STUDY

CLIMATE CHANGE, ENERGY AND ENVIRONMENT

SUSTAINABLE TRANSFORMATION OF EGYPT'S ENERGY SYSTEM

Development of a Phase Model

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By applying a phase model for the renewables-based energy transition in the MENA countries to Egypt, the study provides a guiding vision to support the strategy development and steering of the energy transition process.

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Egypt has successfully taken first steps in the energy transition, but significant efforts are still needed for the country to realise the full potential offered by renewable energy.

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The development of renewable energy offers long-term economic opportunities for Egypt, as the second largest industrialised country in Africa, especially in view of major trading partners around the world aiming for carbon neutrality by 2050.

FRIEDRICH EBERT STIFTUNG

CLIMATE CHANGE, ENERGY AND ENVIRONMENT

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Wuppertal Institut

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INTRODUCTION

The Middle East and North Africa (MENA) region faces a wide array of challenges, including rapidly growing population, slowing economic growth, high rates of unemployment, and significant environmental pressures. These challenges are exacerbated by global and regional issues, such as climate change. The region, which is already extremely vulnerable due to its geographical and ecological conditions, will become more affected by the negative consequences of climate change in the future. In particular, drought and temperatures will increase in what is already one of the most water-stressed regions in the world. With large sections of the population concentrated in urban areas in the coastal regions, people will also be more vulnerable to water shortages, storms, floods, and temperature increases. In the agricultural sector, climate change effects are expected to lead to lower production levels, while food demand will increase due to population growth and changing consumption patterns. Moreover, the risk of damage to critical infrastructure is increasing, and expenditure for repairs and new construction is placing additional strain on already scarce financial resources. These multi-layered challenges, arising from the interplay of economic, social, and climatic aspects, should not be ignored, as they pose serious risks to prosperity and economic and social development – and ultimately to the stability of the region.

Energy issues are embedded in many of these challenges. The region is characterised by a high dependence on oil and natural gas to meet its energy needs. Although the region as a whole is a major energy producer, many of the MENA countries are struggling to meet growing domestic energy demand. Transitioning to energy systems that are based on renewable energy is a promising way to meet this growing energy demand. The transition would also help to reduce greenhouse gas (GHG) emissions under the Paris Agreement. In addition, the use of renewable energy has the potential to increase economic growth and local employment and reduce fiscal constraints.

Against the backdrop of rapidly growing energy demand due to population growth, changing consumer behaviour, increasing urbanisation, and other factors – including industrialisation, water desalination, and the increased use of electricity for cooling – renewable energy is gaining attention in the MENA region. In order to guarantee long-term energy security and to meet climate change goals, most MENA countries have developed ambitious plans to scale up their renewable energy production. The significant potential in the MENA region for renewable energy production, in particular wind and solar power, creates an opportunity both to produce electricity that is almost CO_2 neutral and to boost economic prosperity. However, most countries in the region still use fossil fuels as their dominant energy source, and dependency on fossil fuel imports in some of the highly populated countries poses a risk in terms of energy security and public budget spending.

A transition towards a renewables-based energy system involves large-scale deployment of renewable energy technology, the development of enabling infrastructure, the implementation of appropriate regulatory frameworks, and the creation of new markets and industries. Therefore, a clear understanding of socio-technical interdependencies in the energy system and the principal dynamics of system innovation is crucial, and a clear vision of the goal and direction of the transformation process facilitates the targeted fundamental change (Weber and Rohracher, 2012). An enhanced understanding of transition processes can, therefore, support a constructive dialogue about future energy system developments in the MENA region. It can also enable stakeholders to develop strategies for a transition towards a renewables-based energy system.

To support such understanding, a phase model for renewables-based energy transitions in the MENA countries has been developed. This model structures the transition process over time through a set of transition phases. It builds on the German phase model and is further complemented by insights into transition governance and characteristics of the MENA region. The phases are defined according to the main elements and processes shaping each phase, and the qualitative differences between phases are highlighted. The focus of each phase is on technological development; at the same time, insights into interrelated developments in markets, infrastructure and society are provided. Complementary insights from the field of sustainability research provide additional support for the governance of long-term change in energy systems along the phases. Consequently, the phase model provides an overview of a complex transition process and facilitates the early development of policy strategies and policy instruments according to the requirements of the different phases that combine to form the overarching guiding vision.

In this study, the MENA phase model is applied to the case of Egypt. The current state of development in Egypt is assessed and analysed against the phase model. Expert interviews were conducted to gain insights to specify the previously defined abstract components of the model. As a result, further steps for the energy transition – based on the steps of the phase model – are proposed.

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CONCEPTUAL MODEL

2.1 THE ORIGINAL PHASE MODELS[1]

The phase model for energy transitions towards renewables-based low-carbon energy systems in the MENA countries was developed by Fischedick et al. (2020). It builds on the phase models for the German energy system transformation by Fischedick et al. (2014) and Henning et al. (2015). The latter developed a four-phase model for transforming the German energy system towards a decarbonised energy system based on renewable energies. The four phases of the models correlate with the main assumptions deduced from the fundamental characteristics of renewable energy sources, labelled as follows: »Take-off Renewable Energies (RE)«, »System Integration«, »Power-to-Fuel/Gas (PtF/G)«, and »Towards 100% Renewables«.

Energy scenario studies foresee that in the future most countries, including those in the MENA region, will generate electricity primarily from wind and solar sources. Other sources such as biomass and hydropower are expected to be limited due to natural conservation, lack of availability and competition with other uses (BP, 2018; IEA, 2017). Therefore, a basic assumption of the phase model is a significant increase of wind and solar power in the energy mix. This includes the direct utilisation of electricity in end-use sectors that currently rely mainly on fossil fuels and natural gas. E-mobility in the transport sector and heat pumps in the building sector are expected to play a crucial role. Sectors that are technologically difficult to decarbonise include aviation, marine, heavy-duty vehicles, and high-temperature heat for industry. In these sectors, hydrogen or hydrogen-based synthetic fuels and gases (PtF/G) can replace fossil fuels and natural gas. The required hydrogen can be gained from renewable electricity via electrolysis.

There should be a strong emphasis on adapting the electricity infrastructure because the feed-in and extraction of electricity (particularly from volatile renewables) must be balanced to maintain grid stability. Thus, power production and demand need to be synchronised, or storage options need to be implemented. Electricity storage is, however, challenging for most countries, and the potential remains limited due to geographic conditions. Accordingly, a mix of flexible options that matches the variable supply from wind and solar power plants with electricity demand must be achieved by extending grids, increasing the flexibility of the residual fossil-based power production, storage, or demand-side management. Furthermore, the development of information and communication technologies (ICT) can support flexibility management. By using PtF/G applications, different sectors can be more tightly coupled. This involves adapting regulations, the infrastructure, and accommodating a new market design. Due to the power demand being four or five times higher in a renewables-based low-carbon energy system, improving energy efficiency is a prerequisite for a successful energy transition. Following the »energy efficiency first« principle means treating energy efficiency as a key element in future energy infrastructure and, therefore, considering it alongside other options, such as renewables, security of supply, and interconnectivity (European Commission DG Energy, 2019).

The phase model outlines these socio-technical interdependencies of the described developments, which build on each other in a temporal order. The four phases are crucial to achieve a fully renewables-based energy system. In the first phase, renewable energy technologies are developed and introduced into the market. Cost reductions are achieved through research and development (R&D) programmes and first market introduction policies. In the second phase, dedicated measures for the integration of renewable electricity into the energy system are introduced. These include flexibility of the residual fossil power production, development and integration of storage, and activation of demand side flexibility. In the third phase, the long-term storage of renewable electricity to balance periods where supply exceeds demand is made essential. This further increases the share of renewables. PtF/G applications become integral parts of the energy system at this stage, and imports of renewables-based energy carriers gain importance. In the fourth phase, renewables fully replace fossil fuels in all sectors. All the phases must connect smoothly to achieve the target of a 100% renewables-based energy system. To describe the long-term changes in energy systems in these four phases, the phase model is supplemented by insights from the field of sustainability transition research. Such research is concerned with the dynamics of fundamental long-term change in societal subsystems, such as the energy system.

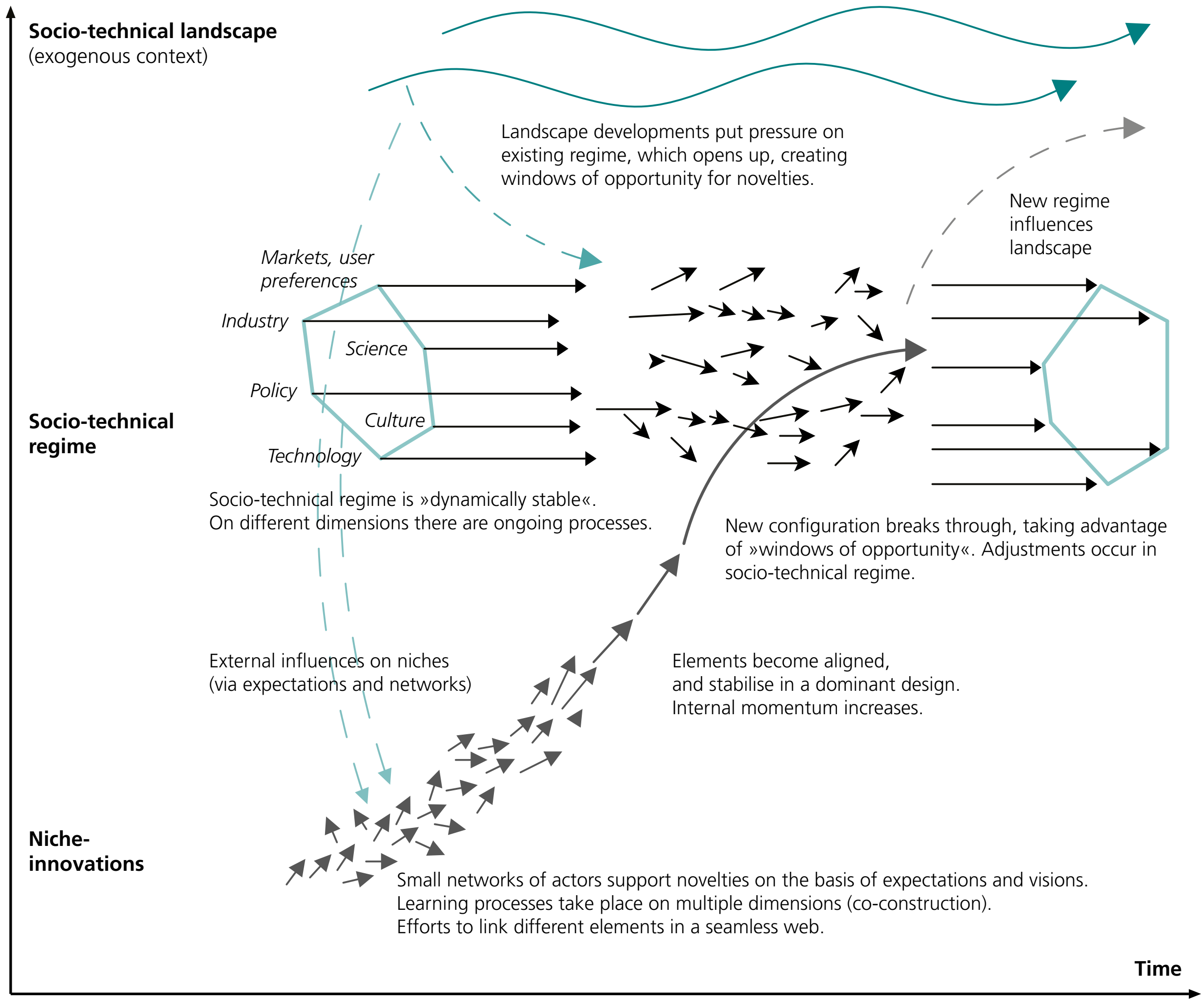
1 Text is based on Holtz et al. (2018).

2.2 THE MULTI-LEVEL PERSPECTIVE AND THE THREE STAGES OF TRANSITIONS

Energy transitions cannot be completely steered, nor are they totally predictable. The involvement of many actors and processes creates a high level of interdependency and uncertainty surrounding technological, economic, and socio-cultural developments. Due to the interlinkage of processes and dimensions, transition research typically applies interdisciplinary approaches. The multi-level perspective (MLP) is a prominent framework that facilitates the conceptualisation of transition dynamics and provides a basis for the development of governance measures (Fig. 2-1).

At »landscape« level, pervasive trends such as demographic shifts, climate change, and economic crises affect the »regime« and »niche« level. The »regime« level captures the socio-technical system that dominates the sector of interest. In this study, the regime is the energy sector. It comprises the existing technologies, regulations, user patterns, infrastructure, and cultural discourses that combine to form socio-technical systems. To achieve system changes at the »regime« level and avoid lock-in and path dependencies, innovations at the »niche« level are incremental because they provide the fundamental base for systemic change. Niches develop in protected spaces such as R&D labs and gain momentum when visions and expectations become more widely accepted. Therefore, actor-network structures that have the power to spread knowledge and change societal values are of key importance for the transition process (Geels, 2012) this paper introduces a socio-technical approach which goes beyond technology fix or behaviour change. Systemic transitions entail co-evolution and multi-dimensional interactions between industry, technology, markets, policy, culture and civil society. A multi-level perspective (MLP. The governance of transitions requires experimentation and learning, continuous monitoring, reflexivity, adaptability, and policy coordination across different levels and sectors (Hoogma et al., 2005; Loorbach, 2007; Voß et al., 2009; Weber and Rohracher, 2012). The development of niches in the framework of »strategic niche management« is an essential precondition for fundamental change. Within transition phases, three stages with associated policy approaches can be distinguished: »niche formation«, »breakthrough«, and

Figure 2-1
The Multi-Level Perspective



(Source: Geels and Schot, 2007)

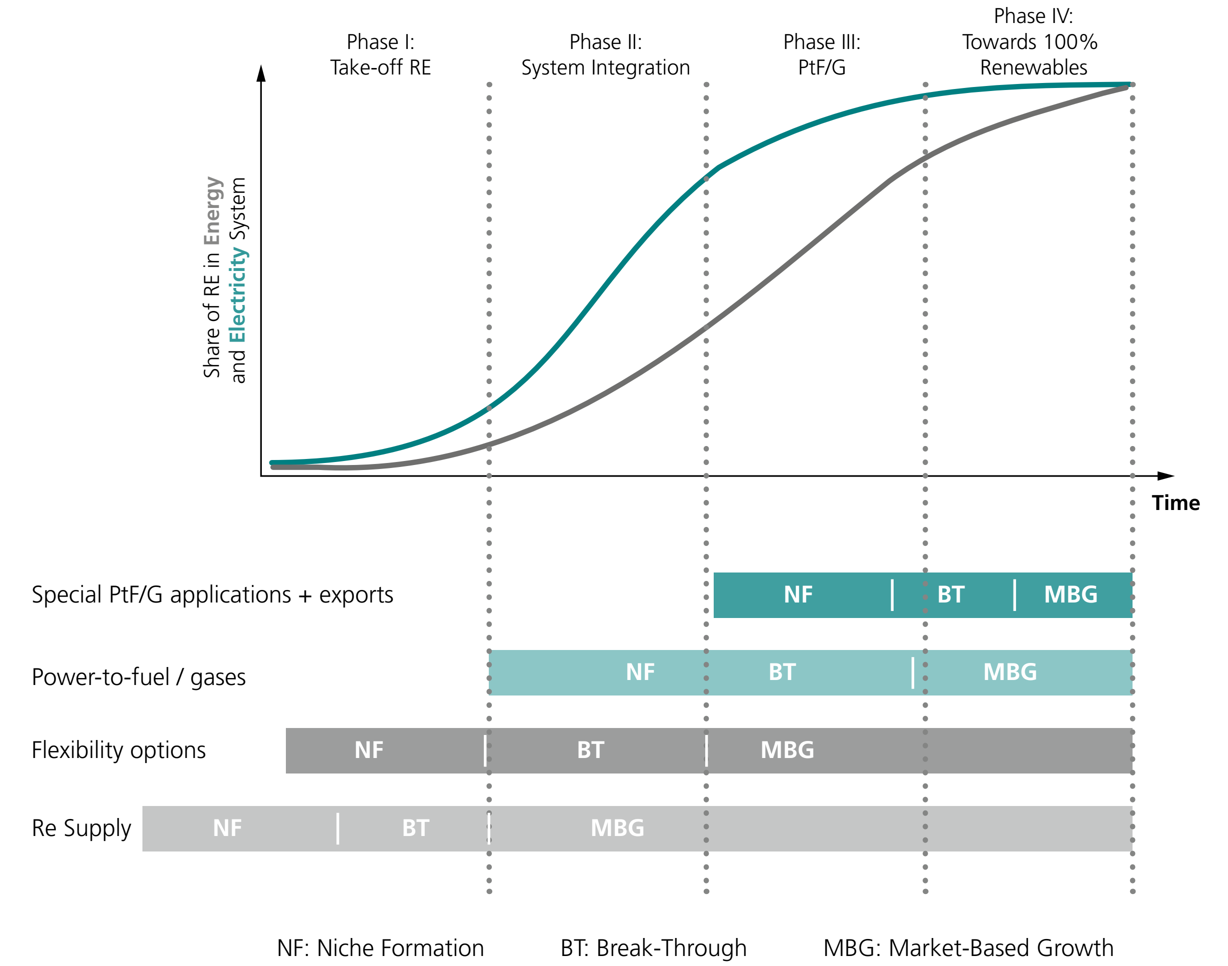
»market-based growth«. In the »niche formation« stage, a niche develops and matures, and it may offer solutions that can be absorbed by the regime. Within this stage, expectations and visions that provide direction to learning processes are essential. In addition, actor involvement and social networks can support the creation of the necessary value chains, and learning processes at different levels have the potential to advance the technology.

In the »breakthrough« stage, the niche innovation spreads by actors involved, market share, and replication in other locations. At this stage, improved price-performance is relevant, and access to necessary infrastructure and markets must be open. Amending rules and legislation as well as increasing societal awareness and acceptance serve to reduce the barriers to deployment. When the niche innovation becomes fully price-competitive and specific supportive policy mechanisms are no longer needed, the »market-based growth« stage is achieved. Renewable energy technologies are, at this stage, fully integrated into the system.

2.3 ADDITIONS IN THE MENA PHASE MODEL

Assuming that the phase model for the German energy transition by Fischedick et al. (2014) and Henning et al. (2015) is relevant for the MENA countries, the four transition phases remain the same. The »system layer«, which was adopted from the original phase models, provides clear targets for the development of the system by orienting guidelines for decision-makers. Since niche formation processes are required for successfully upscaling niche innovations, a »niche« layer was added into the original phase model by Fischedick et al. (2020). A specific cluster of innovations was identified for each phase: renewable energy technologies (phase 1), flexibility options (phase 2), power-to-fuel/gas technologies (phase 3), and sectors such as heavy industry or aviation that are difficult to decarbonise (phase 4). In its breakthrough stage, each innovation cluster is dependent on the niche-formation process of the previous phase. Therefore, specific governance measures support the breakthrough and upscaling processes in the current phase. In later phases, the innovation clusters continue to spread through market-based growth (Fischedick et al., 2020). Consequently, the addition of the »niche

Figure 2-2
Transition Phase Model for the MENA Region



(Source: Geels and Schot, 2007)

layer« creates a stronger emphasis on the processes that must occur to achieve the system targets (Fig. 2-2).

Changing the deployment of technologies across markets is described in a »techno-economic layer«, while the governance stages are captured in the »governance layer«. The aim of this layer is to connect developments in the techno-economic layer with governance approaches to support the transition phases. Specific measures with a strong focus on building a renewables-based energy system are included in the phase model. Factors such as capacities, infrastructure, markets, and the destabilisation of the existing fossil fuel-based regime have also been added to the model. These aspects, however, serve as reflexivity about governance and need to be individually assessed and adapted for each MENA country.

This study pays particular attention to the »landscape« level and its role in pressurising existing regimes and creating opportunities for system change. Questions regarding the influence of international frameworks on climate change, global and regional conflicts, and the long-term impacts of the Coronavirus Disease 2019 Pandemic (COVID-19) on the transition processes are discussed in the individual country case studies. As well as focusing on the need to continuously improve energy efficiency through all the phases, the model is enlarged with resource efficiency. This assumes the continuing reduction of material intensity through efficiency measures and circular economy principles.

3

THE MENA PHASE MODEL

3.1 SPECIFIC CHARACTERISTICS OF THE MENA REGION

The original phase model was developed for the German context, meaning particular assumptions were made. As the MENA region context is different, the fundamental assumptions of the phase model were adapted to suit the characteristics of the MENA countries. Fischedick et al. (2020) outlined the differences and described the adaptations of the MENA phase model, which serves as a starting point for the individual country model transfer in this study.

One of the differences is the current energy situation in the MENA region, which varies from country to country. Several countries, including Iraq, are rich in fossil fuel resources. Others, such as Morocco, Tunisia, and Jordan, are highly dependent on energy imports. Furthermore, subsidised energy prices, as well as non-liberalised energy markets, present further challenges for the energy transition in many MENA countries (IRENA, 2014).

Another fundamental difference to the German context is the growing trend in energy demand in the MENA region. According to BP (2019), the Middle East will face an annual increase in energy demand of around 2% until 2040. The power, transport, industrial, and non-combusted sectors are mainly responsible for the high increase in final energy consumption. An additional contributory factor is population growth, which is expected to further increase – particularly in Egypt and Iraq (Mirkin, 2010). In addition, energy-intensive industries, including steel, cement, and chemical, account for a substantial proportion of the energy demand. Energy demand is increasing due to the installation and expansion of seawater desalination capacities in most MENA countries: the electricity demand for seawater desalination is expected to triple by 2030 compared to the 2007 level in the MENA region (IEA-ETSAP and IRENA, 2012). Furthermore, the energy intensity in many MENA countries is high, due to low insulation quality in buildings, technical inefficiencies of cooling and heating technologies, and distribution infrastructure. The electricity losses in distribution are between 11% and 15% in stable MENA countries compared to 4% in Germany (The World Bank, 2019).

Although the MENA region does benefit from significant renewable energy resources, much of the economic renewable energy potential remains untapped. By exploiting this potential, most of the countries could become self-sufficient in terms of energy, and they could eventually become net exporters of renewables-based energy. As energy and hydrogen imports become an important pillar of Europe's energy strategy (European Commission, 2020), the MENA countries could – in the future – benefit from emerging synthetic fuel markets and profit from energy carrier exports to neighbouring countries in Europe. In this regard, some MENA countries with infrastructure for oil and gas could build on their experience in handling gas and liquid fuels. With the support of power-to-X (PtX) technologies, these energy-exporting MENA countries could switch smoothly from a fossil fuel phase to a renewables-based energy system. However, to achieve this goal, the infrastructure would have to be retrofitted on a large-scale for transmission and storage. For other countries in the MENA region, harnessing their renewable energy potentials at a later transition phase to export PtX products could present new economic opportunities.

Yet a further difference is that the electricity grid in Germany is fully developed, whereas most of the MENA countries have grid systems that need to be expanded, developed nationally, and connected cross-border. Physical interconnections exist, but these are mainly in regional clusters (The World Bank, 2013). Therefore, the region lacks the necessary framework for electricity trade. In addition, technical grid codes would need to be developed to integrate renewable energy and balance its variability. Moreover, as there are few standards for PV and wind, clear regulations would need to be established to enable grid access.

The MENA countries could benefit considerably from global advances in renewable energy technologies. Global experience in the deployment of renewable energy technology adds to the learning curve, which has resulted in cost reductions. Against this backdrop, the costs of PV modules have fallen by around 80% since 2010 and wind turbine prices have dropped by 30% to 40% since 2009 (IRENA, 2019). While the phase model for the German context assumes that renewable energy technologies need time to mature, the phase model for the MENA context can include cost reductions. Additionally, there is already a wide actor network of companies that provide expertise in the field of renewable energy technologies.

The energy systems in the MENA region are in a developmental phase; renewable energies are attractive, as they provide sustainability and energy security. Furthermore, they have the potential to stimulate economic prosperity. However, the conditions for developing renewable energy industries are weak due to a lack of supporting frameworks for entrepreneurship and technological innovation. While in Germany private actors play a major role in small-scale PV and wind power plants, state-owned companies in the MENA region are central to large-scale projects. The mobilisation of capital is an additional significant factor that would require dedicated strategies.

3.2 ADAPTATION OF MODEL ASSUMPTIONS ACCORDING TO THE CHARACTERISTICS OF THE MENA COUNTRIES

The phases of the original phase model must be adapted to correspond to the characteristics of the MENA region. Based on Fischedick et al. (2020), changes to the original model were made within the four phases and their temporal description. In addition, the »system layer« description is complemented by a stronger focus on the destabilisation of the regime, and the »niche layer« is highlighted in each phase to prepare for the subsequent phase.

In order to meet the expected increase in the overall energy demand, the volume of renewables in phases 1 and 2 rises considerably without undermining the existing business of industries that provide fossil fuel and natural gas. The grid in the MENA countries is limited in its ability to accommodate rising shares of renewables, which results in greater emphasis on grid retrofitting and expansion during phase 1. Moreover, phase 2 must start earlier than in the German case, and the development in some countries could include a stronger focus on solutions for off-grid applications and small isolated grids. The growing domestic demand for energy in the MENA countries could be satisfied by renewables-based energies and energy carriers, such as synthetic fuels and gases. While in Germany imports play a considerable role in the later phases (in phase 3 in particular), excess energy in the MENA countries could be exported and offer potential economic opportunities in phase 4. The growing global competitiveness of renewable energies offers the opportunity to accelerate the niche formation stages in all phases of the transition. However, niche formation processes would have to be integrated into domestic strategies. Institutions to support niche developments would need to be established and adapted to the country context.

3.3 PHASES OF THE ENERGY TRANSITION IN MENA COUNTRIES

The Wuppertal Institute developed the phase model for the MENA countries based on the German phase model and the experience gained during the project *Development of a Phase Model for Categorizing and Supporting the Sustainable Transformation of Energy Systems in the MENA Region*, which was supported by the Friedrich-Ebert-Stiftung (Holtz et al., 2018; Fischedick et al., 2020). The phases for the MENA region are presented in detail in their dimensions, which are based on supply, demand, infrastructure, markets, and society. The multi-dimensional perspective of transitions research is reflected in these layers, highlighting the interrelation of these dimensions during the transition phases. Table 3-1 summarises the main developments in the »techno-economic« and »governance« layers, as well as on the »landscape«, »system«, and »niche« levels during the four phases.

The renewable electricity supply capacities are expanded throughout the phases to meet the increasing demand for energy from all sectors. A crucial assumption is the need for energy efficiency to be increased considerably in all phases. The developments in phases 3 and 4 are dependent on many technological, political, and societal developments and, therefore, have high uncertainties from today's perspective.

In addition, a more detailed analysis of the influence of the »landscape« level was conducted. The assumption is made that the following factors would impact on all phases: I) international frameworks on climate change; II) decarbonisation efforts of industrialised countries, including green recovery programmes after the COVID-19 pandemic; III) global and regional conflicts (affecting trade); IV) long-term impacts of the COVID-19 pandemic on the world economy; V) geographic conditions and natural resource distribution; and VI) demographic development.

Phase 1 – »Take-Off Renewable Energies (RE)«

Renewable electricity is already introduced into the electricity system before the first phase, »Take-off RE«, is reached. Developments at the »niche« level, such as assessing regional potential, local pilot projects, forming networks of actors, and sharing skills and knowledge about the domestic energy system, are initial indicators that diffusion is starting. During this pre-phase stage, visions and expectations for the expansion of RE-based energy generation are developed.

In the first phase, the characteristic development at the system level is the introduction and initial increase of renewable energy, particularly electricity generated by photovoltaic (PV) and wind plants. MENA countries could benefit considerably from the globally available technologies and the global price drops of renewable energies, which would facilitate the market introduction of PV and wind energy. As energy demand in the region is growing considerably, the share of renewable energy entering the system would not be capable of replacing fossil fuels at this stage. To accommodate variable levels of renewable energy, the grid must be extended and retrofitted. Laws and regulations come into effect, aiming to integrate renewables into the energy system and to enable renewables-based electricity to be fed into the grid. The introduction of price schemes as incentives for investors facilitates the large-scale deployment of RE and decentralised PV for households.

Developments occurring at the »niche« level pave the way for phase 2. The regional potential of different flexibility options is assessed (e.g. the possibilities for pump storage and demand-side management (DSM) in industry), and visions are developed that broach the issue of flexibility options. At this stage, the role of sector coupling (e.g. e-mobility, power-to-heat) is discussed, and business models are explored. Expected flexibility needs and sector coupling lay the ground for information and communication technology (ICT) start-ups and new digital business models.

Phase 2 – »System Integration«

In phase 2, the expansion of renewable energy continues at the »system« level, while growing markets still provide room for the co-existence of fossil fuel-based energy. The grid extension continues, and efforts to establish cross-border and transnational power lines are made to balance regional differences in wind and solar supply. At this stage, flexibility potentials (DSM, storage) are recognised, and the electricity market design is adapted to accommodate these options. The ICT infrastructure is fully integrated with the energy system (digitalisation). At the political level, regulations in the electricity, mobility, and heat sectors are aligned to provide a level playing field for different energy carriers. The direct electrification of applications in the mobility, industry, and heat sectors adds further flexibility to the system.

PtF/G applications are developed at the »niche« level to prepare the system for a breakthrough in phase 3. Pilot projects test the application of synthetic fuels and gases under local conditions. Green hydrogen is expected to replace fossil fuels in sectors such as chemical production. In the short to mid-term, the production of CO_2 from carbon capture in energy-intensive industries is acceptable. In the long term, however, the focus must shift to direct carbon capture from air or bioenergy to guarantee carbon neutrality. Actor networks create and share knowledge and skills in the field of PtF/G. Based on an assessment of the potentials for different PtF/G conversion routes, strategies and plans for infrastructure development are elaborated, and business models are explored.

The water-energy-nexus gains appropriate consideration in the framework of integrated approaches, as water is becoming even scarcer due to the consequences of climate change. This could result in shortages affecting the energy sector or competition from other uses, such as food production.

Phase 3 – »Power-to-Fuel/Gas (PtF/G)«

At the »system« level, the share of renewables increases in the electricity mix, leading to intensified competition between renewables and fossil fuels and – temporarily – to high, negative residual loads. Green hydrogen and synthetic fuel production become more competitive due to the availability of low-cost electricity. PtF/G, supported by regulations including pricing schemes, enter the market and absorb increasing shares of »surplus« renewables during times of high supply. The mobility and long-distance transport sectors, in particular, contribute to an increase in the application of PtF/G. This, in turn, enables the replacement of fossil fuels and natural gas. The development of hydrogen infrastructure and the retrofitting of existing oil and gas infrastructure for the use of synthetic fuels and gases create dedicated renewable supply facilities for international exports. Price reductions and the introduction of fees and taxes on fossil fuels not only have a negative influence on their market conditions, but they also initiate the phase-out of fossil fuels. These developments stimulate changes in the business models. As PtF/G solutions provide long-term storage, considerable export market structures can be established.

At the »niche« level, experiments with PtF/G applications play an essential role in sectors that are difficult to decarbonise, such as heavy industry (concrete, chemicals, steel), heavy transport, and shipping. In addition, the potential to export hydrogen as well as synthetic fuels and gases is explored and assessed. Actor networks are established, initial learning is gained, and business models are studied.

Phase 4 – »Towards 100% Renewables«

Renewable-based energy carriers gradually replace the residual fossil fuels. Fossil fuels are phased out, and PtF/G is fully developed in terms of infrastructure and business models. As support for renewables is no longer required, price supporting schemes are phased out. Export market structures are expanded and constitute a crucial sector of the economy.

3.4 TRANSFER OF THE PHASE MODEL TO THE COUNTRY CASE OF EGYPT

The MENA phase model was exploratively applied to the Jordan case in Holtz et al. (2018). The model was discussed with high-ranking policymakers, representatives from science, industry, and civil society from Jordan. It proved to be a helpful tool to support discussions about strategies and policymaking in regard to the energy transition; a tool which could also be appropriate for other MENA countries. Therefore, the MENA phase model was applied to the country case of Egypt after necessary adaptations were made to it. The results illustrate a structured overview of the continuous developments in Egypt's energy system. Furthermore, they provide insights into the next steps required to transform Egypt's energy system into a renewables-based system.

As the most populous country in North Africa, Egypt faces a variety of challenges in its energy sector. These include the rising trend of overall energy demand, complex peak load patterns, and increasing demand for air conditioning and energy-intensive desalination. Climate change imposes further constraints on the energy system. For example, the reduced availability of water for hydropower generation lessens the available power generation capacity. Although Egypt currently has excess electricity capacity, it will not be sufficient to meet growing demand in the long run. The shift to renewable energy, therefore, offers Egypt environmental benefits and the opportunity to increase energy security in the country. In the future, it will also create economic and industrial development prospects for exporting renewable energy in various forms.

In order to reflect the specific challenges and opportunities for the energy transition in Egypt, some adaptations to the criteria set of the MENA phase model were made on the landscape level as well. These include factors such as the COVID-19 pandemic and global decarbonisation efforts in light of the Paris agreement. These aspects have either already affected or will affect the international oil and gas prices and the sector development. Furthermore, the details of the dominant role of fossil fuels in the energy system and related challenges for the development of the renewable sector have been assessed. Table 3-1 depicts the developments during the transition phases.

3.5 DATA COLLECTION

Detailed information on the status and current developments of the various dimensions (supply, demand, infrastructure, actor network, and market development) was compiled in order to apply the phase model to individual country situations. In a first step, a comprehensive review of the relevant literature and available data was conducted. Based on the evaluation and analysis of the available data, information gaps were identified. The missing information was completed with the help of expert interviews carried out by the Wuppertal Institute. The aim of the interviews was to investigate the country-specific challenges and barriers that could hinder the unlocking of the renewable energy potential in the country. The interviewees included relevant stakeholders with experience in the energy sector or related sectors from policy institutions, academia, and the private sector. The expert interviews were conducted according to guidelines for structured interviews. The quantitative data used is based on secondary sources, such as databases from the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), or was calculated using available data to identify the current status and future trends.

Table 3-1
Developments During the Transition Phases

			Development before phase I	Phase I: »Take-Off RE«	Phase II: »System Integration RE«	Phase III: »Power-to-Fuel/Gas (PtF/G)«	Phase IV: "Towards 100% RE'
			* Niche formation RE	* Breakthrough RE * Niche formation flexibility option	* Market-based growth RE * Breakthrough flexibility option * Niche formation PtF/G	* Market-based growth flexibility option * Breakthrough PtF/G * Niche formation special PtF/G application and exports	* Market-based growth PtF/G * Breakthrough special PtF/G application and exports
Power Sector	Landscape level		* International frameworks on climate change * Decarbonisation efforts of industrialised countries (incl. green recovery programmes after COVID-19 pandemic) * Global and regional conflicts (affecting trade) * Long-term impacts of the COVID-19 pandemic on the world economy * Geographic conditions and natural resource distribution * Demographic development				
Power Sector	System level	Techno-economic layer		* RE share in energy system about 0%-20%	* RE share in energy system about 20%-50%	* RE share in energy system about 50%-80%	* RE share in energy system about 80%-100%
				* Market introduction of RE drawing on globally available technology and driven by global price drop	* Further grid extension (national and international)	* Extension of long-term storage (e.g. storage of synthetic gas)	* Large-scale construction of infrastructure for PtF/G exports
				* Extension and retrofitting of electricity grid	* ICT structures integrate with energy systems (e.g. introduction of smart meters)	* First PtF/G infrastructure is constructed (satisfying up-coming national/foreign demand)	* Phase-out of fossil fuel infrastructure and business models
				* Regulations and pricing schemes for RE	* System penetration of flexibility options (e.g. battery storage)	* Temporarily high negative residual loads due to high shares of RE	* Consolidation of RE-based export models
				* Developing and strengthening domestic supply chains for RE	* Direct electrification of applications in the buildings, mobility, and industry sectors; changing business models in those sectors (e.g. heat pumps, e-cars, smart-home systems, marketing of load shedding of industrial loads)	* Sales volumes of fossil fuels start to shrink	* Full replacement of fossil fuels by RE and RE-based fuels
				* No replacement of fossil fuels due to growing markets	* No replacement (or only limited replacement) of fossil fuels due to growing markets	* Existing fossil fuel-based business models start to change	* Stabilisation of PtF/G business models and production capacities (e.g. large-scale investments)
					* Development and extension of mini-grids as a solution for off-grid applications and remote locations	* Increasing volumes of PtF/G in transport, replacing fossil fuels and natural gas	
					* Progressing the energy transition in end-use sectors (transport, industry, and buildings)		
					* Progressing the energy transition in the industry sector, reducing the high carbon content of certain products and high emissions of certain processes		

	Development before phase I	Phase I: »Take-Off RE«	Phase II: »System Integration RE«	Phase III: »Power-to-Fuel/Gas (PtF/G)«	Phase IV: "Towards 100% RE'
	* Niche formation RE	* Breakthrough RE * Niche formation flexibility option	* Market-based growth RE * Breakthrough flexibility option * Niche formation PtF/G	* Market-based growth flexibility option * Breakthrough PtF/G * Niche formation special PtF/G application and exports	* Market-based growth PtF/G * Breakthrough special PtF/G application and exports
Power Sector / **System level** / **Governance layer**	* Fundamental recognition that energy efficiency is the second strategic pillar of the energy system transformation	* Support adoption of RE (e.g. feed-in tariffs), set up regulations and price schemes for RE	* Put pressure on fossil fuel-based electricity regime (e.g. reduction of subsidies, carbon pricing)	* Put pressure on system components that counteract flexibility (e.g. phase out base-load power plants)	* Put pressure on fossil fuels (e.g. phase out production)
		• Increasing participation of institutional investors (pension funds, insurance companies, endowments, and sovereign wealth funds) in the transition	* Withdraw support for RE (e.g. phase out feed-in tariffs)	* Withdraw support for flexibility options	* Withdraw support for PtF/G
		* Increasing awareness of environmental issues	* Measures to reduce unintended side-effects of RE (if any)	* Measures to reduce unintended side-effects of flexibility options (if any)	* Measures to reduce unintended side-effects of PtF/G (if any)
		* Provide access to infrastructure and markets for RE (e.g. set up regulations for grid access)	* Adaptation of market design to accommodate flexibility options	* Set up regulations and price schemes for PtF/G (e.g. transport, replace fossil fuels and natural gas)	* Access to infrastructure and markets (e.g. connect production sites to pipelines)
		* Moderate efforts to accelerate efficiency improvements	* Provide access to markets for flexibility options (e.g. adaptation of market design, alignment of electricity, mobility, and heat-related regulations)	* Reduce prices paid for fossil fuel-based electricity	* Support adoption (e.g. subsidies)
			* Support creation and activation of flexibility options (e.g. tariffs for bi-directional loading of e-cars)	* Provide access to infrastructure and markets for PtF/G (e.g. retrofit pipelines for transport of synthetic gases/fuels)	
			* Facilitate sector coupling between power and end-use sectors to support the integration of VRE in the power sector	* Support adoption of PtF/G (e.g. tax exemptions)	
			* Adaptation of market design to accommodate flexibility options		
			* Investments reallocated towards low-carbon solutions: high share of RE investments and reduce the risk of stranded assets		
			* Alignment of socio-economic structures and the financial system; broader sustainability and transition requirements		
			* Facilitate sector coupling between power and end-use sectors to facilitate the integration of VRE in the power sector		
			* Alignment of electricity, mobility, and heat-related regulations		

			Development before phase I	Phase I: »Take-Off RE«	Phase II: »System Integration RE«	Phase III: »Power-to-Fuel/Gas (PtF/G)«	Phase IV: “Towards 100% RE’
			* Niche formation RE	* Breakthrough RE * Niche formation flexibility option	* Market-based growth RE * Breakthrough flexibility option * Niche formation PtF/G	* Market-based growth flexibility option * Breakthrough PtF/G * Niche formation special PtF/G application and exports	* Market-based growth PtF/G * Breakthrough special PtF/G application and exports
Power Sector	Niche level	Techno-economic layer	* Assessment of RE potential	* Assessment of regional potential for different flexibility options	* Assessment of potential for different PtF/G conversion routes	* Experiment with PtF/G applications in sectors such as industry (e.g. steel, cement, and chemical sectors) and special transport (e.g. aviation, shipping)	
Power Sector	Niche level	Techno-economic layer	* Local pilot projects with RE	* Experiment with flexibility options	* Local pilot projects with PtF/G generation based on RE hydrogen and carbon capture (e.g. CCU/CCS)	* Invest in business models for PtF/G exports	
Power Sector	Niche level	Techno-economic layer		* Exploration of business models around flexibility options including ICT start-ups and new digital business models for sector coupling	* Exploration of PtF/G-based business models	* Pilot synthetic fuel exports	
Power Sector	Niche level	Techno-economic layer			• Exploration of new DSM potentials (e.g. smart charging and vehicle-to-grid for EV, flexible heat pump heating and cooling, thermal storage fed by electricity)		
Power Sector	Niche level	Techno-economic layer			* Tap into global experiences of PtF/G		
Power Sector	Niche level	Governance layer	* Development of shared visions and expectations for RE development	* Development of visions and expectations for flex-market and energy system integration (regional and transnational energy markets)	* Development of shared visions and expectations for PtF/G (e.g. strategy and plans for infrastructure development/adaptation)	* Development of shared visions and expectations for PtF/G exports (e.g. about target markets and locations for conversion steps)	
Power Sector	Niche level	Governance layer	* Support learning processes around RE (e.g. local projects)	* Support learning processes around flexibility (e.g. local projects)	* Support learning processes around PtF/G (e.g. local projects for PtF/G generation, tap global experiences of PtF/G, exploration of PtF/G-based business models)	* Support learning about PtF/G in sectors such as industry and special transport (e.g. experiments for using PtF/G products for glass smelting)	
Power Sector	Niche level	Governance layer	* Formation of RE-related actor networks (e.g. joint ventures)	* Formation of actor networks around flexibility across electricity, mobility, heat sectors (e.g. exploration of business models around flexibility including ICT start-ups and new digital business models for sector coupling)	* Formation of PtF/G-related actor network (national and international)	* Support learning around PtF/G exports (e.g. concerning market acceptance and trade regulations)	
Power Sector	Niche level	Governance layer	• Community-based engagement and involvement (e.g. citizen initiatives)	* Development of a shared knowledge base of integrated decarbonisation pathways to enable alignment and critical mass that can help shift the entire sector		* Formation of actor networks for creating large-scale synthetic fuel export structures (e.g. producers, trading associations, marketplaces)	
	* Continuing improvements in energy efficiency						
	* Continuing the reduction of material intensity through efficiency measures and circular economy principles						

(Source: Own creation)

4

APPLICATION OF THE MODEL TO EGYPT

Factsheet	
Paris Agreement ratified	✔
Green growth strategy developed	✔
Renewable energy targets set	✔
Regulatory policies for renewable energy implementation established	✔
Energy efficiency strategy existing	✔
Power-to-X strategy	✗

4.1 CATEGORISATION OF THE ENERGY SYSTEM TRANSFORMATION IN EGYPT ACCORDING TO THE PHASE MODEL

At present, most of Egypt's energy needs are met by oil and gas. Although Egypt is an oil and gas producer, resources are limited. Based on current resource exploitation targets, it is unlikely that the growing domestic demand will be met by existing resources in the long term. Consequently, the government has shown increasing interest in renewables and plans to increase its efforts towards sustainability. In 2016, Egypt ratified the Paris Agreement and launched a strategy for a green economy. However, despite having submitted its Nationally Determined Contributions (NDC) targets, Egypt has provided neither quantified goals nor plans for emission reductions (Abdallah, 2020). Furthermore, it could be challenging for Egypt to reduce greenhouse gas emissions due to plans to construct new coal and gas power plants (Khater, 2016; UN-PAGE, 2020). Nevertheless, Egypt has set itself an ambitious renewable energy target of a 42% share in the energy mix by 2035 under the framework of the Integrated Sustainable Energy Strategy 2035 (ISES to 2035). The objective of this strategy is to make greater use of renewable energy resources, which are abundant in Egypt. Several large renewable energy projects have been implemented, and tenders have attracted significant international interest. Despite these promising developments and Egypt's strategically favourable conditions for becoming an energy hub in the Eastern Mediterranean region, the country has only just begun to tap into its solar and wind energy resource potential.

In addition to internal developments, Egypt's energy transition will be affected by external events; for example, moves in the global energy system away from fossil fuel sources and towards renewables. Global efforts to combat climate change under the Paris Agreement already impact on Egypt's energy strategies. Furthermore, the consequences of the COVID-19 pandemic on the country's economy has put pressure on Egypt's sustainable reform plans, which could constrain the further large-scale deployment of renewable energy projects. Societal and demographic aspects also play a role in the energy transition: Egypt must provide both energy services and opportunities to a young, dynamic, and fast-growing population.

Against this background, the following sections will make a detailed assessment of the current status and development of Egypt's energy transition, according to the proposed phase model.

4.1.1 Assessment of the Current State and Trends at the Landscape and System Levels

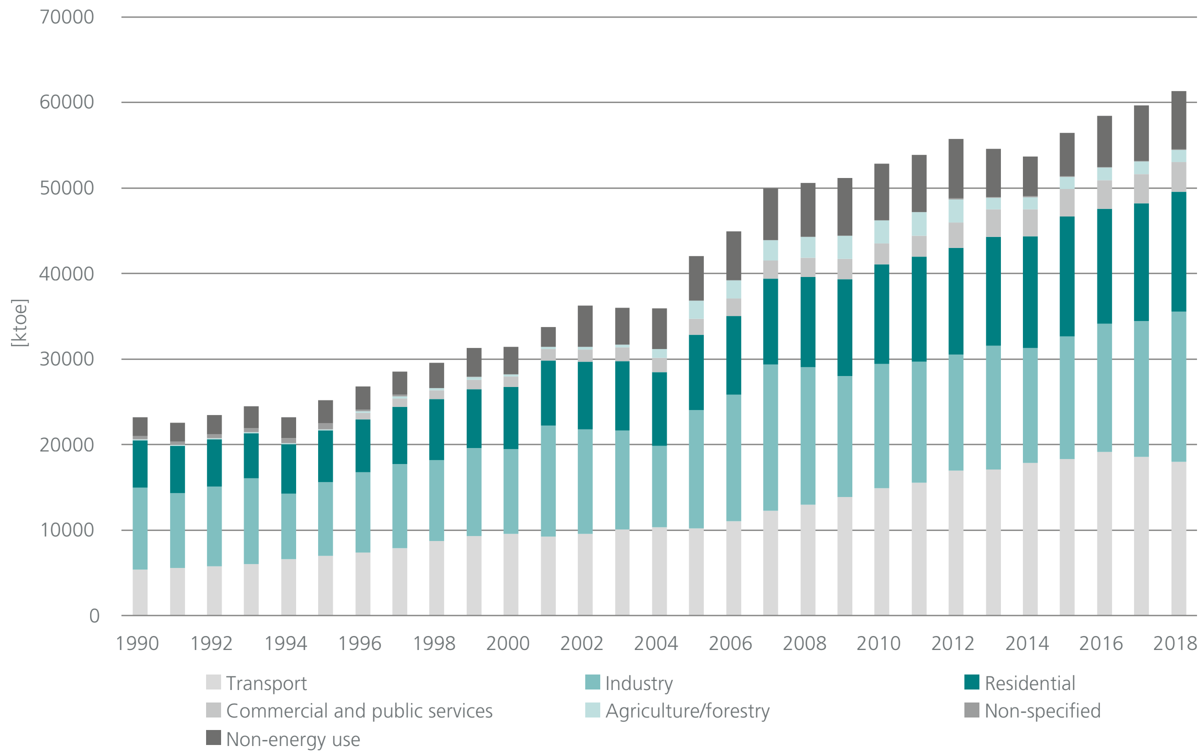
This section discusses the current state and trends of Egypt's energy system in terms of supply, demand, infrastructure, market, economy, and social developments.

Energy Supply and Demand

In the phase model describing the pathway towards a 100% renewable energy system, an important aspect for evaluating the status of the energy transition in a country is the composition of the energy supply and demand.

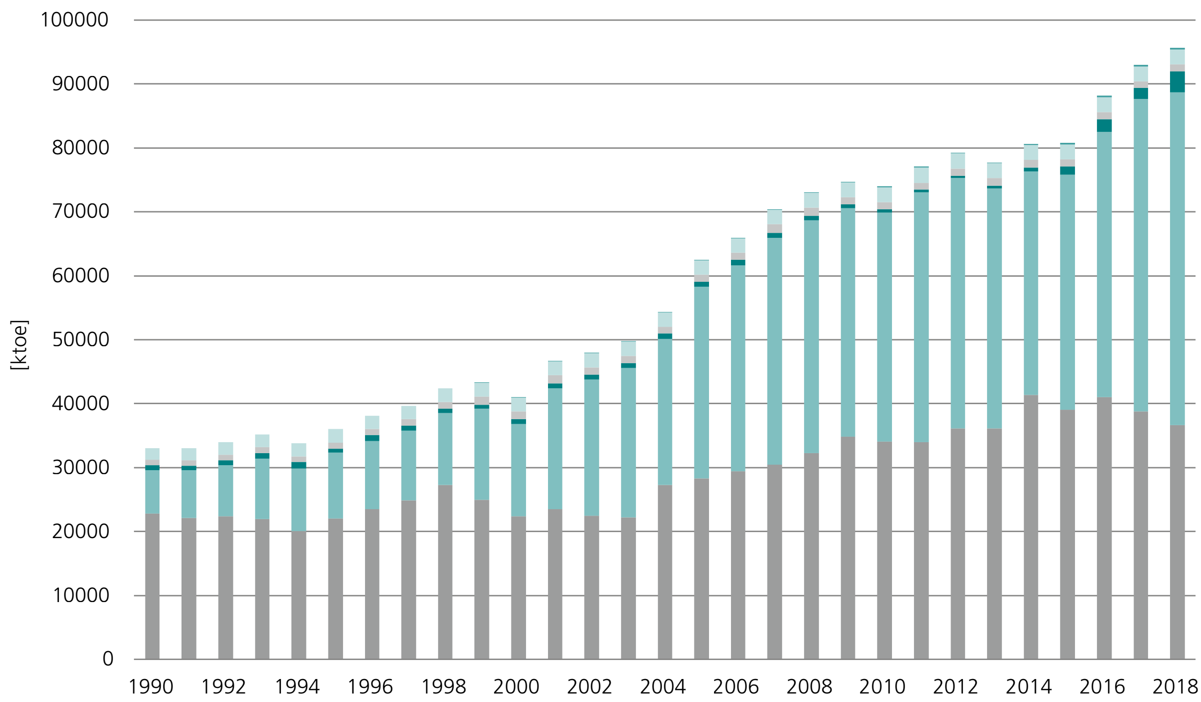
In 2018, Egypt had a total final energy consumption of 61,358 ktoe (IEA, 2020a). The transport and industry sectors dominated with a share of 29% each, followed by households (23%), and other uses (19%) (IEA, 2020a) (Fig. 4-1). Fossil fuels also dominated in the energy mix (Fig. 4-2). In 2018, natural gas had a share of 54%, oil 21%, and coal 3%, while renewable energies in total had a 3% share (IEA, 2020a). In line with several studies, Egypt's current energy mix shows a decline in the share of renewable energy in power generation. Although investment in renewable energy and its diffusion are increasing, the high growth in the overall energy demand is being partially met by an increase in the use of fossil fuels (Mondal et al., 2019).

Figure 4-1
Total Final Energy Consumption (in ktoe), Egypt 1990–2018



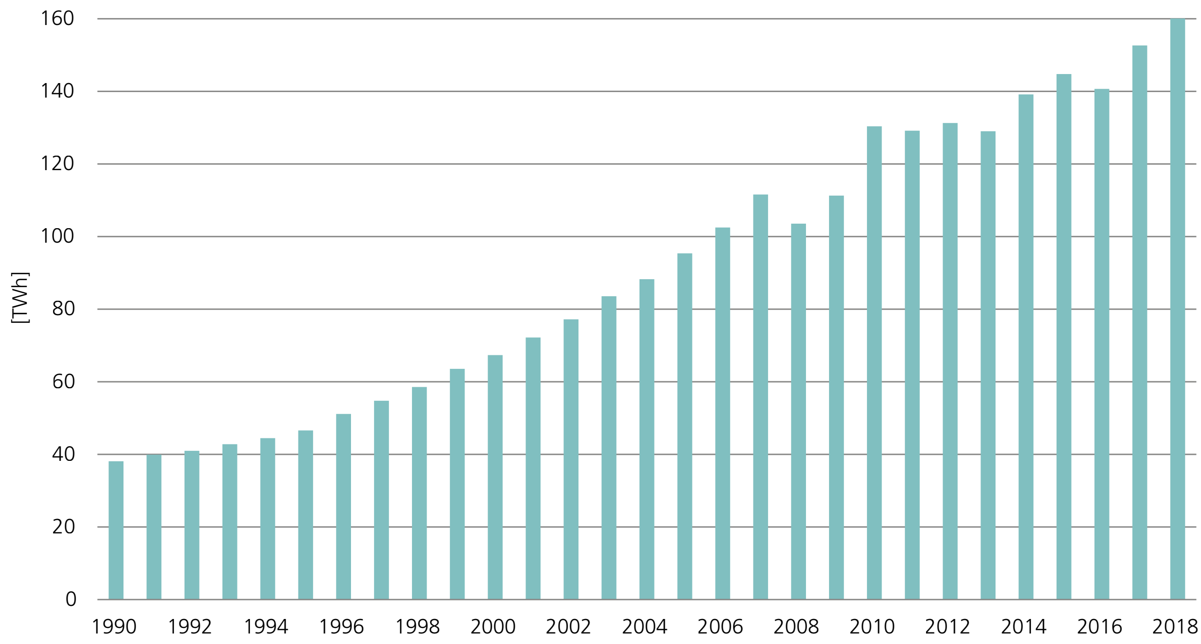
(Source: data based on IEA, 2020a)

Figure 4-2
Total Energy Supply (in ktoe), Egypt 1990–2018



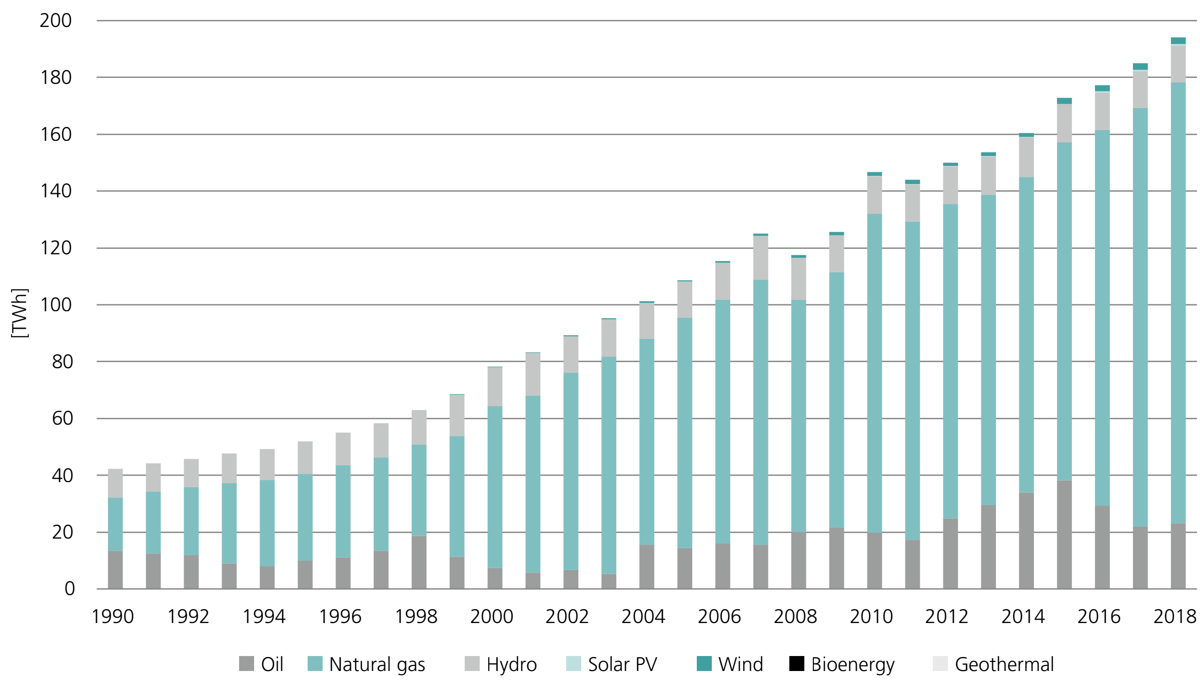
(Source: data based on IEA, 2020a)

Figure 4-3
Electricity Consumption (in TWh), Egypt 1990–2018



(Source: data based on IEA, 2020a)

Figure 4-4
Electricity Generation by Source (in TWh), Egypt 1990–2018



(Source: data based on IEA, 2020a)

Egypt's electricity consumption had increased fourfold compared to 1990 levels, amounting to around 160 TWh in 2018 (Fig. 4-3). This increasing need for electricity was stimulated by population growth and rising industrial demand, resulting in a daily load curve with an evening peak between 7pm and 11pm (Arab Ministry of Electricity and Renewable Energy, 2018). Egypt's energy supply mix has recently become characterised by an increase in the use of natural gas resources, in response to supply shortages. To better understand the challenges Egypt is facing, it is important to distinguish between two phases: 2002–2015 and 2015 to the present day. From 2002 onwards, the peak demand in Egypt increased from 13.3 GW in 2002 to nearly 25.7 GW in 2012 (an average growth rate of 6.8%). At the same time, the installed generation capacity increased from 16.6 GW to 29 GW (an average growth rate of 5.7%). This resulted in low reserve margins (11% in 2013 (The World Bank, 2013)) and heavy load shedding (especially during the summer months) of more than 3 GW (IRENA, 2018b). To manage these supply shortages, in 2015 the Egyptian Electricity Holding Company (EEHC) installed 3.636 GW conventional gas turbine power plants under a fast-track programme. Additionally, the Egyptian cabinet contracted Siemens to add 14.4 GW of capacity into the national grid, which boosted Egypt's power generation capacity by more than 45% (IRENA, 2018b). This explains the increasing share of natural gas in the energy supply depicted in Fig. 4-4.

The boost in power generation resulted from the government's decision to end the power shortages (Butter, 2019). This has caused infrastructure development to exceed load demand over the last five years. Currently, Egypt has around 57–58 GW of generation capacity, whereas the demand peak in summer is 31–33 GW, leading to the current generation surplus. However, energy demand is expected to further grow at an annual rate of between 5% and 6% (RES4MED, 2015), and the export of energy is planned by government officials as part of Egypt's strategy to become an energy hub in the Eastern Mediterranean. EEHC is negotiating an additional three large thermal power station contracts with private investors, one of which is a combined cycle plant and two are coal-fired power plants. Additionally, Egypt has signed a contract with Russia for a 4.8 GW nuclear power plant at El-Dabaa.

After evaluating the situation of the energy supply and demand against the different criteria of the energy transition phase model, it is clear that fossil fuels are the dominant energy source. Fossil fuel generation capacities have recently been expanded, with further extensions planned. In terms of diversifying its overall energy supply, Egypt has not yet made much progress, and the energy regime appears unchanged. Therefore, in terms of its energy supply, Egypt currently only meets the criteria for the beginning of the first phase of the energy transformation.

The Oil and Gas Sector

Egypt has a large oil and gas industry. Hydrocarbon production is Egypt's largest industrial activity, contributing 13.6% of the total Gross Domestic Product (GDP) in 2018 (International Trade Administration, 2020). At the end of 2018, the proven hydrocarbon reserves amounted to 3.3 billion barrels of oil and 77.2 trillion cubic feet of natural gas (ibid.). Recently discovered natural gas fields in the Eastern Mediterranean will add to the reserves, which are estimated to be sufficient in sustaining Egypt's demand for more than the next 15 years (Friedrich-Ebert-Stiftung, 2016). With the newly discovered gas fields, Egypt transformed from being a net energy importer in 2010 to a potential gas exporter. The gas discoveries also eased the struggle to meet domestic demand (Fig. 4-5).

Oil and gas still represent over 90% of primary energy consumption in Egypt. It is assumed that the oil and gas sector will continue to play an important role in the future, although global oil and gas demand are likely to decline (Deloitte, 2021). Egypt's reliance on this sector presents a major obstacle to its transition towards a 100% renewable energy system, particularly in the later phases of the transition when the phasing out of fossil energy sources is required.

Renewable Energy

The progress of the renewable energy sector is crucial for the energy transition. Thus, the Egyptian government has expressed its intention to integrate renewable energy sources into the energy mix by two main actions:

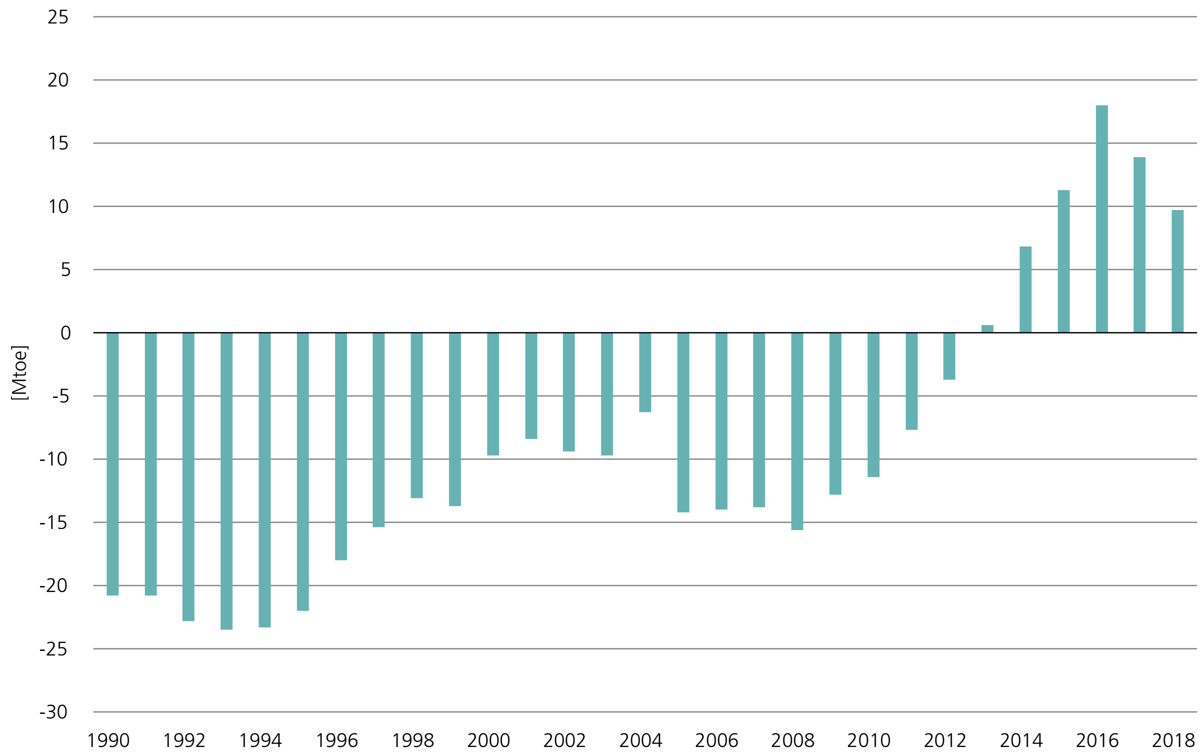
1. In 2014, the Ministry of Electricity and Energy was renamed the Ministry of Electricity and Renewable Energy;

2. Under the ISES to 2035, Egypt set ambitious targets for the increase of renewable energies.

In 2016, the Egyptian Supreme Council of Energy (ESCE) announced that 35% of the country's generation capacity would come from renewables by 2035. In July 2016, this was revised to 42%, and, in October 2020, the Minister of Electricity announced a new target of 60% (Deutsche Botschaft Kairo, 2020). As of 2018, renewable energy sources held a share of around 8% in the electricity generation mix, although the electricity generation sector was mainly dominated by natural gas and oil (IEA, 2020a). Hydropower makes the main contribution to the renewables mix (12,899 GWh), while solar energy generates 543 GWh and wind energy 2,360 GWh (Fig. 4-6). Currently, 5,872 MW of renewable energy capacity is installed; this includes PV in remote areas that are not connected to the grid and net metering (rooftop PV).

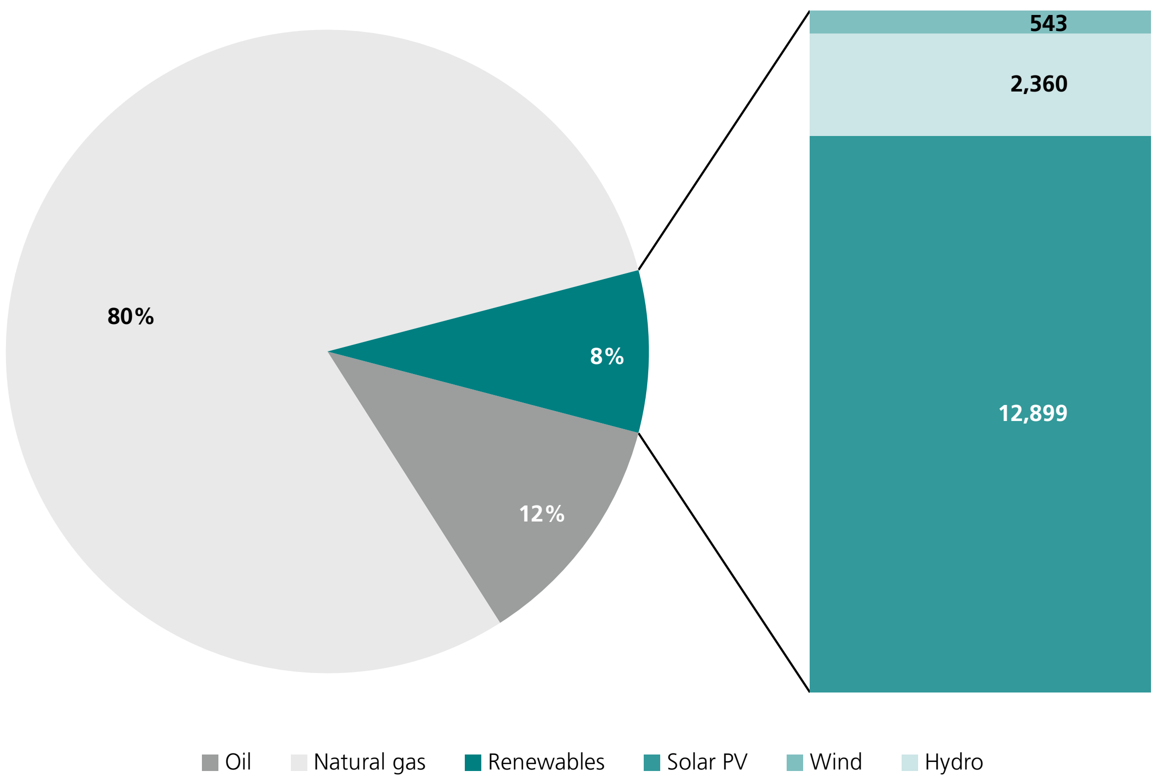
Egypt is a pioneer for wind energy in Africa and the MENA region. The first pilot projects for wind energy in Egypt date back to the 1980s and were initiated with international financial and technical support (George, 2018). According to Egypt's Wind Atlas, there are abundant wind energy resources, in particular in the Gulf of Suez (IRENA, 2018b). The wind speeds in this location are stable and reach, on average, between 8 and 10 m/s at a hub height of 100

Figure 4-5
Net Energy Imports (in Mtoe), Egypt 1990–2018



(Source: data based on IEA, 2020a)

Figure 4-6
Electricity Generation Mix (in GWh), Egypt 2018



(Source: data based on IEA, 2020a)

metres (ibid.). New promising areas are east and west of the River Nile in the Beni Suef and Menya regions as well as the El Kharga Oasis. In cooperation with Germany, Spain, Japan, and Denmark, the New and Renewable Energy Authority (NREA) has established several large-scale wind farms. Windfarms at the Zafarana and the Gulf of El-Zeit have been constructed under an engineering, procurement, and construction (EPC) scheme, and further wind power plants are planned to be installed and operational by 2023 (IRENA, 2018b) under a build-own-operate (BOO) scheme. These projects are being developed by NREA and the Egyptian Electricity Transmission Company (EETC), and they will be constructed by international or Egyptian private sector companies. Additionally, Siemens is involved under an EPC and finance scheme to construct a manufacturing facility for the wind power plants' blades.

According to IRENA (2018b), Egypt is also one of the most promising regions for harvesting solar energy, both for electricity and thermal generation. The daily direct normal irradiation (DNI) varies between 5.2 and 7.6 kWh/m^2, and the global horizontal irradiation (GHI) is between 5.6 and 6.8 kWh/m^2 (Global Solar Atlas, 2020). In remote regions, off-grid solutions are applied within the agricultural sector in the form of solar PV pumping systems, lighting, advertising, cold storage, and desalination (IRENA, 2018b). By the end of 2016, Egypt had a total installed capacity of off-grid power plants of 30 MW (ibid.). With the PV price drop and constant falling costs of solar technology, efforts focusing on PV applications have increased and institutional stakeholders perceive these innovations as opportunities. Consequently, NREA has undertaken several feasibility studies on the application of PV projects. Egypt's first flagship project is the 1,465 MWp Benban solar park. It was supported by the government and aims to attract international key players to invest in utility-scale plants in Egypt. Located in the Aswan governorate in the south of Egypt, the PV solar park is one of the largest worldwide with an investment cost of 3.6 bn Euro (Raven, 2017), and the EETC has offered a power purchase agreement (PPA) over 25 years under a feed-in-tariff scheme (EcoConServ Environmental Solutions, 2016). Another demonstration project is the Kuriemat solar thermal power plant, which is an integrated solar-combined cycle power project located in the Beni Suef governorate, roughly 100 km south of Cairo. It has a 140 MW capacity and combines the benefits of solar energy with a steam combined cycle (natural gas). The solar field consists of parabolic trough collectors with an overall surface area of 130,000 m^2. The power plant was tendered internationally and commissioned by NREA. The total investment costs amount to more than 250 million Euro (Zipp, 2011). Further solar energy projects are outlined in Table 4-1.

Currently, dispatchable hydropower sources account for 80% of the renewable energy mix. The Aswan High Dam along the River Nile contributes 2,650 MW to the total hydropower generation capacity, while smaller hydropower plants account for the rest. As one of the most pivotal structures in Egypt, the High Dam in Aswan has secured grid stability and has played a crucial role in agricultural irrigation (KfW Bankengruppe, 2014). It produces more than 8,000 GWh annually and is run by the Hydro Power Plants Generation Company (HPGC), which sells the generated electricity to EEHC. The dam includes an on-site training centre with courses specialising in mechanical and electrical engineering. Hydropower generation, especially along the

Table 4-1
Operational and Planned Large-Scale Renewable Energy Projects in Egypt

Operational wind power plants						
Site	Zafarana	Gabal El-Zeit	Gabal El-Zeit			
Installed Capacity (MWp)	547	200	200			
Planned wind power plants						
Site	Suez Gulf	Suez Gulf				
Installed Capacity (MW)	250	500				
Status	PPA signed	-				
Operational solar power plants (CSP and PV)						
Site	Kuriemat	Benban Solar Park				
Type	Solar thermal and steam (natural gas)	PV				
Installed Capacity (MW)	140	1,465				
Planned solar power plants (CSP and PV)						
Site	Kom Ombo (PV)	West Nile (PV)	West Nile (PV)	West Nile (CSP)		
Installed Capacity (MW)	200	200	600	100		
Status	n/a	n/a	n/a	n/a		
Operational hydropower plants						
Site	High Dam	Aswan Dam I	Aswan Dam II	Essna	Naga Hamadi	Assuit
Installed Capacity (MW)	2,100	280	270	86	64	32

(Source: data based on Arab Ministry of Electricity and Renewable Energy, 2018; Molina, 2020)

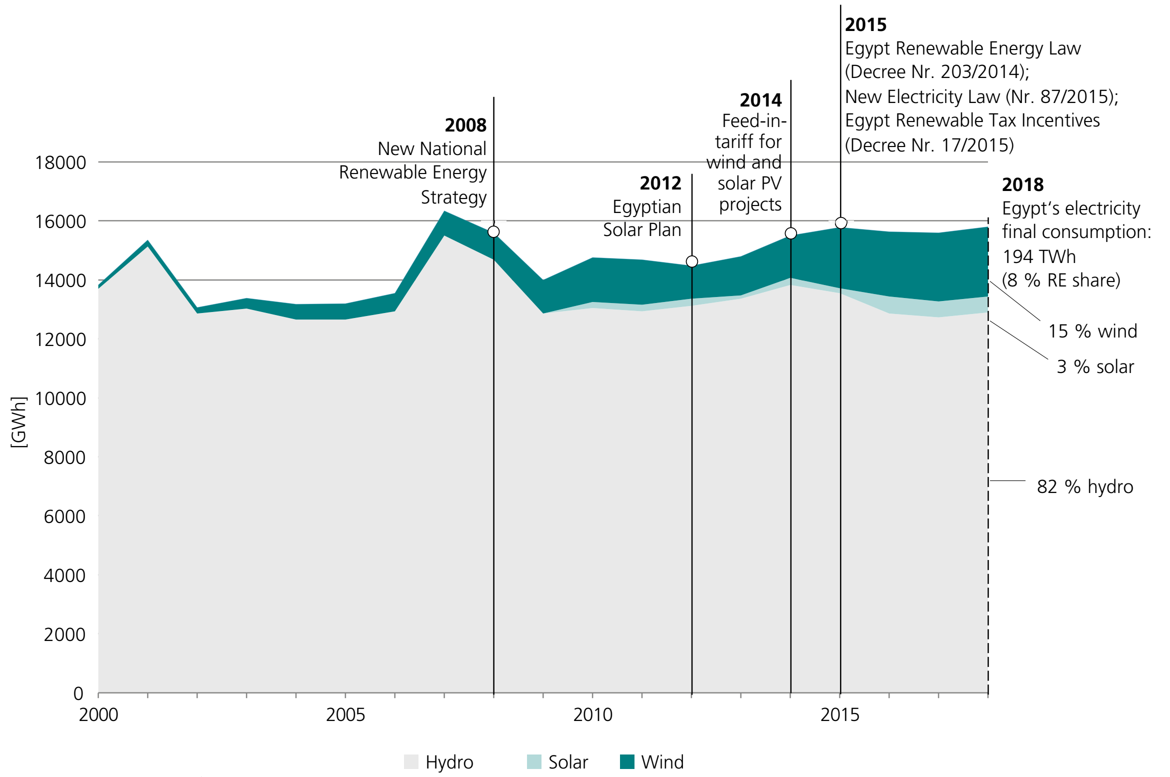
Nile, have an uncertain future due to the construction of the great Ethiopian Renaissance Dam (GERD) on the Nile (Abdelhadi, 2020). Given the importance of the Nile in a country which is mostly desert (arable land accounts for only around 8% of the total landmass of Egypt), the construction of the Ethiopian Renaissance Dam is likely to increase the risk of drought along the Nile if no negotiated international solution is agreed.

Plans to build a 2,400 MW pumped storage hydroelectric plant at Attaqa, in the Gulf of Suez, were also initiated in 2015 (Takouleu, 2019). The plant is designed to operate at peak hours by channelling water from an upper to a lower reservoir with a 28 m height difference. At off-peak times, the flow is reversed by using turbines as pumps and generators as motors (IRENA, 2018b). The project is expected to operate under an EPC scheme.

Topics surrounding hydropower generation in Egypt show that water plays a crucial role for future energy systems and should, therefore, be integrated in energy planning processes. Currently, Egypt's water supply does not meet its water demand. With a minimum water demand of 110 bn m^3, the country's water supply falls short by 30 bn m^3 (Aziz, 2020). In response to concerns about water scarcity, Egypt has plans to expand its desalination capacities. As of 2017–2018, Egypt had 44 desalination stations with an actual production capacity of 122 million m^3 of water (Enterprise, 2020). The government plans to expand the desalination capacity to 2.9 million m^3 per day by 2050 under a 5-year plan starting in 2020 (Molina, 2020). The intention is for these plants to be supplied by renewable energy. Seawater desalination is also likely to be used as a water source for hydrogen production, but costs for desalination in Egypt are relatively high. In recognition of the crucial role that water for energy will play in the future, Egypt should integrate water-energy nexus aspects in its strategies.

The development of renewable energy in Egypt has been supported by several laws introduced by the government. In 2008, the New National Renewable Energy Strategy announced an ambitious plan to generate 20% of the country's electricity from renewables by 2020. The Egyptian Solar Plan, introduced in 2012, set the target of installing around 3,500 MW of solar power plants by 2027, of which 2,800 MW consist of concentrated solar power (CSP) and 700 MW of PV (IEA, 2020b). The investment scheme in this plan was further developed by adding bids, feed-in-tariffs, and third-party access schemes. In 2014, the Ministry of Electricity and Energy and the Regulatory Agency announced a feed-in-tariff system to support solar PV and projects with a capacity of less than 50 MW. This boosted the installation of solar and wind projects in Egypt (IEA, 2016). The transition is also endorsed by the new Electricity Law No. 87 of 2015, which decrees opening up the market to maximise the renewables share in the energy mix (EEHC, 2015; The Middle East Library for Economic Services, 2015). Additionally, the Egypt Renewable Energy Law Decree No. 203/2014 in the same year is a revision of the Renewable Energy Law in 2014. It encourages tenders in the form of BOO contracts, where EETC is responsible for running the auction and NREA

Figure 4-7
Development of Renewable Electricity Generation by Source (in GWh) and Introduction of Energy Policy Measures, Algeria 1990–2018



(Source: data based on IEA, 2020a)

for the land provision (The Middle East Library for Economic Services, 2015). Renewable energy investments were further supported by the Decree No. 17/2015, which regulates renewable energy tax incentives. Under this decree, sales taxes were trimmed to 5% (formerly 10%) and custom duties on equipment used for production are set at 2% (IEA, 2019). Fig. 4-7 depicts the development of renewable electricity generation alongside the introduction of energy policy measures in Egypt.

In terms of financing renewable energy development, banks, such as the European Bank for Reconstruction and Development (EBRD), International Finance Corporation (IFC), Kreditanstalt für Wiederaufbau (KfW), and the World Bank, are active in Egypt and offer multiple finance options for renewable energy projects (The World Bank, 2018). For instance, EBRD and IFC have provided extensive financial support to the Benban solar park (Zgheib, 2019; IFC, 2020), while KfW is financially involved in the wind farms located in the Gulf of Suez. The EBRD, the Agence Française de Développement (AFD), the European Investment Bank (EIB), and the EU have launched a 140 million Euro Green Economy Financing Facility to provide loans for small-scale renewable energy projects by private companies through commercial banks (The World Bank, 2018). Moreover, the initiation of Egypt's Green Bond implementation has supported the construction of the Cairo monorail, the El-Dabaa desalination plant, solid waste management investments, and the 250 MW wind project in the Gulf of Suez (Ministry of Finance, 2020). Financial mechanisms to support the implementation of renewables in Egypt comprise the feed-in-tariff, EPC scheme, BOO scheme, and auctions (Molina, 2020; REN21, 2019). However, the government has currently suspended new tenders and commissions for large facilities due to the Covid-19 pandemic.

Renewable energy projects need to obtain permits and licences to operate in Egypt. These include different power plant construction permits, a licence from the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA) for power generation, and an environmental and social impact assessment (ESIA). The power generation licence needs to be validated annually and renewed after 5 years (Andersen Tax LLC 2020). For several large-scale project sites, such as Benban, the Egyptian authorities took specific steps to ease the process of investing in the renewable energy sector. They obtained all the necessary site-wide permits (e.g. land permits) and prepared the overall environmental impact assessments; these only needed to be supplemented without public consultation addressing plot specific issues (EcoConServ Environmental Solutions, 2016). NREA has allocated a further 7,650 km^2 for the implementation of renewable energy projects, but the private sector still perceives the project planning procedures to be bureaucratic and lengthy.

The analysis shows that despite the small share of renewables in the overall energy mix in Egypt, by 2018 the share of renewables in the electricity mix was significant (8%). The sector is developing dynamically with the support of the Egyptian government. The targets for renewables are ambitious, and the implementation schemes have been successful in attracting investors, resulting in constant growth in the number of large-scale projects over recent years. Consequently, renewables have left the niche level and have increased at the system level, although fossil fuels are still the dominant energy source in Egypt. Accordingly, Egypt's renewable energy expansion has reached the first phase in the energy transition model.

Infrastructure

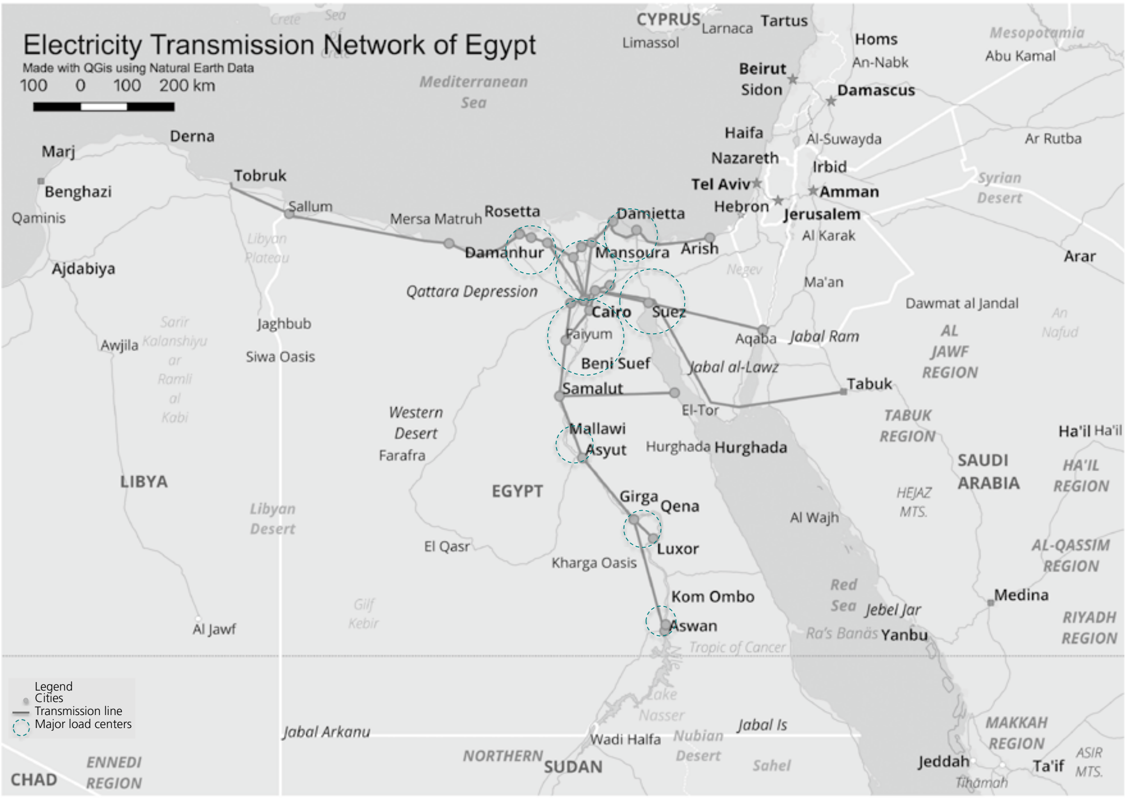
Another factor that plays an important role in the progress of the energy transition is the development of infrastructure for the energy sector. Egypt's infrastructure has significantly improved over the past decade to overcome heavy load shedding at the beginning of the 2010s. Following agreement on the Siemens megaproject, which added over 14 GW to the grid from three combined cycle power plants, the generation capacity was almost doubled by the end of 2017. As previously mentioned, the overall generation capacity further increased over the past five years, resulting in a generation surplus. The current system includes excess generation capacities of roughly 15–20 GW, depending on the season.

On the transmission level, efforts have been made to rehabilitate the existing network with a focus on improving the voltage profile. Over the past 5 years, EETC has invested heavily in grid extensions to improve the voltage profile and enhance the network reactive power capacity. Hence, several projects to expand the transmission grid by 500V are under development, which will connect existing wind and solar parks to the national grid (George, 2018). The share of renewable energies in the installed capacity – including variable solar PV and wind energy – will increase in the medium to long term. This is expected to present the grid with a variety of technical challenges. In response, Siemens Power Technologies International (PTI) has conducted a study to develop a smart grid roadmap for the Egyptian Transmission Company. The study gives recommendations for the smart infrastructure required to accommodate the 42% share of renewables expected by 2035.

According to the interviewed experts, this grid expansion and retrofitting is an urgent priority (particularly in terms of transmission) because the generation excess is already difficult to accommodate in the current grid network. Due to the constraints of transmission lines and substation capacities, most of the excess generation is currently wasted. To help overcome this problem, a plan is installed to create new and upgraded control centres within the transmission networks.

On the distribution side, the integration of rooftop PV systems and electrical vehicle (EV) charging stations at low-voltage levels is a growing concern. Therefore, EgyptERA recently introduced the requirement for new installations to submit a grid impact study in advance. Afterwards, they will be granted a licence to install a system (Egyptera, 2020b). However, few companies in Egypt have the technical know-how to perform such impact studies.

Figure 4-8
Electricity Transmission Network of Egypt Showing Major Load Centres



(Source: own creation data based on EEHC, 2018; Energydata, 2017)

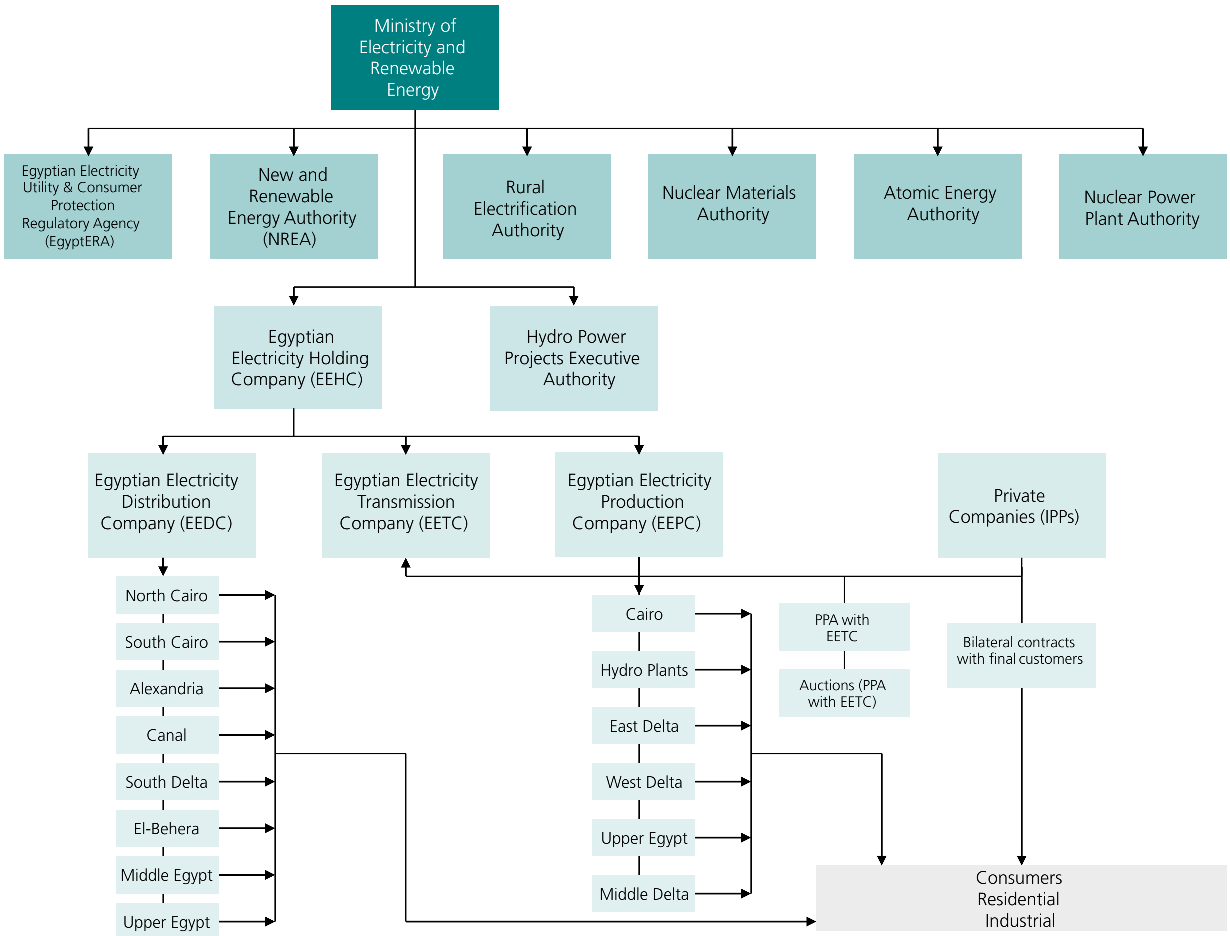
In its Strategy of Sustainable Development 2035, Egypt declared its intention to become a central hub for energy (Arab Ministry of Electricity and Renewable Energy, 2018). With this aim in mind, EEHC has embarked on new policies with ambitious transnational targets to expand transmission systems (primarily to ensure the utilisation of the surplus generation) and to enhance energy trade at regional and international levels. There are currently two operational interconnections, one with Jordan at 400V with a capacity of 450 MW and another with Libya at 220V with a 200 MW capacity. These are both under the eight-country interconnection project (EIJLLPST) (The World Bank, 2013). There is also a plan to build an electrical interconnection with Saudi Arabia to exchange a capacity of 3,000 MW. This is achieved by using HVDC bipolar transmission technology on 500V through one substation in Egypt and two in Saudi Arabia. Another planned interconnection is between Egypt and Sudan at 220V with a 300 MW expected capacity (Arab Ministry of Electricity and Renewable Energy, 2018). An electricity trade plan is under discussion; however, the progress to date is limited to a few Memorandums of Understanding and non-disclosure agreements signed between 2017 and 2020 – no contracts have yet been concluded (ibid). To establish itself as a central hub for energy and electricity trade, Egypt is also creating an electricity trade market among the Eastern Africa Power Pool (EAPP) countries. Additionally, Egypt has joined several regional and international organisations and associations, such as the Association of Mediterranean Transmission System Operators (MED-TSO) and the Union for the Mediterranean (UFM) (ibid). Furthermore, interconnection studies regarding a connection to the EU via Cyprus are being conducted.

In terms of upgrading the electricity distribution network, the distribution companies are working towards grid digitalisation using the net metering system. For instance, the North Cairo Electricity Distribution Company has signed an EPC contract with a consortium comprised of Elsewedy Electric and Toyota Tsusho to install around 500,000 smart meters (Zawya, 2020). This should provide a smart solution to digitalise the network. Custom duties for all imported materials and equipment for renewable energy technologies are limited to 2% (Molina, 2020).

Figure 48 depicts the electricity transmission network in Egypt. The data is based on the year 2017; thus, updated extensions could be missing. However, the map shows the existing transmission network line (red line) with the major load centres across Egypt (Arab Ministry of Electricity and Renewable Energy, 2018).

The evaluation of recent developments to progress the energy transition shows that significant efforts have been made to expand the grid to meet the high peak demand. However, not all parts of the grid have been included in the retrofit, meaning that grid losses at transmission and distribution levels continue to be a challenge. Therefore, in terms of the development of its infrastructure, Egypt can be classified to have entered – but not yet completed – the first phase of the transition model.

Figure 4-9
Electricity Market Structure Showing Relevant Authorities and Companies



(Source: own creation data based on RES4MED, 2015)

Institutions and Governance

Institutional, financial, and political factors, as well as aspects relating to the market and economy, constitute a further layer in the phase model for the energy transition. In terms of its political commitment, Egypt's ISES to 2035 seeks to increase the supply of electricity generated by renewables to 42% by 2035, with CSP providing 4%, PV 22%, wind 14%, and hydro 2% (Ministry of Electricity and Renewable Energy, 2020). Under the strategy framework, the main goals are to ensure energy security, stability, and sustainability. Moreover, ISES to 2035 is based on the least-cost approach, meaning that energy subsidies are eliminated by 2022 and that the market structure is liberalised. The strategy envisages a 16% share of coal and 3.3% share of nuclear energy (IRENA, 2018b). However, this approach is subject to uncertainties due to the rapidly changing energy sector. In response to the new gas discoveries and the sharp price drop of renewables, the strategy should be updated regularly to reflect new developments (ibid.). An updated version for the timeframe to 2040 is said to include hydrogen and a green economy strategy plan for Egypt[2]. Egypt has also developed a »Sustainable Development Strategy – Egypt's Vision 2030« (SDS 2030) in accordance with the international sustainable development goals (SDGs). This strategy serves as a roadmap for Egypt to achieve its goals by 2030. It includes references to energy security, the optimal use of resources, opportunities to enhance Egypt's competitiveness, emission reductions in the energy sector, and its position as an energy hub (Ministry of Planning and Economic Development, 2020). Despite these two strategies focusing on renewables and sustainability, Egypt has also launched a Modernisation Programme for oil and gas with the intention of becoming a leading regional oil and gas hub (Mobarez, 2020).

The key stakeholder in the electricity sector in Egypt is the Ministry of Electricity and Renewable Energy (MoERE), which develops and implements the national energy strategy and supervises the EEHC, EgyptERA, and NREA. EgyptERA regulates and supervises all electricity generation, transmis-

2 Information provided during the event *Egypt's Roadmap to Reaching its Sustainable Energy Goals 2035: Energy Transition and Modernisation of the Egyptian Energy Sector* on the 23rd of November 2020 (https://sustainableenergyegypt.com).

sion, and distribution and is responsible for setting tariffs and for licensing the private sector. EEHC is a state-owned company, which owns and operates almost the whole generation sector – as well as the transmission and distribution grids – through its subsidiaries. EETC is an affiliate company to EEHC and is responsible for managing, operating, and maintaining the transmission network in Egypt (RES4MED, 2015). After restructuring the electricity sector in 2000, Egypt legally unbundled the market by creating the EEHC. Electricity generation, transmission, and distribution retail are now separated into six regionally-based generation companies and nine distribution companies (ibid.). EEHC owns around 90% of the installed generation capacity, while private sector participation is permitted under BOO contracts (ibid.). Contracts in the form of a PPA are signed between private companies and EETC for a period of 20 to 25 years. Independent power producers (IPPs) are normally procured by NREA. At present, IPPs represent a very small share in the overall electricity market in Egypt. EETC works as a single buyer and purchases all the electricity from the generation companies. Consumers connected to the EHV and HV network can also negotiate direct contracts with EETC. Retail is not unbundled. Law No. 87/2015 foresees the liberalisation of the electricity market; however, opening up the market has been delayed due to the restructuring of the sector and ongoing subsidy reform. Fig. 4-9 further depicts the institutional structure of the energy sector in Egypt.

Although Egypt has officially initiated the unbundling of the electricity market, the EEHC comprises various subsidiaries. Since the EEHC owns most of the generation capacities, the market retains the features of a monopoly. To meet the requirements of the next stage of the phase model, the energy market must be further liberalised. In this area, therefore, Egypt is classified as being in phase one according to the energy transition model.

Energy Market and Economy

The electricity tariff structure in Egypt follows an inclining block rate pricing structure, with three blocks in which the electricity price rises as the consumption of electricity increases (Egyptera, 2020a). The tariff differs depending on the voltage level to which the customer is connected: extra high voltage (EHV), high voltage (HV), medium voltage (MV), or low voltage (LV). The highest tariff is 1.45[3] EGP per kWh for consumption exceeding 1,000 kWh per month. The commercial block pricing is at 1.35[4] EGP per kWh, regardless of total monthly consumption. EHV, HV, and MV customers pay a peak and off-peak tariff for energy and power. As well as electricity, Egypt subsidises fossil fuels to a significant level. In 2019, oil was subsidised by 9.1 bn USD, electricity by 6.4 bn USD, and gas by 0.4 bn USD. However, the government plans to phase out the subsidy structure. The capacity extensions in recent years have created a huge financial burden, but the government is committed to ensuring electricity supply. According to The Ministry of Finance, in 2019/20 the budget for electricity projects accounted for 24% of the total loans and credits guaranteed by the Treasury (Butter, 2019). Yet, plans to reform the subsidy structure in Egypt are currently postponed due to the negative economic impacts of the COVID-19 pandemic. Subsequently, in June 2020, the finance minister extended the plan to lift subsidies on electricity for a further three years (to the end of 2024/25 rather than 2021/22). Combined with tariff increases announced in June 2020, the pandemic has severely harmed the energy sector and has led to a significant drop in energy demand.

Efficiency

The anticipated subsidy reform also aims to improve Egypt's energy efficiency performance. With its National Energy Efficiency Action Plan I (NEEAP I), Egypt endeavoured to reduce its energy consumption by 5% during the period 2012–2015 compared to average consumption over the previous five years. NEEAP I had several shortcomings (Elrefaei and Khalifa, 2014), which led to the amendment of the plan and the introduction of NEEAP II for the period 2018–2020 (MoERE, 2018). NEEAP II complies with Egypt's ISES to 2035 and contributes to its vision and goals. It seeks to enforce the provisions made by the Electricity Law No. 87/2015 and its executive regulations in order to improve energy efficiency. NEEAP II includes the use of high efficiency lighting in the housing sector, finance mechanisms to deploy solar heaters in the residential and hotel sectors, energy savings in public lighting, energy consumption rationalisation in water and wastewater stations, and awareness-raising programmes.

Greenhouse Gas Emissions

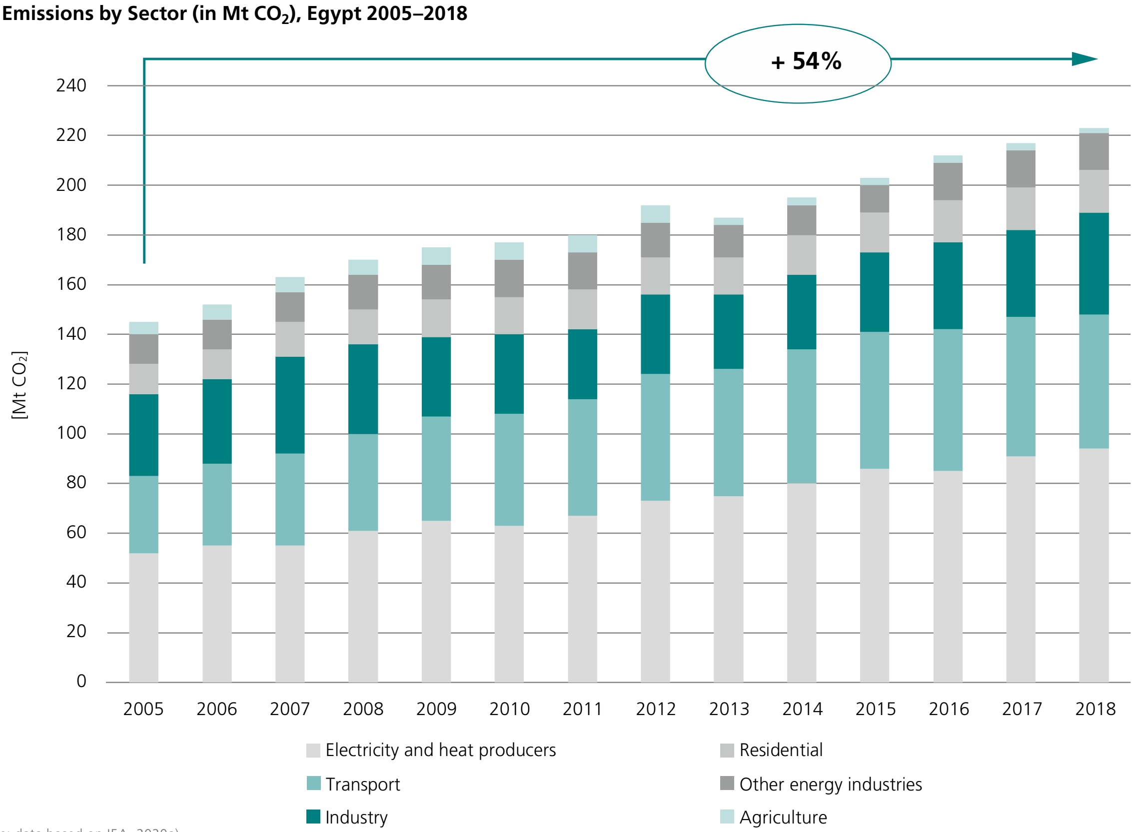
Despite its efforts to comply with the Paris Agreement and energy efficiency measures, Egypt is struggling to reduce its CO_2 emissions. Compared to 2005, Egypt's CO_2 emissions had increased by 54% by 2018. This is largely due to electricity and heat production, but the increase is also caused by the development of the industrial sector. Emissions from the transport sector had risen by smaller amounts. Fig. 4-10 provides a full picture of the CO_2 emissions profile by sector. Fig. 4-11 depicts the CO_2 emissions from electricity and heat generation by source, showing clearly that gas accounts for almost 80% of the emissions.

Part of the EU Green Deal includes the new EU Carbon Border Adjustment mechanism (CBAM), which enforces a carbon price on intensively-polluting imported products. This is perceived with growing concern by Egypt's export sectors. The interviewed experts fear that the EU's decarbonisation efforts could have negative repercussions for the competitiveness of Egyptian products. Nevertheless, this carbon border tax could be an opportunity and a driver for Egypt to reduce its GHG emissions.

3 It equals 0.08 Euro/kWh using the currency converter www.euro-currency.eu

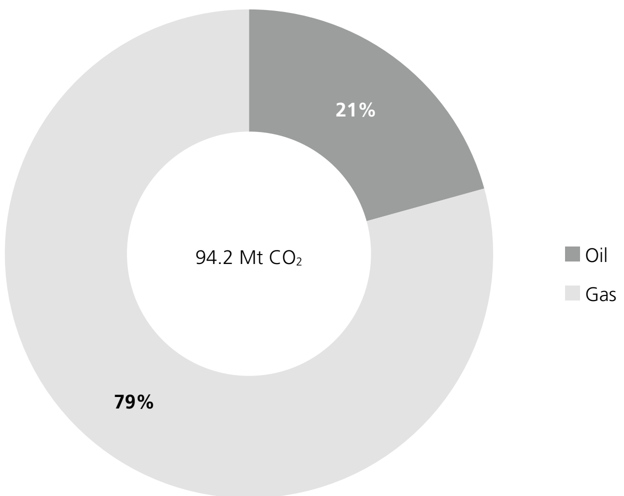
4 It equals 0.07 Euro/kWh using the currency converter www.euro-currency.eu

Figure 4-10
CO_2 Emissions by Sector (in Mt CO_2), Egypt 2005–2018



(Source: data based on IEA, 2020a)

Figure 4-11
CO_2 Emissions from Electricity and Heat Generation by Energy Source (in Mt CO_2), Egypt 2018



(Source: data based on IEA, 2020a)

Society

As well as technical, institutional, and market elements, other relevant factors supporting the energy transition include social awareness, acceptance, and active support. In general, renewable energy technologies in Egypt are well perceived by the population. Topics concerning renewables are frequently discussed on social media platforms. The announcement of the new (higher) electricity tariff in June 2020 was controversial and became a subject of general debate among citizens. The price increase was made in response to the desire for a fair and transparent electricity policy (Egyptian Initiative for Personal Rights, 2017). However, according to interviewed experts, Egypt needs to raise awareness about energy efficiency, savings, and environmental conservation standards. Energy consumption labels on home appliances, which are designed to inform about energy efficiency, are barely understood by salespeople, let alone the general public. Some initiatives and national campaigns have helped to increase awareness, but, so far, such measures have been limited. For instance, between 2018 and 2019, the Gesellschaft für Internationale Zusammenarbeit (GIZ) project, the Egyptian-German Joint Committee on Renewable Energy, Energy Efficiency and Environmental Protection (JCEE), in conjunction with the Ministry of Electricity and Renewable Energy, launched the »Electrical Intelligence«[5] campaign. By using social media, they publicise topics about energy saving measures, show educational short videos, and share promotional materials and events. According to interviewed experts, such social media campaigns have the potential to reduce household consumption by up to 10%.

Yet, fears and misperceptions about renewables still exist among the population. In the late 1990s, solar water heaters were introduced as an alternative to electric and gas heaters. However, the market was pervaded by products from unknown suppliers – most originated from China. Many of these products were built from low quality components; thus, they frequently malfunctioned. This negatively affected the reputation and public perception of renewables, and it took several years for this perception to change to the better. Furthermore, PV solar panels that are mostly manufactured in China do not always meet quality standards. There is also a lack of awareness about the different regulatory frameworks for the installation of PV systems. As a result, people are not aware of the feed-in-tariff and net metering systems, although they have existed since 2014 and 2016 respectively. Additionally, high investment costs and the absence of soft loans from banks discourage people from investing in renewable energy systems. The high interest rates for credits for renewables that many banks require originate from the banks' inability to anticipate the associated risks, given their lack of knowledge about renewable energy technologies. To overcome this situation, Egypt has introduced various initiatives to strengthen the capacities of the banking sector to better understand green technologies. The most recent of these programmes is »Green Banking«[6], which is supported by the GIZ.

Capacity building and educational opportunities are being offered by specialised training centres that provide professional training on renewable energy topics. Most of these programmes are sponsored by donor organisations which are working in partnership with NREA. The GIZ JCEE programme recently trained 300 engineers and installers from Egyptian companies operating in the supply, installation, operation, and maintenance of rooftop PV systems (less than 500 kWp). Bachelor's and Master's degree programmes in engineering are also offered by universities that focus on renewable energies. However, vocational training and study is still a niche and programmes for PtX technologies are uncommon.

Overall, participation by citizens in the energy transition is limited. There are some discussion platforms, such as the »Cairo Climate Talks«[7], which bring together science, government, the private sector, and citizens. Actor networks, such as the Egypt-PV[8] or the Industrial Modernisation Centre[9], provide platforms for different business associations to discuss renewable energy technologies.

In terms of Egypt's classification in the phase model, the »society« cluster clearly shows that Egypt has implemented programmes to raise awareness about renewables. Overall, these campaigns have had a positive impact on people's perceptions. However, Egypt's population is still neither actively involved nor aware of environmental conservation measures and energy saving standards. Therefore, for this criteria Egypt has entered the first phase of the model but has not yet accomplished all the milestones necessary to move onto the second phase. Behavioural and cultural values tend to change very slowly; thus, significant time and effort will be required to promote and embed environmental values in Egypt's culture. Hence, it would require a long period of time for Egypt to progress to the second phase of the energy transition in the society layer.

Summary of the Landscape and System Level Developments

On the landscape level, the COVID-19 pandemic is expected to affect the energy transition at least in the short term, but potentially also in the long term. In Egypt, the pandemic has slowed down the pace of the transition as it has had a negative impact on the supply chain for nearly all the EPC projects under development. These delays are expected to lead to an increase in costs. The crisis has also forced the government to take steps to limit the expansion of renewable energy generation during 2020. Specifically, EgyptERA introduced a cap on the net metering scheme in May 2020, which included limiting overall PV net metering installation to 300 MWp (Egyptera, 2020b). Many PV installers perceived this change as being restrictive to future developments in the PV market.

As well as the pandemic, other barriers of a technical, financial, and regulatory nature are impacting on the development of the energy transition at the system level. Although the EETC is continuously investing in the transmission network, the upgrade has scarcely incorporated advanced economic dispatch methods, and spinning reserve capacities, i.e., additional generating capacities, remain limited. To guarantee the financial sustainability of the energy sector, it is essential to open up the market and integrate the private sector. However, like many MENA countries, Egypt's energy sector is characterised as a single buyer market with the EEHC having a monopoly. Although Egypt originally announced its intentions to restructure the market in 2015 via Law No. 87/2015, little or no progress is yet evident. Egypt

5 More information on the social media platform: https://www.facebook.com/Alzaka2alkahraba2y/

6 More information: https://www.renac.de/projects/current-projects/green-banking/green-banking-mena

7 More information: https://kairo.diplo.de/eg-de/themen/kultur/-/2415226

8 More information: https://egypt-pv.org/

9 More information: http://www.imc-egypt.org

Table 4-2
Current Trends and Goals of the Energy Transition

Category	Indicator	2005	2010	2015	2018	2020	2030	2040
Carbon Emissions (Compared to 1990)	CO_2 emissions per unit of GDP	+19%	+7%	+4%	N/A	N/A	–	–
	CO_2 emissions per capita	+36%	+50%	+57%	+64%	N/A	–	–
Renewable Energy	Capacity growth (MW)	N/A	3,483	3,713	4,81 4220 MW solar PV, 1.1 GW CSP, 7.2 GW wind (2020)		2.8 GW hydro, 700 MW solar PV (2027), 2.8 GW CSP (2030)	
	Share in final energy use	6.5%	5.7%	5.7%	5.5% (2017)	N/A	–	–
	Share in electricity mix	12.1%	10.4%	9.1%	8.1%	20% (2022)	42% (2035)	–
Efficiency (Compared to 1990)	Total primary energy supply (TPES)	+88.7%	+123.5%	+144%	+189.1%	N/A	–	–
	Energy intensity of primary energy	+5.3%	–8%	–12.1%	N/A	N/A	–	–
	Total energy supply (TES) per capita	+33.3%	+50%	+50%	+66.7%	N/A	–	–
	Electricity consumption per capita	+85.7%	+128.6%	+128.6 %	+128.6%	N/A	–	–
	Fossil fuel subsidies (% of GDP 2019)	N/A	N/A	N/A	5.2% of GDP: 9.1 bn USD (oil), 6.4 bn USD (electricity)		–	–
Buildings	Residential final electricity consumption (compared to 2005)	+154.1%	+285.1%	+450%	+411.2%	N/A	–	–
Transport (Compared to 1990)	Total final energy consumption	+89.9%	+176.5%	+241.8%	+235.6%	N/A	–	–
	CO_2 emissions in transport sector	+18.2%	+27.3%	+13.6%	+54.5	N/A	–	–
	Number of e–vehicles	N/A	N/A	N/A	N/A	less than 500	production of 25,000 EV per year	
Industry	Carbon intensity of industry consumption (compared to 1990)	–13.7%	–21.1%	–18.4%	–15.4%	N/A	–	–
	Value added (% of GDP)	34.15%	35.78%	36.6%	34.9% (2019)	–	–	–
Supply Security	Natural gas imports (compared to 2015)	N/A	+37.1% (2016)	+15.3% (2017)	–56.1%	N/A	–	–
	Natural gas exports (compared to 2005)	N/A	–16.2%	–98.3%	–86.4%	N/A	–	–
	Oil products imports (compared to 1990)	+247.2%	+830.2%	+1,781.8%	+1,261%	N/A	–	–
	Oil products exports (compared to 1990)	+136.2%	+44.9%	+1.1%	–19.8%	N/A	–	–
	Electricity imports (compared to 2000)	–12.5%	–18.75%	–68.75%	–56.25%	N/A	–	–
	Electricity exports (compared to 2000)	+189.3%	+389.3%	+128.6%	+35.7%	N/A	–	–
	Electricity access by population proportion	97.98%	99.15%	99.3%	100%	N/A	–	–
	Oil reserves (compared to 1999)		N/A	+16.71%	N/A	–18.3%	–17.8%	–
	Gas reserves (compared to 1999)	N/A	+78%	N/A	+81%	+ 78%	–	–

Category	Indicator	2005	2010	2015	2018	2020	2030	2040
Socio-economy	Population (2019)	100,388,073						
	Population growth	1.8%	1.98%	2.2%	2%	n/A	–	–
	Urbanisation rate	43.03%	43.02%	42.78%	42.7% (2017)	N/A	–	–
	GDP growth	4.42%	5.14%	4.37%	5.31%	N/A	–	–
	Oil rents (% of GDP)	12.19%	7.41%	2.96%	5.28%	N/A	–	–
	Natural gas rents (% of GDP)	2.65%	1.51%	0.73%	1.19%	N/A	–	–
	Jobs in low carbon industries	N/A	N/A	N/A	24,160 (2019)	–	–	
Water	Level of water stress	112.3%	120.7%	120%	117.3% (2017)	N/A	–	–

(Source: based on data from BP, 2020; FAO, 2020; IEA, 2020a; IRENA, 2020; Statista, 2020; The World Bank, 2020)

has a net metering quota and has recently set a PV cap; such regulatory barriers are only expected to be removed once the Egyptian electricity market has been liberalised.

In summary, several factors at the system level currently limit Egypt's progress in the energy transition: the generation surplus, the sector's financial sustainability requirements, and a lack of social readiness to pay for renewables. By introducing and implementing ISES to 2035 and Law No. 87/2015, Egypt entered the first phase of the energy transition phase model. However, current challenges, such as the pandemic, could negatively impact the further development of this strategy. Moreover, renewables are not currently replacing oil and gas due to growing markets. The fossil fuel sector is being expanded (e.g. the Siemens megaproject), which is likely to create future technological lock-ins. Table 4-2 summarises the recent trends and goals of the energy transition according to a selection of relevant indicators.

4.1.2 Assessment of Trends and Developments at the Niche Level

Developments at the niche level during each phase are crucial for reaching the subsequent stages of the energy transition (see Table 3-1). Egypt has already made moderate progress in some of the aforementioned dimensions: combining renewables and desalination technologies, investigating and testing flexibility options, supporting e-mobility, and initiating a strategy discussion on hydrogen and PtX. The following section describes these developments at the niche level in detail.

■ Desalination

Seawater desalination is a promising strategy for overcoming water shortages and is seen by the Egyptian government as an important approach for meeting growing water demand. However, desalination is also a very energy-intensive process and its large-scale application will result in a significant increase in energy demand. Renewable energy can play an important role by providing the necessary energy and reducing the carbon footprint of desalinated water.

In 2018, Egypt inaugurated the MATS solar thermal power plant with a 1 MW capacity, which is connected to a desalination unit with a capacity of about 250,000 litres of water per day (Fluri, 2018; Almohsen, 2018). This demonstration plant was built to train scientists from Africa and the Middle East within the Academy of Scientific Research and Technology in Egypt.

In 2020, the Egyptian government announced plans to build 47 additional seawater desalination plants. They have not yet specified whether these plants will be fuelled by renewable power or conventional fuels.

■ E-mobility

By supporting e-mobility, Egypt has taken the first step towards system integration via direct electrification. Since 2013, custom duty exemptions for electric vehicles (EVs) have been in place (El-Dorghamy, 2020). In late 2017, the electrification of the transport sector attracted attention as a potential solution to manage the electricity surplus. The Ministry of Military Production (MoMP) published a strategy to promote the local manufacture of EVs in Egypt. The strategy comprises three phases: in the first phase, local promotion and manufacture of EVs will be encouraged; the second phase focuses on both local input to produce EVs and positioning Egypt as a player in the R&D of EVs; and the third phase envisages the export of EVs by 2040.

However, the market is still in an early phase of development, with less than 500 licensed vehicles circulating in the country. There is currently roughly only 100 charging points, supplied by two charging point operators (CPOs) – infinity-e and Revolta. The charging stations are scattered across Egypt at shopping centres, highways, and in dense residential areas in Cairo. Currently, CPOs offer free charging to users, as EgyptERA has not yet officially set any tariffs. In addition, the government has introduced a number of incentives to support investment in the field of EVs (Molina, 2020). According to experts, COVID-19 is having an impact on e-mobility in the short and medium term due to the licensing procedures, costs, financing, and decreasing fuel prices. Introducing EVs is recognised as a promising measure for sustainable cities. However, certain challenges remain, such as building the local competences to develop action plans and policies (El-Dorghamy, 2020).

Simultaneously, in its Modernisation Programme for Oil and Gas, Egypt has announced its intention to convert compressed natural gas (CNG) for use in vehicles as a sustainable fuel. Under a three-year plan, the government intends to convert 263,000 cars to a dual fuel system (petrol and CNG) (Mobarez, 2020). However, this is a controversial move as experts claim this approach does not improve air quality but simply reallocates the emissions (El-Dorghamy, 2020).

■ **Flexibility Options**

According to the interviewed experts, flexibility planning is at initiation level in Egypt. In 2019, Siemens PTI conducted an assessment for EETC, which assessed various aspects of flexibility planning. For instance, the management of renewable energy systems was evaluated, and the results showed that Egypt does have a utility to gather data about their activity. In the short-term, energy resources need to be centrally configured, scheduled, and dispatched to optimise the system's operation and to avoid congestion. In the long term, the renewable energy system's owner should be required to submit the schedules ahead of time. In this way, the utility can see the renewables activity in real time. However, the current Egyptian capabilities on flexibility planning are far behind the benchmarking levels for phase two (Germany's level is the benchmark).

■ **Hydrogen and PtX**

Egypt is also taking first steps in the direction of hydrogen and PtX. These areas have attracted political and technological interest in recent months, particularly following the announcement of the German and European hydrogen strategies in 2020 and the strategic hydrogen partnership between Morocco and Germany. The recent virtual event *Egypt's Roadmap to Reaching its Sustainable Energy Goals 2035* declared that a PtX project will be implemented in Egypt using excess renewable energy converted into hydrogen. This pilot project will be part of the development strategy that includes hydrogen as one of the pillars of Egypt's energy vision. Egypt is also currently preparing a hydrogen policy strategy[10] to mirror major energy players on both the regional and international level and to advance its position as an energy hub. In addition, hydrogen generation could be one potential solution for using the generation surplus. According to the interviewed experts, the main potential for PtX is in the industrial sector and the export sector. Energy exporting is under active consideration in Egypt due to its electricity surplus. Moreover, locally produced hydrogen could be exported to nearby countries in Europe as part of a joint hydrogen strategy between Europe and North Africa. If Egypt were to export hydrogen to Europe, transportation could be via a new pipeline through Greece to Italy, with an estimated length of 2,500 km and at a cost of 16.5 bn Euro.

The pipeline could transport 7.6 million tons of hydrogen per year, assuming a load factor of 4,500 hours per year (van Wijk et al., 2019). In terms of the transportation sector, fuel cells could be an option for heavy duty vehicles, while direct electrification could be a more efficient option for smaller vehicles.

4.1.3 Necessary Steps for Achieving the Next Phase

To advance the energy transition towards system integration – described as the second phase in the MENA energy transition model – Egypt's efforts in the area of flexibility must be increased, and the political will to support renewable development must be concretised. Specifically, Egypt must develop and support new business models for small to medium scale projects and decentralised approaches. It must also explore flexibility options, such as demand side flexibility and different storage options (i.e. PtG).

To create a market for flexibility options, these options need to become an integrated part of the programmes and strategies that support the development of the energy system. The government is currently starting to move in this direction by developing incentives for the provision of flexibility. The next step will be to develop, define, and support concrete measures; for example, by defining tariffs for different circumstances to cover load shifting or peak capping. On the infrastructure level, including neighbouring markets would allow for cross-border trading flexibility. Grid extensions should be designed for trading but should also function as backup storage for renewable energies. Better regional cooperation in the field of renewables could further reinforce the development of the trading market.

To advance the energy transition, the focus should not only be on megaprojects. Renewables should be more widely applied. For example, they could be used as decentralised or off-grid solutions in remote locations and in urban areas. They could also provide clean electricity for businesses and companies. Renewable energy solutions could become more attractive for the private sector and for households from a cost perspective, particularly as electricity prices have recently increased in Egypt due to the energy subsidy reforms brought in by the government to meet IMF requirements. The wider application of renewables should consider two pivotal aspects: increasing participation in the energy transition and providing adequate financing mechanisms for small to medium projects. Allowing citizens to produce their own electricity from renewable resources could enhance active participation in the energy transition. This would require access to adequate financing options; for instance, in the form of soft loans with lower repayment costs via public funding. Such a system could be financed by proceeds from the sale of Egypt's Green Bonds.

Egypt does not have renewable energy and efficiency targets for specific sectors other than for electricity generation. Quantified targets for renewables and efficiency for different sectors, such as energy, transport, and industry, could help with the implementation in Egypt. These targets should

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10 In the event, *Egypt's Roadmap to Reaching its Sustainable Energy Goals 2035: Energy Transition and Modernisation of the Egyptian Energy Sector* on the 23rd of November 2020, the preparation of a hydrogen policy plan for Egypt was announced (https://sustainableenergyegypt.com).

be reviewed and adapted regularly to advance the sector's performance in renewable energy use and efficiency measures. To date, the energy efficiency measures in the political framework within the NEEAP have barely been applied due to the lack of a clear institutional framework. As well as target setting and auditing, priority should, therefore, be given to institutional strengthening – including exchange and communication between different institutions, ministries, and stakeholders.

Another key aspect is the digitalisation of Egypt's energy system. Digitalisation can help to ensure that the grid is kept balanced, even with an increasing share of intermittent and fluctuating renewables. Digitalisation is also important for the development of smart grids, which must be consistent with the e-mobility strategy. The charging infrastructure could be coupled with measures such as vehicle-to-grid schemes. In this way, vehicles could act as storage to increase grid ancillary services, such as frequency regulation, load shifting, and demand response. Such developments could also support the management of increasing shares of variable renewable energies (Arab Ministry of Electricity and Renewable Energy, 2018).

However, promoting EVs in Egypt must also consider aspects that go beyond the deployment of the technology. The high urbanisation rates in Egypt have resulted in the loss of public space, parking options, and green recreational zones. An EV strategy should, therefore, be designed to go hand in hand with the conservation of cultural heritage and public spaces – for example, by promoting shared mobility options. The replacement of traditional tuk-tuks with similar electric mini-vans could be a solution for retaining Egypt's cultural mobility heritage (El-Dorghamy, 2020).

In terms of societal awareness, Egypt is still at the beginning of the first phase according to the MENA phase model. Public perception and awareness do exist, but they have not yet reached the same levels as in the EU. To overcome this barrier, targeted and large-scale campaigns combined with information and advisory centres could be a step in the right direction. Support and interest in renewables could be enhanced by focusing on the benefits of renewable energy and energy efficiency. Such benefits include energy security as well as positive impacts on health and job creation (European Commission DG Energy, 2019).

However, effectively harvesting the socio-economic benefits of the energy transition towards renewables will depend on the development of domestic supply chains. These could be strengthened by redirecting revenues regionally; for example, by introducing carbon taxes and phasing out fossil fuel subsidies.

In summary, while renewables are in the start-up phase and Egypt has taken its first steps, the transition to system integration requires the scaling up of efforts in several areas. System integration of renewables requires the alignment of regulations for electricity, mobility, and heat. Thus, Egypt must develop and implement an overall strategy to target sector coupling.

4.2 OUTLOOK FOR THE NEXT PHASES OF THE TRANSITION PROCESS

It is evident from the analysis that Egypt has already made considerable progress in the field of renewable energies, including the establishment of economic and legal frameworks. In particular, it has experience with solar and wind power projects. Egypt has a national energy strategy plan (the ISES to 2035), which is a useful short to medium term concept to address challenges in the energy sector. ISES to 2035 is a strategy supported by the EU with a focus on a diversified and sustainable energy mix, based on a series of energy scenarios. The strategy will be updated and extended to 2040 to reflect the increasing role of renewable energy and to integrate a roadmap for the transition to a green economy. Hydrogen is expected to be an important component in the updated strategy. Consequently, this strategy will also comprise new cooperation opportunities with the EU, including hydrogen, EVs, and energy storage (Molina, 2020).

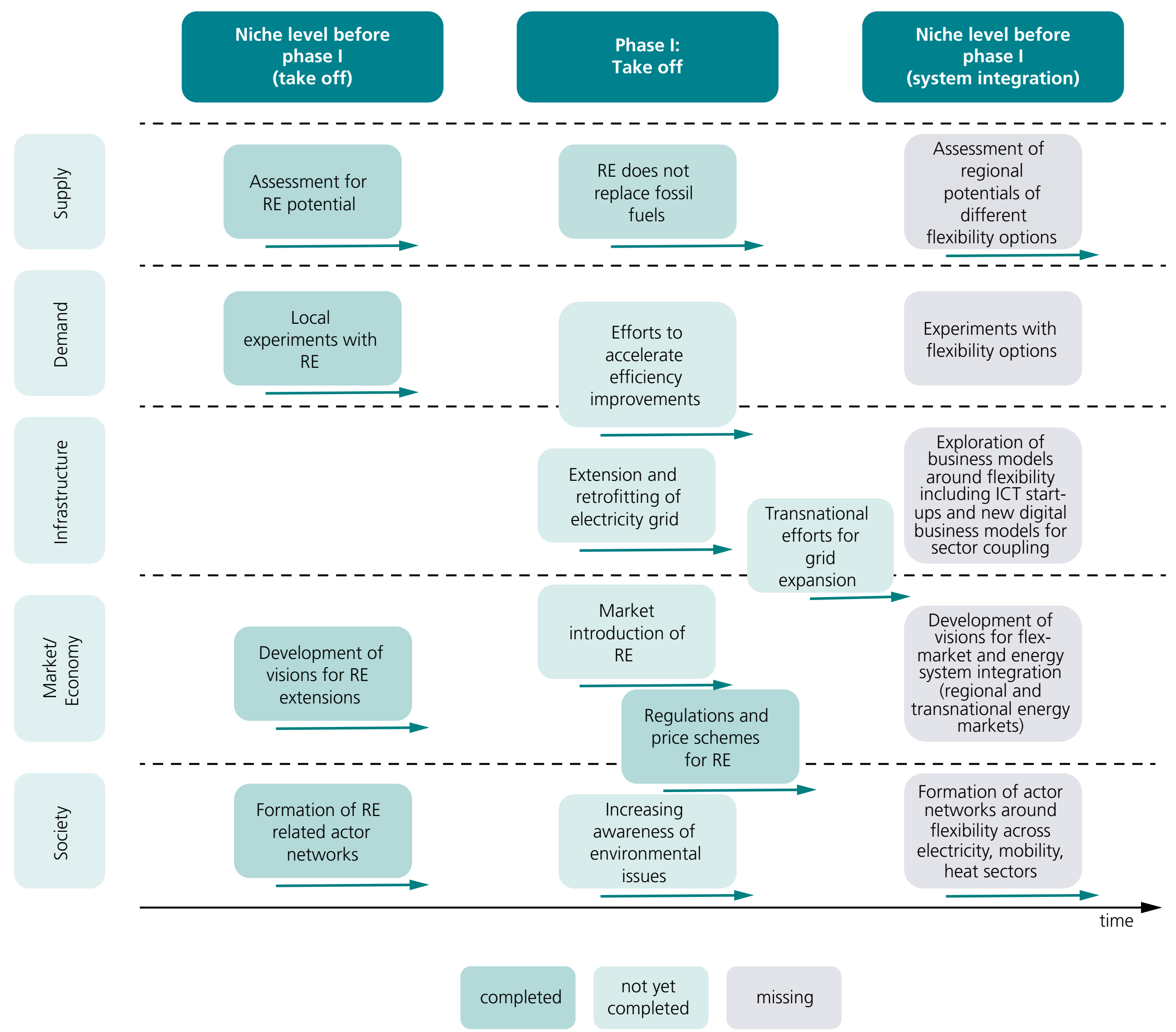
Yet, it takes more than launching a strategy to proceed with the energy transition. The ISES to 2035 is a good starting point that provides a number of recommended actions, but the government needs to ensure that these targets are being met. According to the interviewed experts, conventional resources represent the Egyptian »comfort zone", as they are well accepted by Egyptian institutions and industries. However, the exploitation of natural gas, coal, and nuclear will create not only new path dependencies in the energy system but also potential dependencies on foreign technologies and know-how. Egypt has already gained experience in utility-scale solar and wind projects and has shown how local industries can successfully integrate renewables into their business models. The ISES to 2035 strategy, which includes coal and nuclear power, does not consider the recent price drops of renewables due to global learning effects. This strategy should be revised, seeing as it is based on the least-cost option and that renewables are now cost compatible with coal and nuclear power. Furthermore, if Egypt follows the pathway towards increasing shares of renewables, nuclear power plants will not be a good fit. This is because nuclear power plants are incompatible with the fluctuating nature of renewable energies, meaning that negative residual loads could occur at a later phase when the shares of renewable energies increase. Instead, investment in flexibility options, cross-border grid expansion, digitalisation, and PtX solutions should become priorities.

Moreover, Egypt should immediately consider pathways to industrial decarbonisation, for it is the second most industrialised African country after South Africa. The cornerstones of the Egyptian industrial sector are energy-intensive industries such as the cement, steel, chemicals (the production of fertilisers), and petrochemical industries. With important trading partners around the world aiming at carbon neutrality by 2050, the demand for low carbon products will increase in the long term. In this scenario, if Egypt continues to rely on fossil fuels, Egyptian products will become less competitive – especially with mechanisms such as the carbon border adjustment planned by the EU. Therefore, Egypt would be well advised to develop industrial infrastructure roadmaps, taking into account decarbonisation options for heavy industry.

Egypt's ambition to become internationally recognised as a renewable energy hub is underlined by prestigious projects, such as the Benban solar park. Egypt's recent announcement to develop a hydrogen strategy is a response to the increasing importance of the topic, especially as part of the debate on decarbonisation in industrialised countries. While the phase model foresees hydrogen and PtX capacity development occurring at a later stage (with export only expected in the final stage on the way towards 100% renewables), Egypt has the potential to leapfrog in this area. However, it is important to note that hydrogen development for export should not be undertaken at the expense of Egypt's energy transition. The two pathways, hydrogen and renewable energy, must complement one another.

To achieve a smooth energy transition, it is necessary to be well prepared for the subsequent phases in advance. The current pandemic could present an opportunity for a sustainable energy transition. By supporting the transition to a green economy ahead of or in parallel with the EU countries, Egypt could seize this momentum. Egypt should, therefore, develop a more detailed long-term strategy. The phase model analyses could be the starting point for developing such a strategy, which should include the entire energy system and its transition to a fully renewable energy-based system. Fig. 4-12 summarises Egypt's current status in the energy system transition and provides an outlook for the following steps.

Figure 4-12
Overview of Egypt's Status in the Energy System Transition Model



(Source: data based on IEA, 2020a)

5

CONCLUSIONS AND OUTLOOK

A clear understanding and structured vision are prerequisites for fostering and steering a transition towards a fully renewables-based energy system. The MENA phase model was adapted to the country case of Egypt in order to provide information that would support the energy system's transition towards sustainability. The model, which built on the German context and was complemented by insights into transition governance, was adapted to capture differences between general underlying assumptions, the characteristics of the MENA region, and the specific Egyptian context.

The model, which includes four phases (»Take-off RE«, »System Integration«, »Power-to-Fuel/Gas«, and »Towards 100% Renewables«), was applied to analyse and determine where Egypt stands in terms of its energy transition towards renewables. The application of the model also provides a roadmap detailing the steps needed to proceed on this path. The insights from the analysis and expert interviews allow for a deeper and more detailed understanding of the Egyptian case. Egypt, with its abundant solar and wind energy potential, has excellent preconditions to embark on the pathway towards a 100% renewable energy system. The country has successfully taken its first steps in this direction by attracting international finance and implementing several large-scale solar and wind projects. However, Egypt is also expanding its fossil fuel production and investing in nuclear energy. While this may seem beneficial in the short to medium terms to meet the country's growing energy demand and generate revenue from potentially exporting natural gas, this pathway could result in technological lock-ins and stranded investments. Major trading partners are aiming for carbon neutrality by 2050, which will reduce the demand for fossil fuels and fossil-fuel based products, and financing institutions are increasingly considering the climate risks of their investments, which is decreasing the availability of capital for conventional resource exploitations. By placing stronger focus on renewables large-scale as well as small to medium-sized projects, Egypt could seize the opportunity for economic development within a decarbonising world economy.

To continue in this direction, renewables must become integrated in the energy system. This will require the support and implementation of flexibility options, ranging from tariff adaptations to grid extension and interconnections with neighbouring countries. Furthermore, it will be important to increase participation from the private sector and the general population in the energy transition; otherwise, important developments at the small and medium scales will be hindered.

While Egypt has made significant progress in the energy transition and renewable energy is in the take-off phase, increased efforts are still required for the country to proceed with the transition towards a fully renewables-based system. The results of the analysis along the transition phase model towards 100% renewable energy are intended to stimulate and support the discussion on Egypt's future energy system by providing an overarching guiding vision for the energy transition and the development of appropriate policies.

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LIST OF ABBREVIATIONS

AFD	Agence Française de Développement
bn	billion
BOO	Build, own, and operate scheme
CBAM	Carbon border adjustment mechanism
CCS	Carbon capture and storage
CCU	Carbon capture and use
CNG	Compressed natural gas
COVID-19	Coronavirus disease 2019
CPO	Charging point operator
CSP	Concentrated solar power
DNI	Direct normal irradiation
DSM	Demand-side management
EBRD	European Bank for Reconstruction and Development
EEHC	Egyptian Electricity Holding Company
EETC	Egyptian Electricity Transmission Company
EGP	Egyptian Pound
EgyptERA	Egyptian Electric Utility and Consumer Protection Regulatory Agency
EIJLLPST	Eight Country Interconnection Project
entso-e	European Network of Transmission System Operators for Electricity
EPC	Engineering, procurement, and construction
ESCE	Egyptian Supreme Council of Energy
ESIA	Environmental and social impact assessment
EU	European Union
EV	Electrical Vehicle
GDP	Gross Domestic Product
GHG	Greenhouse gas
GHI	Global horizontal irradiation
GIZ	Gesellschaft für Internationale Zusammenarbeit
HPGC	Hydro Plants Generation Company
ICT	Information and communication technologies
IFC	International Finance Corporation
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
ISES to 2035	Integrated Sustainable Energy Strategy 2035
JCEE	Egyptian-German Joint Committee on Renewable Energy, Energy Efficiency and Environmental Protection
KfW	Kreditanstalt für Wiederaufbau (Credit Institute for Reconstruction)
LNG	Liquefied natural gas
MED-TSO	Mediterranean Transmission System Operators
MENA	Middle East and North Africa
MLP	Multi-level perspective
MoERE	Ministry of Electricity and Renewable Energy
MoMP	Ministry of Military Production
NDC	Nationally Determined Contributions
NEEAP	National Energy Efficiency Action Plan
NREA	New and Renewable Energy Authority
PPA	Power Purchase Agreement
PtF	Power-to-fuel
PtG	Power-to-gas
PtX	Power-to-X
PV	Photovoltaic
R&D	Research & Development
RE	Renewable Energy
SDG	Sustainable Development Goal
SDS 2030	Sustainable Development Strategy 2030
Siemens PTI	Siemens Power Technologies International
UFM	Union for the Mediterranean
USD	US-Dollar

LIST OF UNITS AND SYMBOLS

%	Percent
CO_2	Carbon dioxide
EHV	Extra high voltage
GW	Gigawatt
GWh	Gigawatt hour
HV	High voltage
HVDC	High voltage direct current
km	Kilometre
ktoe	Kilo tonnes of oil equivalent
kV	Kilo Volt
kW	Kilowatt
kWh	Kilowatt hour
LV	Low voltage
m	Metre
m^3	Metre cube
m/s	Metre per second
Mt	Megatonne
Mtoe	Million tonnes of oil equivalent
MV	Medium voltage
MW	Megawatt
MWp	Megawatt peak
TWh	Terawatt hour
W/m^2	Watts per square metre

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ABOUT THIS STUDY

This study is conducted as part of a regional project applying the energy transition phase model of the German Wuppertal Institute to different countries in the MENA region. Coordinated by the Jordan-based Regional Climate and Energy Project MENA of the Friedrich-Ebert-Stiftung, the project contributes to a better understanding of where the energy transition processes in the respective countries are at. It also offers key learnings for the whole region based on findings across the analysed countries. This aligns with FES's strategies bringing together government representatives, civil society organisations along with supporting research, while providing policy recommendations to promote and achieve a socially just energy transition and climate justice for all.

SUSTAINABLE TRANSFORMATION OF EGYPT'S ENERGY SYSTEM

Development of a Phase Model

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A clear understanding of socio-technical interdependencies and a structured vision are prerequisites for fostering and steering a transition to a fully renewables-based energy system. To facilitate such understanding, a phase model for the renewable energy transition in MENA countries has been developed and applied to the country case of Egypt. It is designed to support the strategy development and governance of the energy transition and to serve as a guide for decision makers.

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Egypt, with its abundant solar and wind energy potential, has excellent preconditions to embark on the pathway towards a 100% renewable energy system. The country has successfully taken its first steps in this direction by attracting international finance and implementing several large-scale solar and wind projects. Yet, while Egypt has made significant progress, increased efforts are still required if the country aims to proceed towards a fully renewables-based system. The stronger system integration of renewable energies requires, for example, an alignment of regulations for the electricity, mobility and heat sectors. In this context, Egypt would be well advised to develop and implement an overall strategy for the energy transition that includes not only electricity generation but all sectors.

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By placing a stronger focus on renewable energy, also to decarbonise the industrial sector, Egypt, as Africa's second most industrialised country, could seize the opportunity for economic development within a decarbonising global economy. The results of the analysis along the transition phase model towards 100% renewable energy are intended to stimulate and support the discussion on Egypt's future energy system by providing an overarching guiding vision for the energy transition and the development of appropriate policies.

For further information on this topic:
https://egypt.fes.de
https://mena.fes.de/topics/climate-and-energy

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