countries in the region, such as Morocco and the emirates of Dubai and Abu Dhabi in the UAE, have received a lot of attention for the declining prices of their renewables and for their ambitious renewables deployment targets, pointing to a way forward to address the region's energy challenges.

Against this background, this study pursues four main objectives:

- Present a systematic overview of the status quo and plans for coal-fired power generation in the MENA region.

- Assess the main motivations for the development of coal-fired generation in the region.

- Highlight the impacts of utilising coal in the power sectors of the MENA region by modelling possible generation expansion pathways for a synthetic yet representative power system with and without coal as a potential source for electricity supply.

- Present recommendations for policy-makers on how to ensure the current opportunity to take a sustainable energy path is not lost.

The approach employed in the study encompasses a mix of expert interviews, literature analysis and conclusions drawn from the power system modelling results. Interviews with 16 experts on both the examined countries and the overall MENA region as well as background conversations were used as sources to validate information on the status quo and plans for coal power plants and to understand the motivations and caveats for coal deployment in the region.[2] Based on this approach, the study is intended as a basis for dialogue on the common aim of ensuring that the objectives of the Paris Agreement are reached, while ensuring a secure and affordable energy supply in the MENA region.

2 The identity of the experts has in some cases been kept confidential in accordance with these contributors' preferences. A list of the interviewees, who herein are each given a number (e.g. 'Interviewee 1'), is provided in Appendix 1. This list displays the country the interviewee provided input on and, where appropriate, their name, position and institution.

2 Overview of the current situation and outlook for coal in the MENA energy mix

This chapter presents the role and plans for coal in the six countries addressed in this study, working country-by-country from west to east (from Morocco, through Egypt, Jordan, the UAE and Oman, to Iran). It then explores the motivations and caveats for coal deployment.

2.1 Country portrait: Morocco

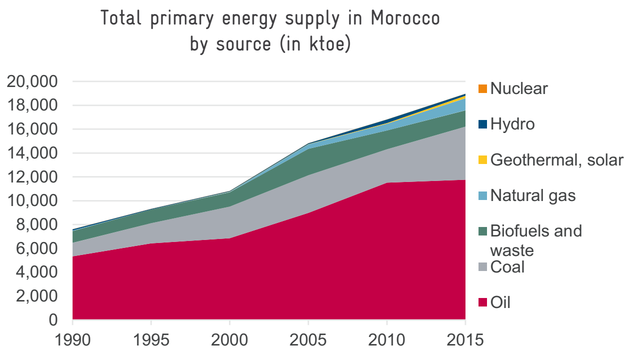
2.1.1 Morocco's energy mix

Morocco's total primary energy supply (TPES) has grown considerably in the past decade: while its TPES was about 14.9 million tons of oil equivalent (Mtoe) in 2005, it reached 19.3 Mtoe in 2015 (IEA, 2017a), as shown in Figure 7 below. This increase was the result of the country's rapidly growing economy, which saw average annual GDP growth of 2.7–4.5% between 2010 and 2015 (World Bank, 2017). Coal is already a highly important part of the energy mix in Morocco, in contrast to the MENA region generally where oil and gas are the predominant sources of energy. In 2015 Morocco's energy mix was dominated by oil (60.7%), followed by coal (22.9%), biofuels and waste (7.0%) and natural gas (5.2%).

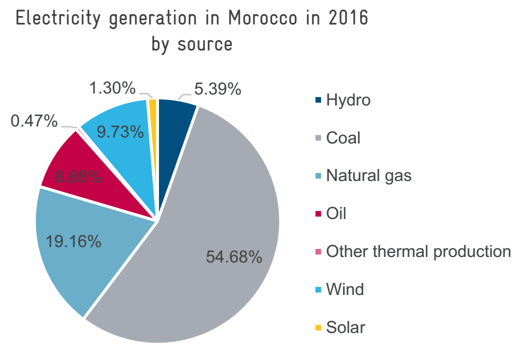
Morocco is highly dependent on imported hydrocarbon energy because its domestic supply of oil, gas and coal is either negligible or suffers from high per-unit costs of production. Indeed, more than 96% of the country's net energy supplies are imported: oil largely from Saudi Arabia, gas almost exclusively from Algeria and coal from Russia and South Africa (IEA, 2014; Amegroud, 2015).

The country's total installed power generation capacity of 8,262 MW generated 30,840 GWh of electricity in 2016 (ONEE, 2016). The main sources for electricity generation in that year were fossil fuels: coal (54.7%), gas (19.2%) and oil (8.9%). Wind contributed 9.7%, while the share of solar power was 1.3%. Projects in the pipeline from 2016 to 2030 account for 4,560 MW from solar energy, 4,200 MW from wind energy and 1,330 MW from hydroelectric projects (RVO, 2018). Morocco imports electricity from abroad, mostly from Spain (through an interconnection of 1,400 MW) and, less regularly, from Algeria (through an interconnection of 1,200–1,500 MW) (Schinke and Klawitter, 2016).

Figure 7: Total primary energy supply in Morocco by source (ktoe) (left) and electricity generation in Morocco in 2016 by source (right)



Source: IEA, *World Energy Balances 2017*
Excludes electricity trade (in 2015: 442 ktoe imported, 14 ktoe exported)



Source: ONEE Branche Electricité, *Rapport d'Activités 2016*

2.1.2 Current role of coal in the Moroccan energy landscape and planned coal projects

Coal mining in Morocco ended in 2000, when output amounted to approximately 12,000 tons per year. The Jerada Mine, located in Morocco's Oriental region, was closed for technical and economic reasons, following a continual decline in production since the 1980s (IEA, 2014). Morocco therefore depends on coal imports, mostly from South Africa and Russia, to meet demand. The electricity sector accounts for virtually all coal consumption (4,266 ktoe or 99.6%) (IEA, 2017a).

After the coalmine was closed, the Jerada power plant (at that time comprising three units of only 55 MW each) continued to operate by burning coal transported from the port of Nador. In July 2013 the Chinese company SEPCO III launched a project to expand the plant, installing a fourth unit of 350 MW. The original three units[3] (units 1–3) used subcritical[4] technology and emitted 0.63 million tons of CO_2 annually (Carbon Brief, 2017). These units stopped operations in 2017 and underwent decommissioning in 2018 (Interviewee 4, 2018), with the regional government mentioning environmental impacts and high water needs as reasons for the closure (H24, 2018). The new 350-MW unit (unit 4) uses supercritical technology and emits 0.44 million tons of CO_2 annually[5] (NRDC, 2017). The addition of a fifth unit is being examined by the regional government, and this project's potential for job creation has been put forward as a motive for its construction. However, no further information is available on this plan (H24, 2018).

Despite the closure of the Jerada Mine, the Government of Morocco was keen to maintain coal's share in the electricity mix and encouraged the construction of a coal power plant in Jorf Lasfar, 100 km southwest of Casablanca on the Atlantic coast (IEA, 2014). The Jorf Lasfar power station has a total capacity of 2,060 MW and comprises two 330-MW units and four 350-MW units (Carbon Brief, 2017). The power station uses subcritical technology at 37% efficiency and emits 7.82 million tons of CO_2 annually (Carbon Brief, 2017).

The 300-MW Mohammedia coal power plant, commissioned in the early 1980s, is operated by state-owned utility, ONEE. Initially, the power plant was to have four 150-MW units using oil as fuel. Due to the oil crisis in the mid 1970s, the government decided to adapt two units (units 3 and 4) to use coal. The power station uses subcritical technology and emits 1.14 million tons of CO_2 per year (Carbon Brief, 2017).

Lastly, the Safi power station was commissioned in mid-December 2018 (Cala and Belmonte, 2019). It has a capacity of 1,386 MW, which is provided by two 693-MW units. The power station uses ultra-supercritical technology and is expected to emit 1.58 million tons of CO_2 annually (NRDC, 2017). In addition to the ultra-supercritical combustion technology, the project will use 'clean carbon' technologies for treating emissions (desulphurisation) and waste (dust discharge) (IEA, 2014). By the end of 2018, the Safi and Jorf Lasfar power plants had become the main electricity suppliers in Morocco. Together, the power plants cover approximately 3,400 MW of the 4,000 MW of baseload demand (6,400 MW peak demand) (Interviewee 4, 2018).

3 Units 1–3 of the Jerada power plant in Morocco often operated with a load factor of 45% – i.e. the electricity from this power plant was more for back up and not baseload power.

4 The efficiency of coal-fired power plants is measured based on the ratio between the energy contained in the fuel (coal) and the electricity generated from this energy. In subcritical plants only 33–37% of the energy is converted to electricity, in supercritical units this percentage is higher at 37–40%, while in ultra-supercritical units it goes above 40%.

5 The National Resources Defense Council (NRDC) reports emissions in tonnes (i.e. metric tons). The value is therefore 0.4 million tonnes of CO_2/year which, divided by 0.907185, results in 0.44 million tons of CO_2/year (1 ton = 0.907185 tonnes).

Table 2. Overview of current coal power plants in Morocco

Plant	Location	Capacity	Age	Efficiency	Emissions
Casablanca power station	Casablanca (Grand Casablanca)	60 MW	Decommissioned in the early 1990s (operated from 1968).	N/A	0.23 million tons CO_2/year
Jerada power station	Jerada (Oriental)	515 MW; units 1–3 are 55 MW each, unit 4 is 350 MW	Units 1–3 stopped operations in 2017, underwent decommissioning in 2018. Unit 4 started operations in 2017.	Unit 4: supercritical (37–40% efficiency). Units 1–3 operated on subcritical efficiency.	Units 1–3: 0.63 million tons CO_2/year Unit 4: 0.44 million tons CO_2/year
Jorf Lasfar power station	Doukkala-Abda	2,060 MW; units 1–2 are 330 MW each, units 3–6 are 350 MW each	4–24 years (unit 1 operating since 1994, units 5 and 6 operating since 2014).	Subcritical (33–37% efficiency)	7.82 million tons CO_2/year
Mohammedia power station	Grand Casablanca	300 MW; units 3 and 4 are 150 MW each[5]	32 years in operation (since 1986). Units were renovated some years previously and will continue to operate for 10–15 years.	Subcritical (33–37% efficiency)	1.14 million tons CO_2/year
Safi power station	Agadir	1,386 MW; units 1 and 2 are 693 MW each	Started operations in December 2018. Electricity will be sold to ONEE for 30 years after commissioning.	Ultra-supercritical (44–46% efficiency)	1.58 million tons CO_2/year (estimated)

To meet the increase in electricity demand beyond 2020, Morocco announced the launch of an additional coal-fired power plant at Nador (see Table 3 below) with a capacity of 1,320 MW (two 660-MW units). Commissioning of the plant was initially scheduled for 2023–24, but the project currently remains in the planning stage. Although it is part of the country's capacity expansion plan, no further decisions towards its concrete implementation have been made and the project appears to be shelved for the moment.

Table 3. Overview of the planned coal plant in Morocco

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
Nador power station	Nador	1,320 MW, with two 660-MW units	2023–24	Construction was initially planned to begin in 2019, but project appears to be shelved)	N/A	N/A

2.1.3 The Moroccan energy strategy

In 2009 the Moroccan government announced its National Energy Strategy, which has five main pillars: optimise the fuel mix in the electricity sector; accelerate the development of energy from renewable sources (especially wind, solar and hydropower); make energy efficiency a national priority; encourage more foreign investment in the energy sector; and promote greater regional integration (IEA, 2014).

Under the first pillar (namely, building an optimised electricity mix around reliable and competitive technologies), the strategy intends to maintain the use of coal as a main source with a share of 27% of total installed electricity capacity (Amegroud, 2015). The strategy foresees gas reaching 21% of the total installed capacity and renewables reaching 42%. The intention is to build 6 GW of installed renewables capacity by 2020, divided equally between wind, solar and hydropower (2 GW each). This goal for renewables' share of electricity generation capacity has since been increased to 52% by 2030.

The generation expansion plan (le Plan d'équipement) for 2013–17 lays out the envisioned capacity additions for coal, oil, hydro, wind, and solar, that are compatible with Morocco's 2020 energy strategy. For coal in particular, the plan provides for the construction of two 350-MW units (units 5 and 6) at the Jorf Lasfar power plant, the expansion of the Jerada power plant (the 350-MW unit 4) and the construction of the Safi power station (IEA, 2014). Similarly, the plan for the 2016–20 period foresees the addition of 5,770 MW, including 1,736 MW in coal-fired capacities through the expansion of Jerada power station and the construction of the Safi power station (L'Economiste, 2016).

2.1.4 The Moroccan regulatory framework for coal

Morocco's Decree No 2-09-631 of 2010 sets limits for the clearance, emission or discharge of pollutants into the air from stationary sources of pollution and establishes procedures for air monitoring, which consist of voluntary self-monitoring and annual self-reporting. The decree mentions emissions resulting from coal combustion, such as sulphur dioxide (SO_2), nitrogen oxides (NO_X) and particulates, but does not establish specific limits for coal or the electricity sector.

Article 4(3) establishes a limit of 500 mg/m3 for a mass flow greater than 5,000 g for inorganic pollutants in the form of gas or vapour for class 4 substances, which include sulphur dioxide and nitrogen oxides (Decree No 2-09-631, 2010).

The governing environmental laws, including the decree, do not grant the main environmental authorities explicit powers of inspection and enforcement. While there are environmental inspectors in Morocco, no system of compliance monitoring is in place. Resources dedicated to compliance are very modest. As a result, there is no programme of inspections, not even in highly industrialised regions such as Grand Casablanca (UNECE, 2012).

2.1.5 Morocco's NDC and climate goals

Morocco's NDC contains an unconditional target of reducing GHG emissions by 17% below business as usual (BAU) by 2030. If it receives enough international support, Morocco aims to further decrease emissions by 42% below BAU by 2030 (Climate Action Tracker, 2018a). Planned mitigation actions under the National Energy Strategy include the implementation of an ambitious 42% target of installed electricity production capacity from renewable sources by 2020, increasing to 52% by 2030. Recent developments show that Morocco is on track to meet its 2020 renewable energy targets, and its work to meet its 2030 renewable energy targets is at an advanced planning stage (Climate Action Tracker, 2018a). However, the current and planned role of coal in Morocco appears at odds with the achievement of the Paris Agreement targets (see Table 4).

Table 4. Morocco's coal expansion plans in light of the Paris Agreement climate goals

	Morocco
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	The current and planned role of coal in Morocco does not correspond with an energy pathway that leads to the achievement of the Paris Agreement targets. To stay well below 2°C, a worldwide phase-out of inefficient, unabated coal-fired plant technologies and of coal-fired plant fleets not retrofitted with CCS technology or biomass conversion is needed before 2040 (GIZ, 2017). According to an assessment by Climate Action Tracker, Morocco's projected emissions levels in 2030 under current policies[6] would be rated as '1.5°C Paris Agreement compatible'. This rating indicates that a government's efforts are in the most stringent part of its fair share range. However, a shift away from coal is essential if Morocco is to achieve its 2030 Paris Agreement targets (Climate Action Tracker, 2018a). If all countries were to follow Morocco's approach, and depending on the source of data used, warming would be too high to be consistent with the Paris Agreement, coming in either some way below but not well below 2°C (Climate Action Tracker, 2018a) or at 2.6°C (Paris Equity Check, n.d.). Morocco's plans for coal up to 2020 are not mentioned in the country's NDC (Morocco, 2016). So far, a decommissioning of coal power plants before 2030 has not been announced. Moreover, two of the country's four coal plants use a subcritical combustion technology. To limit warming to 1.5°C, no new coal-fired power plants should be built and emissions from existing coal-fired power plants need to be reduced by at least 30% by 2025 (Climate Action Tracker, 2016) worldwide. Moreover, the IPCC's Special Report on Global Warming of 1.5°C states that coal-fired electricity generation needs to be phased-out by 2050, moving from a global share of 32.3% in 2020 to 0.82% in 2050 (median values) (IPCC, 2018). Recently commissioned and planned coal-fired power plants in Morocco are not compatible with the required mitigation pathway. The Safi coal-fired power plant commissioned in mid-December 2018 is, in terms of efficiency, an ultra-super-critical installation. However, if no coal phase-out is implemented, the plant can be assumed to have a lifetime of 30 years, meaning it will likely operate until 2048. Similarly, although the planned Nador coal-fired power plant appears to have been shelved, were this decision to be reversed, the building of this plant would see Morocco's energy planning diverge even further from a Paris-compatible trajectory.
Compatibility of domestic energy and climate policies	Morocco's current energy policy and its use and plans for coal make the achievement of its NDC more difficult. Although the National Energy Strategy sets targets for renewable energy deployment by 2020 and 2030, it also states Morocco's current intent of maintaining the use of coal as a main source, with coal's share comprising 27% of total installed electricity capacity by 2020 (Amegroud, 2015). Moreover, Morocco's plans for coal up to 2020 are not mentioned in the country's NDC (Morocco, 2016).

2.1.6 Motivations for coal among Moroccan decision-makers

Coal's share of the energy mix in Morocco is high, both in terms of TPES and electricity generation. Although coal mining ended in 2000, building an electricity mix around 'reliable and competitive technologies' remains a pillar of the country's energy strategy, with 'clean coal' being kept as the main generation base. There are several factors explaining Morocco's interest in coal (Interviewee 4, 2018):

Factor	Description
Ease of supply with coal	Supply of coal can be easier to arrange compared to gas. While importing gas usually involves entering into long-term agreements for a minimum capacity, coal supply is more diversified and can be more 'modular/flexible'. The only gas used domestically is imported from Algeria and this supplies the only two combined-cycle power plants in the country. The infrastructure required to further develop combined-cycle power plants is currently available.
Cost-competitive-ness of coal	Generating electricity from coal is seen as being less expensive than alternatives like gas and renewables if coal plants are run at a load factor of 60–70%. Therefore, in contexts where externalities are not being factored in and where devel-oping coal is viable, there is little incentive to opt for alternative sources.
System adequacy and security of supply	Baseload concerns are often mentioned, with sources pointing out that a viable power system would need more than renewables but also baseload production. Reducing the role of coal could be achieved by increasing the share of gas or extending power interconnections to Europe. However, these options present political and technical obstacles that call into question security of energy supply – a high priority in Morocco's energy policy.

6 The Climate Action Tracker rates (I)NDCs, 2020 pledges, long-term targets and current policies against whether they are consistent with a country's fair share effort towards the Paris Agreement 1.5°C temperature goal.

Caveats on the prospects for coal in Morocco

- There is already an interest to develop gas: 15 years ago Morocco began developing an LNG terminal. Although progress has been slow, lately there has been renewed commitment, and the aim is to commission the terminal in 2026–27. If the planned LNG terminal is commissioned by that date, the decision to build the Nador coal power station (1,320 MW) could be further delayed.
- Financing coal plants has become more difficult due to the increasing restrictions international lenders face with regard to financing new coal investments. Institutions like the World Bank and the African Development Bank, but also private banks like HSBC, are reducing investment in coal power plants, which means the lending pool is shrinking. Countries like China and Japan do still provide funding, but on condition that their boiler and turbine technology is used and their construction companies are brought in to build the scheme.
- There is also considerable local opposition to the construction of new power plants, especially in the regions with the highest demand (Casablanca and Marrakesh). Building a coal power plant in more remote locations would increase the transmission costs to the demand centres.

2.2 Country portrait: Egypt

2.2.1 Egypt's energy mix

Egypt is the largest oil producer in Africa outside of the Organization of the Petroleum Exporting Countries (OPEC) and is the third-largest natural gas producer on the continent following Algeria and Nigeria (EIA, 2018a). Egypt's TPES increased by 28.8% in the past decade: while TPES was about 61.7 million tons of oil equivalent (Mtoe) in 2005, it reached 79.5 Mtoe in 2015 (IEA, 2017b).

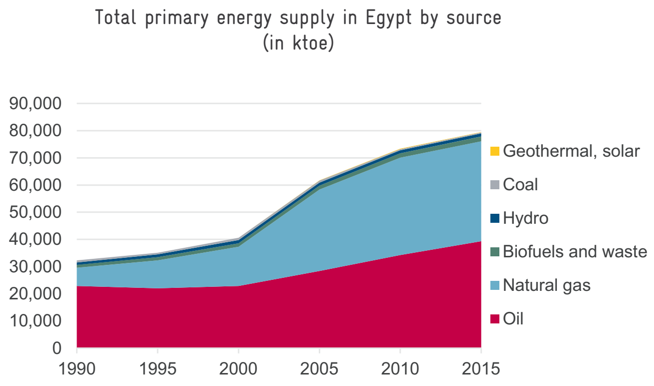
Egypt's energy mix is dominated by fossil fuels, which make up 96.2% of TPES, and virtually all of this comprises oil (49.5%) and natural gas (46.2%). Coal currently represents 0.4% of TPES and has seen its share more than halved, dropping from 802 Mtoe in 2005 to 355 Mtoe in 2015.

One of Egypt's main challenges is to satisfy increasing domestic oil demand amid falling production. The country's energy sector has been particularly sensitive to political turmoil, most notably in 2011 and 2013, which revealed structural and financial problems in the sector. One example was the Egyptian General Petroleum Corporation's (EGPC) accumulation of arrears with international oil companies, which, in response, suspended new investments in the sector (Kouchouk and Alnashar, 2015). These developments led to continuous supply bottlenecks, complicated by deficiencies in power plants and the transmission infrastructure (IFC, 2016).

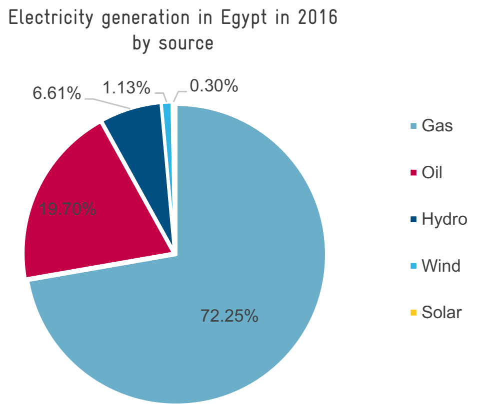
Current total crude oil consumption is roughly 800,000 barrels per day, while production is close to 660,000 barrels per day (EIA, 2018a). In 2015 Egypt also became a net importer of natural gas because of growing domestic demand and declining production levels. The (EIA, 2018a) argues, however, that substantial natural gas discoveries may potentially boost production and allow Egypt to become a net exporter again in the medium term.

The country's total installed power generation capacity of 45,008 MW generated 189,392 GWh of electricity in 2017 (EEHC, 2017). In 2016 the main sources for electricity generation were fossil fuels, most of which comprised gas with 72.3%, followed by oil with 19.7%. Hydropower contributed 6.6%, while the share of wind was 1.1% and solar 0.3%. Coal and nuclear power are not part of the current generation capacity, but coal and nuclear power plants are expected to be commissioned to diversify the generation mix (RES4MED, 2015).

Figure 8. Total primary energy supply in Egypt by source (ktoe) (left) and electricity generation in Egypt in 2016 by source (right)



Source: IEA, *World Energy Balances 2017*
Excludes electricity trade (in 2015: -100 ktoe exports und -4 ktoe imports)



Source: IEA, *Electricity Information 2018*

2.2.2 Current role of coal in the Egyptian energy landscape and planned coal projects

The role of coal in Egypt's energy mix has so far been minor. Coal represented 2% of Egypt's TPES in 2016 (SDS Egypt 2030, 2016), and most of this (92%) is consumed by the industry sector (Enerdata, 2017). Moreover, there is currently no installed capacity for electricity generation from coal.

In 2012, in the face of frequent electricity blackouts, the Egyptian government decided to divert natural gas away from heavy industrial users and towards electricity generation. As a result of this decision, most of the country's 25 cement companies were forced to operate using only a fraction of the gas needed for their operations. In light of these shortages, the industry lobbied to switch from natural gas to other fossil-fuel-based alternatives, such as coal and petcoke (IFC, 2016).

The importation and use of coal for cement production and other industries was approved in 2014 as part of a broader effort to diversify the country's energy mix. Moreover, Egypt's long-term energy strategy foresees the addition of a considerable 16,800 MW of capacity from coal by 2030 (see the next section on the Egyptian energy strategy). This is reflected in a pipeline of concrete coal projects amounting to some 12,640 MW. Despite these projects already being well advanced in their planning, a reversal of the Egyptian government's position is putting the timeline for coal additions to the power mix into question: In November 2019, it has been reported that the Egyptian Ministry of Electricity and Renewable Energy considers stopping all coal-fired projects (Almalnews, 2019). The announcement came after delays in the financial closure of the Ayoun Moussa (Farag, 2019) and Hamrawein plants had been reported during the summer 2019 and is linked to current overcapacities in the country's electricity generation fleet.

The largest project under consideration in Egypt is the Hamarawein IPP coal project with a capacity of 6,600 MW. It was to be built at the Red Sea port of Hamarawein. In June 2018 the Egyptian Electricity Holding Company (EEHC) announced that the consortium comprising Shanghai Electric (China), Dongfang Electric (China) and Hassan Allam Construction (Egypt) had won the tender to build the project with an offer of 5.4 USD cents/kWh (Sourcewatch, 2019), the lowest offer submitted (Sourcewatch, 2018a). A Memorandum of Understanding was signed between EEHC and the consortium in September 2018 for a coal plant composed of six 1,100 MW units. The power plant is planned to use supercritical combustion technology with an efficiency of 37-40% and would emit 7.20 million tons of CO_2 per year[7] (NRDC, 2017).

In accordance with Egypt's 2030 Agenda, which includes reducing carbon dioxide emissions, the Ayoun Moussa coal power station in Suez would use ultra-supercritical combustion technology with low-nitrogen-oxide (NO_X) pulverised-coal burners (SDS Egypt 2030, 2016). It was expected that the station would emit 3.09 million tons of CO_2 per year[8] (NRDC, 2017). The project would have a total capacity of 2,640 MW, split between four 660-MW units. The commissioning of the project was initially planned for 2020 but was deferred by the Ministry of Electricity in January 2017 until the release of the 2022–27 economic plan. The Electricity Observatory of the Egyptian Electricity Regulatory Authority (ERA) announced in January 2018 that Egypt had 8,150 MW of surplus power (Utilities ME, 2018).

In March 2015 the EEHC and Al Nowais Investments Group (UAE) signed a construction agreement for the Ayoun Moussa project, and in December 2017 the Ministry of Electricity allocated land to Al Nowais for project development. In January 2019, the Egyptian Electricity Transmission Company agreed to sign an agreement to purchase power from the plant at a value of 4.01 ct/kWh (Sourcewatch, 2018a). However, the agreement was reportedly put on hold by EEHC in July 2019 (Farag, 2019).

The second largest coal project under consideration is the Marsa Matruh power station coal project with a capacity of 4,000 MW to be built at Marsa Matruh on the Mediterranean coast. In May 2016 a memorandum of understanding was signed between the Government of Egypt and the consortium of El Sewedy Electric (Egypt) and Marubeni (Japan). The power plant would be built in two phases, each with a capacity of approximately 2,000 MW. Also, the project would be used to desalinate approximately 360,000 m^3 of seawater daily. The power plant would use ultra-supercritical combustion technology and it is estimated that it would emit 5.06 million tons of GHG emissions per year.[9] In November 2017, it was reported that the status of the project was unclear after the Ministry of Electricity decided to focus on moving forward with the Hamarawein project (Frontier Egypt, 2017).

In November 2019, EEHC announced that the Egyptian Ministry of Electricity and Renewable Energy is considering stopping all planned coal-fired power plants, including the already very advanced Hamarawein coal project (Almalnews, 2019). The Ayoun Moussa coal project has been shelved by the Ministry of Electricity and Renewable Energy by the end of 2019, according to news reports (Enterprise, 2019). The project consortium and the Ministry reportedly started negotiations two weeks after the announcement for the implementation of a renewable energy project with 500 MW capacity instead (Enterprise, 2019).
Even though the further development of coal-fired generation appears to be halted in Egypt due to overcapacities in the system, strongly growing power demand in the country will likely bring the question of additional fossil fuel fired power capacities back to the agenda in the future.

7 The NRDC reports emissions in tonnes. The value is 6.83 million tonnes of CO_2/year which, divided by 0.907185, results in 7.20 million tons of CO_2/year (1 ton = 0.907185 tonnes).

8 The NRDC reports emissions in tonnes. The value is 3 million tonnes of CO_2/year which, divided by 0.907185, results in 3.31 million tons of CO_2/year (1 ton = 0.907185 tonnes).

9 The NRDC reports emissions in tonnes. The value is 4.55 million tonnes of CO_2/year which, divided by 0.907185, results in 5.06 million tons of CO_2/year (1 ton = 0.907185 tonnes).

Table 5. Overview of planned coal projects in Egypt

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
Hamarawein IPP coal project	Hamarawein Port	6,600 MW	Commissioning was expected by 2023-24	Likely shelved, project was awarded in June 2018 to a consortium of Shanghai Electric, Dongfang and Hassan Allam offering USD 5.4 cents/kWh and already in an advanced development stage.[10]	Supercritical (37-40% efficiency)	7.20 million tons of CO_2 per year. Lifetime emissions of 288 million tons of CO_2 (40 years in operation).
Ayoun Moussa power station	Suez	2,640 MW, with four 660-MW units	Commissioning was expected by 2020	Likely shelved, previously commissioning had already been deferred until the 2022 27 economic plan.	Ultra-supercritical (44-46% efficiency)	3.31 million tons of CO_2 per year. Lifetime emissions of 132 million tons CO_2 (40 years in operation).
Marsa Matruh power station	Marsa Matruh	4,000 MW	Uncertain	Likely shelved. The project had already appeared to be deferred due to the electricity ministry's focus on moving forward with a single plant at Hamarawein.	Ultra-supercritical (44-46% efficiency)	5.06 million tons of CO_2 per year. Lifetime emissions of 201 million tons CO_2 (40 years in operation).

2.2.3 The Egyptian energy strategy

Egypt's current energy strategy was published in 2017 and covers the 2018–30 period. Egypt's electricity demand has grown consistently over the past decade, recording an annual growth rate of 6% in average (IRENA, 2018b). Driving this growth is a rising population, improving income levels, industrialisation, and also subsidised electricity prices. Egypt's estimated capacity of 45 GW (EEHC, 2017) is currently sufficient to meet demand but, while gas-fired power plants have recently been added, growth in demand will require the addition of further capacity. Previously, power outages were frequent, especially during the summer months when citizens might experience blackouts more than three times a day on average (Apicorp, 2016). While these outages were caused by a lack of generation capacity, those that occur today are due to the lack of necessary investment in the distribution grid.

The current energy strategy aims to diversify energy sources. Egypt aims to add 51,738 MW to its electricity mix between 2018 and 2030, including 16,800 MW from coal, 9,350 MW from wind, 6,950 MW from solar thermal, 9,020 MW from solar PV, 4,650 MW from natural gas and oil projects, and 4,800 MW from nuclear power plants (Farag, 2017). Egypt has also adopted the 'Sustainable Development Strategy: Egypt Vision 2030'. The objectives under this strategy's energy pillar include ensuring energy security (i.e. providing the required energy while maintaining the aspired growth rates), increasing the energy production of local resources and maximising reliability, and reducing emission and pollutant levels in the energy sector (SDS Egypt 2030, 2016).

The strategy also defines what the optimal electricity mix in Egypt should be by 2030. While generation from oil and gas-fired plants accounted for 91.7% of the mix in 2017 (EEHC, 2017), the aim is to decrease their share to 27% by 2030. It is envisioned that coal, which is currently not present in the electricity mix, will reach a share of 29% of electricity generation by 2030 (SDS Egypt 2030, 2016). Similarly, nuclear would go from zero to supplying 9% of electricity generation in the country. Over the same period, Egypt is seeking to grow the share of wind in the mix from 1.2% at present to 14% and solar's share from 0.3% at present to 16%. As mentioned above, the implementation of the energy strategy with regard to the further development of coal-fired power plants appears to be subject to new strategic priorities and changes regarding the assessment of overcapacities in the system.

10 Sourcewatch, 2019

2.2.4 The regulatory framework for coal in Egypt

In 2014 Egypt approved the importation and use of coal for cement production and electricity generation and for other industries where it is used as input for manufacturing (e.g. iron, steel, aluminium, tyres) (Elshishini, 2018). The proposed use of coal, however, sparked strong public debate on the potential environmental and health impacts, as well criticism around the importation of a fossil fuel largely unavailable in the local market and around the lack of existing infrastructure to support the switch from natural gas to coal (IFC, 2016). In response to this debate, the Egyptian government issued Decree No 964/2015, which defines the emission limits and control measures for coal permits.

Companies handling coal or using coal as a fuel must obtain a permit issued by the Egyptian Environmental Affairs Agency (EEAA). Coal licences will be granted only to those firms presenting a mandatory greenhouse gas (GHG) reduction plan. In fact, any user of coal (e.g. industrial users or electricity power plants) is required to offset the increase in CO_2 emissions that result from the introduction of coal compared to a baseline scenario by either using alternative fuels or implementing energy efficiency measures (Interviewee 13, 2018). The permit is valid for two years and is only renewed subject to the EEAA's approval of the environmental performance reports submitted by the facility in question.

For power plants of more than 600 MW, the following emission limits have been set (Elshishini, 2018):

Table 6. Maximum allowable emission limits in Egypt

Substance	Emission limit
Sulphur dioxide (SO_2)	850 mg/Nm³ [11] (450 mg/Nm³ in sensitive areas)
Particulates	50 mg/Nm³
Nitrogen oxides (NO_x)	200–500 mg/Nm³ (200 mg/Nm³ in sensitive areas)
Carbon monoxide (CO)	250 mg/Nm³
Lead (Pb)	2 mg/Nm³
Mercury (Hg)	1 mg/Nm³

The amount of coal allowed for power plants is estimated based on an efficiency of no less than 40%, which means the consumption rate of coal does not exceed 340–380 g/kWh through the use of supercritical boilers (Elshishini, 2018). In addition, power plants are required to minimise the amount of fly ash they send to landfill by selling this ash to local cement plants or exporting it to neighbouring countries.

2.2.5 Egypt's NDC and climate goals

Egypt was one of the few countries without a quantitative emission target in its INDC (Egypt, 2015). Instead, Egypt's submission to the UN included a range of high-level mitigation and adaptation goals such as the increased use of renewable energy and energy efficiency across subsectors (including transportation, agriculture and industry) and a pledge to eliminate fossil fuel subsidies worth USD 6 billion by 2020 (Pashley, 2015). In June 2017 Egypt submitted its first official NDC, which was unchanged from the preceding INDC. A clear target and/or reference baseline is not provided; all the indicated contributions are formulated as broad statements of intent (Rowihil, 2017).

Egypt has put forward a strategy to achieve a share of 20% renewables in the electricity mix by 2020, has implemented a feed-in-tariff programme for solar, wind and waste-management projects, has reduced government expenditure on energy subsidies, has improved energy efficiency in the transportation sector by extending the electrified underground metro to new areas in Greater Cairo, and has released the National Energy Efficiency Action Plan (NEEAP) for the electricity sector for the 2018–20 period (Egypt, 2018).

11 A normal cubic metre (Nm³) of a gas is the volume of that gas measured under the standard conditions of zero degrees Celsius and one atmosphere of pressure. When a gas is presented in cubic metres (m3), this describes the gas's volume at the actual operating conditions of the process. Because gas volume changes with temperature and pressure, it is necessary to establish 'normal' temperature and pressure conditions to ensure measurements are comparable.

Table 7. Egypt's coal expansion plans in light of the Paris Agreement climate goals

	Egypt
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	The planned role of coal in Egypt is not in line with energy pathways that lead to the achievement of the Paris Agreement targets. Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector, with the share of unabated coal (i.e. coal-fired power plants without carbon capture and storage) being completely phased out by around the mid-century globally (Climate Analytics, 2016) If all countries were to follow Egypt's level of ambition on emission reduction, the temperature increase by the end of the century would roughly amount to 3.3°C (Paris Equity Check, n.d.). Moreover, a recent study on the optimisation of Egypt's power sector found that, under a reference scenario,[12] CO_2 emissions jumped about threefold in 2050 compared to emissions levels in 2016 (97 $MtCO_2$[13]) due to fossil-fuel dependent power generation choices. The increase in emissions would be higher were coal-fired power plants to be incorporated in the analysis, assuming the installations are not equipped with CCS (Modal et al., 2019). The coal-fired power plants planned in Egypt are not compatible with the required mitigation pathway. The commissioning of almost 17 GW of coal-fired capacity by 2030 would result in a coal-fired power plant operating well beyond mid-century, assuming that the plant has a lifetime of 30 years and no coal phase-out is implemented. To mitigate emissions from these power plants, the country has defined standards that imply the facilities must have an efficiency of no less than 40% and can only consume up to 340–380 g of coal per kWh of electricity generated. However, the emissions that would result from the construction of all the currently envisaged coal-fired power plants will undermine long-term climate targets globally (Edenhofer, Steckel and Bertram, 2018).
Compatibility of domestic energy and climate policies	Egypt's NDC does not provide an emission reduction target. Furthermore, the fact that Egypt plans to add considerable coal capacities makes it difficult to achieve the emission reductions that would otherwise result from renewables having a 20% share of the electricity mix by 2020. The coal plans are at odds with Egypt's climate policy at the national level, which focuses on promoting measures that increase energy efficiency and the share of renewables and, in so doing, reduce GHG emissions.

2.2.6 Motivations for coal among Egyptian decision-makers

There are several factors explaining Egypt's interest in coal (Interviewee 14, 2018; Interviewee 2, 2018; Interviewee 15, 2018; Interviewee 7, 2018; Interviewee 13, 2018):

Factor	Description
Diversification of the energy mix and security of supply	The decision in 2014 to allow the industrial and power generation sectors to use coal was taken in order to increase security of supply. The decision opened up the possibility for foreign companies to import fuel sources themselves since the government did not want to remain responsible for the supply of the industrial sector. For the cement industry, coal was the most feasible fuel and cheaper than domestic gas, despite its being imported.
Coal as a replacement for natural gas	Before the supply crisis in 2013–14, which saw severe shortages in the country's natural gas supply, the government had been responsible for securing fuel for cement factories and had been using natural gas for this. With the supply crisis, the alternatives were either to close cement factories or allow the use of coal.
Cost-competitiveness of coal	Another factor driving the shift to coal in cement production is that, given the potential profits for government from the sale of, for example, fertilisers and petrochemical products, the government prefers to divert gas towards these industries and to fuel cement factories with coal instead. In addition, the plans announced regarding the exploration of new gas and oil fields in Egypt seem to be motivated by the prospect of selling gas to neighbouring countries, which is also more profitable than using this new gas to fuel domestic industries. At the time of the supply crisis, oil prices were high and solar PV was still seen as unfeasible, prompting the consideration of coal as an option. While coal is currently regarded as the most cost-competitive source, this does depend on the development of prices in international markets.

Caveats on the prospects for coal in Egypt

- The end of capacity shortages in the electricity sector due to the coming online of four new diesel and gas plants is delaying, or possibly halting, the development of some of the planned coal-fired power generation capacity.
- In addition, the Egyptian government is currently re-evaluating its renewable energy targets. When the 2035 energy strategy was developed in 2014–16, the economics of renewables, particularly solar, were different. The initial target was for renewables to comprise 37% of the electricity mix by 2035. In February 2008 Egypt's Ministry of Electricity and Energy announced an additional target of 20% of electricity to come from renewable energy resources by 2020. This development also points to a reduced role of coal in Egypt's energy mix.

12 This scenario does not impose any policy intervention and considers a continuance of the existing energy-economic dynamics. It serves as a reference for comparing alternative policy options and their technology selection and investments, technology capacity, energy requirement, cost, and GHG emissions.

13 $MtCO_2$ – million tons of CO_2

2.3 Country portrait: Jordan

2.3.1 Jordan's energy mix

Energy supply remains one of Jordan's top challenges: Jordan has almost no indigenous fossil fuel resources, and imports account for roughly 96% of the energy it consumes, with most of these imports purchased at global market prices. In 2015, imports (8,756 ktoe) covered 97% of the country's TPES[14] (IEA, 2017c). To reduce dependency on oil imports, Jordan is heavily pushing the exploration and development of its oil shale reserves. According to Jordan's energy minister, discussions are under way with four companies and exploration agreements have been signed with one Jordanian and one Saudi firm. The envisioned production of 25,000 barrels of oil per day from what are considered the world's eighth largest oil shale reserves would be the first time that oil has been produced in Jordan. (The National, 2019). Population increases, industrial development and a growing economy have led to a rise in annual growth of primary energy demand of 7% and of electricity demand of 2.5% (MEMR, 2017). Jordan's TPES has increased by 30% over the last decade.

Jordan's energy mix is dominated by fossil fuels, which make up 98% of TPES and comprise mostly oil (72.3%) and natural gas (22.5%). Coal currently represents 2% of TPES and was largely absent from the electricity mix as late as 2010.

The country's total installed power generation capacity of 4,430 MW generated 20,088.2 GWh of electricity in 2017 (NEPCO, 2017a). The main sources for electricity generation are fossil fuels, namely natural gas (84.7%) and oil (9.77%), but not coal. Solar contributed 2.9%, while the share of wind was 2.2% and of hydro 0.3%. Coal and nuclear power are not part of the current generation capacity, but coal and nuclear[15] power plants are planned as a means of diversifying the generation mix (NEPCO, 2016).

2.3.2 Current role of coal in the Jordanian energy landscape and planned coal projects

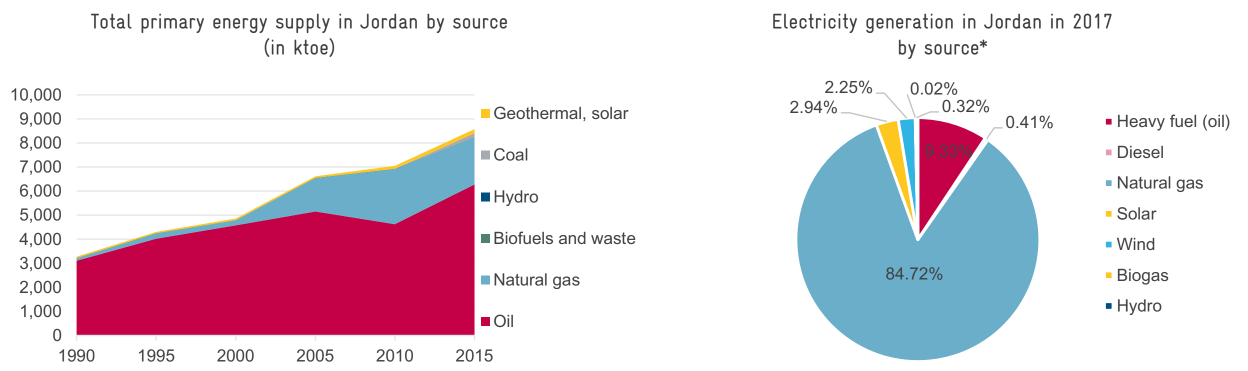
The role of coal in Jordan's energy mix has been minor, representing 2% of TPES in 2015 consumed by the industry sector (IEA, 2017c). Jordan's updated National Strategy for the Energy Sector, however, foresees coal having a 5% share of the energy mix by 2025 (NEPCO, 2016).

There is only one coal project in Jordan and this has been in operation since mid-September 2018 (Manaseer Group, 2018). The Qatraneh power plant has a capacity of 30 MW and is located in Karak Governorate. The power plant, which runs on coal and petcoke, was built inside the Qatraneh cement factory operated by Manaseer Group's Modern Cement and Mining Company and supplies electricity to the factory. In 2016 Jordan's Ministry of Energy and Mineral Resources (MEMR) announced initial plans to build the project, even though no environmental impact assessment (EIA) had been conducted at that time (Namrouqa, 2016). The Ministry of Environment requested that Manaseer Group submit an EIA and, following its receipt, went on to issue an approval (Interviewee 5, 2018).

The Qatraneh power station uses subcritical combustion technology with an efficiency of 33–37%. The approval of this project to power the cement factory, in addition to the approval given to the Arab Potash Company to build and operate its own gas power plant, is seen by many as the government giving the 'green light' for other industries to request the construction of coal power plants for self-supply (Interviewee 1, 2018).

An important consideration for future coal power stations in Jordan is that there are no domestic coal resources in the country. If the plan is to import coal from, for example, Australia, Indonesia or South Africa, it would be necessary to locate the power plant site near the port of unloading to keep the cost of transportation down (JICA, 2017b).

Figure 9. Total primary energy supply in Jordan by source (in ktoe) (left) and electricity generation in Jordan in 2017 by source (right)



Source: IEA, *World Energy Balances 2017*
Excludes electricity trade (in 2015: 4 ktoe exports and 52 ktoe imports)

*Does not include generation from biogas (4.1 GWh) and renewables in the industrial sector (33 GWh)

14 For the purposes of illustration, the number given for TPES in 2015 is 9,037 ktoe, which factors in production and imports. If one subtracts exports, international marine bunkers, international aviation bunkers and stock exchanges, the TPES is 8,624 ktoe. Energy imports amounted to 8,756 ktoe.

15 A 1 GW nuclear power plant in Amrah is expected to start operations in 2025 (NEPCO, 2016).

Table 8. Overview of current coal projects in Jordan

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
Qatraneh power station	Karak Governorate	30 MW (coal and petcoke)	September 2018	In operation	Subcritical (33–37% efficiency)	N/A

2.3.3 The Jordanian energy strategy

Before 2003, Jordan's energy supply relied overwhelmingly on oil imported from Iraq at discounted prices. The war in Iraq in 2003 meant Jordan had to find alternative sources of energy. This prompted the development of the National Energy Strategy, which centres on the utilisation of domestic sources of energy and the signing of a natural gas import agreement with Egypt at discounted prices mainly for electricity generation (Rahim and Eid, 2017). In 2014, natural gas imports, which generated most of the country's electricity, were almost completely halted due to the repeated bombing of the Arab gas pipeline and the domestic gas shortages occurring in Egypt.[16]

Jordan's National Energy Strategy has three main aims: maximise the utilisation of domestic resources, expand the development of renewable energy projects, and promote energy conservation and awareness (MEMR, 2017). The updated National Strategy for the Energy Sector foresees coal having a 5% share of the energy mix by 2025 (NEPCO, 2016) and, so far, there are no plans to increase this share in the coming decades (Interviewee 1, 2018). Facing high debt and fiscal pressures, Jordan decided to remove general fuel (gasoline, diesel and other fuel) subsidies in 2012. Between 2011 and 2013 the Jordanian utility NEPCO lost USD 7 billion due to its provision of petroleum products and electricity at below market prices (Moerenhout, Vezanis and Westling, 2017). The country is still working to complete its reform of electricity subsidies.

The National Energy Strategy aims to increase the share of renewables to 10% of Jordan's primary energy mix by 2020, which would be equivalent to 20% of electricity generation. It also foresees increases in the share of gas in the primary energy supply (35.3% in 2016) and the use of nuclear energy to cover 43% of the electricity mix by 2030 (Hashemite Kingdom of Jordan, 2015). Similarly, Jordan's Vision 2025, a 10-year socio-economic blueprint for the country launched in 2015, aims to raise the proportion of energy consumption met using local supplies from 2% to almost 40% within the next decade. The contribution of domestic resources will be promoted through energy conservation and awareness, the use oil shale, and the generation of electricity from nuclear energy and renewables. (Rahim and Eid, 2017).

2.3.4 The regulatory framework for coal in Jordan

Jordan has adopted regulations aimed at: reducing emissions that have a negative impact on the environment,[17] setting ambient air quality standards[18] and limiting values for industrial emissions.[19] The Jordanian Standard 1189/2006 on industrial emissions mentions emissions resulting from coal combustion, such as sulphur dioxide (SO_2), nitrogen oxides (NO_X) and particulates, and sets industrial emissions limits, as shown in Table 9 (Ababsa, 2013). However, it does not establish specific limits for such emissions from the coal or electricity sectors.

Table 9. Maximum allowable emission limits in Jordan

Substance	Sources	Emission limit
Nitrogen oxides (NO_x)	Combustion plants	200 mg/m^3
Sulphur dioxide (SO_2)	Oil industry	6,500 mg/m^3
Particulates	Cement industry	50 mg/m^3

16 Egypt used to supply 2.47 billion m³ gas per year to Jordan under a long-term contract with the Jordanian state-owned power utility NEPCO, but there have been frequent interruptions in gas flows since 2011. In 2015 the pipeline switched to reverse flows towards Egypt, which, under an agreement signed in August 2015, began importing some of the regasified liquified natural gas (LNG) delivered to Aqaba. Jordan will resume pipeline gas imports from Egypt in January 2019 (Argus, 2018).

17 Environment Protection Law No 1 of 2003; Environment Protection Law No 52 of 2006.

18 The ambient air quality standards (Jordanian Standard 1140 of 1999, updated in 2006) provide limits for total suspended particulates (TSP), particulate matter (PM) and gaseous substances (sulphur dioxide [SO_2], carbon monoxide [CO], nitrogen dioxide [NO2], hydrogen sulphide [H2S] and lead [Pb]).

19 The standards for emissions from stationary sources (Jordanian Standard 1189 of 1999, updated in 2006) set limits for TSP by type of industry as well as for gaseous substances.

2.3.5 Jordan's NDC and climate goals

According to Jordan's Nationally Determined Contribution (NDC) commitments, the country will reduce its GHG emissions by 14% in 2030 compared to the base year of 2006. Of this 14%, 1.5% will be met unconditionally compared to a business-as-usual scenario, while the remaining 12.5% will be achieved subject to the availability of international financial aid and support (Climatescope, 2017).

The targets are accompanied by plans for a range of GHG emission reduction actions across several sectors and adaptation actions in targeted sectors. Jordan's 2016 NDC focuses on energy efficiency and renewable energy projects as the most feasible mitigation instruments. The country aims to increase renewable energy from 2% of the overall energy mix in 2013 to 10% in 2020, and to improve energy efficiency by 20% by 2020 (EBRD, 2017).

Table 10. Jordan's coal expansion plans in light of the Paris Agreement climate goals

	Jordan
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	The recent commissioning of the Qatraneh power plant in Jordan is not compatible with energy pathways that are needed globally for the achievement of the Paris Agreement targets. Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector, with the share of unabated coal (i.e. coal-fired power plants without carbon capture and storage) being completely phased out by around the mid-century globally (Climate Analytics, 2016). The Qatraneh power station uses subcritical combustion technology and is so far not equipped with CCS. The recent commissioning of the power plant means that, assuming the plant has a lifetime of 30 years and no coal phase-out is implemented, it would operate well beyond mid-century. If all countries were to follow Jordan's level of ambition in reducing emissions, the temperature increase by the end of the century would amount to roughly 3°C (Paris Equity Check, n.d.). Jordan's recent commissioning of the Qatraneh power plant makes the achievement of its NDC more difficult. For its part, the Jordanian NDC sees energy efficiency and renewable energy projects as the most feasible mitigation instruments. Moreover, while Jordan's energy policy envisages increases in the shares of different energy sources over the coming years, so far it does not indicate a commitment to increase the share of coal beyond 2025 (Interviewee 1, 2018). However, what the commissioning and operation of the Qatraneh power plant does is cancel out the emission reduction that would otherwise be achieved through renewable energy having a 2% share of the energy mix and energy efficiency being increased by 20% by 2020.
Compatibility of domestic energy and climate policies	Emissions during the lifetime of the power plant represent additional emissions that Jordan will need to offset. Furthermore, the approval of a coal power plant project to supply a cement factory with electricity could be perceived by other industry-sector actors as a 'green light' to lobby for the construction of coal power plants in their vicinity (Interviewee 1, 2018).

2.3.6 Motivations for coal among Jordan's decision-makers

Several factors explain Jordan's interest in coal (Interviewee 5, 2018; Interviewee 1, 2018; Interviewee 10, 2018):

Factor	Description
Supply for energy-intensive industry	Plans are in place to develop a 30-MW coal power plant project that will supply the local cement factory with electricity, much like the gas power plant that exclusively supplies power to the Arab Potash Company (which is primarily involved in harvesting minerals from the Dead Sea). Approval for this coal power plant could encourage other industry actors to request approvals to build coal power plants for self-supply.
Diversification of energy sources	With political turmoil in the region, coal is also seen as a means to (in small measure) diversify the energy mix and thereby increase security of supply. This goal is not however a major driver for coal, with the envisaged share of coal attaining only 4% by 2025.

Caveats on the prospects for coal in Jordan

- It seems unlikely that Jordan will continue to expand the use of coal in its energy mix beyond 4% by 2024–25. Advances in the supply of natural gas make an expansion of coal less likely. For instance, there is an agreement with Israel for the supply of natural gas, the pipeline for which is currently under construction and is expected to come online by the end of 2019.
- Similarly, the installation of the liquified natural gas (LNG) terminal at the Port of Aqaba marked an important step forward in Jordan's effort to secure a reliable and affordable energy supply. Before the terminal opened, Jordan had struggled to find a substitute for Egyptian gas, the supply of which was repeatedly being interrupted as a result of attacks on the gas pipeline connecting the two countries. LNG imports, although costlier than the imports from Egypt, were cheaper than the interim purchase of oil and diesel – an option that Jordan has been forced to resort to in recent years.

2.4 Country portrait: The UAE

2.4.1 The UAE's energy mix

The UAE's energy sector is dominated by fossil fuels, with natural gas representing 78% of TPES in 2015 and oil 19%. While non-hydro renewables (0.2%) played a marginal role in 2015 (IEA, 2017d), their share has more recently increased. Coal, which is imported and remained absent from the energy mix until 2005, represented 2.3% of TPES in 2015 and all of it is consumed in the industry sector. The UAE's TPES increased by 65% between 2005 and 2015.

The UAE's total installed power generation capacity of 28,761 MW generated 129,596 GWh of electricity in 2016 (FCSA, 2016). Natural gas is by far the largest source of electricity generation, accounting for 98.4% of generation, followed by oil- and diesel-fired power plants, which generate 1.23% of the country's electricity. Solar only accounted for 0.27% of the UAE's electricity generation in 2016, but this share is set to increase with the connection of the large-scale Noor plant in Abu Dhabi's Sweihan Solar Park and the extension of the Al Maktoum Solar Park.

The UAE holds the seventh-largest proven reserves of natural gas in the world, at slightly more than 215 trillion cubic feet. Despite this, the country became a net importer of natural gas in 2008 as a result of, on the one hand, reinjecting approximately 26% of gross natural gas production in 2015 into its oil fields as part of enhanced oil recovery (EOR) techniques and, on the other, its heavy reliance on electricity from natural-gas-fired facilities and strongly increasing demand[20] (EIA, 2017).

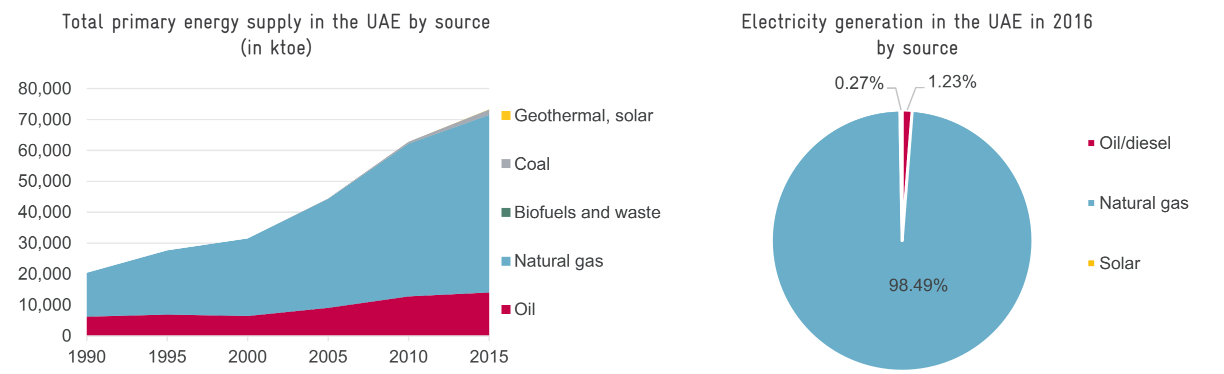
The UAE's growing reliance on natural gas imports has made energy diversification a national priority. The country has seen rapidly rising electricity consumption at an annual rate of 5% over the past five years, propelled by strong economic activity, a rising population, and industrialisation. In a context where the country's power demand is expected to increase at an annual rate of 5–6% up to 2021, the UAE published its Energy Strategy 2050 (Apicorp, 2017a), which targets a mix of renewables, nuclear, 'clean coal' and gas. Moreover, the country plans to increase its power generation capacity by around 21 GW by 2030 through various projects. These projects, both planned and under development, are comprised of 26.8% nuclear, 24.3% coal-fired and 22.5% gas-fired capacities of the planned 21 GW capacity addition by 2030. For its part, solar capacity is expected to make up 26.1% of the total additional generation capacity (EIA, 2017).

2.4.2 Current role of coal in the UAE energy landscape and planned coal projects

The role of coal in the UAE's energy mix has so far been minor. Coal represented 2% of the UAE's TPES in 2015 and all of it is consumed by the industry sector (IEA, 2017d). Moreover, there is currently no installed capacity from coal for electricity generation. However, the UAE Energy Strategy 2050 sets a target for 'clean coal' to represent 12% of the energy mix by 2050.

The largest project in the pipeline and the UAE's first coal-fired electricity generation plant is the Hassyan coal power plant, with a capacity of 2,400 MW, that is set to be built in Dubai. In October 2015 the Dubai Electricity and Water Authority (DEWA) awarded the project to the consortium of ACWA Power (Saudi Arabia) and Harbin Electric (China), which offered to build the project for 4.2 USD cents/kWh (DEWA, 2016) based on May 2015 coal prices (ACWA Power, 2017; DEWA, 2016). The power plant will use ultra-supercritical combustion technology with an efficiency of more than 40%. According to ACWA Power, the project design ensures EU guidelines on maximum permissible emission levels and seawater discharge requirements are not exceeded, ensures ultra-clean flue gas emissions, and features a carbon-capture-ready design.

Figure 10. Total primary energy supply in the UAE by source (in ktoe) (left) and electricity generation in the UAE in 2016 by source (right)



Source: IEA, *World Energy Balances 2017*

Source: IEA, *World Energy*

20 To help meet the growing demand for natural gas, over recent years the UAE has boosted imports from neighbouring Qatar via the Dolphin Gas Project pipeline. This pipeline runs from Qatar to Oman via the UAE and is one of the principal points of entry for the UAE's natural gas imports. In addition to the imports from Qatar, Dubai (as an importer) and Abu Dhabi (as an exporter) both participate in the liquefied natural gas (LNG) trade (EIA, 2017)

The Dubai Integrated Energy Strategy 2030 (DIES 2030), published in 2010 and approved by the Dubai Supreme Council of Energy (DSCE), opts for the addition of 3,600 MW of coal-fired generation capacity as a way to diversify the Emirate's energy mix (ACWA Power, 2017). Phase I (2,400 MW) of the Hassyan project is currently under construction and commissioning of the plant will take place in four phases of 600 MW each between 2020 and 2023. Phase II (1,200 MW) of the project has been announced, and commissioning is planned to take place between 2025 and 2026, also in two phases of 600 MW each (Matar, 2018).

In addition to the above-mentioned coal plans, Dubai's Clean Energy Strategy 2050 sets as targets a 25% share of clean energy by 2030 and 75% by 2050 of total primary energy supply, as well as the construction of 5,000 MW of solar capacity by 2030. Abu Dhabi set a target in 2009 for renewable energy to make up 7% of generation capacity by 2020.

The UAE's Energy Plan 2050 was presented on 10 January 2017 by Sheikh Muhammad bin Rashid Al Maktoum, who holds the offices of UAE Vice President and Prime Minister and ruler of Dubai. The Plan's strategy was jointly developed by all the energy-related authorities in the UAE and the Emirates Executive Councils under the leadership of the Federal Government of the UAE (Ministry of Energy, Ministry of Cabinet Affairs and Future Affairs). The Plan aims to develop the UAE's energy mix by increasing the share of renewable energy and the role of nuclear energy and reducing energy consumption. At the same time, CO_2 emissions from power generation are to be reduced by 70%.

Table 11. Overview of planned coal projects in the UAE (Hassan, 2017; DEWA, 2016; ACWA Power, 2017; Interviewee 8 and Interviewee 9, 2018)

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
DEWA Hassyan plant – phase I	Dubai	2.4 GW of capacity, comprising four 600-MW units	2020–23 in phases of 600 MW	Under construction	Ultra-supercritical (+40%)	N/A
DEWA Hassyan plant – phase II	Dubai	1.2 GW of capacity, comprising two 600-MW units	2025–26 in phases of 600 MW	Announced, no final decision taken	Ultra-supercritical (+40%)	N/A
FEWA Ras al-Khaimah (RAK) plant	Ras al-Khaimah	1,800 MW	2022	Announced, but project implementation is unlikely as FEWA has no access to land and cannot provide sovereign guarantees for PPA	N/A	N/A

The third project in the pipeline is the Ras al-Khaimah (RAK) coal power plant, with a capacity of 1,800 MW, to be built in the Emirate of Ras al-Khaimah. In October 2017 the Federal Electricity and Water Authority (FEWA) announced that the coal power plant was to be commissioned in 2022. Construction of the plant might however be delayed because of issues related to land ownership and a lack of sovereign guarantees for the PPA (Interviewee 8 and Interviewee 9, 2018).

2.4.3 The UAE's energy strategy

Prior to the release of the UAE Energy Plan 2050 in January 2017, targets for the energy sector in the UAE were set out in the country's Vision 2021. The strategy focused on the diversification of the economy and envisaged 'clean energy' (renewable and nuclear) having a 27% share of the total primary energy supply by 2021. This vision was complemented by the plans of the individual Emirates. The key goals of Dubai's Integrated Energy Strategy 2030 were to secure uninterrupted energy supply and to moderate the growing energy and water demand in the Emirate. Dubai has a high dependency on energy imports and a growing economy (Taqati, 2016), despite a slow-down in the growth rate.

The targets set in the Energy Plan 2050 are for 44% of the UAE's total energy mix to comprise renewable energy, 38% gas, 12% 'clean coal' and 6% nuclear energy (Government of UAE, 2017). Nuclear energy is expected to be produced in four reactors near the city of Barakah. Currently under construction, they will start operations in 2021 and will have a total output of 5.6 GW (World Nuclear Association, 2018). On the demand side, the Energy Plan 2050 envisages a 40% reduction in residential sector energy consumption by 2050 compared to a BAU scenario. Annual assumed growth of 6% was factored in when developing the Plan's strategy.

The implementation of the strategy of the Energy Plan 2050 will take place in three phases:

- The first phase will focus on efficient consumption, diversification of energy supply and security of supply.
- The second phase will focus on the promotion of innovative energy and transport solutions.
- The third phase will focus on research and development (R&D) and innovation.

2.4.4 The regulatory framework for coal in the UAE

The UAE's Cabinet Decree No 12 of 2006 defines emission limits for air pollutants stemming from hydrocarbon fuel combustion sources. Although the country does not have regulations in place that specifically govern emissions from power plants, article 4 of this Cabinet Decree states that, 'during the combustion of any sort of hydrocarbon fuels (…) for the sake of industrial purposes or for power generation, smoke, gases, and vapor emitted shall be within the allowable limits specified in annex (2)' (Cabinet Decree 12 of 2006).

2.4.5 The UAE's NDC and climate goals

With the ratification of the Paris Agreement in 2016, the UAE's Intended Nationally Determined Contribution (INDC) became its Nationally Determined Contribution (NDC). A target for GHG emission reduction was not defined (World Bank, 2016). Instead, the country pledged to pursue 'a strategy of economic diversification that will yield mitigation and adaptation co-benefits'. The UAE specifies that part of these efforts is to increase the share of renewable and nuclear energy in the total energy mix to 27% by 2021 (up from an initial target of 24% set in the UAE Vision 2021) (MOCCAE, 2017). Abu Dhabi is aiming for 7% of its energy mix to comprise renewables by 2020, while Dubai has set renewables targets of 7% of the energy mix by 2020, 25% by 2030 and 75% by 2050.

Table 12. Maximum allowable emission limits in the UAE

Substance	Sources	Emission limit
Visible emissions	**All sources**	**250 mg/Nm³**
Nitrogen oxides (NO_x)	Fuel combustion units Gas fuel Liquid fuel Turbine units Gas fuel Liquid fuel	 350 mg/Nm³ 500 mg/Nm³ 70 mg/Nm³ 150 mg/Nm³
Sulphur dioxide (SO_2)	All sources	500 mg/Nm³
Total suspended particles	All sources	250 mg/Nm³
Carbon monoxide (CO)	All sources	500 mg/Nm³

Table 13. The UAE's coal expansion plans in light of the Paris Agreement climate goals

	UAE
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	The planned role of coal in the UAE is not in line with the achievement of the Paris Agreement targets. Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector, with the share of unabated coal (i.e. coal-fired power plants without carbon capture and storage) being completely phased out by around the mid-century globally (Climate Analytics, 2016). Factoring in the original target share of 24% clean energy in total primary energy supply, as initially defined in the UAE's Vision 2021, results in emission levels (283 to 308 $MtCO_2e/a$ in 2021, or 350% to 390% above 1990 levels) that are slightly lower than Climate Action Tracker's current policy projections for 2021 (286 to 315 $MtCO_2e/a$).[21] If the updated target of 27% clean energy is implemented, emissions will be slightly lower again in 2021, at 276 to 305 $MtCO_2e/a$ or 290% to 340% above 1990 levels. Nevertheless, under current policies, overall emissions are estimated to grow (Climate Action Tracker, 2018b). According to an assessment by Climate Action Tracker, the UAE's projected emissions levels in 2030 are 'highly insufficient'. The UAE's climate commitment in 2021 is deemed inconsistent with holding warming to below 2°C, let alone limiting it to 1.5°C. If all countries were to follow the UAE's approach, the temperature increase by the end of the century would roughly amount to over 3°C and up to 4°C (Climate Action Tracker, 2018c). The country's planned coal-fired power plants are not compatible with the required mitigation pathway. The commissioning of the Hassyan plant (phase I by 2023 at the latest and phase II by 2026 at the latest) would result in a coal-fired power plant operating until at least the mid-century, assuming it has a lifetime of 30 years and no coal phase-out is implemented. Similarly, although the planned Ras al-Khaimah coal-fired power plant scheme currently seems unlikely to go ahead, were this decision to be reversed, the building of this power plant would not be compatible with the goals of the Paris Agreement.
Compatibility of domestic energy and climate policies	The UAE's NDC does not provide an emission reduction target. In any case, the fact that the UAE's Energy Strategy 2050 foresees 'clean coal' having a 12% share of the energy mix makes it difficult to achieve the emission reductions that would otherwise result from renewable energy having a 44% share of this mix by 2050. Moreover, it sets the country on a path that will make it more difficult to achieve the emission reduction target planned in the 2050 Strategy. In addition, the strategy does not specify what 'clean coal' is and, even though the coal-fired power plant currently being built is pre-equipped with carbon capture and storage, the effectiveness of the technology remains to be seen.

2.4.6 Motivations for coal among the UAE's decision-makers

Several factors explain the UAE's interest in coal (Interviewee 8 and Interviewee 9, 2018; Interviewee 6, 2018):

Factor	Description
Diversification of the energy mix and security of supply	The Northern Emirates are net importers of electricity, so the diversification strategy is a means to reduce reliance on imports and maintain security of supply. In addition, for Dubai, where roughly 99% of the energy mix is imported natural gas supplied under long-term international agreements, diversifying the energy mix means decreasing dependence on gas imports by deploying coal-fired capacity and renewable energy capacities in the form of solar PV, CSP and, to a limited extent, waste energy. The Mohammed bin Rashid Al Maktoum Solar Park is currently operating 413 MW of solar PV and installing 1,750 MW of solar PV and CSP, with plans for 5,000 MW of capacity by 2030 (Interviewee 6, 2018). However, the limitations imposed by the scarcity of available land in the small Emirate of Dubai for the deployment of additional renewable capacity may prove to be an obstacle (Interviewee 8 and Interviewee 9, 2018). Dubai's bid to diversify through coal is comparable to Abu Dhabi's nuclear plans, which are also aimed at meeting growing demand and freeing up natural gas for exports while maintaining high standards of security of supply.
Cost-competitiveness of coal	DEWA, Dubai's electricity and water authority, has access to cheap gas through existing long-term contracts. However, the prices charged for any additional gas required are much higher, which makes coal cost-competitive. In response to an invitation to tender issued by the DEWA, ACWA Power submitted a bid of 4 USD cents/kWh (DEWA, 2016) for the coal power plant and its associated port/transport.
System reliability	DEWA maintains very high standards of reliability, which requires high reserve margins (over 20% of total capacity). Coal power plants would operate for more than eight months per year to help meet the summer peak demand. In the winter months, when peak demand decreases, these plants would either not be dispatched or would be used for water desalination. Other arguments put forward for coal are that the deployment of coal, nuclear and gas is aimed at ensuring system reliability.

Caveats on the prospects for coal in the UAE

- It appears relatively unlikely that the UAE will increase the current target where coal comprises 12% of the total energy mix by 2050. Indeed, coal's share may not even end up reaching 12%. The cost-competitiveness of solar, the potential of CSP (which also provides storage), and the large electricity capacity provided by the nuclear plant and soon to come online will likely defer any further coal plants beyond those announced for Dubai. However, the future development of coal and gas prices and how they compare is likely to influence choices, as is economic and population growth, which is currently difficult to foresee and will shape decisions on the additional capacity needed.

21 $MtCO_2e/a$ – million tons of CO2 equivalent per year.

2.5 Country portrait: Oman

2.5.1 Oman's energy mix

Oman's TPES shows a strong upward trend, more than doubling in size between 2005 (9,905 ktoe) and 2015 (25,379 ktoe). This increase was the result of the country's rapid economic growth, urbanisation and industrialisation. Although the country's GDP shrunk slightly in 2017, decreasing by 0.28%, the four preceding years saw average annual increases of 5.3% (World Bank, 2018). Oman's growing economy, intensive urbanisation due to a growing population, and increasing industrialisation aimed at diversifying the economy have all resulted in an annual increase in domestic energy demand of 8–10% (Lisker-Goldeböt & Samra-Rohte, 2017).

The country's energy mix wholly comprises fossil fuel sources, namely natural gas (83.7%) and oil (16.3%) (IEA, 2017e). Coal is currently not part of the energy mix.

Despite high national gas production volumes (28,270 ktoe in 2015), domestic demand for natural gas cannot be met with domestic supplies due to the fact that nearly one third of gas production is exported as part of long-term supply contracts. With gas in increasing demand for power generation, desalination plants and oil production, approximately 5.4 million m3 (4.86 ktoe) of gas are being imported from Qatar every day. Furthermore, the construction of a gas pipeline between Iran and Oman is under discussion, which should be completed by 2020 (Lisker-Goldeböt and Samra-Rohte, 2017).

Oman generated approximately 32,758 GWh of electricity in 2017 (Lisker-Göldenbot and Samra-Rohte, 2017). Natural gas is by far the largest source of electricity generation, accounting for 97.5% of total generation. The remaining 2.5% is generated by oil/diesel power plants. Peak demand will increase from 5,565 MW (2015) to 9,529 MW or, depending on the scenario, even to 11,000 MW by 2022, making it necessary to expand generation and grid capacities[22] (Lisker-Goldeböt and Samra-Rohte, 2017).

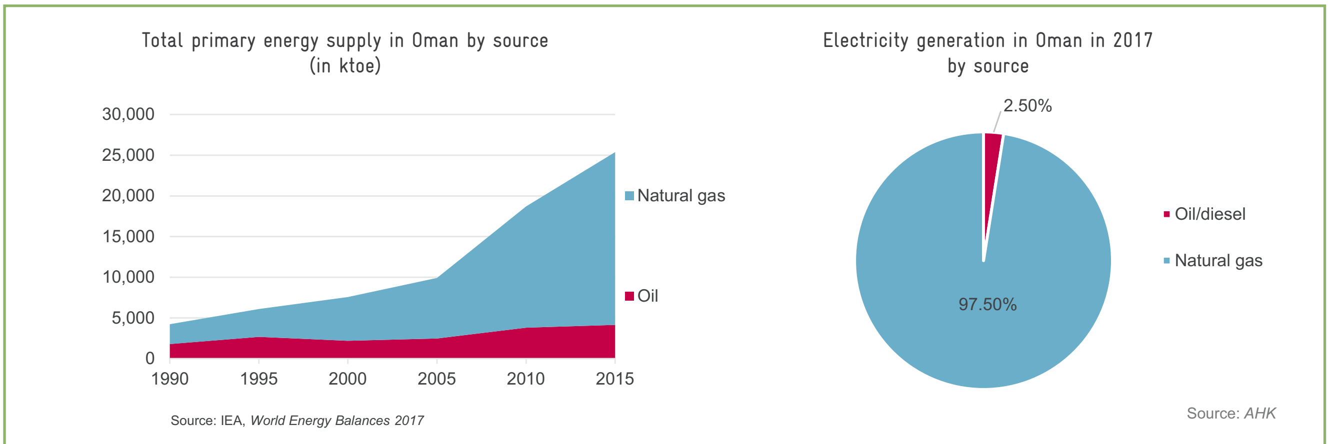
In 2017 the Ministry of Oil and Gas announced that new allocations of natural gas to the electricity sector would remain 'capped for some time' as an incentive for the predominantly gas-dependent sector to look for fuel alternatives (Oman Daily Observer, 2017) and to ensure gas could be used in industry, where economic diversification is sought.

In November 2016 the National Programme for Enhancing Economic Diversification (Tanfeedh) unveiled a proposal that envisions a role for non-renewable alternative resources, such as coal and petcoke, in manufacturing industry. Also, it has been proposed to install a coal-fired power plant in Duqm to cater to the electricity needs of that town's Special Economic Zone (SEZ) (Prabhu, 2017).

2.5.2 Current role of coal in the Omani energy landscape and planned coal projects

Coal has not been part of Oman's energy mix so far. However, the Oman Power and Water Procurement Company (OPWP) has announced plans to commission the country's first coal power plant within the current seven-year planning period (2018–24). These plans have not yet been approved by the Omani government and the implementation of the project is uncertain. OPWP's announcement was based on the Fuel Diversification Policy adopted by the government's Financial and Energy Resources Council in December 2017. The coal power plant and renewable energy installations should serve to reduce the amount of natural gas committed to the electricity sector, with gas supply shifting to new industrial projects in an effort to boost economic growth (OPWP, 2018).

Figure 11. Total primary energy supply in Oman by source (in ktoe) (left) and electricity generation in Oman in 2017 by source (right)



22 *There is no interconnected power grid in Oman. Transmission and distribution take place via three different power grids: the Main Interconnected System (MIS) in the north, the Salalah Power System in the south, and the networks of the Rural Areas Electricity Company SAOC (RAECO), which uses small, mostly diesel-operated island facilities to supply rural areas. There is a connection to the power grid of the UAE (Lisker-Goldeböt and Samra-Rohte, 2017).*

Table 14. Overview of planned coal projects in Oman

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
Duqm IPP power station	Duqm	1,200 MW	2025	Government has not yet given its final approval. Feasibility study completed in 2016. A Request for Qualification process has been carried out, no announcement of qualified bidders.	Supercritical (usually 37–40%)[23]	N/A

Currently, only one coal project – the Duqm coal power plant – is under consideration in Oman. This power station, which has a proposed capacity of 1,200 MW, is referred to by the OPWP as a 'clean coal' independent power producer (IPP) project and would use supercritical combustion technology (Expert from OPWP, 2018). The OPWP's expected renewables projects and the Duqm coal power plant will make it possible to reduce the share of gas for electricity generation from 97% to 83% by 2024 (OPWP, 2018). Moreover, the coal power plant would provide electricity to the Duqm industrial hub and export surplus to Oman's Main Interconnected System (MIS) (OPWP, 2018).

The first 600-MW block was expected to be commissioned in 2024 and the remaining 600 MW in 2025, assuming timely regulatory approvals by Oman's Authority of Electricity Regulation (AER). Once the regulatory approvals are in place, the OPWP would begin the procurement process (OPWP, 2018). Pre-qualification documents from developers were received in June 2018, which OPWP is reviewing before finalising the list of pre-qualified bidders. However, no announcement of pre-qualified bidders has been made since the project has not yet been approved by the government. An annual review of the decision of whether or not to go forward with the construction of a coal-fired power plant will be undertaken.

To contribute to covering the load of the Duqm industrial hub, OPWP has started to develop a thermal solar power station with a capacity of 600 MW. The state-owned utility announced that the thermal solar power station should be implemented by 2025 if the government does not grant approval for the Duqm coal-fired power plant by the end of 2019. The solar project corresponds to the capacity of the first block of the planned coal-fired power plant and is capable of providing base load due to the coupling with a heat storage system. (Oman Observer, 2019).

2.5.3 The Omani energy strategy

Energy policy comes under Oman's Tanfeedh (Arabic for 'implementation') programme. This programme was set up to implement Oman's ninth five-year plan (2016–20), which focuses on economic diversification and the privatisation of the economy (SCP, 2016). The five-year plan comprises five focal themes (manufacturing, logistics, tourism, finance and employment), with energy falling within the 'manufacturing' domain.

The Tanfeedh programme has defined three policy goals for the energy sector (Tanfeedh, 2017): formulate a national environmental policy for the energy sector; review the gas-pricing policy for industrial uses; and promote energy resource diversification. For the latter goal, an additional 3,000 MW of electricity capacity are envisaged in the form of coal power plants and solar installations.[24]

In December 2017 the Omani government's Financial and Energy Resources Council adopted the Fuel Diversification Policy, which includes the following goals for the electricity sector (OPWP, 2018):

- Install coal capacity of up to 3,000 MW by 2030 (as defined in the Tanfeedh programme).
- Ensure renewable energy comprises at least 10% of the electricity mix by 2025.
- Prioritise efficiency in gas-fired electricity generation.
- Assess the potential for replacing local gas used for electricity generation with alternative sources (e.g. imported gas).

23 The Request for Qualification issued by the OPWP in April 2018 stated that the Duqm coal power plant will be the first 'clean coal' IPP in Oman. One interviewee commented that the power plant will use supercritical technology but did not specify a percentage. The efficiency requirements will likely be made public once the OPWP requests proposals for the projects (Prabhu, 2019).

24 Tanfeedh has assessed the costs for coal and solar and deems coal to be the cheapest source of electricity at present. One ton of coal costs OMR 15.5 (USD 40.26) and generates 1,900 kW. For solar, 1 KW costs USD 2,362 (Tanfeedh, 2017).

Recently, Oman announced that it was increasing its renewable energy targets. According to the OPWP, 30% of the Omani energy mix should be based on renewables (solar 21%, wind 6.5 % and waste energy 2.5%) by 2030. A new intermediate goal of 16% by 2025 was also announced, up 10% on the goal set for that year in 2017 (Khan, 2019). To achieve these targets, major tenders for renewable energy capacity were implemented in Oman. In July 2019, a tender for 1.1 GW of solar was announced (Bellini, 2019), following up on 500 MW of solar already tendered in 2018 and won by ACWA power (Bellini, 2018).

2.5.4 The regulatory framework for coal

Ministerial Decision No 118/2004[25] Promulgating the Rules and Regulations Controlling Air Pollutants Emanating from Immovable Sources (Air Pollutants Regulations) provides emission standards for specific industries. For the electricity sector, the Decision sets limits for gas- and oil-fired power plants. Because coal is not covered by these regulations, international standards have been adopted. The following emission standards were defined for stationary sources using coal as fuel (SEZAD, 2017):

Table 15. Maximum allowable emission limits for coal in Oman

Substance	Emission limit
Particulates	30 mg/m³
Nitrogen oxides (NOĐ)	100 mg/m³
Sulphur dioxide (SOĐ)	100 mg/m³
Mercury (Hg) steam	0.03 mg/m³
Total organic carbon (C)	10 mg/m³
Hydrogen chloride (HCl)	10 mg/m³
Hydrogen fluoride (HF)	1 mg/m³
Dioxin/furan	0.1 ng/m³
Cadmium (Cd), thallium (Tl)	0.05 mg/m³
Antimony (Sb), arsenic (As), lead (Pb), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mg), nickel (Ni), vanadium (V)	0.5 mg/m³

One of the goals of the Tanfeedh programme is to formulate is to formulate a National Environmental Policy for the Energy Sector (NEPE). As part of this work, Oman can set a new national environmental policy for the electricity sector that encourages generation from alternative sources based on international practices. While environmental standards exist for coal, natural gas and oil, there are no standards related to petcoke, diesel and renewables (Tanfeedh, 2017).

The elaboration of Oman's National Environmental Policy for the Energy Sector is being overseen by the Implementation Support and Follow-up Unit (ISFU),[26] a task force operating under the auspices of the Diwan of Royal Court. The new policy identifies four focus areas where clear criteria are needed for environmental standards: environment (air, water and waste), pollutants (e.g. nitrous oxide, carbon dioxide and sulphur dioxide), health (severe and chronic respiratory difficulties), and externality costs (waste disposal, health care and so on). Around 70% of the milestones in the process to formulate the policy have been met (Prabhu, 2018).

2.5.5 Oman's NDC and climate goals

The INDC submitted by Oman included a target to cut GHG emissions by 2% by 2030, compared to emission levels in 1994. This reduction, as estimated by the Government of Oman, translates into keeping GHG emissions in 2030 at 88,714 gigagrams compared to 90,524 gigagrams in a business-as-usual scenario (Climate Watch, 2015). The World Health Organization estimated Oman's emissions in 1994 to be roughly 20 $MtCO_2e$ (WHO, 2015a), which would translate into an emission reduction of 0.4 $MtCO_2e$ by 2030. The 2% emission reduction target is conditional on international assistance in the form of finance, capacity building and technology transfer. Oman's INDC does not make any reference to the role of coal in the future energy mix.

The 2% emission reduction target is to be achieved by:
- reducing gas flaring in the oil industries;
- increasing the share of renewable energy and increasing the number of energy efficiency projects in different industries;
- developing new legislation on climate change that will support the adoption of low-carbon and energy-efficient technologies;
- reducing HCFC use in the foam and the refrigeration sectors.

The aim of Oman's Vision 2020 is the 'creation of a stable holistic economic climate with a view of [sic] developing a private sector able to optimize the use of human and natural resources of the Sultanate through efficient methods and maintain environment integrity' (Al-Sahiri, 2018). Although climate policies do not feature prominently in Oman's diversification strategy, this does not necessarily mean that climate change is perceived as unimportant. Oman aims to develop a national GHG emissions inventory programme as part of the upcoming national climate mitigation plan, to facilitate the development of a database for emissions from all sectors and to identify the main sectors that contribute to GHG emissions (Al-Sahiri, 2018).

25 The Decision defined air emission standards for gas and oil power plants. For gas: nitrogen dioxide 0.150 g/m3; particulates 0.050 g/m3; unburned hydrocarbons 0.010 g/m3; and carbon dioxide 5 g/m3. For oil power plants: sulphur dioxide 0.035 g/m3; carbon monoxide 0.050 g/m3; nitrogen dioxide 0.150 g/m3; particulates 0.100 g/m3; and unburned hydrocarbons 0.010 g/m3 (MRMWR, 2004).

26 The ISFU's mandate is to ensure the timely implementation of a large portfolio of initiatives proposed by Tanfeedh and other programmes advancing Oman's economic diversification efforts.

Table 16. Oman's coal expansion plans in light of the Paris Agreement climate goals

	Oman
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	The construction of the Duqm coal power plant is not compatible with the achievement of the Paris Agreement targets. Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector, with the share of unabated coal (i.e. coal-fired power plants without carbon capture and storage) being completely phased out by around the mid-century globally (Climate Analytics, 2016). According to public sources, the Duqm coal power plant would not be equipped with CCS, yet the project is described by the OPWP as the country's first 'clean coal' IPP. If the power plant is commissioned by 2025, and assuming that it has a lifetime of 30 years and no coal phase-out is implemented, it would operate well beyond mid-century. If all countries were to follow Oman's level of ambition in reducing emissions, the temperature increase by the end of the century would amount to roughly 5.1°C (Paris Equity Check, n.d.).
Compatibility of domestic energy and climate policies	Oman's planned commissioning of the Duqm coal power plant will make the achievement of its NDC more difficult. The energy sector is the largest contributor to Oman's GHG emissions,[27] which amounted to 106.30 $MtCO_2$ in 2014 (WRI, 2014). Although the Government of Oman plans to reduce the role of gas in the electricity sector and offset its GHG emissions with the installation of renewable capacity, coal has been defined also as a source to plug the gap left by gas in a context where electricity demand is increasing. Although coal has so far not been part of Oman's energy mix, the current 1,200-MW project in Duqm and the plan to install 3,000 MW of coal capacity by 2025 would add to the GHG emissions tab of the energy sector. Emissions during the lifetime of the power plant represent additional emissions that Oman will need to offset.

2.5.6 Motivations for coal among Oman's decision-makers

Although coal has so far not been part of Oman's energy mix, the country's decision to consider its first coal power plant, intended to be operational within the current seven-year period (2018–24), can be explained by the following factors (Interviewee 16, 2018):

Factor	Description
Diversification of the energy mix and security of supply	The National Energy Strategy 2035 largely focuses on fuel availability and concerns over security of supply. A major driver is that gas exploitation is becoming increasingly expensive and difficult to implement, and this at a time when demand for electricity is increasing (annual growth in electricity demand stands at 6%). This situation has made alternative energy sources such as solar and coal more attractive options for maintaining secure supply. In addition, the fall in solar technology costs has also driven up interest in solar renewables as a solution.
Making gas available for other sectors	The Omani government is seeking to reduce the gas footprint of the electricity sector so that it can make gas available to other industries and, in so doing, generate more in-country value.

Caveats on the prospects for coal in Oman

- The lack of available land in Oman's northern coastal area restricts the development of future coal plants to more remote locations. The Duqm coal power plant project would be located in the Duqm Special Economic Zone (SEZ) on the Sultanate's southeast coast. However, given the environmental and social concerns, issues around competing land use, and the emergence of larger-scale renewables as a potentially viable economic alternative, decision-makers opinions on this first coal project remain diverse.
- If the Duqm project is ultimately approved, further coal development may be restricted by land availability. Coal plants require access to water, which, in Oman, restricts their siting to coastal locations. However, coastal sites are also in demand from other rapidly going sectors.

27 The most recent emissions data for Oman available in the UNFCCC Greenhouse Gas Data Inventory is from 1994. At that time, the energy sector accounted for 60% of Oman's 20,878.7 Gg of CO_2 equivalent.

2.6 Country portrait: Iran

2.6.1 Iran's energy mix

Iran holds the world's fourth-largest proven crude oil reserves and the world's second-largest natural gas reserves. Crude oil production declined between 2012 and 2016 due to the nuclear-related international sanctions targeting Iran's oil exports, which hindered progress across Iran's energy sector. Natural gas development was also affected by the sanctions because of the lack of foreign investment and technology (EIA, 2018b). In January 2016 the oil-sector and banking sanctions were lifted, as outlined in the Joint Comprehensive Plan of Action (JCPOA), following which oil and natural gas production gathered pace.[28] The US Government's re-imposing of sanctions on Iran in 2018 is affecting the Iranian oil and gas sector, and exports have decreased despite waivers that allow large importing countries like China and Turkey to import gas from Iran.

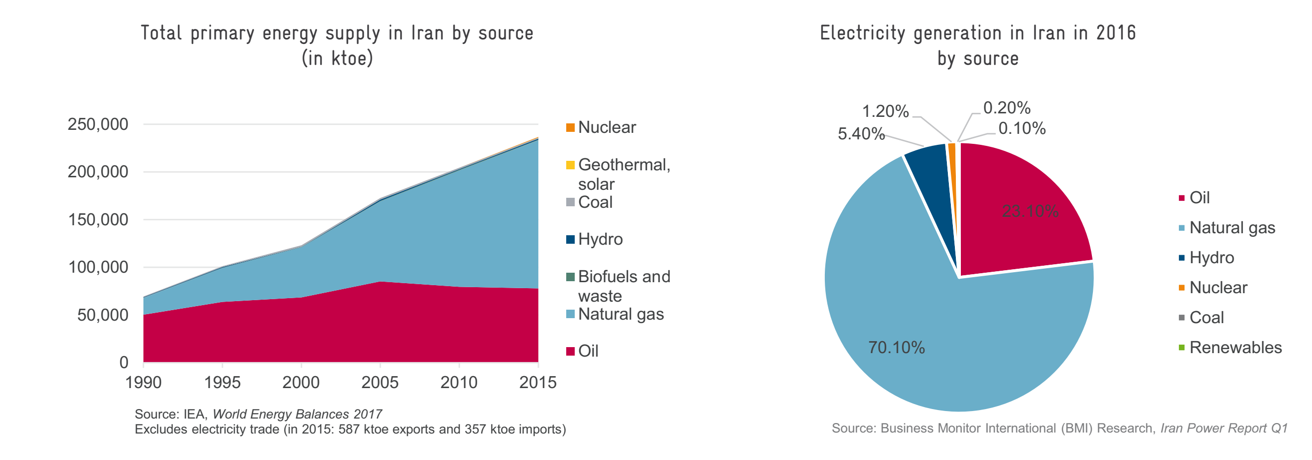
Iran's TPES has grown rapidly over the past decade and continued to grow even though economic growth was depressed by sanctions. Between 2005 and 2015 Iran's TPES expanded by 37%. The country's energy mix[29] is dominated by natural gas (65.6%) and oil (32.9%), with marginal contributions from hydro (0.5%), nuclear (0.3%) and non-hydro renewables (0.2%) (IEA, 2017f).

Coal represented 0.5% of TPES in 2015. Although the share of coal is marginal, the amount of coal in the energy mix was 1,682 ktoe in 2005, 2.5 times its share in 1990 (710 ktoe). By 2015, however, this figure had dropped to 1,073 ktoe. To better control growth in domestic demand and reduce budgetary exposure to high subsidy costs, the Iranian government implemented an energy subsidy reform between 2010 and 2014, which resulted in increasing domestic prices for domestic petroleum, natural gas and electricity (EIA, 2018b).

Iran's total installed power generation capacity of 76,428 MW generated approximately 289,196 GWh of electricity in 2016[30] (Tavanir, 2017). Natural gas is the largest source of fuel for electricity generation in Iran, accounting for 70.1% of total generation, followed by oil with 23.1%. Hydropower (5.4%), nuclear (1.2%) and non-hydro renewables (0.1%) make up the remaining sources used to generate electricity in Iran (BMI, 2018). According to international reports, coal is only used to a very minor extent (0.2%) in electricity generation (BMI, 2018), possibly in industrial self-consumption, while Iranian sources (Tavanir, 2017) indicate that there is no electricity generation from coal-fired power generation.

Electricity demand in Iran is expected to increase by 6.5% annually until 2020. Due to the stagnation in infrastructure renewal caused by the economic sanctions, investment in capacity expansion will be required. Moreover, 67% of the country's steam power plant capacities, which produce a stable output for baseload supply and other important facilities, started operations more than 20 years ago and are ageing (JICA, 2017a).

Figure 12. Total primary energy supply in Iran by source (in ktoe) (left) and electricity generation in Iran in 2016 by source (right)



28 Oil production and exports rose to pre-2012 levels (EIA, 2018b)

29 The numbers shown are for 2015, as reported in the IEA's World Energy Balances 2017.

30 In 2017 Iran's installed power capacity of 78,351 MW generated approximately 291,822 GWh of electricity (status: February 2018) (Iran Daily, 2018).

Table 17. Overview of planned coal projects in Iran

Plant	Location	Capacity	Planned commissioning	Status	Efficiency	Emissions
Tabas power station	Khorasan	650 MW, comprising two 325-MW units	Officially, by the end of 2019. However, project appears to be abandoned	Unclear	N/A	0.74 million tons CO_2/year

2.6.2 Current role of coal in the Iranian energy landscape and planned coal projects

The role of coal in Iran's energy mix has so far been minor, representing 0.5% of TPES in 2015 (IEA, 2017f). While it has 1.15 billion tons of proven coal reserves, Iran produces only 1.1 million tons of coal per year (Financial Tribune, 2017a).

Currently, there is only one coal project under consideration in Iran, which appears to be abandoned for the moment: the 650-MW Tabas coal power station. This station would be located in the Tabas region in South Khorasan Province, which holds 55-76% of Iran's coal reserves (Sourcewatch, 2018b). According to the Iran Power Transmission, Generation and Distribution Company (Tavanir), the project is under development (JICA, 2017a), with 60% of the build completed (Interviewee 11, 2018; Tasmin News, 2017), while other sources report it as abandoned (Financial Tribune, 2017). It is estimated that the Tabas power station would emit 0.82 million tons of CO_2 per year[31] (NRDC, 2016).

2.6.3 The Iranian energy strategy

Iran's Fifth Development Plan (2010–15) defined the following key targets for its electricity sector (Tavanir, 2017): to continue developing gas turbine technology (higher efficiency), with a focus on the further development of combined-cycle power plants; to complete all hydroelectric power plants under construction; to increase spinning reserve capacity; and to encourage private sector participation under the build-own-operate (BOO) and build-operate-transfer (BOT) modalities.

The plan for the development of the electricity sector, based on the Fifth Development Plan (2010–15), made the following estimates of expected capacities in 2018 (Tavanir, 2017) but did not mention coal:

- Combined cycle: 24,956 MW (from 19,470 MW in 2016).
- Gas: 27,940 MW (from 27,980 MW in 2016) – these plants are being progressively changed over to combined-cycle power plants to save on fuel consumption and reduce negative environmental impacts.
- Steam (power plants fired by natural gas and oil): 15,830 MW (the same as in 2016).
- Hydro: 12,222 MW (11,578 MW in 2016).
- Other renewables: 1,000 MW (400 MW in 2017).

In March 2017 the Iranian Parliament approved the Sixth Five-Year Economic, Cultural and Social Development Plan for 1396–1400 (2016–21). The plan sets out the goals for the country to achieve by 2021. For the electricity sector, the aim is to increase installed capacity by 25,000 MW through public-private partnerships (Kordvani and Berenjforoush, 2017).

The Iranian government is aiming to reduce the role of hydrocarbons in the electricity mix and, in so doing, 'free up' oil and gas for export and allow electricity to be produced more cost effectively. The Fifth Development Plan (2010–15) included plans to install 5,000 MW of renewable energy by the end of the period through incentives like feed-in tariffs. The target was not achieved: by the end of 2017, non-hydro renewables made up 400 MW of installed capacity (Renewables Now, 2018). The Sixth Development Plan (2016–20) aims to install 5,000 MW of renewables by 2021 and includes plans for an additional 2,500 MW by 2030 (Kordvani, Hassan, Dalton and Berenjforoush, 2016).

31 The NRDC reports emissions in tonnes. The value is therefore 0.74 million tonnes of CO_2/year which, divided by 0.907185, results in 0.82 million tons of CO_2/year 32 (1 ton = 0.907185 tonnes).

2.6.4 The regulatory framework for coal in Iran

The production of coal in Iran began in 1960. Due to the country's abundant oil and gas reserves, coal has played a marginal role in the Iranian energy sector, with the lion's share being consumed by Iran's steel industries (Rostamihozori, 2002). However, emission standards issued by Iran's Department of Environment set the following allowable limits for power plants (JICA, 2017a):

Table 18. Maximum allowable emission limits for power plants in Iran

Substance	Sources	Emission limit	
		New plants:	Old plants:
Nitrogen oxides (NO_x)	Gas	150 mg/Nm³	300 mg/Nm³
	Mazut fuel	200 mg/Nm³	400 mg/Nm³
	Gasoline	200 mg/Nm³	250 mg/Nm³
Sulphur dioxide (SO_2)	Gas	100 mg/Nm³	200 mg/Nm³
	Mazut fuel	700 mg/Nm³	800 mg/Nm³
	Gasoline	100 mg/Nm³	150 mg/Nm³
Particulates	Coal	100 mg/Nm³	150 mg/Nm³
Carbon monoxide (CO)		150 mg/Nm³	200 mg/Nm³

2.9.5 Iran's NDC and climate goals

The INDC submitted by Iran included a target to cut GHG emissions by 12% by 2030, compared to emission levels in 2010. The target is split in two: a 4% reduction to be achieved unconditionally, and an 8% reduction conditional on the lifting of sanctions and the receipt of international climate financing (DOE, 2015). Iran's INDC does not make any reference to the role of coal in the future energy mix.

The 4% unconditional emission reduction target is to be achieved through:

- the development of combined-cycle power plants, renewables and nuclear in the electricity sector;
- the reduction of gas flare emissions;
- enhanced energy efficiency in various energy-consuming sectors;
- the substitution of high-carbon fuels with natural gas, and strategic planning for utilising low-carbon fuels.

Iran has not yet submitted its first Nationally Determined Contribution (NDC). While the cabinet of ministers and the Majlis (parliament) have approved the Paris Agreement, the Guardian Council, which holds veto power over all legislation approved by the Majlis, has not yet ratified the agreement. The Guardian Council has proposed amendments that are being considered by the agriculture, water and natural resources group of the Majlis (Qarehgozlou, 2018).

Table 19. Iran's coal expansion plans in light of the Paris Agreement climate goals

	Iran
Paris Agreement: 'Staying well below 2°C' 'Limit temperature increase to 1.5°C'	Meeting the Paris Agreement goal of 'staying well below 2°C' requires a rapid decarbonisation of the power sector, with the share of unabated coal (i.e. coal-fired power plants without carbon capture and storage) being completely phased out by around the mid-century globally (Climate Analytics, 2016). The construction of the Tabas coal power plant is not in line with the achievement of the Paris Agreement targets. According to public sources, the Tabas coal power plant would not be equipped with CCS. If it is commissioned by the end of 2019, and assuming it has a lifetime of 30 years and no coal phase-out is implemented, the power plant would operate well beyond mid-century. If all countries were to follow Iran's level of ambition in reducing emissions, the temperature increase by the end of the century would amount to roughly 5.1°C (Paris Equity Check, n.d.).
Compatibility of domestic energy and climate policies	Iran's planned commissioning of the Tabas coal power plant will make the achievement of its NDC more difficult. Even excluding the impact on emissions of operating this power plant, a 2015 study on energy scenarios to 2030 estimates that total CO_2 emissions will grow on average by 2.8% yearly, from 547 million tons in 2010 to 950 million tons in 2030, in a business-as-usual scenario[32] (Moshiri and Lechtenboehmer, 2015). The energy sector accounts for over 90% of Iran's GHG emissions (Financial Tribune, 2017b), hence mitigation in this sector is essential for target achievement. Although coal currently plays a minor role in the country's energy mix (0.5% in 2015), the current 650-MW coal project in Tabas County, if built, would add to the GHG emissions tab of an energy sector that is already almost exclusively based on fossil fuels like natural gas and oil. The government has support mechanisms in place for renewables, and 1 GW of installed capacity is expected by the end of 2018. Although coal does not feature prominently in Iran's power sector development plans and energy strategies, the country's 1.15 billion tons of proven reserves represent an untapped potential that could be directed into the electricity sector as the role of oil and gas is reduced, potentially leading to further emissions increases.

2.6.6 Motivations for coal among Iran's decision-makers

The mining of coal got underway in 1960 in Iran. Due to the country's abundance of oil and gas reserves, coal has played a marginal role in the Iranian energy sector. However, there are several factors explaining Iran's interest in coal (Interviewee 3, 2018; Interviewee 11, 2018; Interviewee 12, 2018):

Factor	Description
Diversification of the energy mix	With its Energy Consumption Pattern Reform, Iran planned to diversify its energy mix and include other technologies such as coal or renewables. The Iranian government is aiming to reduce the role of hydrocarbons in the electricity mix to 'free up' oil (liquid fuel) and gas (LPG) resources for export.
Availability of coal resources and technology	Iran's 1.15 billion tons of proven coal reserves represent an untapped potential that could be directed into the electricity sector as the role of oil and gas is reduced. Domestic knowledge of and expertise in coal mining technology makes coal especially attractive compared to renewables, given that the technology and most of the know-how for renewables is provided by international companies
Obstacles for investment in renewables	Most of the investment in renewables in Iran has come from international investors, partly because of the attractive feed-in tariff of approximately 9 EUR cents/kWh and an attractive PPA that fully covers currency risk. International investment in renewables and, indeed, in any other industry has been disrupted by the US's re-imposing of economic sanctions. Local investment in renewables also faces obstacles due to a lack of attractive financial conditions: for local investors, keeping money in the bank or investing it in gold or USD currency is seen as offering a better value proposition than investment in renewables.

Caveats on the prospects for coal in Iran

- In Iran's energy mix, the trend is for thermal plants fuelled with mazut oil to switch to using natural gas. This is because part of the liquid fuels used in Iran are imported, so switching over to natural gas reduces the need to import oil. In addition, the geopolitics of gas supply provides Iran with the incentive to keep investing in this technology. Iran and Qatar have common natural gas reserves, which both countries are currently exploring. Should Qatar be successful in exploiting these resources, it might use them to produce LNG, an option that is not possible in Iran because the country currently lacks the required infrastructure.
- Coal is also unlikely to become a major source for electricity generation because it is in high demand as a raw material for the metallurgic industry; it is more appealing to use coal as raw material than for electricity generation. Moreover, the slow progress in the construction of Tabas coal power plant raises questions about the feasibility and ease of substantial coal capacity additions. The consulted experts stated that there are currently no plans to build additional coal power plants.
- Another major and growing concern regarding the viability of thermal power generation in Iran is the country's acute water scarcity situation. More than half of the world's thermal power plants are located in areas with major water stress (WRI, 2018), and Iran is one of the countries most heavily affected by water scarcity and drought. Questions hang over the planned power plant in Tabas due to concerns around water availability in this particularly dry region of Iran (Financial Tribune, 2016).

32 The BAU scenario describes a likely energy demand path if no far-reaching changes in consumption patterns are made. The scenario incorporates new developments in the economy and likely policy changes at the time of publishing (2015). For instance, it includes the policies outlined in the national Five-Year Development Plan (FYDP) and the country's 20-Year Vision, such as those on investment priorities in manufacturing industries and on increasing the share of natural gas for domestic consumption (Moshiri and Lechtenboehmer, 2015).

3 Impacts of coal as an energy source

The production and utilisation of coal as an energy source has various side effects on the environment and is related to a range of health impacts mainly caused by emissions released during the combustion of the energy carrier. The promotion of coal power also has an impact on the energy system (hindering the integration of renewable energy due to coal's lower flexibility), affects the future integration of renewable energy, and runs counter to the climate change mitigation measures that most countries in the MENA region envisage for the future development of their energy sectors. Promoting coal energy also implies an increasing dependency on energy imports because, except for Iran, the MENA countries lack the potential to mine their own coal. Finally, opposition from citizens has hindered coal projects, especially in Morocco and Egypt, and required governments and operators to revise their plans.

3.1 Environmental impacts

Coal[33] is considered the most polluting source of energy and creates substantial environmental problems. Coal mining is the first stage in the procurement process of this energy carrier, followed by its transport and then combustion in power stations or industrial facilities. Strong detrimental effects are felt along this entire value chain, with the strongest environmental impacts occurring during coal mining and coal combustion. That said, the emissions associated with transporting coal are also significant.

Coal mining has a major impact on landscapes and affects local communities and wildlife through noise, air pollution and other environmental impacts. The extraction of coal from its underground deposits requires lowering the groundwater level. Some of the extracted water is consumed on site, with the remainder usually introduced into nearby watercourses and bodies of water. Lower groundwater levels have been identified as a cause for landslides and slumps in the areas surrounding coalmines (IEA, 2013). Coal mining also gives off significant methane emissions. Methane occurs naturally in coal deposits and must be vented out to avoid explosions in underground mines. In the United States, emissions from coal mining and abandoned coalmines accounted for 10% of the country's total methane emissions and for 1% of its total GHG emissions (EIA, 2018c). Surface mines additionally affect the surrounding area through flying particle emissions. While coal mining issues are not applicable in MENA countries other than Iran, by consuming coal these countries will ultimately contribute to such environmental hazards elsewhere in the world.

The combustion of coal in power plants is highly emission-intensive and releases pollutants into the air, water and soil. Numerous toxic substances enter the environment from smokestacks, from the clinker that is removed from the fireboxes and from the disposal of filter equipment. In particular, carbon dioxide (CO_2) emissions are significant, exceeding those of gas- and oil-fired power stations by far. Further emissions from coal combustion include carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NO_X), dioxin, furan, mercury and other heavy metals.

Emissions of sulphur and nitrogen oxides cause ozone depletion, acid rain and increased clouding and rainfall. In addition, fly ash and particulates coming from smokestacks and from ash and coal stores increase the likelihood of smog and haze.

According to Davies, Malik, Li and Aung (2017), emissions resulting from coal use can be reduced but not avoided. The amount of emissions released during combustion can be decreased to a certain extent by using technical solutions such as scrubbers and other filtering equipment (EIA, 2018c). These processes are often referred to as 'clean coal technologies'. Coal washing, for example, separates impurities from crushed coal using a chemical flocking agent. Wet scrubbers remove sulphur dioxide (SO_2), a major cause of acid rain, by spraying flue gas with a mixture of limestone and water. Low-nitrogen-oxide (NO_X) burners reduce the creation of nitrogen oxides, a cause of ozone depletion, by manipulating the combustion process. Carbon capture and storage (CCS) is a relatively new concept for mitigating emissions from coal-fired power generation and, at present, is one of the most widely discussed such concepts. In this process, carbon dioxide (CO_2) is captured and sequestered in a deposit where it cannot escape into the atmosphere – typically, underground geological formations. The deposit must be secure and able to contain the captured CO_2 for hundreds of years. CCS systems reduce the efficiency of the power plant and increase wear on system materials and are therefore expensive to retrofit at present. The use of processes referred to as 'clean coal technologies' does not prevent health and environmental

33 Since lignite is not being used in the MENA region, the term 'coal' refers to anthracite in the following text.

damage and significantly increases the average costs of electricity from coal. The additional costs of emission reduction measures may hinder their uptake. Policy-makers will therefore need to establish emission limits, performance standards, obligations to deploy specific equipment or other measures to ensure that plant operators minimise the environmental damage arising from their coal use. Factoring the external cost of coal use into its price also makes renewable energy technologies even more attractive, as shown in the sensitivity analyses in the next chapter.

Air pollution is receiving increasing attention in the MENA region. This can be observed in the example of the UAE, where compliance with air quality standards is monitored through national Key Performance Indicators that have been defined for specific pollutants. The monitoring of these indicators shows that compliance in different Emirates is not optimal. For example, as shown in Table 20 below, the Emirate of Abu Dhabi does not comply with the air quality standards for ozone and particulate matter. Compared to the limits set in the EU's air quality standards, those in the UAE's are in general less demanding. For example, the EU's limits for nitrogen dioxide and particulate matter are a lot stricter than the UAE's. The comparison of air quality standards between the UAE and EU as well as Abu Dhabi's compliance with UAE limits is depicted in the following table.

Air pollution is a major concern in the UAE – particularly in its urban areas. Air quality issues in Abu Dhabi are mainly caused by industry and transport as well as by natural dust events (EA Abu Dhabi, 2017).

Emission limits are in place in many MENA countries, as described in the country portraits. Table 21 below provides an overview of power plant emission standards in Egypt, Iran and the UAE as well as a comparison with the standards in place in the EU. In several MENA countries it is not so much standards but rather the tracking and monitoring of emissions that is a concern. Specific emissions caused by coal use are not being tracked, and the expansion of coal generation capacity runs counter to efforts to increase air quality. An additional challenge for the MENA region, but also for many other countries, is the enforcement of existing standards. Since environmental standards are often not enforced properly, there is a strong indication that the emissions limits set are being exceeded (Hassaballa, 2015; Fredriksson and Svensson, 2003).

Table 20. Comparison of air quality standards in the UAE and EU, and results of compliance monitoring in Abu Dhabi (EC, 2018; EA Abu Dhabi, 2017; EA Abu Dhabi, 2018)

Substance	Average time	EU air quality standards	UAE air quality standards	Compliance in Abu Dhabi	Trend (2007–15) in Abu Dhabi
Carbon monoxide (CO)	1 hour 8 hours	– 10 μg/m³	30 μg/m³ 10 μg/m³	Yes	↓
Nitrogen dioxide (NO_2)	1 hour 24 hours 1 year	200 μg/m³ – 40 μg/m³	400 μg/m³ 150 μg/m³ –	Yes	•
Sulphur dioxide (SO_2)	1 hour 24 hours 1 year	350 μg/m³ 125 μg/m³ –	350 μg/m³ 150 μg/m³ 60 μg/m³	Yes	↑
Particular matter (PM_{10})	24 hours 1 year	50 μg/m³ 40 μg/m³	150 μg/m³ –	No	•
Ozone (O_3)	1 hour 8 hours	– 120 μg/m³	200 μg/m³ 120 μg/m³	No	

Table 21. Comparison of power plant emission standards in Egypt, Iran, the UAE and the EU (Elshishini, 2018; SEZAD, 2017; Cabinet Decree 12 of 2006; European Parliament and the Council of the European Union, 2010)

Substance	Egypt	Iran		UAE		EU[34]	
Carbon monoxide (CO)	250 mg/Nm^3		New plants: 150 mg/Nm^3 Old plants: 200 mg/Nm^3		500 mg/Nm^3	100 mg/Nm^3	
Sulphur dioxide (SO_2)	850 mg/Nm^3 (450 mg/Nm^3 in sensitive areas)	Gas	New plants: 100 mg/Nm^3 Old plants: 200 mg/Nm^3		500 mg/Nm^3	Total rated thermal input of 50–100 MW	400 mg/Nm^3
		Mazut fuel	New plants: 700 mg/Nm^3 Old plants: 800 mg/Nm^3			Total rated thermal input of 100–300 MW	250 mg/Nm^3
		Gasoline	New plants: 100 mg/Nm^3 Old plants: 150 mg/Nm^3			Total rated thermal input >300 MW	200 mg/Nm^3
Nitrogen dioxide (NO_2)	200–500 mg/Nm^3 (200 mg/Nm^3 in sensitive areas)	Gas	New plants: 150 mg/Nm^3 Old plants: 300 mg/Nm^3	Gas fuel	Fuel combustion units: 350 mg/Nm^3 For turbine units: 70 mg/Nm^3	Total rated thermal input of 50–100 MW	300 mg/Nm^3
		Mazut fuel	New plants: 200 mg/Nm^3 Old plants: 400 mg/Nm^3	Liquid fuel	Fuel combustion units: 500 mg/Nm^3 For turbine units: 150 mg/Nm^3	Total rated thermal input of 100–300 MW	200 mg/Nm^3
		Gasoline	New plants: 200 mg/Nm^3 Old plants: 250 mg/Nm^3			Total rated thermal input >300 MW	150 mg/Nm^3
Particular matter (PM_{10})	50 mg/Nm^3		New plants: 100 mg/Nm^3 Old plants: 150 mg/Nm^3	250 mg/Nm^3		Total dust	10 mg/Nm^3
Lead (Pb)	2 mg/Nm^3		N/A		N/A	0.5 mg/Nm^3	
Mercury (Hg)	1 mg/Nm^3		N/A		N/A	0.05 mg/Nm^3	

3.2 Health-related impacts

Air pollution has severe consequences for human health and is directly related to various diseases. Coal combustion for energy generation substantially contributes to poor local air quality, causing cancer and cardiovascular and respiratory disease (WHO, 2014). Table 22 below provides an overview of the most important emissions associated with the use of coal and their environmental and health impacts.

Table 22. Most important emissions associated with the production and utilisation of coal and their health and environmental impacts (WHO, 2014)

Emission	Environmental impact	Health impact
Carbon dioxide (CO_2)	GHG	–
Carbon monoxide (CO)	Ozone depletion, smog	Toxic hazard in underground mines
Sulphur oxides (SO_x)	Acid rain, increased clouding and rainfall	Respiratory illnesses, premature death
Nitrogen oxides (NO_x)	GHG (N_2O), ozone depletion, acid rain, smog	Respiratory illnesses, lung disease
Methane (CH_4)	GHG	–
Mercury (Hg)/other heavy metals	Neurological and developmental damage in humans and animals	
Particulate matter (PM_{10})	Smog, haze	Respiratory illnesses, lung disease

34 Based on Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

According to the World Health Organization (WHO), air pollution is the biggest environmental risk to human health and is linked to seven million deaths per year. Deaths attributed to outdoor air pollution may be caused by ischemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, and acute lower respiratory infections in children (WHO, 2014). In the MENA region, 125,000 deaths per year are estimated to be caused by diseases associated with outdoor air pollution (World Bank, 2016b). According to the UAE's Environmental Burden of Disease Assessment, outdoor air pollution is the leading environmental cause for respiratory and cardiovascular diseases and for medical visits in the country (MacDonald, 2013). Introducing or increasing coal generation would further worsen these negative effects on public health.

In Morocco, where more than 50% of electricity generation is reliant on coal, outdoor air pollution is estimated to have caused 2,000–6,000 premature deaths in 2014 alone, with the urban areas of Casablanca, Marrakesh and Tangier being most affected (Croitoru and Sarraf, 2017). More than 70% of the deaths were caused by ischemic heart disease and stroke. The country's economic loss due to ambient air pollution ranges between USD 462 million and USD 1.26 billion. The total health cost of air pollution in Morocco ranges between USD 734 million and USD 1.6 billion corresponding to 1.05% of the country's GDP in 2014 (Croitoru and Sarraf, 2017).

3.3 Energy system impacts

Today, power systems in the MENA region are largely dominated by power plants that use natural gas and oil for electricity generation (Arab Union of Electricity, 2017). However, the share of power generation from renewable energy sources will increase significantly in the region over the coming decades due not only to the climate mitigation targets formalised in the Paris Agreement but also to renewables' expected positive effects on electricity supply costs and security of supply in the medium and long term. Results from auctions already indicate the cost-competitiveness of renewables, as shown in Table 23 below. This growing uptake of renewables will lead to a reduction in the capacity factors of conventional thermal power plants (utilisation effect), and it will increase the need for flexible generation and storage units as well as demand-side measures to balance the load of the system with the intermittent electricity generation of variable renewable energy (VRE) sources such as PV and wind power (balancing effect) (Sijm, 2014). The utilisation and balancing effects both favour investments in generation technologies that have fast start-up and load-following capabilities and a fairly low investment cost (e.g. open-cycle and combined-cycle gas turbines) over investments in capital-intensive and relatively inflexible technologies like coal or nuclear power plants (baseload technologies). Therefore, investments in coal power plants hinder the integration of VRE and, in so doing, impede climate change mitigation efforts. Furthermore, deploying coal power plants often reduces the utilisation of gas-fired power plants, which have lower specific CO_2 emissions but typically higher marginal generation costs in the absence of an appropriate CO_2 price. By reducing gas adoption in this way, the negative impacts that investing in coal power plants has on efforts to mitigate climate change are magnified even further.

Table 23. Selected recent prices from power purchase agreements (PPAs) for coal power plants and renewable energy sources (RES) in MENA countries and in South Africa (based on Navigant's own research)

Country	Lowest PPA prices for coal plants	Lowest PPA prices for renewable energy projects
Morocco	8 USD cents/kWh (2016)[35]	2.5 USD cents/kWh (onshore wind; 2016)[36] 4.5 USD cents/kWh (solar PV; 2017)[37] 7 USD cents/kWh (CSP-PV; 2019)[38]
Egypt	5.4 USD cents/kWh (2018)[39]	2.8 USD cents/kWh (solar PV; 2018)[40] 4.1 USD cents/kWh (wind; 2015)[41]
Jordan	N/A	2.5 USD cents/kWh (solar PV; 2018)[42]
Iran	N/A	7.6 USD cents/kWh (solar PV; since 2016; feed-in-tariff) 8.1 USD cents/kWh (wind; since 2016; feed-in-tariff)
Oman	N/A	First RES auction set awarded to ACWA Power in 2019, price yet unknown[43]
UAE	4.2 USD cents/kWh (2015)[44]	2.42 USD cents/kWh (solar PV; 2017)[45] 7.3 USD cents/kWh (CSP; 2017)[46]
South Africa	7.2 USD cents/kWh (2018)[47]	5.9 USD cents/kWh (RES in general; 2018; price cap)[48]

35 According to a statement of Abderrahim El Hafidi in his function as Morocco's vice minister for energy and environment at the World Future Energy Summit in Abu Dhabi in January 2016.
36 Agora Energiewende, 2018.
37 Tsagas, 2017.
38 Kraemer, 2019.
39 Sourcewatch, 2019.
40 Bellini, 2018.
41 Lekela, 2015
42 PV Magazine, 2018.
43 Bellini, Emiliano, 2018
44 DEWA, 2016.
45 Agora Energiewende, 2018.
46 Solar Paces, 2017.
47 Moya, 2018.
48 Bellini, Emiliano, 2018

As described in the previous section, generating electricity from coal has a strongly negative impact on human health and the environment. The costs of the unpriced side-effects that coal electricity generation imposes on the environment, society and other third parties are approximated in the external costs of coal electricity. External costs of coal electricity mainly result from its impacts on climate, human health, crops and biodiversity. Estimates by the RCREEE show that the price of coal energy would more than double in most MENA countries if external costs were added to the average costs of electricity. The external costs of coal per unit of electricity are estimated at between 3 and 9.5 USD cents/kWh (RCREEE, 2013).

3.4 Societal impacts

New power plants using heavy-emitting coal-firing often lack public support and instead face significant public opposition. Popular protest significantly hindered the development of new coal power plants in Morocco and Egypt for example (Griffiths, 2017). The resistance against coal projects in the MENA region is mainly motivated by concerns around their negative impacts on health, the environment and tourism. Most protesters fear that plans to expand coal use in the power sector will result in degrading air quality further (Schinke, 2017).

In a survey on different electricity generation technologies in Morocco, stakeholders expressed major concerns regarding the use of coal energy. Respondents did, however, generally agree with the government's policy framework for low-carbon development (Schinke, 2017). After community protests, a power plant planned for construction in Agadir was relocated to Safi. The protesters were motivated not only by environmental concerns but also by fears that the plant would damage their health (The Observers, 2014; Attac Maroc, 2015).

3.5 Geopolitical impacts

The promotion of coal energy in the region implies an increase in dependency on imported energy. Coal mining is not viable in the MENA region except in Iran. Therefore, almost all the coal burned in the planned coal-fired power plants described herein would have to be imported. The promotion of coal consequently increases dependency on countries outside the MENA region and increases the exposure of the energy supply sector to foreign influence.

4 Modelling the impacts of coal power plants on future electricity supply in the MENA

In this chapter we analyse the impacts of coal power plants on power systems in the MENA region by modelling alternative expansion pathways (i.e. with and without utilising coal as a source for electricity supply) for a synthetic, yet very representative, power system of the region. To define the alternative expansion pathways and analyse their consequences, we applied Navigant's capacity expansion optimisation model, PowerFys-Invest. In the first section of this chapter, we explain the methodology employed. Next, we describe the characteristics of the representative power system and then present the results of the analysis. Finally, in the last section of this chapter, we summarise and draw conclusions from the findings of our modelling analysis.

4.1 Methodology

PowerFys-Invest is a mixed integer linear programming (MILP) model formulated with the General Algebraic Modelling System (GAMS). The model calculates the least-cost capacity expansion plan for a power system required to meet future electricity demand in a reliable manner based on a set of input parameters – i.e. development of annual electricity demand; hourly load and availability of renewable energy resources; techno-economic data of existing and candidate generation and storage technologies; and fuel costs. The model minimises the net present value (NPV) of total system costs for the planning time frame. The NPV is composed of all capital expenditures (CAPEX) and operational expenditures (OPEX) of existing and candidate units over the analysed time frame. All costs of the system are discounted to the first year of the planning time frame based on a defined system discount rate. The CAPEX of a unit depend on its investment costs, the cost of financing according to its weighted average cost of capital (WACC) and the lifetime of a unit. The OPEX of a unit are composed of annual costs for non-fuel operational and maintenance costs (O&M) as well as of fuel, start-up, ramping and eventually CO_2 emission costs over the technical lifetime of the unit. The capacity expansion plans determined are subject to various constraints at the system level (e.g. load and supply balance, adequacy reserve, RE targets, etc.) and single unit level (e.g. minimum stable generation level, start-up costs, etc.).

Table 31 in the Appendix provides an overview of the model set-up used for the analysis at hand.

We use the model to calculate different capacity expansion pathways for the time frame 2020–50 for a synthetic, yet very representative, power system for countries of the MENA region. In total, we have calculated eleven scenarios, separated into three groups, to analyse the impacts of a potential future deployment of coal power plants for power systems in the Middle East and North Africa (see Table 24 below).

Scenario Group 1 consists of four scenarios (the main scenarios of this study) and has the aim of analysing the impacts on results for least-cost capacity expansion optimisation when investments in coal power plants are allowed or not and the respective targets for renewable energy are applied or not. When targets for renewable energy are applied, the model is forced to increase the share of renewable energy to cover annual electricity demand from 5% in 2020 to 80% by 2050 (see Table 25). In Scenario Group 2 we analyse the consequences of the introduction of a moderate CO_2 price in 2035 (45 USD/t) on results for least-cost capacity expansion optimisation and highlight the associated risk for energy planning authorities and investors when such a regulatory change is not foreseen and planned for. The third group of scenarios includes the sensitivity analysis for our modelling results.

Table 24. Overview of calculated scenarios

Scenario group	Scenario name	Rationale
Group 1 (Main scenarios, no external costs considered)	S1: RE targets & coal allowed	Used as a reference scenario
	S2: No RE targets & coal allowed	Analysing supply costs and CO_2 emissions of the system compared to the reference scenario when no RE targets are applied
	S3: RE targets & no coal allowed	Analysing supply costs and CO_2 emissions of the system compared to the reference scenario when investments in coal power plants are suspended
	S4: No RE targets & no coal allowed	Analysing supply costs and CO_2 emissions of the system compared to the reference scenario when no RE targets are applied and investments in coal power plants are suspended
Group 2 (Risk of coal investments)	S5: No RE targets & coal allowed; with CO_2 costs and perfect foresight	Analysing the impact of CO_2 prices (45 USD/t from 2035) on the competitiveness of coal power plants
	S6: No RE targets & coal allowed; with CO_2 costs and limited foresight	Highlighting the risk of investing in CO_2-intensive power generation technologies (45 USD/t CO_2 price applied from 2035 and not foreseen by the model for investment decisions made between 2020 and 2030)
Group 3 (Sensitivity analysis)	S7: S1 but with 3% WACC	Exploring the impact of a lower cost of capital on the selected capacity mix
	S8: S1 but with 8% WACC	Exploring the impact of a higher cost of capital on the selected capacity mix
	S9: S1 but with external costs	Investigating the impact of considering the externalities of electricity generation based on the reference scenario
	S10: S2 but with external costs	Investigating the impact of considering the externalities of electricity generation based on a scenario without RE targets
	S11: S2 but with CO_2 costs introduced in 2025 and assuming a linear increase in these costs up to 2050	Analysing the impact of CO_2 prices introduced in 2025 (25 USD/tCO_2) and a linear increase until 2050 (75 USD/tCO_2)

Table 25. Shares of renewable energies required to cover annual electricity demand when renewable energy targets are applied in a scenario

	2020	2025	2030	2035	2040	2045	2050
Target	5%	20%	40%	50%	60%	70%	80%

4.2 Representative power system for countries in the Middle East and North Africa

The countries of the MENA region have experienced a significant increase in electricity demand over several decades. For the 1990–2014 period, the annual growth rates of individual countries have been in the range of 5–11.5% (Menichetti, El Gharras and Karbuz, 2017). The Arab Union of Electricity (AUE) forecasts annual growth rates for electricity demand up to 2028 of between 4% and 7% (Arab Union of Electricity, 2017).

In several studies it is assumed that annual electricity demand in most MENA countries will more than double between today and 2050 (World Energy Council, 2013; Trieb et al., 2015). Table 26 below presents the assumed annual growth rates for electricity demand over the planning time frame considered for our representative power system. The assumed growth rates lead to an increase of the annual electricity demand in our representative power system from about 93 TWh in 2020 to roughly 230 TWh in 2050 (see Figure 13, next page).

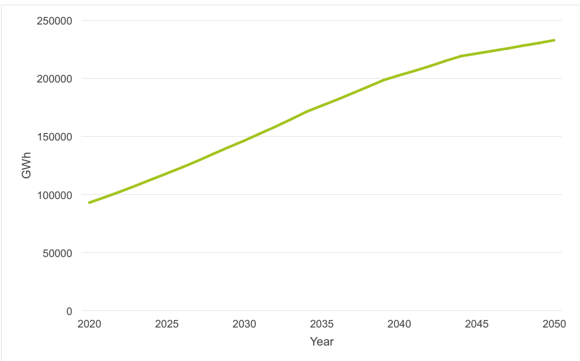
Table 26. Annual growth rates of electricity demand over the planning time frame considered for the representative power system

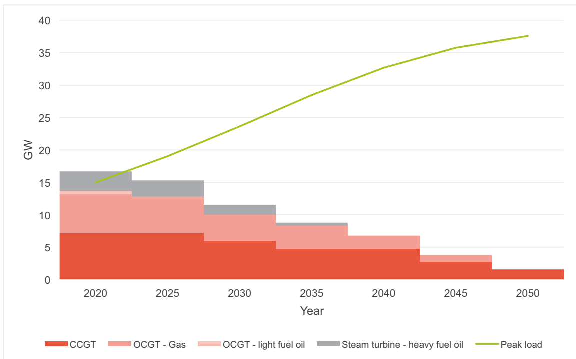
Time frame	2020 – 24	2025 – 29	2030 – 34	2035 – 39	2040 – 44	2045 – 50
Target	5%	4.5%	4%	3.0%	2.0%	1.0%

Today, power systems in the MENA region are dominated by conventional thermal power plants fired by natural gas and oil products. Electricity generation from renewable energy sources and coal power plants plays only a marginal role. Until the middle of the 1990s, electricity was supplied mainly by open-cycle gas turbine (OCGT) and steam power plants. Since then, the more efficient combined-cycle gas turbine (CCGT) technology has been the preferred option for new generation capacities in the region. In 2016, OCGT (37%), CCGT (30%) and steam power plants (26%) fired by natural gas and oil represented more than 93% of the installed capacity in the MENA region. Renewable energies and coal power plants, with about 5% and 1% of total installed capacity respectively, play only a minor role today (International Renewable Energy Agency, 2016; Arab Union of Electricity, 2017). Most of the steam and OCGT power plants installed in the 1970s and 1980s will reach the end of their technical lifetime within the next few years and will be decommissioned. This, together with the expected strong growth in electricity demand, will make meeting future electricity demand particularly challenging.

Figure 13 below (right-hand chart) presents the assumed existing generation capacity for the representative power system in 2020 and its decommissioning over the coming decades, as well as the development of the annual system peak load up to 2050. Similar to the situation in MENA countries today, in 2020 the system is dominated by CCGT, OCGT and steam power plants. Over the coming years, large parts of this existing capacity will be decommissioned. This being the case, more than 35 GW of firm generation capacity must be installed by 2050 to ensure the system remains adequate.

Figure 13. Development of annual electricity demand (left), and existing capacity and its decommissioning over the planning time frame of 2020–50 considered for the representative power system (right)

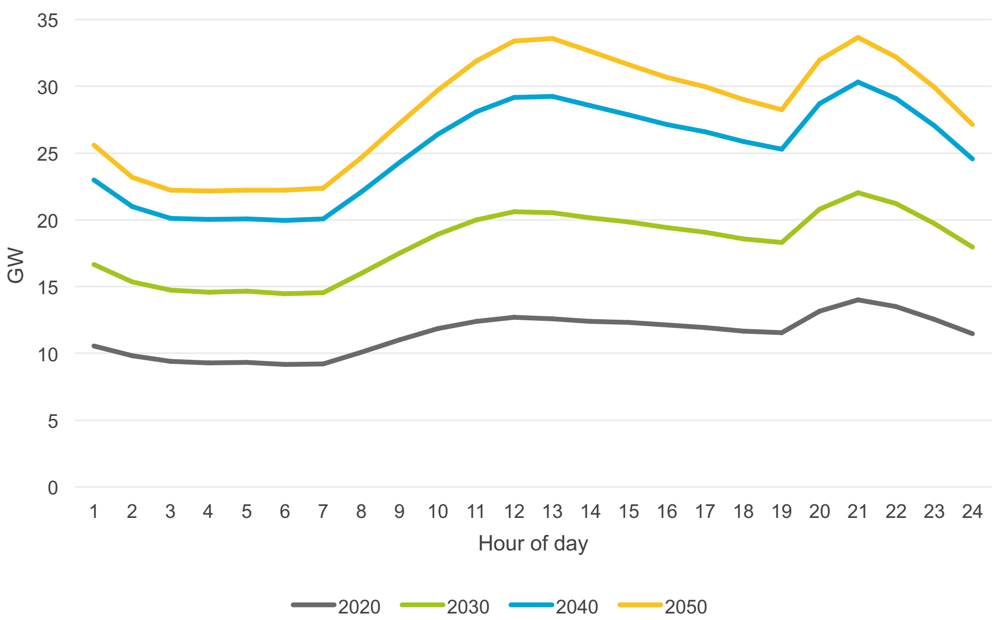




Seasonal and daily electricity demand is heterogeneous in the MENA region. The seasonality of electricity demand is very pronounced in the countries of the Arabian Peninsula (very high demand during summer months), whereas it is less pronounced in North African countries. However, throughout the region, absolute annual system peak loads occur during summer. Daily peak loads occur around midday and the early afternoon in many countries of the MENA region. The exceptions are, for example, Egypt, Morocco and Lebanon, where the highest daily loads can be observed during the evening hours after sunset (Arab Union of Electricity, 2017). However, also in Egypt, Morocco and Lebanon a shift towards a more pronounced midday peak can be observed, which is mainly the result of increased electricity demand for air conditioning during midday and afternoon hours (GIZ, 2011).

Figure 14 below presents the assumed average daily load curve in August for the representative power system for the years 2020, 2030, 2040 and 2050. In the early years of the planning time frame, the stylised load curve is more aligned to that of the MENA countries in that period, which experience daily peak loads during the evening hours. From a system integration perspective for solar and wind power, this shape of daily load curve is more challenging than load curves with a pronounced midday/afternoon peak load, as not only solar but also wind power availability is often highest during midday/afternoon hours in the MENA (World Meteorological Organization, 2018). As the years progress, we assume there will be a more strongly pronounced midday peak for the synthetic MENA country, driven by increased electricity demand for air conditioning. Therefore, the shape of the daily load curve becomes progressively more aligned to the situation of the MENA countries in those later decades, which experience daily peak loads between midday and the afternoon hours.

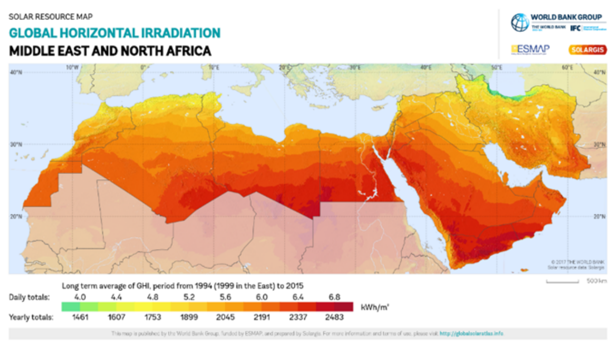
Figure 14. Average daily load of the representative power system in August over the planning time frame considered

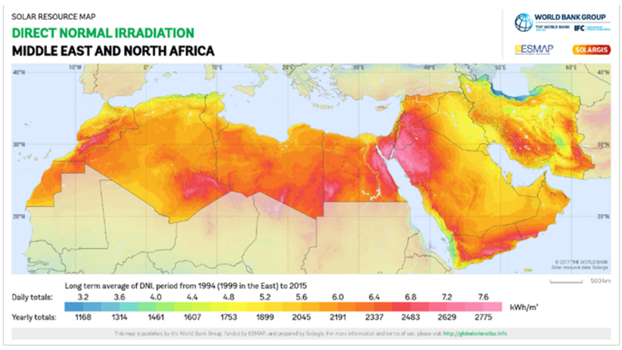


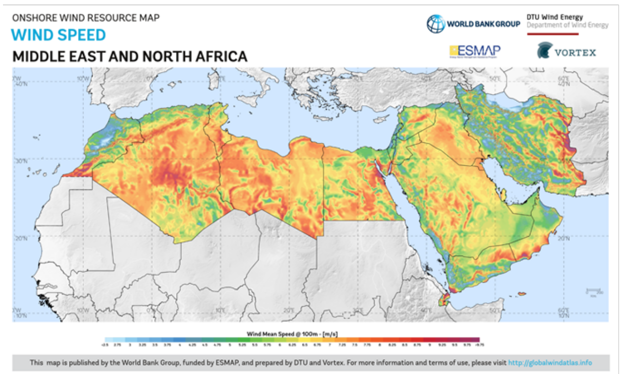
The MENA region is blessed with the world largest solar potential and some countries also have excellent wind resources. In contrast, the potentials for hydropower are low and the majority of the existing potential has already been developed. The best solar sites for PV in the MENA region receive an annual global horizontal irradiation (GHI) of more than 2,300 kWh/m2, but values for most sites range between 1,900 and 2,100 kWh/m2 per year. Full load hours (FLH) are therefore typically in the range of 1,800–2,000 hours for fixed-mounted PV systems and between 2,000 and 2,300 hours for PV with tracking systems. Annual direct normal irradiation (DNI), the solar resource for concentrated solar power (CSP) plants, can be higher than 2,600 kWh/m² at the best available sites. However, DNI values often range between 2,000 and 2,400 kWh/m². Annual capacity factors for CSP are not only defined by the annual DNI availability but also by the plant design – i.e. the size of the solar field and storage, and the co-firing share. Average annual wind speed varies considerably across the MENA. There are a few areas with excellent wind resources offering average annual wind speeds above 9 m/s at 100 m above sea level (e.g. in Morocco and Egypt), but there are also large areas with annual average wind speeds of only 5–7 m/s, which are economically less attractive. The FLH for wind power in the MENA can therefore vary, ranging from over 3,000 hours to significantly less than 1,800 hours. Our assumptions for renewable energy resource availability in the representative power system are presented in Figure 15 below. The performance indicators in this figure represent upper means rather than best-in-class values and therefore take a fairly conservative view of the performance of renewable energy technologies.

To meet the electricity supply required over the 2020–50 planning time frame, several investment options are available for the representative power system. Conventional thermal technologies comprise coal (with and without CCS), nuclear, CCGT (with and without CCS) and OCGT power plants. Renewable energy technologies are represented by PV (with and without single-axis tracking), CSP and onshore wind power. In addition, pumped-storage hydro (maximum of 3 GW) and battery systems are available. The major cost assumptions for these investment options are presented in Appendix 3.

Figure 15. Solar and wind resources in the MENA region (Global Wind Atlas, 2017; Solargis, 2018), and assumed potential for renewable energies for the modelled representative power system





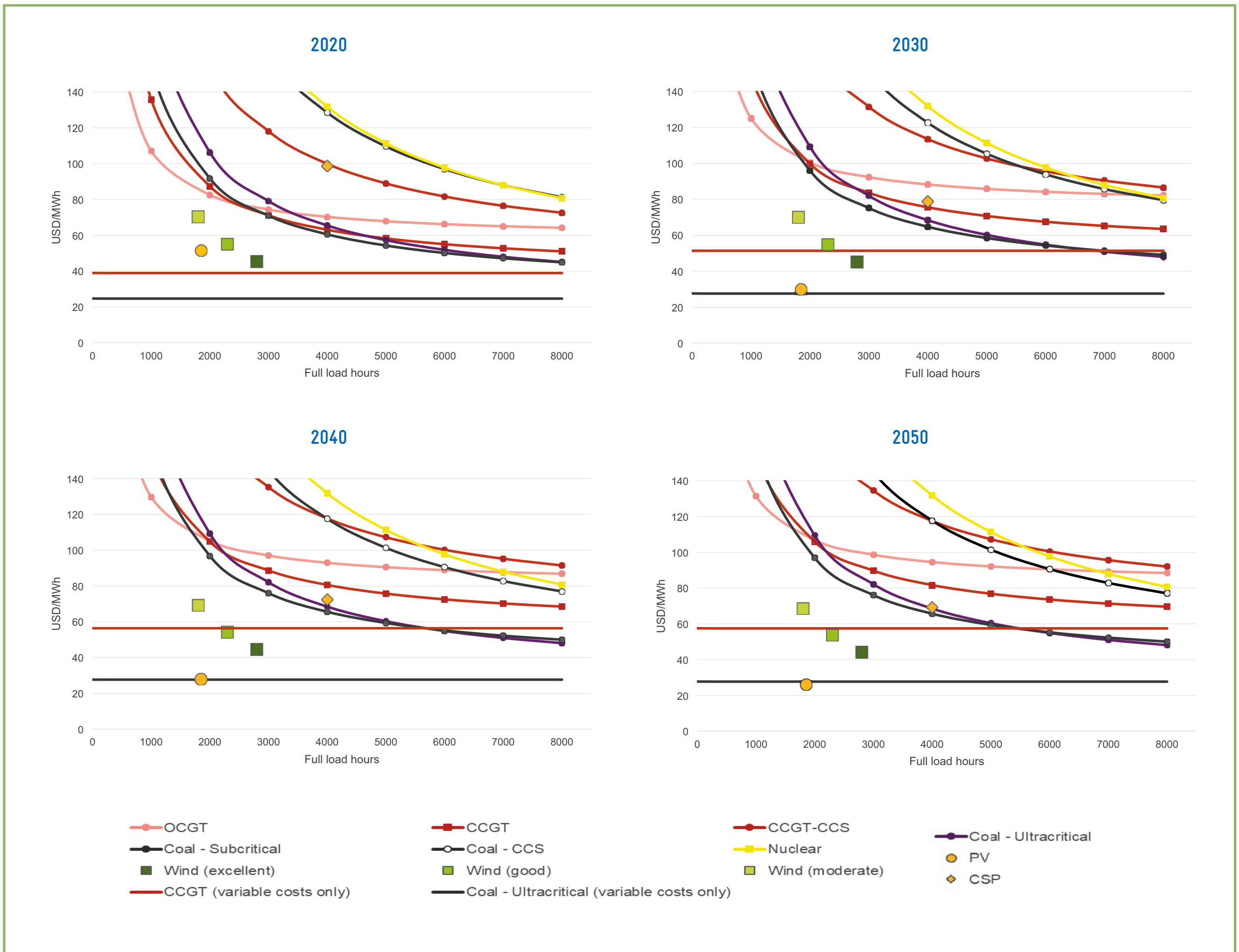


Assumed renewable energy performance indicators and available potential for the representative power system

	Performance indicator	Available potential
PV	GHI: 2,100 kWh/m² p.a.	Unconstrained
CSP	DNI: 2,350 kWh/m² p.a.	Unconstrained
Wind (excellent)	FLH: 2,800	2 GW
Wind (good)	FLH: 2,300	8 GW
Wind (moderate)	FLH: 1,800	Unconstrained
Pumped-storage hydro	-	3 GW

In the next section, we look at the results from the least-cost capacity expansion optimisation for the representative MENA power system under the different scenarios. Before this, it is useful to consider the levelised cost of electricity (LCoE) of the various generation investment options over the planning time frame as a function of full load hours (FLH), as presented in Figure 16 below. This figure provides an overview of the applied input data of the optimisation model, and it highlights the development of the variable operational costs of coal and CCGT units. The presented values are calculated from the applied technology-specific input parameters of PowerFys-Invest – i.e. investment costs, O&M costs, fuel prices, WACC, efficiency, and lifetime of and resource availability for renewable energy technologies. As can be observed, coal power plants without CCS systems remain the cheapest baseload (>4,000 full load hours [FLH]) generation technology over the planning time frame in the absence of a CO_2 price. The LCoE of renewable energy technologies decreases significantly over the planning time frame. After 2020, the LCoE of PV and wind farms at excellent sites is lower than the variable costs of CCGT power plants, making these variable renewable energy technologies an attractive way to save natural gas. According to the applied input data, the LCoE of dispatchable CSP units is reduced from about 100 USD/MWh in 2020 to around 70 USD/MWh in 2050. From 2030 on, CSP is cost-competitive against CCGT units and can provide similar system services through its application of thermal energy storage and back-up burners – e.g. dispatchable firm capacity and operating reserve to balance the intermittent generation of PV and wind power. When compared with recent PPAs in the MENA region (see Table 23 in the previous chapter), our applied cost and resource assumptions for renewable energy technologies are fairly conservative.

Figure 16. Comparison of the LCoE of different generation investment options in 2020, 2030, 2040 and 2050 as a function of full load hours (without CO_2 costs). The values are calculated from the techno-economic parameters of the various investment options used in PowerFys-Invest.



4.4 Scenario modelling results

Results for Scenario Group 1: Main Scenarios

Figure 17 below shows the cumulative installed net generation capacity and the annual electricity generation over the 2020–50 planning time frame for Scenario 1. In 2050, renewable energies represent 66% of the total installed generation capacity and cover 81% of annual demand. PV and the best wind power sites are competitive from the beginning of the planning time frame. More than 41 GW (AC rating) of PV are installed by 2050. With 5 GW, wind power deployment is comparably low and is limited to the best sites only (2,800 FLH). From 2030 on, the model installs large amounts of CSP capacity (with 10 hours of storage and a fossil back-up burner) for additional bulk electricity generation from renewable energy sources and to provide the highly necessary firm and dispatchable generation capacity to balance out the intermittent generation of PV and wind power. Large-scale investments in OCGT power plants provide additional firm generation capacity and fast-reacting operating reserve to ensure the adequacy of the system and a reliable system operation. All the available 3 GW of pumped-storage hydro units are installed by 2035. To add further flexibility to the system, large amounts of battery storage (7 GW by 2050) are installed from 2030 onwards.

Despite the large-scale deployment of renewable energies, the model invests considerably in coal power plants in the first half of the planning time frame (9 GW by 2030). From a least-cost system perspective, coal power plants outperform less-CO_2-intensive but more-expensive electricity generation from CCGT. The capacity factors of the existing CCGTs are reduced significantly between 2020 and 2050 and no new CCGT units are installed.

Figure 17. Cumulative installed net capacity (left) and annual electricity generation (right) over the planning time frame for Scenario 1

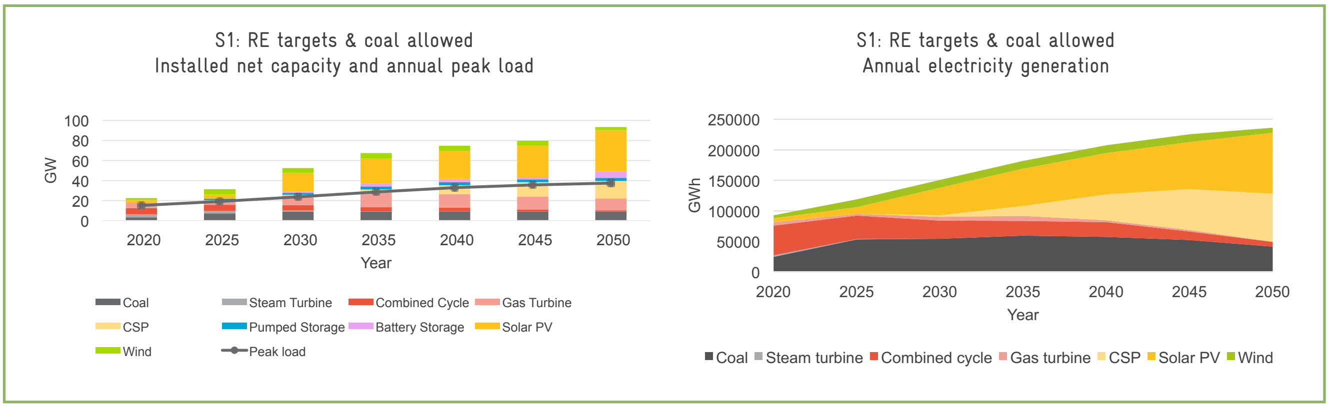


Figure 18 (right) shows the exemplary dispatch of the system during a summer day in 2040. Electricity generation from PV provides the major part of the system load during the day. In contrast, CSP units operate with full capacity when PV generation is low, making use of the thermal energy they have stored. Pumped-storage hydro facilities and battery systems are charged during the day, thus shifting electricity generation from PV to the evening hours and avoiding shutdowns of coal units.

The large-scale deployment of coal power plants in the early years of the planning time frame leads to a significant increase of CO_2 emissions from the system up to 2035 (more than 40%). This runs counter to the climate change mitigation efforts expressed through renewable energy targets (Figure 19, left-hand chart). In 2050 the system's CO_2 emissions are only about 13% lower than those of 2020, even though 80% of annual electricity demand is covered by renewable energy. This is due to the strong increase in electricity demand and the utilisation of coal power plants for electricity generation. The newly installed coal power plants are responsible for more than 75% of the system's CO_2 emissions up to 2050. The specific supply costs of the system have increased by 18% by 2050 (Figure 19, right-hand chart).

Figure 18. Exemplary dispatch for a summer day in 2040 for Scenario 1

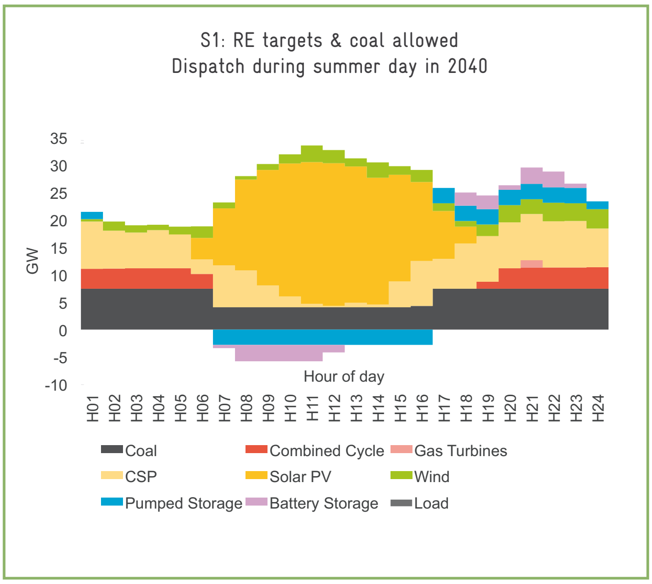


Figure 19. Index values for CO_2 emissions (left) and for the specific supply costs and total CO_2 emissions of the system (right) for Scenario 1

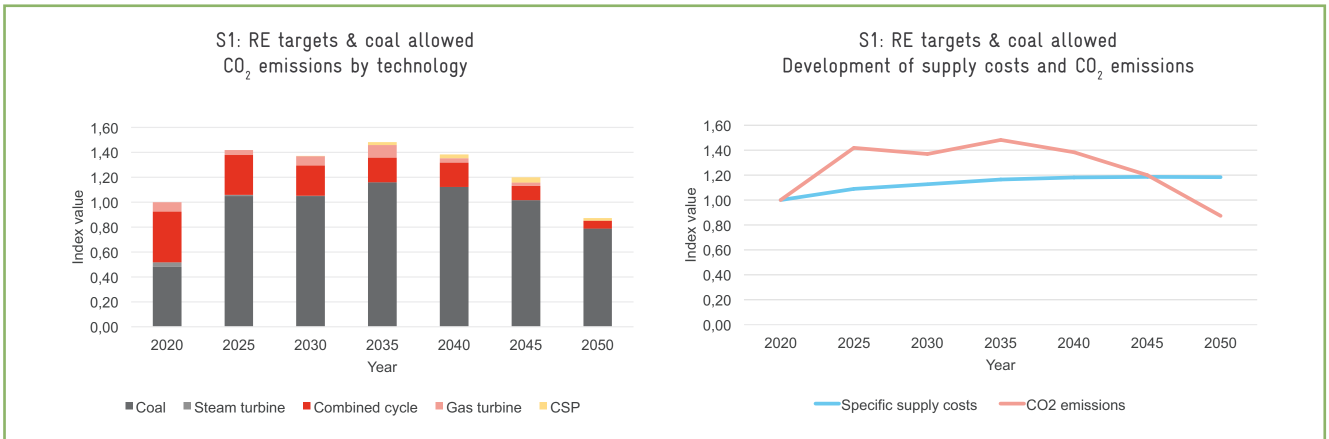


Figure 20 below compares the installed net generation capacity and annual electricity generation of the four scenarios of Scenario Group 1. In Scenario 2, where no targets for renewable energies are applied, coal power plants are the dominant source for electricity generation, accompanied by some investments in PV, wind power and storage systems. In 2050, coal power plants cover around 61% of annual electricity demand (compared to 18% in Scenario 1). Renewable energies only have a share of 35% of the total electricity supply. In Scenario 3, which does not allow investments in coal power plants and does apply renewable energy targets, CCGT power plants replace investments in coal power plants early on in the planning time frame. In this scenario, renewable energies cover around 83% of annual electricity demand in 2050. The results of Scenario 4, where renewable energy targets are not applied, are very similar to the results of Scenario 3, where these targets are applied. In Scenario 4, renewable energies cover 84% of annual electricity demand in 2050. Scenario 4's results demonstrate that a large-scale deployment of renewable energies to meet more than 80% of electricity demand in 2050 is the least-cost option when investments in coal power plants are not allowed.

Figure 20. Cumulative installed capacity and annual electricity generation by technology over the planning time frame for Scenario Group 1

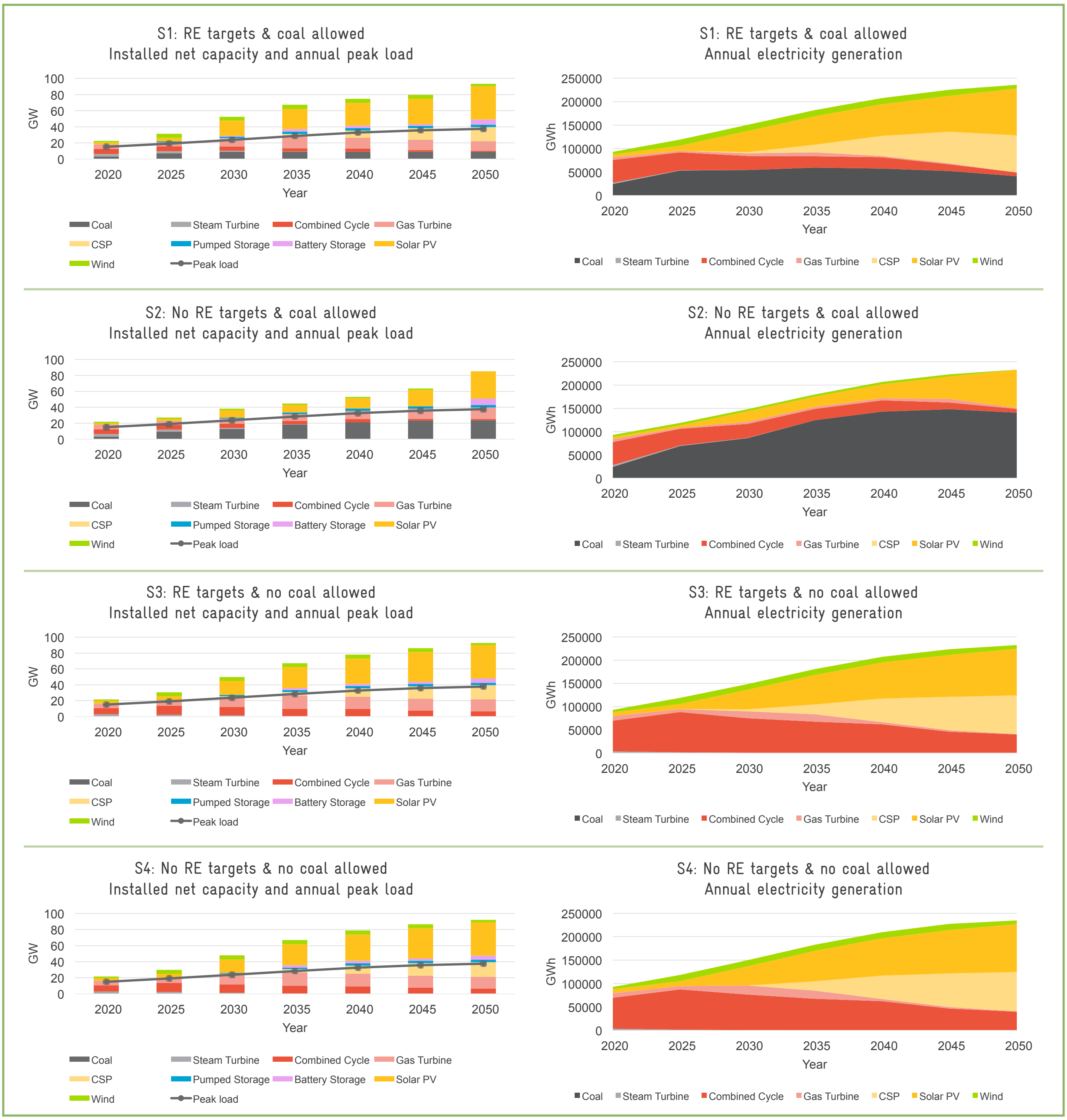


Figure 21 and Table 27 summarise the results of the four scenarios of Group 1. Scenario 2 has the lowest net present value of total system costs. Scenario 1's total system costs are 5% higher than Scenario 2's, while Scenario 3 and 4's are 13% higher. However, the lower supply costs of Scenario 2 lead to significantly higher CO_2 emissions compared to the other scenarios. Compared to Scenarios 3 and 4, the CO_2 emissions of Scenario 2 are around 340% higher. The CO_2 emissions of Scenario 1, which applies targets for renewable energies but allows investments in coal, are also significantly higher than (almost double) those of Scenarios 3 and 4, which both avoid investments in coal power plants.

Ex-post analysis for external costs

In the calculation of the four main scenarios of Group 1, no external costs for the different electricity generation technologies were factored into the least-cost capacity expansion optimisation. It was shown that, based on the applied input assumption, coal power plants play a significant role in the least-cost electricity supply when allowed as an investment alternative (Scenarios 1 and 2). While Scenarios 1 and 2 have significantly higher CO_2 emissions over the 30-year planning time frame than have Scenarios 3 and 4, in which investments in coal power plants are suspended (approximately twofold and 3.4-fold respectively), the total system costs of these first two scenarios are about 7–12% lower (see Table 27).

Figure 21. Index values for specific supply costs (left) and CO_2 emissions (right) of the system over the planning time frame

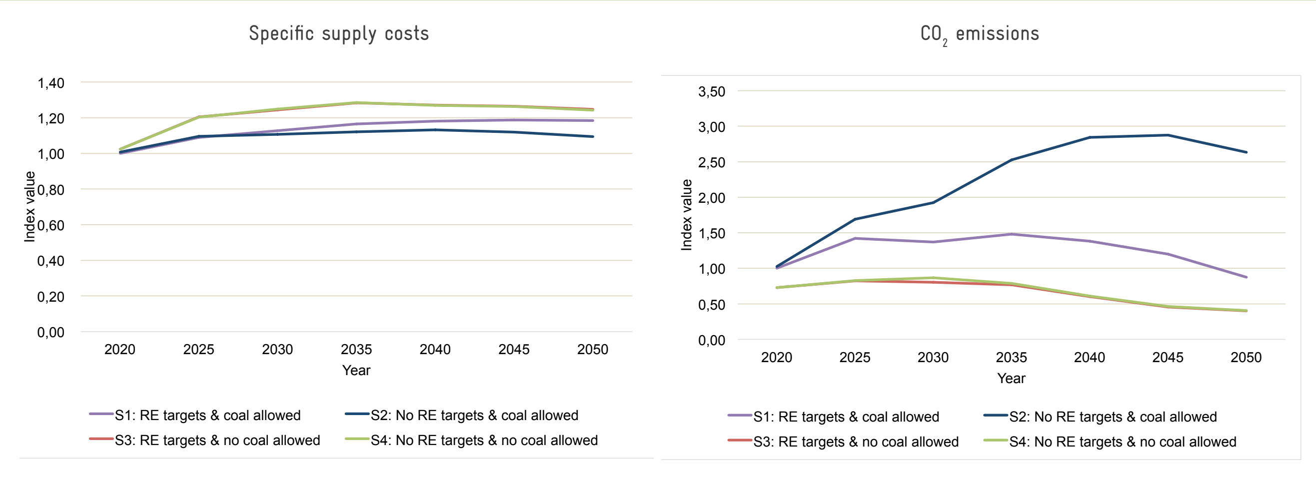


Table 27. Overview of the results of Scenario Group 1 (scenarios 1–4)

	Scenario 1: RE targets & coal allowed	Scenario 2: No RE targets & coal allowed	Scenario 3: RE targets & no coal allowed	Scenario 4: No RE targets & no coal allowed
Total system costs (net present value)	100%	95%	107%	107%
Total CO_2 emissions	100%	178%	52%	54%
RE share in 2050	81%	36%	83%	84%
CO_2 emission in 2050	100%	301%	46%	46%
Coal share in 2050	18%	61%	0%	0%

Table 28. Range of external-cost estimates for electricity generation technologies in USD cents/kWh (RCREEE, 2013)

	Coal	Gas	Nuclear	Hydro	Wind	Solar
Minimum	3.0	0.49	0.2	0.03	0.001	0.25
Maximum	9.5	3.0	1.5	1.0	0.25	0.6
Mean	5.4	1.7	0.6	0.4	0.1	0.5

By means of an ex-post analysis, it was investigated in a simplified way whether Scenarios 1 and 2 would also be the least-cost option for meeting electricity demand over the planning time frame when the external costs of the power generation technologies are considered and added to the total system costs. For each scenario, the generation fleet's electricity generation over the planning time frame was multiplied by the technology-specific external costs for electricity generation, discounted to the base year and added to the net present value of the original total system costs. The data for the external costs of electricity generation technologies were drawn from RCREEE's publication Environmental Externalities from Electric Power Generation (RCREEE, 2013) and are presented in Table 28 above.

Calculating the external costs of power generation technologies is highly complex and is still the subject of ongoing research. The external costs put forward by RCREEE (2013) are based on the internationally recognised projects ExternE and NEEDS (Bickel and Friedrich, 2005; Ricci and ISIS, 2010). The NEEDS project takes into account the consequences of airborne pollutants, biodiversity losses due to land use and the damage costs of GHG emissions, while ExternE differentiates between environmental impacts, global warming impacts and the cost of accidents. For the sake of simplicity, it is assumed that the technology-specific external costs remain constant over the planning time frame.

The results of the ex-post analysis are presented in Figure 22 below. Even when considering only the minimum values for external costs, Scenarios 1 and 2 have significantly higher total costs (composed of electricity supply and external costs) than have Scenarios 3 and 4. This is due to the high share of coal in the electricity supply mix of Scenario 1 and especially of Scenario 2. The external costs of coal power plants are significantly higher than those of renewable energy and gas-fired power plants, which are the dominant electricity supply technologies in Scenarios 3 and 4. The ex-post analysis clearly shows that scenarios with low CO_2 emissions and high shares of renewable energy (i.e. Scenarios 3 and 4) have significant cost advantages when the external costs of electricity generation technologies are considered.

Figure 23 below shows the results of a sensitivity analysis for the external costs of coal power plants. As Scenarios 3 and 4 do not utilise coal for electricity generation, the total costs of these two scenarios (composed of electricity supply and external costs) do not change when external costs for electricity generation from coal is varied. Scenario 2, which is highly dominated by coal power plants, becomes the most expensive scenario as soon as the external costs of coal power plants move higher than 1.5 USD cents/kWh. This is only 50% of the minimum value of the external costs provided in the RCREEE publication (RCREEE, 2013). Scenario 1, which has an 80% renewable energy share in 2050 but also relies heavily on electricity generation from coal to meet growing demand, becomes more expensive than Scenarios 3 and 4 when the external costs for coal move higher than 2 USD cents/kWh. Again, this is significantly lower than the minimum values for the external costs of coal power plants provided in the literature.

Figure 22. Comparison of the total costs (electricity supply costs + external costs) and CO_2 emissions of the representative MENA power system over the 2020–50 time frame for scenarios 1–4

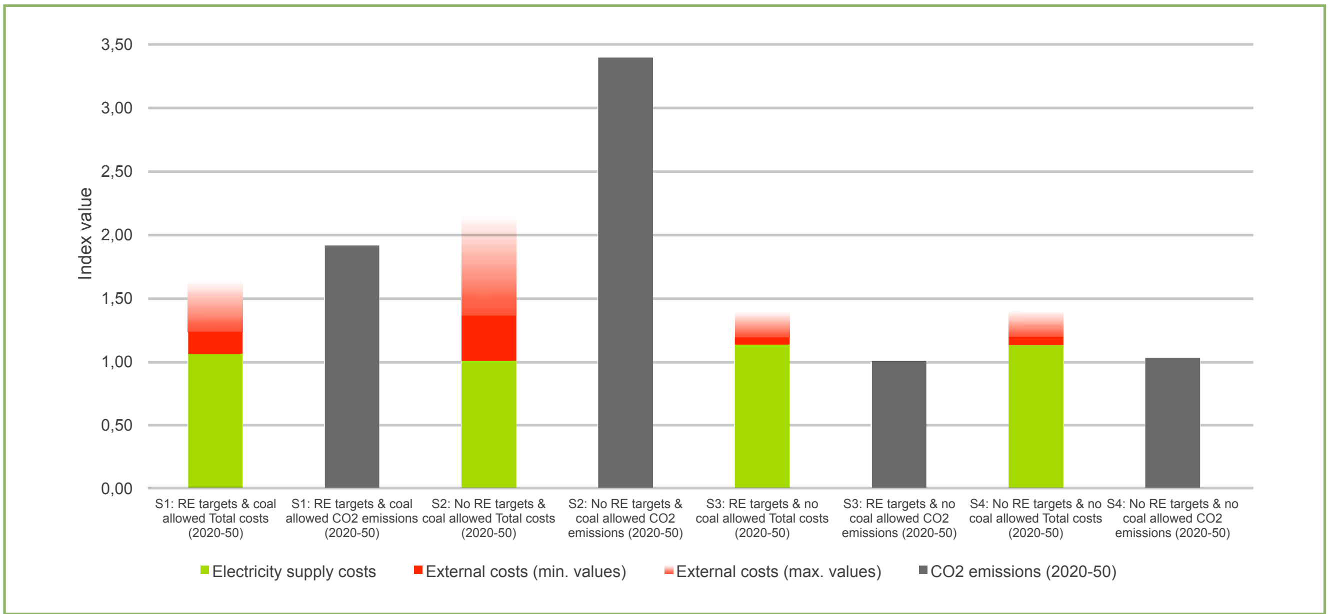
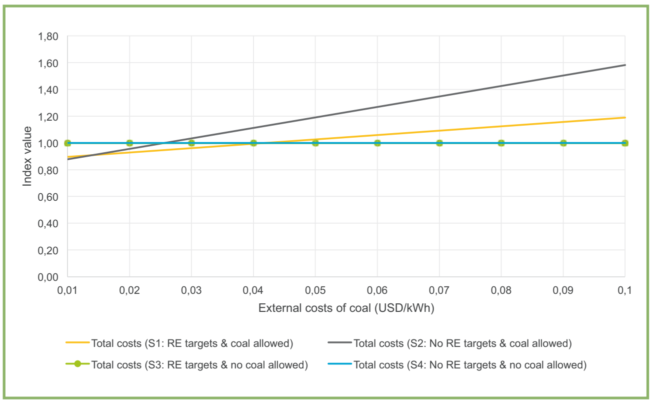


Figure 23. Sensitivity analysis for the external costs of coal and their impact on the total costs (electricity supply + external costs) of scenarios 1–4

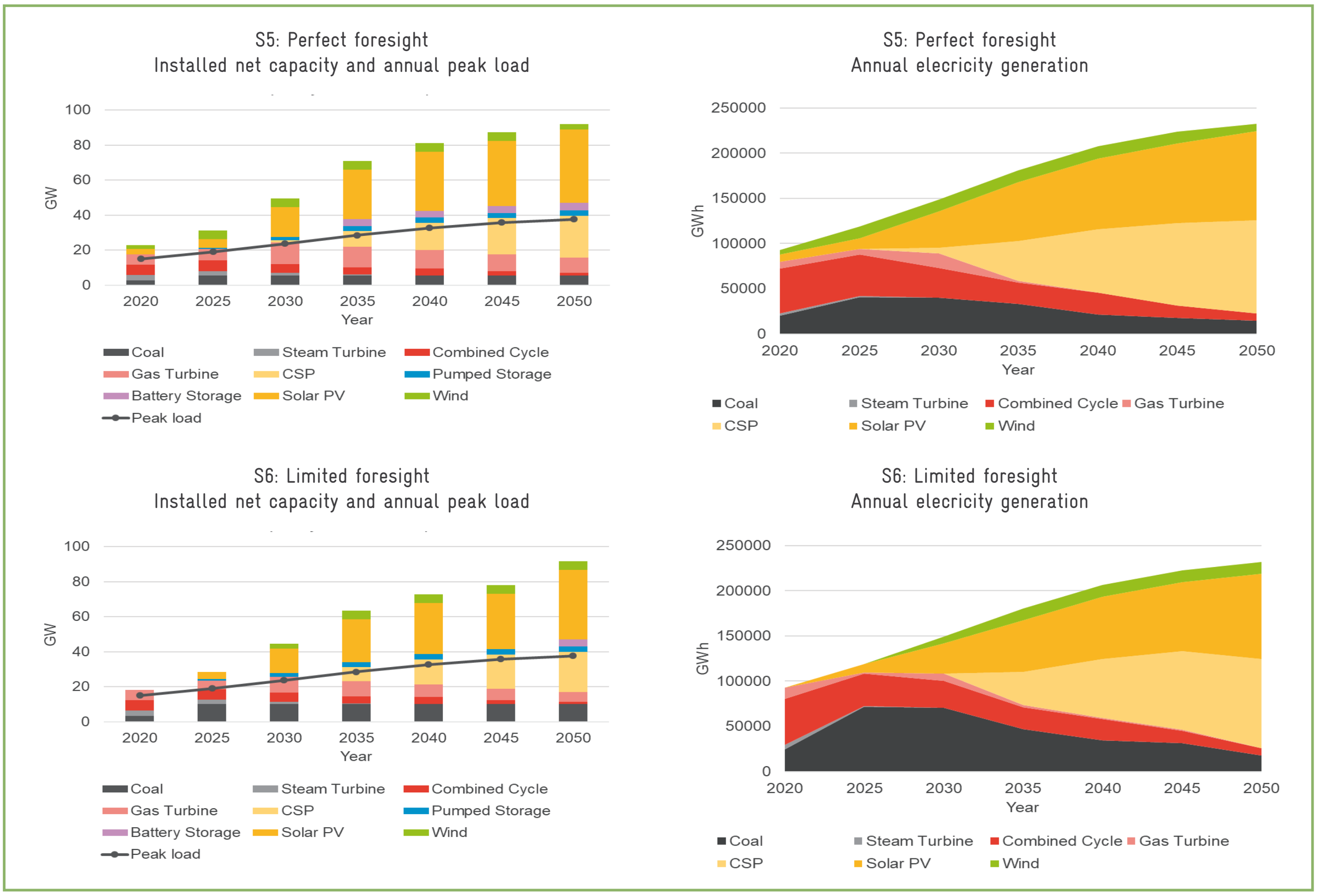


Results for Scenario Group 2: Risk of coal investments

Figure 24 below presents the net installed generation capacity and annual electricity supply for Scenarios 5 and 6 over the planning time frame. Significant investments in coal power plants take place in both scenarios despite the introduction of a CO_2 price of 45 USD/t in 2035. However, it can be observed that in Scenario 6, where limited foresight in the optimisation model is applied and thus the introduction of CO_2 prices is not foreseen at the beginning of the planning time frame, significantly more coal power plants are installed. In Scenario 6, coal power plants totalling around 10 GW are installed whereas in Scenario 5 just 5.5 GW are installed. The sizeable coal plant capacity of Scenario 6 is deployed to replace electricity generation from CCGT and postpones the large-scale integration of renewable energy, especially in the first 10 years of the planning time frame. However, despite the absence of renewable energy targets, the introduction of a CO_2 price in 2035 prompts a transformation of the fossil-fuel-dominated system towards a system that, in the long term, largely comprises renewable energy. In both scenarios, the share of renewable energy increases to around 90% in 2050.

The larger investments in coal power plants in Scenario 6 lead to CO_2 emissions over the planning time frame that are 30% higher than those of Scenario 5, yet the total system costs are fairly similar for both scenarios. While the capacity factors of coal power plants reduce over time in both scenarios, they are significantly higher in Scenario 6 where the introduction of CO_2 prices in 2035 was not foreseen when investment decisions were made in the first decade of the planning time frame. The average capacity factors of coal power plants are reduced from more than 80% in 2020 to around 20% in 2050 (compared to 30% in Scenario 5). In fact, once the CO_2 price is introduced in 2035, electricity production from coal is substantially reduced to minimise the system's electricity supply costs.

Figure 24. Installed net generation capacity and annual electricity generation over the planning time frame for Scenario 5 (perfect foresight) and Scenario 6 (limited foresight) assuming the introduction in 2035 of a CO_2 price of 45 USD/t



Results for Scenario Group 3: Sensitivity analysis

This section briefly describes the results of the sensitivity analysis. Table 29 below summarises the results for scenarios 7–11.

Table 29. Summary of sensitivity analysis

Scenario group	Results summary
S7: S1 but with 3% WACC for technologies	• Does not lead to less investment in coal • Ultra-supercritical coal power plants favoured over subcritical ones, which results in lower total CO_2 emissions due to the higher efficiency of ultra-supercritical coal plants • CSP capacity increases while PV+BATTERY+OCGT capacity decreases • Impact on investment decisions is limited because the focus of the least-cost system approach is on overall system costs and not on the LCoE of single technologies
S8: S1 but with 8% WACC	• Leads to significantly higher CO_2 emissions because subcritical coal is favoured over ultra-supercritical coal • PV+BATTERY+OCGT capacity increases while CSP decreases • Impact on investment decisions is limited because the focus of the least-cost system approach is on overall system costs and not on the LCoE of single technologies.
S9: S1 but with external costs	• Coal power plants are no longer part of least-cost solution • RE targets in 2050 are significantly exceeded (89% instead of 80%)
S10: S2 but with external costs	• Similar results to S9 • RE targets are not required for the transition of the power system to high RE shares when external costs are considered
S11: S2 but with CO_2 costs introduced in 2025 and assuming a linear increase in these costs up to 2050	• Significantly less investment in coal power plants (1.6 GW against 23 GW in Scenario 2) • Instead, there is more investment in RES and storage • RE targets in 2050 significantly exceeded because it is the most economical solution (98% of final demand supplied by RES)

Applying a lower WACC (3% instead of 5%) to the investment options in Scenario 7 favours investments in capital-intensive technologies. Ultra-supercritical coal and CSP units are the most capital-intensive technologies deployed in Scenario 1. Compared to these technologies, PV and wind power are relatively low-capital-intensive technologies (as is evident from a comparison of their specific investment costs in USD/kW). As a consequence, at the beginning of the planning time frame, the model invests in more capital-intensive ultra-supercritical coal power plants than it does in subcritical ones (overall coal investment remains the same) and, as it moves towards the end of the planning time frame, it increases investments in CSP capacity. The increased deployment of CSP results in lower investments in PV, battery and OCGT units. Mainly as a result of the switch to ultra-supercritical coal power plants, which are more efficient than subcritical ones, the CO_2 emissions over the entire planning time frame are about 5% less in Scenario 7 than in Scenario 1 (WACC 5%).

An inversion of these results can be observed in Scenario 8, where the WACC for investment options is increased from 5% to 8%. CO_2 emissions in Scenario 8 are about 7% higher than those in Scenario 1 (WACC 5%). Figure 25 and Figure 26 below present the annual electricity generation for Scenarios 7 (3% WACC) and 8 (8% WACC) respectively and compare their annual generation to that of Scenario 1 (WACC 5%).

Figure 25. Annual electricity generation of Scenario 7 (3% WACC) (left), and difference in annual generation between Scenario 7 and Scenario 1 (5% WACC) (right)

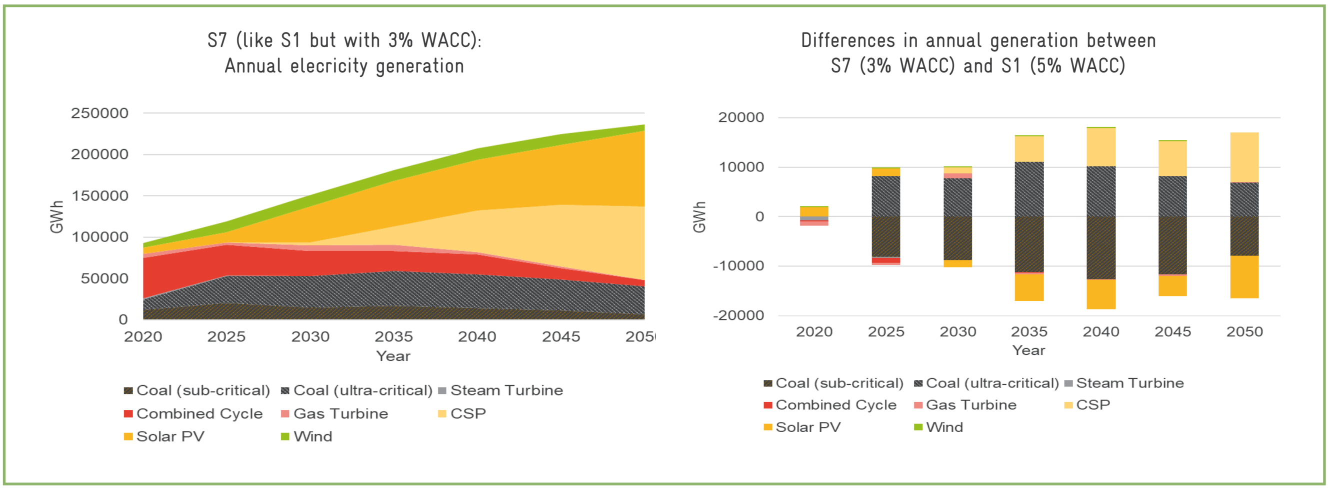
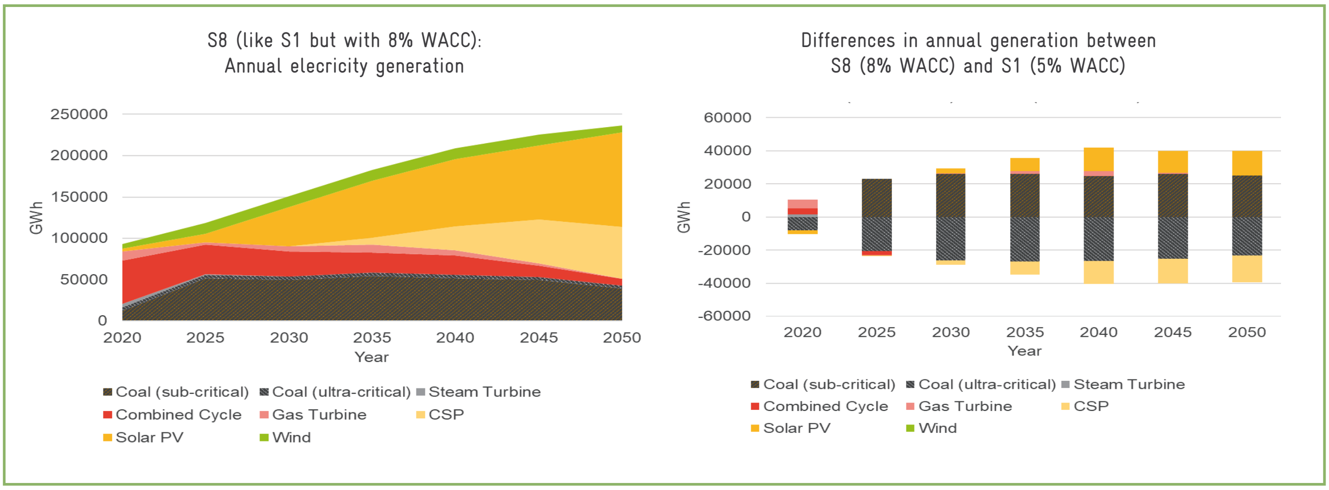
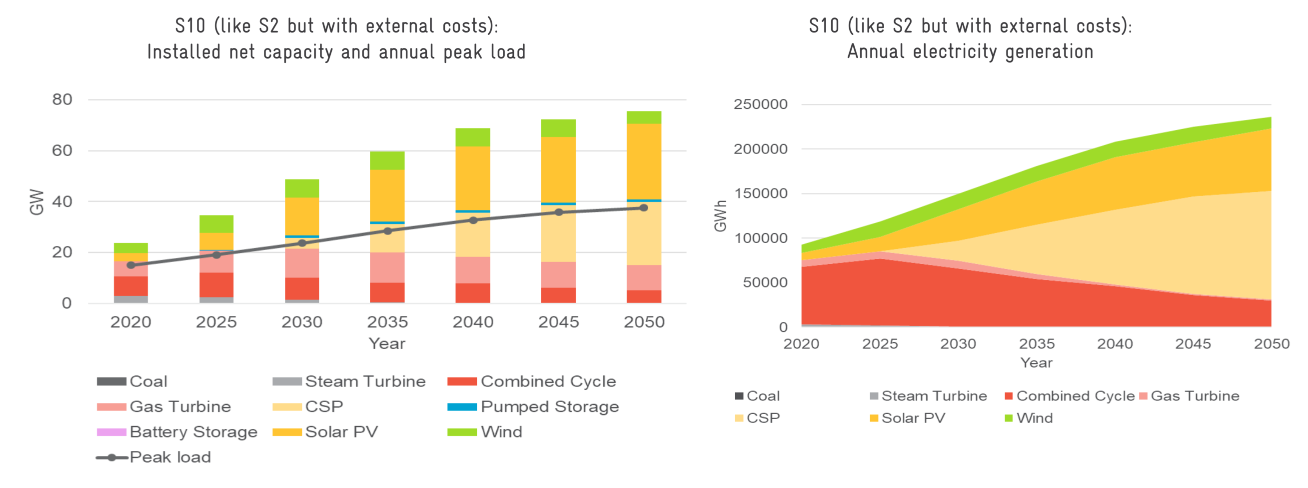


Figure 26. Annual electricity generation of Scenario 8 (8% WACC) (left), and difference in annual generation between Scenario 8 and Scenario 1 (5% WACC) (right)



In Scenarios 9 and 10, the external costs of power generation technologies are factored into the least-cost capacity expansion optimisation. The limitations of this approach have been described above in the section 'Results for Scenario Group 1: Main Scenarios'. In Scenarios 9 and 10 we have applied the lower-range values shown in Table 28. The results of running the model for these two scenarios confirm the findings from our ex-post analysis in terms of the external costs for our main scenarios. Even when considering only the minimum values for external costs set out in Table 28, coal power plants do not form part of the least-cost solution and RE deployment is increased significantly without the need for any RE targets. Figure 27 below shows the cumulative installed net capacity and annual electricity generation over the planning time frame for Scenario 10 (like S2 but with external costs). From the very beginning of the planning time frame, the deployment of PV and wind power is strongly increased. After 2025, a large number of CSP units are also installed and, in 2050, renewable energy capacity represents almost 80% of installed generation capacity. The remaining capacity is provided by flexible CCGT and OCGT power plants. The high share of DRE technologies (in this case CSP) reduces the need for other flexible options like battery storage and pumped-storage hydro. In Scenario 10, only 1 GW of the latter is installed (available potential of 3 GW) and no battery storage units are deployed. In 2050 almost 90% of the annual electricity demand is supplied by renewable energies.

Figure 27. Cumulative installed net capacity (left) and annual electricity generation (right) over the 2020–50 planning time frame for Scenario 10



In Scenario 11 it is assumed that CO_2 prices of 25 USD/t are introduced in 2025 and that CO_2 prices increase in a linear fashion up to 75 USD/t by 2050. The impact of this assumption on the least-cost capacity expansion plan to meet electricity demand over the 30-year planning time frame can be observed in Figure 28 below. Investments in coal power plants are almost completely avoided due to the early introduction of a CO_2 price. Whereas in Scenario 2 more than 23 GW of coal power plants are installed, in Scenario 11 less than 2 GW of coal power plants are installed at the beginning of the planning time frame. Three coal units, each with a gross capacity of 600 MW, are installed in 2020. After this, no further investments are made in coal power plants. Instead, large-scale investments are made in PV, wind power, CSP, battery storage and OCGT (for back-up purposes). In 2050, electricity generation from renewable energy technologies represents 98% of the final electricity demand (94% of total electricity generation).

Scenario 11 forgoes the electricity generation from coal power plants that features in Scenario 2, replacing it early on in the planning time frame (2020–2025/30) with CCGT, PV and wind power and in the later decades mainly with CSP (see Figure 29). This again highlights CSP's role in ensuring a successful transition to a sustainable electricity supply in the MENA region. As a dispatchable power generation technology, CSP complements cheap PV and wind power and can replace dispatchable capacity and electricity generation from fossil-fuel-fired power plants.

Figure 28. Cumulative installed net capacity (left) and annual electricity generation (right) over the 2020–50 planning time frame for Scenario 11

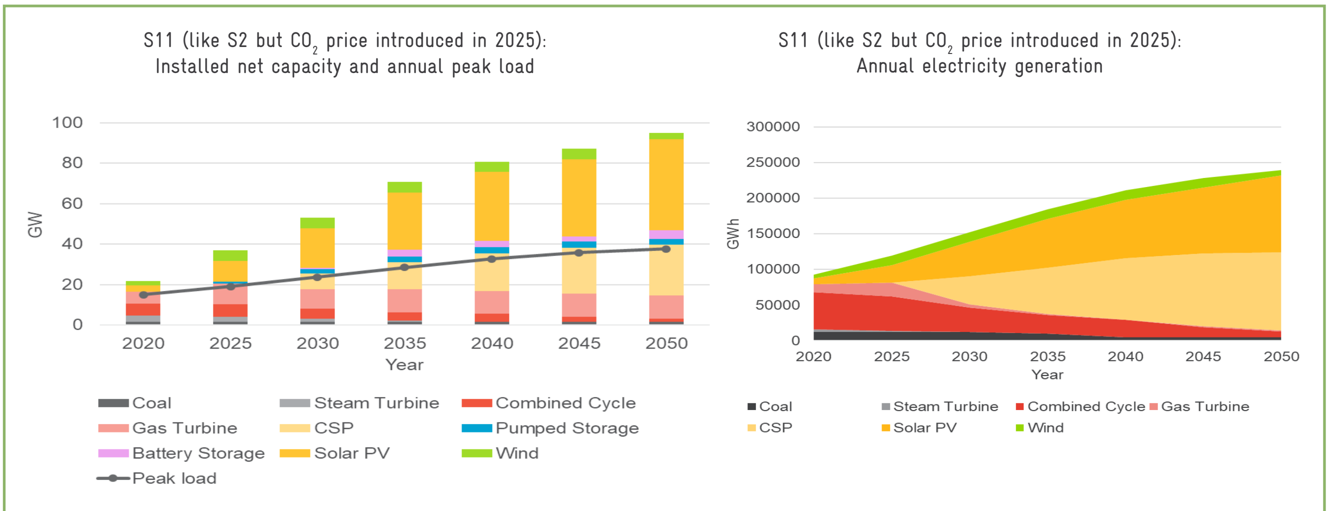
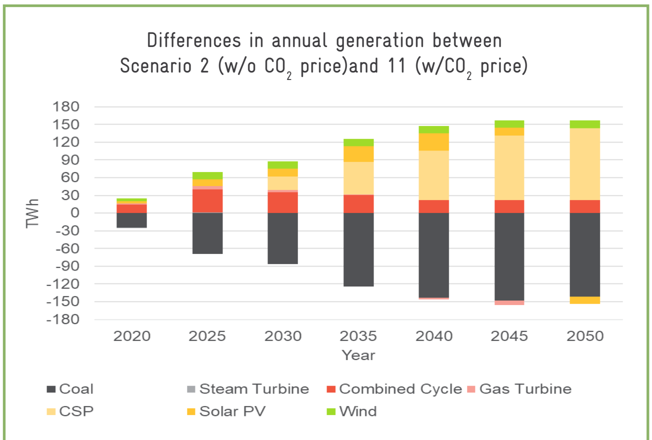


Figure 29. Differences in annual electricity generation between Scenario 2 (without CO_2 prices) and Scenario 11 (with CO_2 prices)



4.5 Summary and conclusions from the modelling of different electricity supply scenarios

Our analysis of a synthetic yet representative power system for the MENA region shows that the large-scale deployment of coal power plants is chosen solely from a least-cost system perspective that ignores external costs and runs very much counter to the region's efforts to mitigate climate change. The modelling results highlight that a large-scale introduction of coal power plants leads to a very significant increase in CO_2 emissions, while the cost benefits are far less pronounced, even if externalities are excluded, as shown in Table 30 below. Scenario 2, which sees coal power with a share of around 60% of annual electricity supply in 2050, has total system costs over the planning time frame that are only around 12% lower than those of Scenario 4. In the latter scenario, 84% of annual electricity demand in 2050 is supplied by renewable energy technologies, with the remainder coming from efficient gas power plants. The CO_2 emissions over the planning time frame that result from Scenario 2 are about 330% greater than those from Scenario 4. This is due to fact that the costs of generating electricity with renewable energy technologies are already very low in the MENA region and are expected to drop much further in future.

The results of the ex-post analysis on the external costs of electricity generation technologies show that the scenarios with a large share of coal power plants to meet strong growth in electricity demand (Scenarios 1 and 2) are significantly more expensive than scenarios that avoid electricity generation from coal (Scenarios 3 and 4) when the external costs of electricity generation technologies are considered. This is even true in cases where the minimum values for external costs are assumed.

The analysis highlights that, for power systems in the MENA region, a transition towards very high shares of renewable energy (>80% in 2050) appears to be an affordable and secure option and is by far the most sustainable approach. Such a transition is also the least-cost option when investments in coal power plants are prohibited and/or when externalities are considered. A power system based on high shares of variable (PV and wind) and dispatchable (CSP) renewable energy technologies, smartly combined with gas-fired power plants and energy storage systems, can supply electricity reliably at almost the same costs as a system dominated by coal power plants. Such a well-balanced system has significantly less CO_2 emissions than a coal-dominated power system, and it greatly enhances security of supply because, unlike in a coal-dominated system, there is diversification of local supply sources.

Table 30. Key differences between a coal- and RE-dominated scenario for future electricity supply when the external costs of power generation technologies are not factored in

	Coal-dominated future electricity supply (Scenario 2)	RE-dominated future electricity supply (Scenario 4)
Total system costs 2020–50 (index value)	100%	112%
Total CO_2 emissions 2020–50 (index value)	100%	30%
RE share of annual supply in 2050	36%	84%
Coal share of annual supply in 2050	61%	0%
Gas share of annual supply in 2050	3%	16%

Today, the cost of electricity generation from PV and wind power (at excellent sites) is already competitive against the marginal generation costs of gas-fired power plants. PV and wind power should therefore be used as 'fossil fuel savers' as much as possible. To achieve very high shares of renewable energy in the overall electricity supply (>40%), dispatchable renewable energy (DRE) technologies (such as CSP, reservoir hydro power or biomass/biogas), energy storage, spatial smoothing of VRE electricity generation via long-distance electricity transmission, and demand-side management and sector-coupling efforts become increasingly important. As the resource potential of other DRE technologies is very limited, CSP has a key role to play in enabling a transition towards a sustainable electricity supply in the MENA. Being equipped with thermal energy storage and a back-up burner with high capacity, CSP plants are able not only to produce large quantities of electricity from solar resources but also to provide firm and dispatchable generation capacity to support VRE integration. However, it must be ensured that the assumed cost reductions for this technology are achieved in future. For this to happen, CSP will need political support similar to that so far given to PV and wind power. The results of recent auctions for CSP are promising and already show power purchase agreement (PPA) tariffs dropping considerably from the levels recorded for previous auctions in the MENA region. For instance, in 2017 a record 7.3 USD cents/kWh for CSP was achieved in the UAE.

Factoring in externalities makes new coal-fired power plants unattractive. Even if only a moderate CO_2 price of 45 USD/t is assumed to be introduced around 2035, the lower utilisation of coal-fired power plants would lead to significant risks of stranded investments for investors. If CO_2 prices were introduced earlier, around 2025, or at higher levels, investments in coal power plants would become almost entirely unattractive. Investments in coal power plants therefore represent a significant risk for investors, but also for energy planning authorities. Since the 'risk' of a sudden introduction of CO_2 prices cannot be completely excluded, investors would seek to avoid stranded investments by demanding long-term PPAs that ensure high-capacity factors for their investments and transfer the potential additional costs of a CO_2 price to the planning authority. Planning authorities would need to offer such agreements to attract investors but, as a consequence, would be exposed to the risk that these PPAs prevent electricity generation from other, cheaper electricity generation sources once a CO_2 price is introduced (technology lock-in).

5 Conclusions and recommendations

Based on interviews and desktop research, this study shows that even though recent decisions appear to have slowed down the development of coal-fired power generation in the MENA region, developments are afoot that may lead to a significant increase in the role of coal in the energy systems of MENA countries if plants under consideration were to be built.

The major arguments given for coal plans in the MENA region include:

- an aim to diversify the energy supply away from natural gas and to 'free up' gas reserves for use in industry;
- the perceived cost-competitiveness of coal;
- a need for 'baseload' and firm capacity; and
- reliability and security of supply, particularly for energy-intensive industries.

Even though these concerns are understandable, these goals can be achieved by taking alternative, affordable and strikingly more sustainable energy pathways. The decision to increase the role of coal in the energy mix brings with it risks for investors and strongly negative effects on public health, air quality and the environment, and it is incompatible with the goals set by the international community in the Paris Agreement. The MENA region is extraordinarily well positioned to take future-proofed energy pathways and, in so doing, avoid the short- and long-term negative effects of coal, which should be reflected in decision-making. In addition to the overwhelming advantages of alternative pathways in terms of their social and environmental costs, energy strategies with high shares of renewables also increase energy independence and offer the opportunity for leadership in a region with some of the world's best renewable energy resources. So that decision-makers in MENA countries can harness the potential of these alternative pathways, as is already reflected in increasing renewable energy targets and a growing number of renewable energy projects in many countries, we offer the following recommendations:

1 Seize the benefits of cost reductions for renewables and assess the externalities of coal when comparing energy pathways

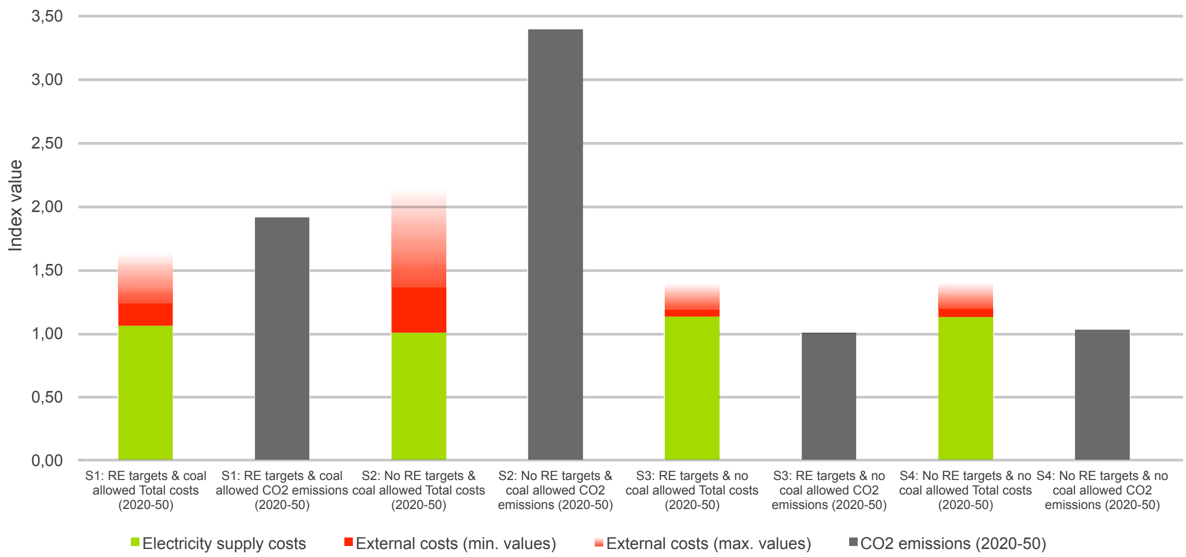
Coal appears to be a comparatively slightly cheaper source of electricity only in the case that externalities, social and environmental costs and long-term risks are not considered. Our modelling of a representative MENA power system shows that scenarios allowing coal come at a cost – massively higher CO_2 emissions, reduced system flexibility and carbon risks for investors – yet they only achieve minor cost savings.

Figure 30 below shows that the costs of scenarios which extensively use coal for electricity generation (Scenarios 1 and 2) are only 7–12% lower than those of scenarios which avoid electricity generation from coal (Scenarios 3 and 4) – but only if externalities are not considered. At the same time, the CO_2 emissions in coal-dominated scenarios are up to around 340% higher than in those without coal. These differences do not even take into account the fact that the external costs of a unit of electricity from coal are between 3 and 9.5 USD cents/kWh (RCREEE, 2013) and, were they to be factored in, would push the cost of such a unit way above the prices achieved in auctions for renewable energy in the MENA region, as presented in Table 23 above. As soon as external costs are considered, scenarios that are based on high shares of renewable energy (>80% in 2050) and use natural gas as a valuable complement show significantly lower costs than scenarios that largely use coal for electricity generation. The region offers some of the best resources for renewables globally and can seize the opportunity to hold on to its position as an energy hub in future by tapping into this resource. It should also be noted that cost estimates for renewables have traditionally been too conservative and cost reductions have regularly outperformed expectations – as shown in the record-breaking auctions in the MENA region which provided PPA prices as low as 2.42 USD cents/kWh for solar PV in UAE; see Table 23 in section 3.3 for details.

Another important way to minimise the cost of future electricity supply is to exploit the region's considerable potential for energy efficiency in areas such as cooling, buildings and industrial applications. Measures to increase efficiency and to reduce the demand that would need to be covered through additional power plants include assessing and improving energy performance standards in buildings, improving the enforcement of existing building codes, developing and implementing minimum performance standards for appliances such as refrigerators and air conditioning units, educating people and raising their awareness regarding the need for energy savings, and working with industrial users to assess the potential for retrofitting and optimal energy management.

In summary, decision-makers should reconsider the definitions of costs and benefits applied when assessing different energy strategies so that assessments fully reflect the actual cost of coal and the additional benefits of renewables to the local environment, agriculture and public health. Developing renewable energy also means using a local source of energy, thus minimising import dependence and contributing to local value creation. As the opposition to coal plants in Egypt and Morocco shows, an

Figure 30. Comparison of total costs (electricity supply costs + external costs) and CO_2 emissions of the representative MENA power system over the 2020–50 time frame for the four main scenarios of this study



energy transition based on less polluting sources of energy is also likely to gain more support from citizens and therefore constitutes a more sustainable long-term solution for energy supply.

2 Adopt a long-term perspective and strategies to mitigate investor risks

Similar to many other countries, the MENA countries are prioritising energy security and cost minimisation in their energy transition efforts (Griffiths, 2017). Market trends such as renewable energy deployment and emission restrictions create a high level of uncertainty around investments in coal power plants and their ability to generate the desired profit margins for investors. Given the increasing focus on climate change in the MENA region, regulatory changes that negatively impact on the competitiveness and utilisation of coal plants during their lifetimes are very likely. Potential regulatory changes, together with high upfront investment costs and with operational expenditures that will potentially increase due to rising coal prices, the introduction of CO_2 prices and increased variability in operation hours in response to growing electricity generation from VRE all carry a very high risk for investors in that newly installed coal power plants could end up as stranded investments.

An additional argument decision-makers will need to consider when taking decisions on long-term energy pathways is the growing reluctance of financial institutions to sponsor coal-fired power generation. Numerous multilateral financial institutions have either ended or reduced their engagement in this area, while climate finance is widely available to bridge the short-term cost difference between renewables and coal. The fossil fuel divestment movement has already gained considerable influence, receiving broad public support. Global funds for financing fossil fuel projects, including those of the World Bank, are declining. Further restrictions on the financing and support of carbon technologies by international development organisations, private banks and export credit agencies are likely.

As shown in the results of Scenarios 5 and 6 modelled in this study, regulatory changes that may become inevitable affect the prospects for investors. As a result of the limited foresight built into the Scenario 6 model, the introduction of CO_2 prices is not foreseen at the beginning of the planning time frame. The coal-fired power plants that are built in this scenario therefore become underutilised once a CO_2 price is introduced and may end up as stranded investments. In spite of the absence of renewable energy targets in these scenarios, the introduction of a CO_2 price in 2035 leads to a transformation towards a system dominated by renewable energy in the long-term. In both scenarios, the share of renewable energy increases to around 90% in 2050, making coal-fired power generation virtually unviable.

The main goals for decision-makers who find themselves at a decisive point in the development of their energy systems are to provide frameworks that are viable for investors in the long term, to reduce regulatory risk and to take decisions today that are compatible with a future in which power sectors must be almost entirely decarbonised. Long-term energy strategies and reliable policy decisions – e.g. foreseeable, regular auction rounds for renewables – are therefore needed. Investment in renewables can be de-risked through government-backed long-term power purchase agreements or through programmes supported by multilateral financial institutions that can bring down the overall cost of developing renewables even further. Bankable contracts reduce the investor risks and financing costs of renewables. To offer the right signals to investors, renewable energy needs to be embedded in energy and grid development plans and backed with adequate funding. Non-economic barriers, such as land availability, permit-related issues and grid-connection barriers should also be addressed. Finally, building renewable energy knowledge and capacities, both within institutions and the workforce, requires dedicated training or retraining and the corresponding resources.

Infrastructure investments lock the energy system into pathways that are difficult to reverse. The energy decisions made today will affect MENA countries' energy systems for decades to come. A forward-looking energy strategy therefore needs to be aligned with long-term policy goals, ensure a stable and affordable energy supply and, at the same time, reflect climate protection commitments and social and environmental goals. Alignment with different policy goals can be evaluated by conducting impact assessments of the strategies and policies under development or implementation. To ensure the consistency and reliability of long-term strategies, these assessments should be conducted through a joint effort involving ministries, relevant agencies, stakeholders and citizens.

3 Enhance power system flexibility to support the integration of PV and wind power

From an LCoE perspective, PV and wind power at excellent sites are already the cheapest electricity generation technologies in the MENA region. Recent PPAs agreed for these technologies have been as low as 2.4 and 2.5 USD cents/kWh respectively. The economic considerations alone leave no doubt that these VRE technologies will cover a large share of the future electricity demand in the MENA region.

However, as electricity generation from VRE is intermittent, the residual system needs to be highly flexible in order to balance out VRE generation and system load and to maintain a reliable electricity supply from a short-term operation perspective (balancing) and a long-term planning perspective (adequacy). This requires the utilisation of flexible thermal power plants able to provide firm capacity (OCGT, internal combustion engines, CCGT and CSP), short- and long-term energy storage solutions, the spatial smoothing of VRE generation via long-distance electricity transmission, and the facilitation of demand-side management and, in the longer term, sector coupling.

Even though significant efforts have been made to increase coal power plants' capability for flexibility, it still falls far short of the flexibility provided by other available thermal power generation technologies. In practice, then, a large-scale deployment of coal power plants would jeopardise the integration of cheap VRE in the MENA and would unnecessarily increase the integration costs of these technologies. What is needed instead is a well-balanced mix of flexible gas-fired power plants, energy storage and CSP, which would ideally complement cheap VRE in the MENA and would provide at least the same level of system reliability.

Energy planning authorities in the MENA should focus on increasing system flexibility and should cooperate with energy planning authorities that have already gained significant experience in the integration of VRE (e.g. those of Europe and of certain US states like California). The most appropriate technologies for integrating VRE should be identified and efforts to facilitate electricity transmission capacities between national electricity grids in the region further increased.

Measures that can be taken by decision-makers to enhance power system flexibility include the definition of an integrated roadmap for a large-scale and concerted integration of renewable energy into the energy system, and the development of the skills and methods required to plan and operate an energy system with high shares of VRE (e.g. RE generation forecasting, operating reserve calculation, etc.). On a more technical level, enhancing power system flexibility also requires, on the one hand, the development of appropriate grid codes to ensure a reliable system operation with high shares of VRE and, on the other, long-term system planning and adequacy analysis methods to optimise system design across all sectors of the energy system and facilitate VRE integration. As the modelling results in this study show, a viable and sustainable energy mix is not only based on VRE but should also make use of dispatchable renewable energy and storage technologies. Demand-side management, grid expansion and reinforcement, and sector coupling also facilitate the integration of higher shares of renewables further down the line and ease the implementation of recommended alternatives to coal.

In summary, the findings of this report show that deploying significant amounts of coal is not a solid long-term solution for MENA energy systems and that much more attractive, viable and sustainable solutions exist. Global trends in the energy and financing space strongly indicate that the MENA region's energy leadership and status as an energy hub can only be maintained by harnessing its outstanding renewable energy resources. Decision-makers should therefore make full use of the region's competitive advantage in renewables and its long-term potential to remain an exporter of green energy (which also constitutes a basis for future applications such as green hydrogen and synthetic fuels) to other countries.

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Appendix 1. Interviewees

Countryy	Identifier	Name	Institution
Egypt	Interviewee 15	Dr Mohamed Salheen	Founder and Director, Integrated Development Group (IDG)
Egypt	Interviewee 13	Anonymous	Anonymous
Egypt	Interviewee 14	Dr Dalia Sakr	Senior Energy and Resource Efficiency Consultant, Adjunct Faculty, Environmental Management Engineering and Science Services, the American University in Cairo
Egypt	Interviewee 2		
Egypt	Interviewee 7	Dr Shadia El-Shishini	Consultant, Egyptian Environmental Affairs Agency (EEAA)
Iran	Interviewee 3	Behzad Aghababazadeh	Advisor to CEO, Iranian Fuel Conservation Company (IFCO)
Iran	Interviewee 11	Anonymous	Anonymous
Iran	Interviewee 12	Anonymous	Anonymous
Jordan	Interviewee 5	Anonymous	Anonymous
Jordan	Interviewee 10	Malek Kabariti	Former Minister of Energy and Mineral Resources, Jordan
Jordan	Interviewee 1	Dr Ayoub Abo Dayyeh	President, Energy and Green Buildings Consultant
Morocco	Interviewee 4	Tayeb Amegroud	Founder, GPower Consultants
Oman	Interviewee 16	Anonymous	Anonymous
UAE	Interviewee 8	Anonymous	Anonymous
UAE	Interviewee 9	Anonymous	Anonymous
UAE	Interviewee 6	Anonymous	Anonymous

Appendix 2. Electricity tariffs in MENA countries

Source: Arab Future Energy Index (RCREEE, 2017)

Domestic tariff of 500 kWh/month (sorted by rate in USD cents)				
	Average tariff/kWh			Average monthly bill
Country	USD cents	**Local**	**(Sub-)currency**	**USD**
Djibouti	26.12	46.40	franc	130.60
Palestinian territories	13.58	0.53	shekel	67.90
Morocco	11.57	1.15	dirham	57.85
Tunisia	10.80	220.40	millime	54.00
Mauritania	9.86	30.74	ouguiya	49.30
Jordan	9.18	65.00	fils	45.90
UAE	8.03	29.50	fils	40.16
Egypt	4.81	37.70	piastre	24.05
Lebanon	4.57	69.00	pound	22.85
Yemen	4.04	8.70	rial	20.20
Sudan	3.66	22.80	piastre	18.30
Algeria	3.34	357.90	santeem	16.70
Oman	2.60	10.00	baisa	12.99
Qatar	2.20	8.00	dirham	10.99
Libya	1.63	20.00	dirham	8.14
Bahrain	1.59	6.00	fils	7.95
Saudi Arabia	1.33	5.00	halala	6.65
Iraq	0.90	10.00	dinar	4.50
Kuwait	0.66	2.00	fils	3.30
Syria	0.53	1.00	pound	2.65
Average	6.99			34.97

Industrial tariff of 30,000 kWh/month (sorted by rate in USD cents)				
	Average tariff/kWh			Average monthly bill
Country	USD cents	Local	(Sub-)currency	USD
Djibouti	30.96	55.00	franc	9,288.00
Morocco	16.29	1.62	dirham	4,887.00
Syria	14.39	27.20	pound	4,317.00
Yemen	13.95	30	rial	4,185.00
Jordan	13.32	94	fils	3,996.00
Mauritania	12.84	40.04	ouguiya	3,852.00
Palestinian territories	11.64	0.453	shekel	3,492.00
UAE	10.75	40.00	fils	3,225.00
Lebanon	7.96	120.00	pound	2,388.00
Tunisia	6.87	140.25	millime	2,061.00
Egypt	6.14	48.05	piastre	1,842.00
Bahrain	4.91	18.50	fils	1,473.00
Saudi Arabia	4.79	18.00	halala	1,437.00
Iraq	4.19	46.33	dinar	1,257.00
Oman	4.16	16.00	baisa	1,247.00
Algeria	3.90	418	santeem	1,170.00
Qatar	3.57	13	dirham	1,071.00
Libya	3.42	31	dirham	1,026.00
Sudan	2.89	18	piastre	867.00
Kuwait	0.33	1	fils	99.00
Average	10.04			3,011.06

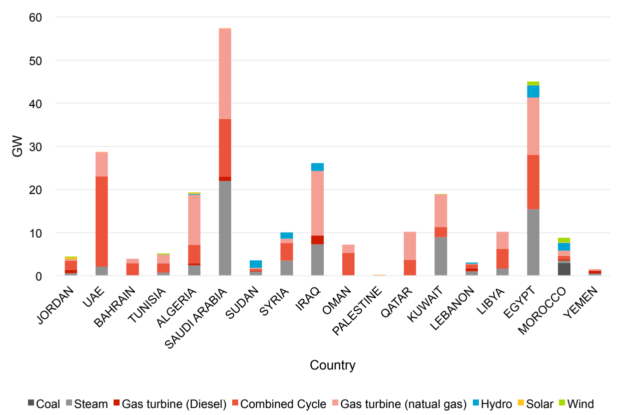
Commercial tariff of 1,500 kWh/month (sorted by rate in USD cents)

	Average tariff/kWh			Average monthly bill
Country	USD cents	Local	(Sub-)currency	USD
Djibouti	30.96	55.00	franc	464.40
Mauritania	18.93	59	oughiya	283.95
Jordan	18.19	129.00	fils	272.85
Morocco	16.45	1.63	dirham	246.75
Syria	16.42	31.00	pound	246.30
Palestinian territories	16.07	0.63	shekel	241.05
Yemen	13.95	30.00	rial	209.25
Tunisia	13.07	266.80	millime	196.05
Egypt	12.26	96	piastre	183.90
Sudan	11.48	71.40	piastre	172.20
Lebanon	10.36	156.33	pound	155.40
Iraq	9.79	108.33	dinar	146.85
UAE	8.03	30	fils	120.48
Libya	5.54	68	dirham	83.05
Oman	5.19	20	baisa	77.85
Saudi Arabia	4.26	16	halala	63.90
Bahrain	4.24	16	fils	63.60
Algeria	3.90	418	santeem	58.50
Qatar	2.47	9	dirham	37.08
Kuwait	0.66	2	fils	9.90
Average	12.66			189.87

Appendix 3. Modelling

The following tables and figures display some of the background information that was used to create the representative power system for MENA region countries and to formulate the most important input data for modelling different capacity expansion pathways with PowerFys-Invest.

Figure 31. Installed capacity (left) and annual electricity generation (right) by country in 2016 Source: Arab Union of Electricity, 2017



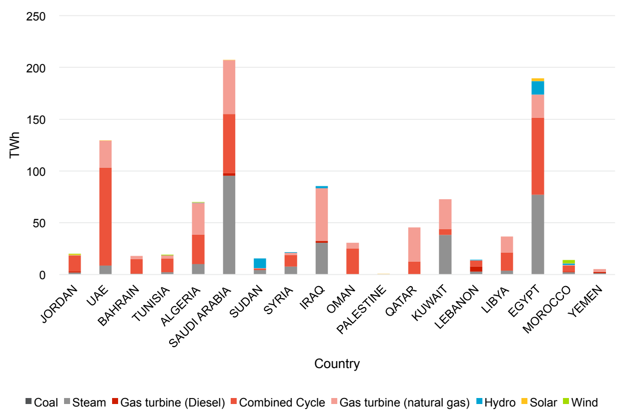


Figure 32. Occurrence of annual peak loads in 2016 by country, Source: Arab Union of Electricity, 2017

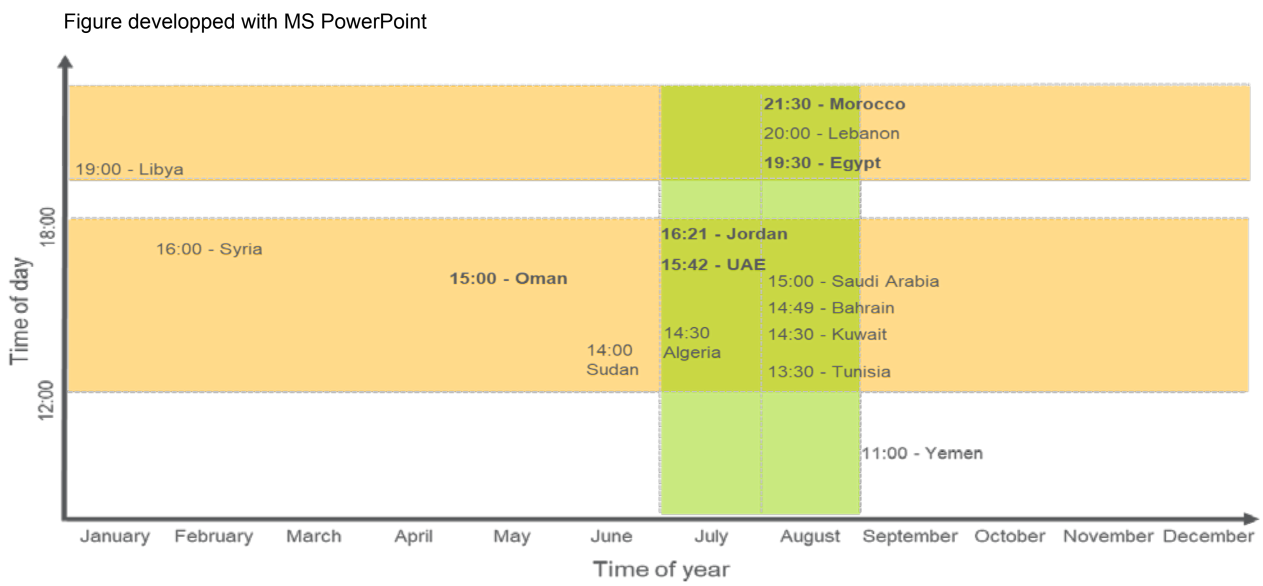


Figure 33. Seasonal distribution of PV (global horizontal irradiance), CSP (direct normal irradiance) and wind (m/s) resources in the representative power system

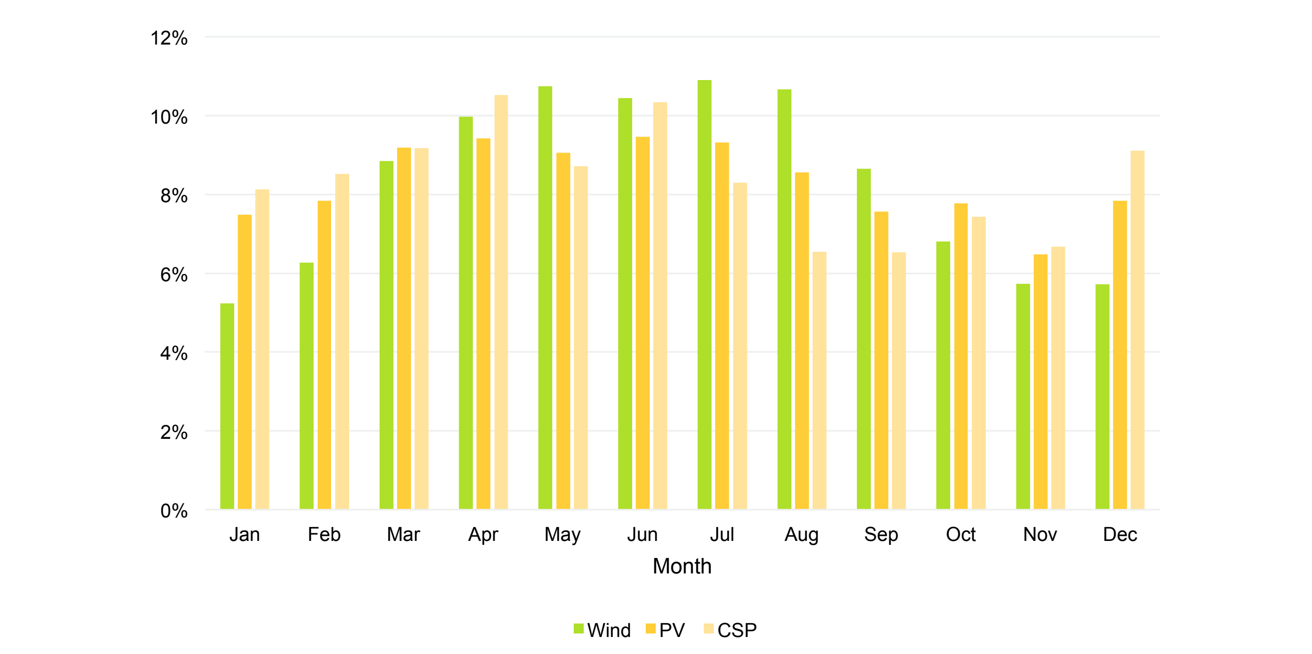


Figure 34. Average hourly capacity factors per month of wind power at excellent sites (left) and PV (right) for the representative power system

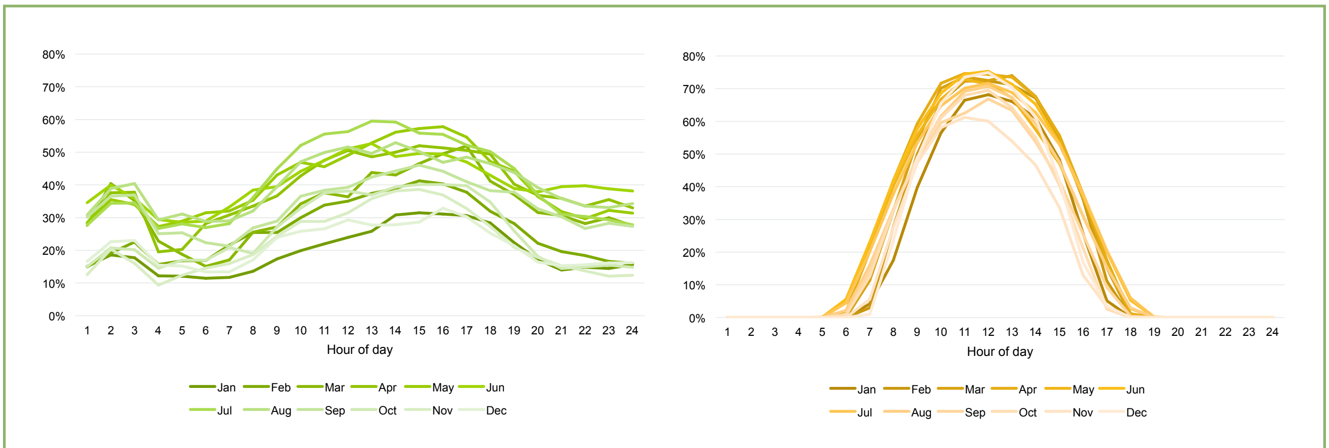


Table 31. PowerFys-Invest model set-up applied in the conducted analysis

Methodology	Deterministic mixed integer linear programming
Objective	Minimise net present value of total system costs
Planning time frame	2020–50
Milestone years	2020, 2025, …, 2050
Typical days per year	12
Temporal resolution typical days	Hourly (24 chronological time-slices)
Total number of annual time-slices	288
Selection of typical days	Representative day method
System discount rate	3%
End year effects	Perpetuity
Generation adequacy reserve	10% of annual peak load
Fast standing reserve (fully activated within 15 minutes)	600 MW (tripping of largest unit)
Considered integration costs of VRE	Balancing and adequacy impacts

Table 32. Investment cost assumptions for candidate generation and storage technologies (in USD_{2015}/kW)

Technology	2020	2025	2030	2035	2040	2045	2050	Reference
Gas turbine	450	450	450	450	450	450	450	(IEA, 2016); and own assumptions
Combined cycle	800	800	800	800	800	800	800	(IEA, 2016); and own assumptions
Combined cycle – CCS	2,300	2,250	2,200	2,150	2,100	2,050	2,000	(IEA, 2016); and own assumptions
Coal – subcritical	1,300	1,300	1,300	1,300	1,300	1,300	1,300	(IEA, 2016); and own assumptions
Coal – ultra-supercritical	1,600	1,600	1,600	1,600	1,600	1,600	1,600	(IEA, 2016); and own assumptions
Coal – CCS	3,900	3,900	3,550	3,350	3,350	3,350	3,350	(IEA, 2016); and own assumptions
Nuclear	3,500	3,500	3,500	3,500	3,500	3,500	3,500	(IEA, 2016); and own assumptions
PV – fix-mounted	890	725	645	625	600	580	560	DLR, Fichtner, M+W Group and LUT University, 2016; and own assumptions
PV – single-axis-tracking	1,060	865	765	740	715	670	660	DLR, Fichtner, M+W Group and LUT University, 2016
Wind – onshore	1,320	1,310	1,300	1,290	1,285	1,280	1,275	(IEA, 2016); and own assumptions
CSP (SM2, 10h)	4,700	4,200	3,750	3,600	3,450	3,350	3,300	DLR, Fichtner, M+W Group and LUT University, 2016; and own assumptions
Pumped storage (8h)	1,000	1,000	1,000	1,000	1,000	1,000	1,000	EASE and EERA, 2017; Galvan-Lopez, 2014
Battery (4h)	1,200	850	650	580	530	490	460	Navigant Research, 2018; BloombergNEF, 2018; and own assumptions

Table 33. Gross efficiency (lower heating value) assumptions for fossil-fuel-fired candidate technologies

Technology	2020	2025	2030	2035	2040	2045	2050	Reference
Gas turbine	38%	39%	39%	40%	41%	41%	41%	(IEA, 2016); and own assumptions
Combined cycle	57%	58%	58%	59%	59%	59%	59%	(IEA, 2016); and own assumptions
Combined cycle – CCS	49%	50%	50%	51%	51%	51%	51%	(IEA, 2016); and own assumptions
Coal – subcritical	37%	37%	37%	37%	37%	37%	37%	(IEA, 2016); and own assumptions
Coal – ultra-supercritical	44%	45%	45%	46%	46%	46%	46%	(IEA, 2016); and own assumptions
Coal – CCS	32%	33%	34%	35%	35%	35%	35%	(IEA, 2016); and own assumptions

Table 34. Techno-economic assumptions for candidate generation and storage technologies

Technology	Unit size (MW)	WACC (%)	Lifetime (years)	O&M costs (%)	Reference
Gas turbine	100	5	25	4	(IEA, 2016); and own assumptions
Combined cycle	400	5	30	3	(IEA, 2016); and own assumptions
Combined cycle – CCS	400	5	30	3	(IEA, 2016); and own assumptions
Coal – subcritical	600	5	35	4	(IEA, 2016); and own assumptions
Coal – ultra-supercritical	600	5	35	4	(IEA, 2016); and own assumptions
Coal – CCS	600	5	35	4	(IEA, 2016); and own assumptions
Nuclear	1,200	5	40	4	(IEA, 2016); and own assumptions
PV – fixed-mounted	100	5	25	2	DLR, Fichtner, M+W Group and LUT University, 2016
PV – single-axis-tracking	100	5	25	2	DLR, Fichtner, M+W Group and LUT University, 2016
Wind – onshore	100	5	25	3	(IEA, 2016)
CSP (SM2, 10h)	100	5	35	3	DLR, Fichtner, M+W Group and LUT University, 2016
Pumped storage (8h)	200	5	50	2	EASE and EERA, 2017; Galvan-Lopez, 2014
Battery (4h)	10	5	10	2	Navigant Research, 2018; BloombergNEF, 2018

Table 35. Coal and natural gas price assumptions (in USD_{2015}/MWhth)

Fuel	2020	2025	2030	2035	2040	2045	2050	Reference
Coal	10.0	11.0	11.5	11.6	11.8	11.8	11.8	(IEA, 2016); and own assumptions
Natural gas	21.8	27.0	29.3	31.1	32.8	33.1	33.4	(IEA, 2016); and own assumptions

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and Nuclear Safety

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