STUDY

CLIMATE CHANGE, ENERGY AND ENVIRONMENT

# SUSTAINABLE TRANSFORMATION OF YEMEN'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 Yemen, the study provides a guiding vision to support the strategy development and steering of the energy transition process

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The »solar revolution« in Yemen is focused on small, decentralised applications and is mainly driven by energy scarcity as a result of the ongoing conflict.

→

A shift towards a sustainable energy system in Yemen could contribute to improving the humanitarian situation by providing a secure and affordable electricity supply, achieving environmental benefits, and offering long-term economic opportunities.


FRIEDRICH EBERT STIFTUNG

CLIMATE CHANGE, ENERGY AND ENVIRONMENT

# SUSTAINABLE TRANSFORMATION OF YEMEN'S ENERGY SYSTEM

Development of a Phase Model

Wuppertal Institut

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# 1

# 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. 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 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 (RE) 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 RE 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 – RE is gaining attention in the MENA region. To guarantee long-term energy security and to meet climate change goals, most MENA countries have developed ambitious plans to scale up their RE production. The significant potential in the MENA region for RE 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 RE 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 Yemen. The current state of development in Yemen 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. This application is based on findings from previous studies and projects conducted in the MENA region, while case study specific data was collected for this study by local partners.

# 2

# 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 REs. The four phases of the models correlate with the main assumptions deduced from the fundamental characteristics of RE sources, labelled as follows: »Take-off REs«, »System Integration«, »Power-to-Fuel/Gas (PtF/G)«, and »Towards 100% Renewables'.

The four phases are crucial to achieve a fully renewables-based energy system. In the first phase, RE technologies are developed and introduced into the market. 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, renewabl es fully replace fossil fuels in all sectors.

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

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. 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. The multi-level perspective (MLP) is a prominent framework that facilitates the conceptualisation of transition dynamics (Fig. 2-1).

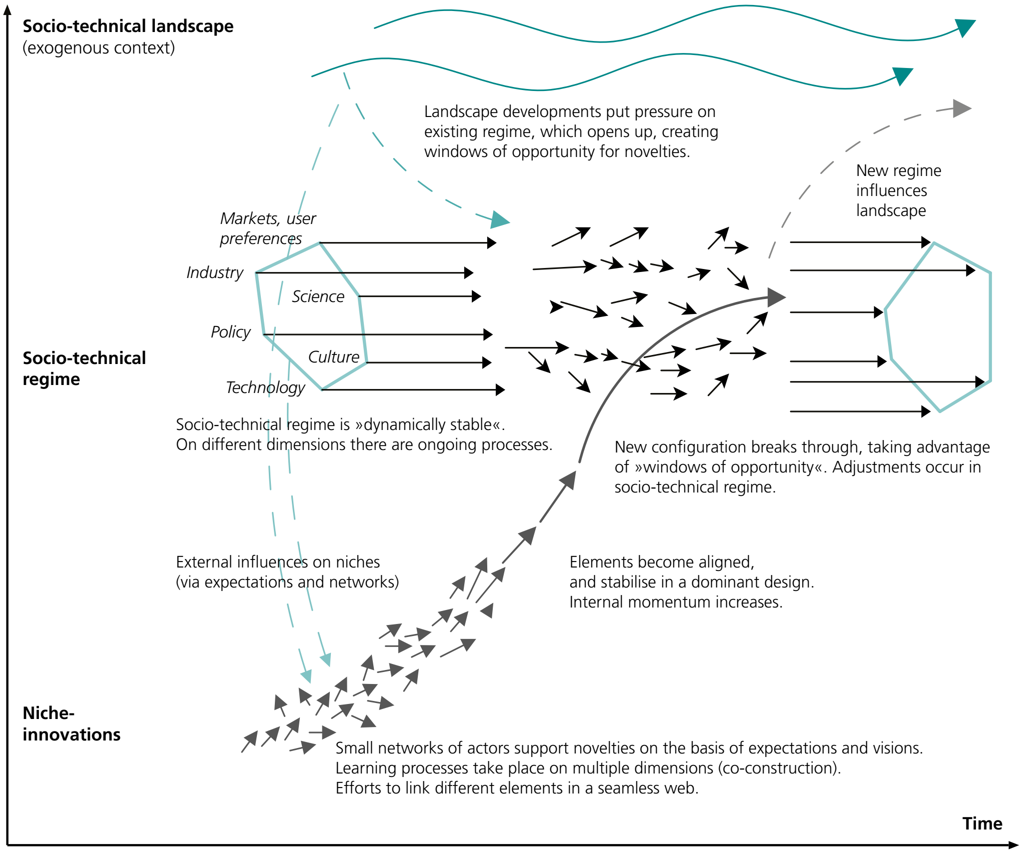
At »landscape« level, pervasive trends such as demographic shifts, climate change, and economic crises affect the »regime« and »niche« level. The »regime« level captures the socio-technical system that dominates the sector of interest. In this study, the regime is the energy sector. It comprises the existing technologies, regulations, user patterns, infrastructure, and cultural discourses that combine to form socio-technical systems. To achieve system changes at the »regime« level, innovations at the »niche« level are incremental because they provide the fundamental base for systemic change (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. Within the transition phases, three stages can be distinguished: »niche formation«, »breakthrough«, and »market-based growth«. In the »niche formation« stage, a niche develops and matures. In the »breakthrough« stage, the niche innovation spreads and when the niche innovation becomes fully price-competitive and specific supportive policy mechanisms are no longer needed, the »market-based growth« stage is achieved. RE 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. 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: RE technologies (phase 1), flexibility options (phase 2), PtF/G 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. Consequently, the addition of the »niche layer« creates a stronger emphasis on the processes that must occur to achieve the system targets (Fig. 2-2).

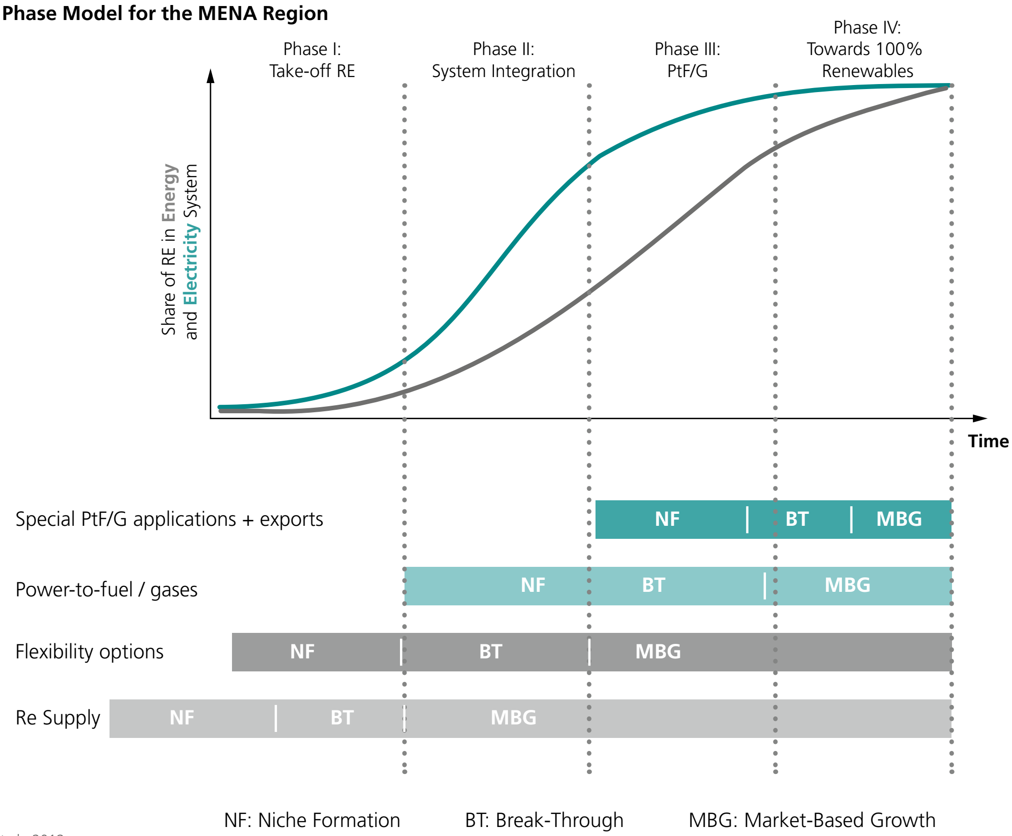
1 Text is based on Holtz et al. (2018).

Figure 2-1
**The Multi-Level Perspective**




Source: Geels and Schot, 2007

Figure 2-2
**Transition Phase Model for the MENA Region**




Source: Holtz et al., 2018

# 3

# THE MENA PHASE MODEL

## 3.1 SPECIFIC CHARACTERISTICS OF THE MENA REGION

One of the 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. 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 RE resources, much of the economic RE 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.

Another 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.

The MENA countries could benefit considerably from global advances in RE technologies. While the phase model for the German context assumed that RE technologies need time to mature, the phase model for the MENA context can include cost reductions. However, the conditions for developing RE 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 photovoltaic (PV) and wind power plants, state-owned companies and large-scale projects take centre stage in most countries in the MENA region. 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 were adapted to correspond to the characteristics of the MENA region.

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. While in Germany imports play a considerable role in the later phases, excess energy in the MENA countries could be exported and offer potential economic opportunities in phase 4. The growing global competitiveness of REs 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

**Phase 1 – »Take-Off REs«**

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 RE, particularly electricity generated by PV and wind plants. As energy demand in the region is growing considerably, the share of RE entering the system would not be capable of replacing fossil fuels at this stage. To accommodate variable levels of RE, the grid must be extended and retrofitted. Laws and regulations come into effect, aiming to integrate renewables into the energy system. 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.

**Phase 2 – »System Integration«**

In phase 2, the expansion of RE 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 information and communication technologies (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. 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.

**Phase 3 – »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.

**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.

Table 31 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.

## 3.4 TRANSFER OF THE PHASE MODEL TO THE COUNTRY CASE OF YEMEN

The MENA phase model originally applied to the Jordan case in Holtz et al. (2018) was applied and partly adapted in the course of this project for nine countries in the MENA region, one of which is Tunisia. The aspects associated to the different phases of the model were discussed with policymakers, representatives from science, industry, and civil society in the respective countries. Based on the experience in Jordan the model proved to be a helpful tool to support discussions about strategies and policymaking in regard to the energy transition in MENA countries. The results of the application to Yemen illustrate a structured overview of the continuous developments in Yemen's energy system. Furthermore, they provide insights into the next steps required to transform Yemen's energy system into a renewables-based system.

In order to reflect the specific challenges and opportunities for the energy transition in Yemen, 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 coronavirus disease 2019 (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, details about 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 and on-site research by local partner institutions. In addition, the local partner organisations helped to identify the country-specific challenges and barriers that could hinder the unlocking of the RE 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 mostly 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.

Expert interviews were carried out in Yemen by the local partners of Yemen Solar, Prof. Marwan Dhamrin and Dr. Abdulrahman Baboraik. They also contributed to the investigation of the country-specific challenges and barriers that could hinder the unlocking of the RE potential in the country. The main interview partners are relevant stakeholders with several years of experience in Yemen's energy sector from political institutions, academia, and the private sector.

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<br>* Niche formation flexibility option | * Market-based growth RE<br>* Breakthrough flexibility option<br>* Niche formation PtF/G | * Market-based growth flexibility option<br>* Breakthrough PtF/G<br>* Niche formation special PtF/G application and exports | * Market-based growth PtF/G<br>* Breakthrough special PtF/G application and exports |
| Power Sector | Landscape level | | * International frameworks on climate change<br>* Decarbonisation efforts of industrialised countries (incl. green recovery programmes after COVID-19 pandemic)<br>* Global and regional conflicts (affecting trade)<br>* Long-term impacts of the COVID-19 pandemic on the world economy<br>* Geographic conditions and natural resource distribution<br>* 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<br>* Niche formation flexibility option | * Market-based growth RE<br>* Breakthrough flexibility option<br>* Niche formation PtF/G | * Market-based growth flexibility option<br>* Breakthrough PtF/G<br>* Niche formation special PtF/G application and exports | * Market-based growth PtF/G<br>* 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<br>* Niche formation flexibility option | * Market-based growth RE<br>* Breakthrough flexibility option<br>* Niche formation PtF/G | * Market-based growth flexibility option<br>* Breakthrough PtF/G<br>* Niche formation special PtF/G application and exports | * Market-based growth PtF/G<br>* 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 YEMEN

| ***Factsheet*** | |
|---|---|
| Paris Agreement ratified | ✔ |
| Green growth strategy | ✗ |
| Renewable energy targets set | ✔ |
| Regulatory policies for RE implementation established | (✗) |
| Energy efficiency strategy existing | ✗ |
| Power-to-X (PtX) strategy | ✗ |

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

Yemen has been devastated by civil wars and political unrest in the past decades. The conflicts have left their mark on the country, which has been labeled by UNICEF (2021) as »one of the largest humanitarian crises in the world«. As a result of the war, the public electricity grid was destroyed, leaving the majority of citizens without electricity. Thus, the use of decentralised solar technology has become an important alternative for the generation of electricity for self-consumption.

However, Yemen's energy mix and economy are still dominated by fossil fuels. Revenues from oil production constitute the largest share of the country's government revenues and exports. Consequently, the country's economy is exposed to the fluctuations of oil prices in the world market. Moreover, generous fuel and electricity subsidies exacerbate the fiscal situation of Yemen (Atamanov, 2017). Against this background, RE technologies have become relevant for increasing the electricity supply and electricity access in isolated areas (Al Asbahi et al., 2020). In the future, renewables could play a bigger role, seeing as Yemen has rich renewable potentials, especially for solar, wind, and geothermal energy generation (Qasem, 2018).

This report studies the current energy and electricity status of Yemen, assesses the country along the phase model, and gives a guiding outlook on how to achieve the next phases for the transition towards a renewables-based energy system.

### 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 Yemen's energy system in terms of supply, demand, the fossil fuel sector, RE, infrastructure, actor network, and market development.

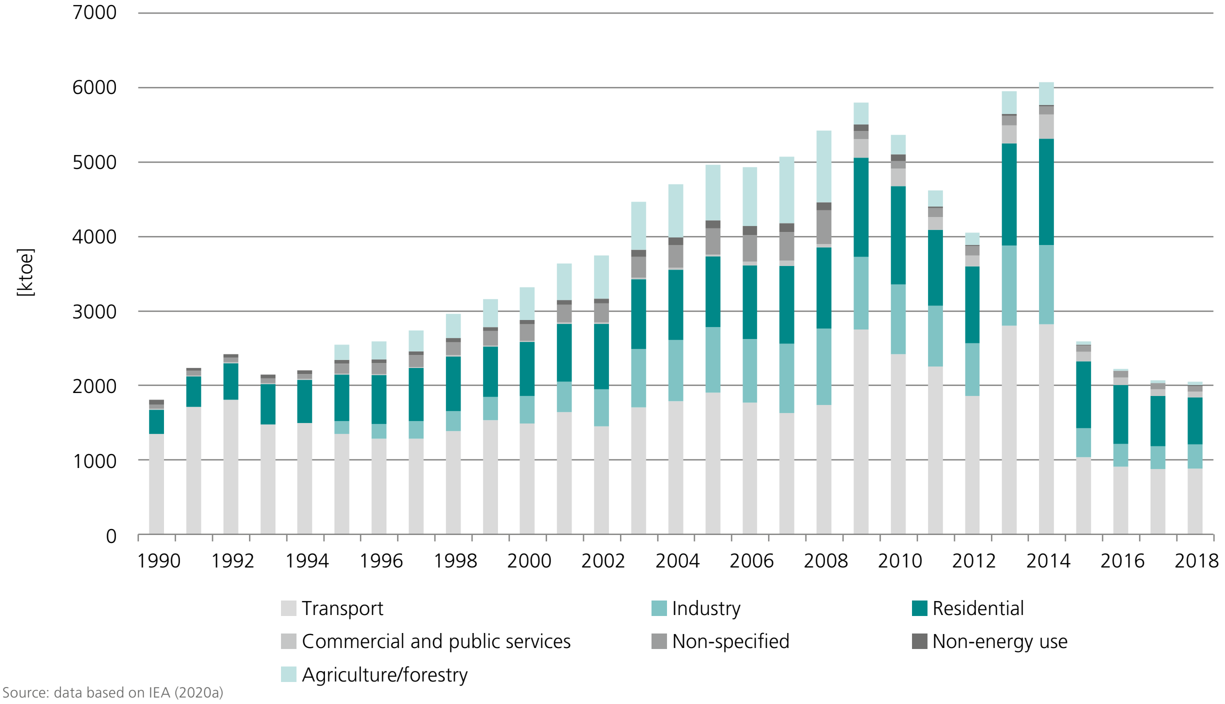
**Energy Supply and Demand**

Yemen's energy supply is characterised by critical shortages and power deficiencies. This situation has intensified during the military operations since 2015. In 2018, Yemen's total final energy consumption was 2,051 ktoe (IEA, 2020a). The residential sector dominated energy consumption (31%), followed by the transport sector (43%), industry (16%), and others (10%) (IEA, 2020a) (Fig. 4-1).

In 2018, the energy mix was dominated by fossil fuels (Fig. 4-2), with heavy fuel oil (HFO), light fuel oil (LFO), and diesel constituting around 90%, natural gas accounting for 3%, coal for 2%, while biofuels and waste had in total a share of 4%, and other REs 1% (IEA, 2020a).

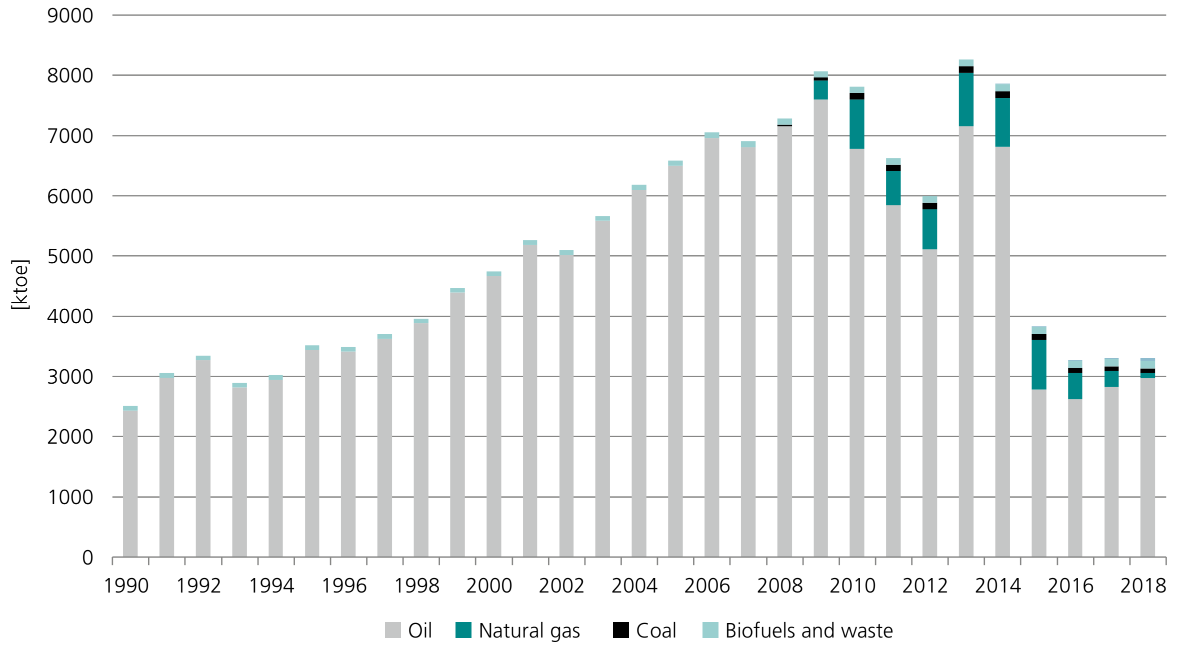
Yemen's current electricity demand remains unserved for most governorates. Although the Public Electricity Corporation (PEC), which runs the electricity transmission and power production in Yemen, has an installed capacity of 1.5 GW, the actual power production remains well below the actual available nominal capacity (Almohamadi, 2021). After 2013, barely around 1.1 GW of the installed capacity was utilised. This is due to the closure of several generation units in the power plants because of their low efficiency, constant failures, high losses in the power system, and grid dismantling and cuts. In addition, there are several isolated grids, such as Hadramaut with a capacity of 150 MW, or small isolated grids in Al Mahrah, Sada, and Shabawa. The regions of Sana'a, Aden, Al Hudaydah, Ibb, and Hadramaut face electricity shortages and outages that last several hours per day (Mubaarak et al., 2020). According to Mubaarak et al. (2020) and expert interviews, Sana'a usually needs a capacity around 500 MW, while Aden requires 390 MW, Hadramaut demands 276 MW, Al Hudaydah and Ibb need

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




Source: data based on IEA (2020a)

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




Source: data based on IEA (2020a)

280 MW in total, and Taiz requires 111 MW, all of which cannot be met.

The deficit in the electricity production is a result of outdated and inefficient power plants, the destruction of electricity infrastructure during the war, and sabotage attacks on power towers and stations (Al-Fakih & Li, 2018; Almohamadi, 2021). Even with the grid conditions before the war, the power infrastructure was too fragile to meet Yemen's demand. The damage caused during the war has exacerbated the situation, leading to a near collapse of the national electricity grid (Almohamadi, 2021). As a result, the Yemeni population has the lowest level of electricity access in the MENA region, for only 40% of the population is connected to electricity (Alkholidi, 2013; Al-Saidi, 2020b; Baharoon et al., 2016). There are several small diesel power plants across the country located in rural areas that are isolated from the national grid. They belong to either the PEC or to the private sector. Some of these diesel power plants provide electricity just for several hours per day. Rural areas are the most impacted, but industrial and service facilities, hospitals, commercial shops, and hotels also cannot rely only on the grid. Thus, they operate their own diesel-powered back-up generators. The lack of electricity access and power shortages affect vulnerable groups as well as the operation of other sectors such as water, sanitation, industrial production, health services, food storage, transportation, and schools (Al-Saidi, 2020b). Additionally, the energy crisis is responsible for water and energy tariff increases that add to the financial distress of households and the commercial sector. Plans from several governments to build power plants have been discussed and were about to be implemented, but they have been suspended due to the war.

The typical day and annual load curve are mainly influenced by the household sector, which accounts for around 73% of the electricity consumption. The peak electricity consumption in Yemen is recorded between 7 and 23 pm with average hourly power demand between 1,300 and 1,500 MWh. The maximum load is at 23 pm, whereas the minimum load is recorded at 6 am. During the fasting month of Ramadan, the load curve deviates from this usual pattern and has a peak that lasts all night from evening to 4 am. In terms of seasons, the minimum load occurs in January and gradually increases until it reaches its peak in June, which continues until the end of September. Afterwards, the demand decreases starting from the end of summer until the end of January (PEC, 2021).

The electricity consumption per capita rarely exceeds 255 kWh annually, which represents the lowest rate compared to the average per capita rate in the MENA region (2,900 kWh) (Almohamadi, 2021). Even with less than 2 million subscribers connected to the national power grid, PEC is unable to meet the demand. The ongoing conflict widens the gap between supply and demand and makes it difficult to maintain and upgrade existing power plants or build new ones.

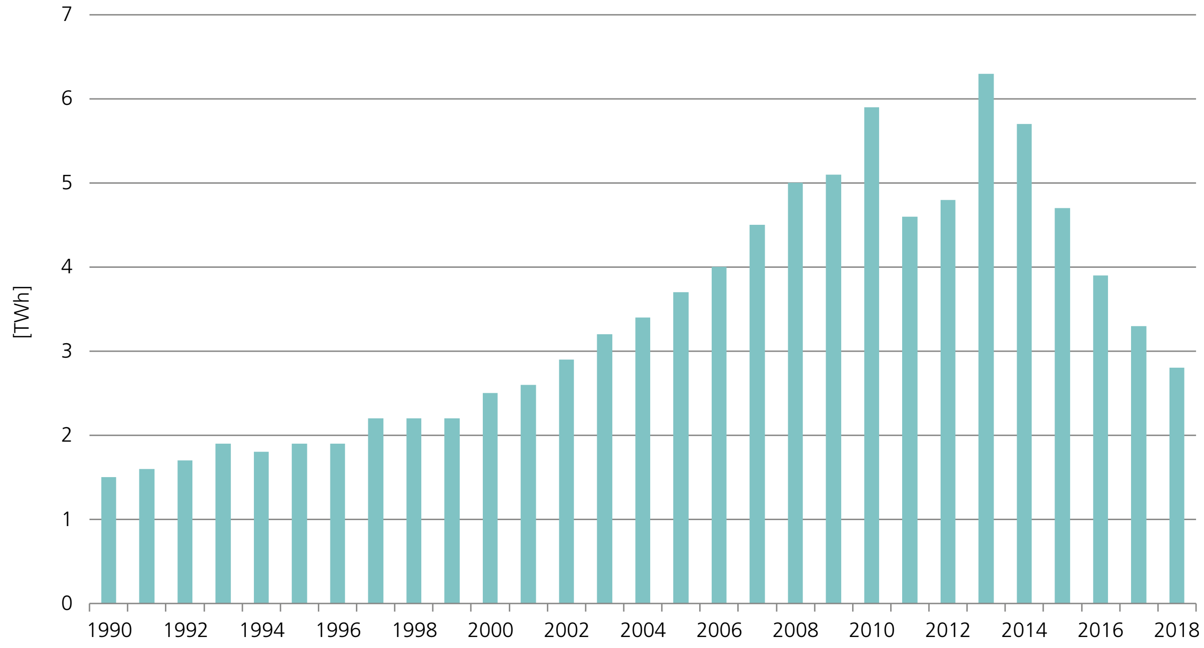
Electricity consumption in 2018 amounted to around 2.8 TWh, which is almost half the electricity demand in the beginning of the last decade (Fig. 4-3). In the Fichtner electricity projection the following three scenarios were elaborated on: installed capacity requirement at 3,081 MW for a base demand case, 3,658.3 MW for a high demand case, and 1,842.2 MW installed capacity for a lower demand case. These scenarios excluded the industrial and commercial sectors and considered the 40% of the population connected to the main distribution network. This underlines the current high latent demand for electricity in Yemen.

Fig. 4-4 depicts electricity generation by source, highlighting the role of oil (HFO, LFO, and diesel) as the most important electricity generation source throughout the history of Yemen's power supply, with a share between 60–99% in the electricity mix since 2008. In 2009, when the Marib I gas power plant (with an installed capacity of 340 MW) started its operation, natural gas diversified the power mix and accounted for 20–40% of the power generation. In 2015, the power plant stopped its operations because of the war. In 2018, natural gas held a share of nearly 9%, while solar PV, for the first time, contributed a record share of 13%.

To sum up, the electricity supply sector in Yemen can be divided into the following three components: 1) the grid connected electricity generation by power plants in Sana'a, Aden, Taiz, Hodeidah, Dhamar, Rada, Yarim, Ibb, Al-Dhale, Lahj, Abyan, Amran, Al-Mahwit, and Hajjah; 2) off-grid electricity generation by power plants in Hadhramout, Al-Mahra, Socotra, Shabwa, Saada, Al Jauf, and Rayma; and 3) small-scale decentralised electricity generation traditionally by diesel generators but increasingly also by solar energy technologies (Almohamadi, 2021). The war has severely damaged the existing electricity infrastructure, especially the central grid, which is concentrated around the urban centres and served only 40% of the population to begin with (Ansari et al., 2019). It is estimated that during the war around 55% of the electricity infrastructure has been damaged and 8% has been destroyed (ibid.).

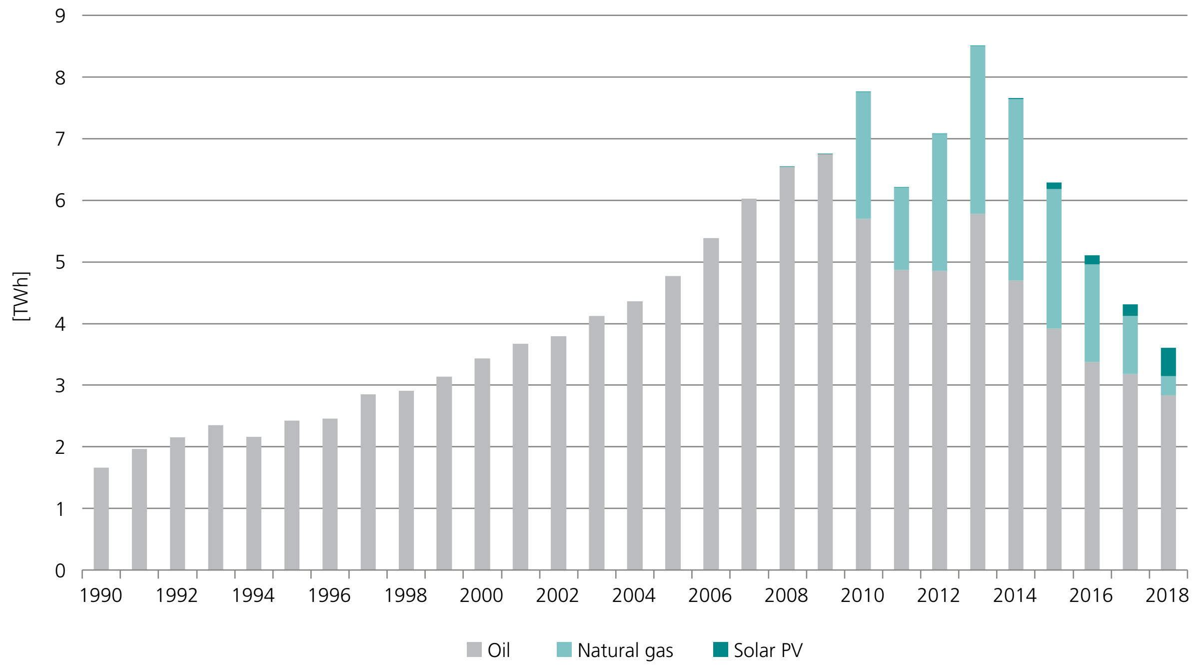
Moreover, the demand for electricity in the grid connected areas cannot be met. In addition to the supply challenges, the demand is also growing due to population growth. As a result, load shedding occurs daily in a way that basic needs cannot be met and essential public services cannot be provided. To meet daily energy needs, the majority of the population, especially in rural areas, use biomass resources for residential cooking and heating, which contributes to deforestation (Alkholidi, 2013). Industrial companies, hospitals, and hotels use private back-up generators in order to secure their daily needs. Clearly, Yemen possesses an outdated, partly destroyed, and insufficient energy system, which is unable to meet the demand for electricity. Furthermore, renewables are currently playing only a marginal role in the country. Due to these factors, Yemen can be classified as being in the pre-phase of the initial phase described in the applied MENA phase model.

Figure 4-3
**Electricity Consumption (in TWh), Yemen 1990–2019**




Source: data based on IEA (2020a)

Figure 4-4
**Electricity Generation by Source (in TWh), Yemen 1990–2019**




Source: data based on IEA (2020a)

**Renewable Energy**

*Solar*

The annual average solar insolation in Yemen ranges between 5.2–6.8 kWh/m²/day (Al-Ashwal, 2016; Sufian, 2019). The governorates of Al Beida and Dhamar in the central-western region account for the highest annual average radiation levels at around 6.8 kWh/m²/day (Sufian, 2019). The regions of Amran, Sana'a, Ibb, Al-Dhalee, and Marib receive an insolation between 6.6–6.7 kWh/m²/day. The areas of Hajjah, Al Mahwit, Al Hodeida, and Al Mahara have the lowest insolation levels at 5.4–5.8 kWh/m²/day, while the governorates of Al Jowf, Shabwa, and Hadramout receive 6.0–6.3 kWh/m²/day. Insolation in the Yemeni island Socotra ranges around 6.6 kWh/m²/day (ibid.). Hence, in general, Yemen has rather suitable conditions to harvest solar energy, seeing as the total technical solar potential is estimated at around 17 GW for large scale concentrated solar power (CSP) and at 2.2 GW for solar PV systems (Sufian, 2019).

Moreover, renewables benefited from the energy crisis in Yemen. Initially, after the public grid was unable to provide reliable electricity, the Yemeni population responded by using more diesel generators (Ansari et al., 2019). However, due to fuel shortages, this option became less attractive, which paved the way for the increasing use of solar energy. This has been dubbed »Yemen's solar revolution'. Indeed, Yemen had already began experimenting with solar energy in 1980 with its first Solar Research Group at college of Physic in University of Sanna. Nevertheless, real application of solar energy in Yemen started at a later stage in time and can be described in the following four stages:

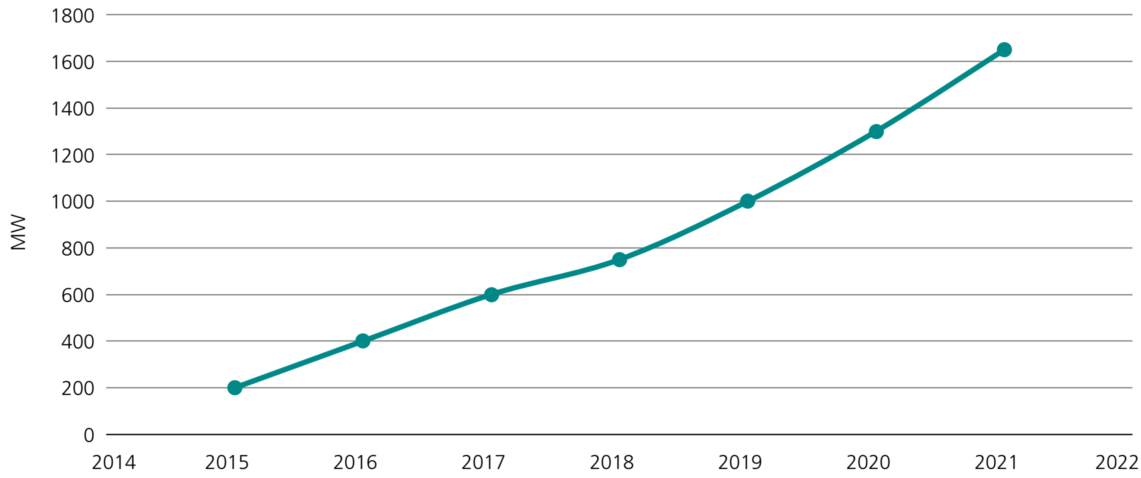
1) First stage (2010–2015): Solar energy became one of the methods in off-grid areas to meet the electricity demand, and diesel shortages started to develop at the beginning of the conflict in 2011. Yet, the cost of the PV system was much higher than that of small diesel generators, which dominated the market.
2) Second stage (from the start of the war in 2015 to 2017): The severe diesel and gas shortages in the country because of the war allowed for solar energy to become the most popular and suitable option to secure people's basic needs for electricity.The annual capacity of the solar PV energy amounted to 200–250 MW. However, cheap and low-quality solar panels dominated the market; according to experts, around 70% of the PV system's components, mainly modules and batteries, were forged or were of low quality.
3) Third stage (2018–2019): The demand for PV systems in the residential sector decreased due to the significant failure and weak performance of the installed PV systems. Most of the people returned to buying electricity from local commercial diesel generators owned by the private sector. This, in turn, motivated traders to start importing only high-quality PV components. Furthermore, a large amount of PV capacity in the agricultural sector was installed by farmers, who began to replace diesel systems with solar PV for the water pumping systems. It is estimated that the annual capacity of the solar PV energy increased by approximately 200 MW in 2018 and amounted to 300 MW in 2019.
4) Fourth stage (2020 to October 2021): Slightly larger PV systems with a capacity of around more than 100 kW in the agricultural, commercial, and industrial sectors started to be applied. Moreover, in May 2020, the republican decree for the exemption from customs and taxes contributed to increasing the application of the PV systems. In other words, the total capacity of the imported PV systems was around only 250 MW from the beginning of 2020 until May 2020, while it reached about 350 MW after the decree (by the end of 2020).

Solar energy rapidly gained popularity, as it provides secure and reliable electricity. During the ongoing conflict, solar energy has, in many regions, become the most important energy source for households, particularly the agricultural sector, which in turn played an important factor in enhancing food security during the war and maintaining the stability of agricultural prices to some extent. It has also become a significant energy source for medical and educational facilities as well as hotels.

According to experts, the current solar generation exceeds the conventional electricity generation. The official governmental data reported that in 2013 the actual capacity was 1.1 GW, which was well below the installed capacity of 1.5 GW (Almohamadi, 2021). Data after 2013 is nearly unavailable, and experts assume that the actual capacity has further decreased since then. According to estimates that differ from the official statistics, about 1,650 MW of solar systems were installed in 2021. (Fig. 4-5). All of the solar energy generation is private and off-grid. However, not all this capacity is functioning efficiently due to the low quality of the solar systems, inaccurate installation, and some damages from bombing. Furthermore, professional, qualified installation and maintenance of solar energy systems remain high challenges in Yemen and often cannot be ensured due to the lack of skilled personnel (Ansari et al., 2019).

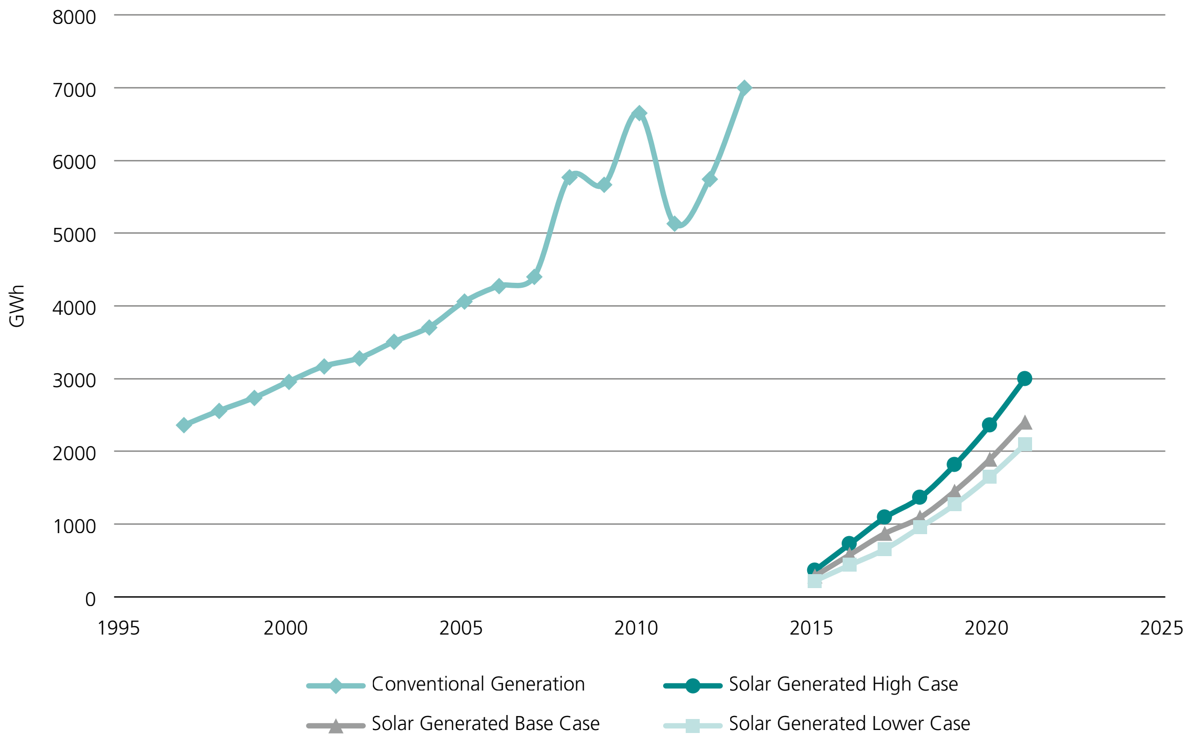
It is estimated by the Yemeni experts that many of the PV systems installed before 2018 are out of service. Yet, there is no official data on the performing output of the PV systems, which can vary greatly according to the quality of the modules and the installation expertise from technicians. To better evaluate the performance of the solar modules from 2015–2021, three hypotheses (cases) on the total generated electricity output were explored: 1) Solar generated base case assumes a performance of 80% of the modules, 2) solar generated low case assumes a 60% performance for the years 2015–2017 and a 70% performance for the years from 2018 onwards, and 3) solar generated high case assumes that all the technical potential of the solar modules can be met, as the installation of the modules follows the right angle and inclination by the technicians preventing any technical losses. Fig. 4-6 depicts the solar generation for the three cases until 2021 compared to the conventional gen-

Figure 4-5
**Installed Solar Modules (MW)**




(Source: own compilation, data provided by Marwan Dhamrin)

Figure 4-6
**Electricity Generation With Conventional Sources Until 2013 (Statistical Data) and Estimations on Solar Power Generation After 2015 (GWh)**




Source: own compilation, data provided by Marwan Dhamrin eration provided by the government owned stations until 2013 (private generation is not included).

Accordingly, the solar energy business in Yemen increased remarkably from 2015 onwards. In 2016, the Food and Agriculture Organisation (FAO) started the Enhanced Rural Resilience in Yemen (ERRY) project to enhance the resilience of rural communities, hence supporting the uptake of solar energy (Al-Saidi et al., 2020a). As part of this project, solar water pumping systems and solar-powered desalination pilot projects have been established.

Despite the customs exemptions that have been implemented in May 2020 for renewable technology, the closure of the majority of shipping ports greatly contributed to increasing PV component prices and to delaying the arrival time of shipments. Currently, most of the PV components, such as solar panels, batteries, and electric wires, are imported from China and India. As the majority of the Yemeni ports are closed and controlled by Coalition forces, the equipment enters via Salalah in Oman, then the Yemeni port Shahn, and it requires around 3–4 months to reach the main stores in Yemeni cities. Before May 2020, the custom fees on PV modules amounted to 18.5%, while the percentage of customs on batteries and inverters ranged between 22–24% of the total cost. After the introduction of the customs exemption law, the tariffs decreased to 3% and 1% for land and sea shipments, respectively. This decree of customs exemptions has been introduced only for the traders who provide quality test certificates according to the international standards of the International Electrotechnical Commission (IEC). As a result, the solar energy market noticed a considerable change in terms of products, as traders and customers began to realise the importance of purchasing high-quality PV components rather than cheap products with a lower quality. First contracts were signed by traders with the international company Trina Solar. In 2020 and 2021, it is estimated by the Yemeni experts that between 45% and 50% of the total shipped PV modules were from well-known international companies. For instance, until the end of October 2021, 100 MW of Trina PV modules and 60 MW of Jinko PV modules were shipped to Yemen.

Despite the boom of small-scale systems, there are currently no large-scale solar energy projects. The largest PV projects in Yemen are as follows:

1) 2.2 MW Hadiboh Solar Farm in Socotra used to store and fishes to be exported;
2) 800 kW Qalansiyah Solar Farm in Socotra used to operate big refrigerators for fishing industry;
3) 610 kW-PV power plant that supplies a water station in Bir Al-Nasser in Aden city;
4) 537 kW-PV power plant that supplies a water station in Thala in Mukalla city;
5) 505 kW-PV power station that supplies the water station in the Samah field in Dhamar city;
6) 300 kW-PV power plant that supplies the Republican Hospital;
7) 256 kW-PV power plant that supplies the water station in the Al Nawaem in Hajah city; and
8) 206 kW-PV power plant that supplies Saudi German Hospital in Sana'a City.

Despite the boom of small-scale systems, there are currently several main obstacles to developing PV systems above 50 kW, particularly in the C&I sectors. Firstly, there are financial barriers like the lack of financing mechanisms as well as difficulties to obtain high-quality components (such as inverters, control systems, instrumentation and measurement tools) for the hybrid PV systems. Secondly, technical challenges, such as the absence of data about the current electrical system and insufficient engineering expertise, hinder the market expansion. Finally, long-term guarantees from PV installers and contractors are not provided for the owner. To address some of these challenges, a law was issued in 2021 to develop local codes and requirements for installing PV systems in buildings and other facilities.

In spite of its overall success, the use of solar energy is characterised by a big geographical discrepancy. While 85% of the households in mountainous areas around Sana'a own solar panels, other governorates, where the grid still works like in the east, south, and in Aden, have rather small shares of solar systems (Ansari et al., 2019). The latter regions are either connected to the public grid and receive limited supply from PEC, or they have a better access to the supply of diesel to run conventional generators. Although the implementation of solar energy in Yemen has been successful and is already playing a crucial role in supplying the country with electricity, barriers to its wider uptake remain.

*Wind*

To exploit wind energy resources, a wind resource map has been developed, which shows Yemen's high wind energy potential. Based on this map, the technical potential for wind power is estimated to be around 34 GW (Sufian, 2019). Appropriate sites that could potentially provide more than 3,000 full load hours would be able to produce around 14 GW, while sites with 3,500 full load hours could generate 2.5 GW (Al-Ashwal, 2016; Sufian, 2019). The average annual wind speed at the coastal strip exceeds 8 m/s, resulting in high potentials for on and off-shore wind energy (Alkholidi, 2013). Specifically, the coasts of the Red Sea and the south-west coastal area of Yemen have high wind potentials. The north-west area of Mokha, in particular, is one of the most suitable zones for wind power installation. According to estimates, this region could provide around 2 GW of wind power, as the average annual wind speed amounts to around 7.4 m/s (ibid.). In addition to the potential wind speeds, advantageous open spaces and the existing transportation infrastructure make Mokha especially attractive for wind energy projects. Moreover, the Yemeni island Socotra receives high wind speeds between 5–12 m/s. The capital Sana'a enjoys wind speeds between 4.1–5.2 m/s, while Aden records wind speeds of 3.7–5.9 m/s, and Taiz receives 6 m/s as maximum wind speeds (ibid.). However, despite the wind energy potential being among the best worldwide, there are currently no wind farms operating in Yemen. Projects that have been developed before the war, such as the Al Mokha at the Red Sea with a capacity of 60 MW, have been suspended due to the political turmoil (Alkholidi, 2013). As well as the ongoing war, the complicated bureaucratic decision-making structures and the lack of a dedicated authority are further critical obstacles to the development of wind energy projects, according to experts.

*Geothermal*

Due to Yemen's optimal location at the intersection of three tectonic plates, the country has a high geothermal energy potential (Sufian, 2019). According to Al-Fakih and Li (2018), Yemen has eight promising fields for harvesting geothermal energy: Al-Lisi Esbil, Damet, Alkafer-Aldrabi, Alsyani-Algandyah, eastern and southeastern Taiz, Resyan-Aldhbub, and Kirsh. These fields could potentially generate 28.5 GW (Al-Ashwal, 2016). Furthermore, there was a project to build geothermal power plants in Dhamar city in Alisi and Isbel, as they represent the most promising fields that are close to the national transmission network. The power plants would have constituted a total capacity of 125–250 MW, backed by a power purchase agreement (PPA) model. Although the initial engineering works started, the project was suspended because of the war and local conflict.

According to the experts, the geothermal energy fields in Yemen are distinguished by their location in the middle of population growth areas, their proximity to agricultural regions that have high carbon dioxide reserves, and their proximity to the national grid, which makes these sources more competitive and economically feasible.

*Hydro*

Hydropower is considered an unsuitable RE technology in Yemen, as the country has low levels of water availability, which is most needed for agricultural production (Sufian, 2019). The wadi riverbeds in Yemen are normally dry, and infrequent peaks and runoff make the water availability highly uncertain. Water storage projects and reservoirs that are under development take into consideration only the use of drinking water supply and irrigation and not the electricity production. The high evaporation rates and the infrastructure connection to demand centres remain challenging for this source of energy.

*Ocean Energy*

Ocean energy has not been considered in the political discussion, although studies have assessed different types of ocean energy potentials. According to interviewees, wave energy assessments have been conducted in the Red Sea in the Bab al-Mandab area, but the southern part of the coastal area (Gulf of Aden and the Arabian Sea) was not included. The results indicate that the wave energy potential ranges between 2–3.5 kW/m in this area, with considerable wave activities observed during the winter months. Additionally, tidal energy assessments concluded that for the same area the annual average tidal height ranges between 1–1.5 m. Despite the suggestion for sea-based turbines, no experimental measurements or pilot studies have been conducted. The southern coast is characterised by a large temperature difference between the surface and deep-sea water. This difference could be used to generate electricity and desalinate water through ocean thermal energy projects. However, the ocean energy technology is still at a very premature stage and faces challenges of high costs. Therefore, adopting ocean energy is a potential option to generate electricity, but it is neither feasible nor compatible under the current circumstances.

*Biomass*

Yemen could also generate energy from biomass. However, according to Sufian (2019), the potential from crop and forest residues is minimal. Yet, biogas could be an option for large-scale farms or at wastewater treatment plants. For the region of Aden, it is estimated that potentially 0.53 MW of biogas could be generated for heating, lighting, or cooking (Sufian, 2019). Several small-scale biogas power plants are operating in villages within Yemen, and one pilot project (biomass power plant) with a capacity of 100 kW is located in Lahj.

*Renewable Energy Regulation*

The deployment of RE systems in Yemen started in 2003. Back then, the government provided funds to increase the use of small-scale technologies (such as PV systems), especially in remote areas with no access to the national grid (Baharoon et al., 2016) fuel crises and poverty in Yemen and most developing countries is a crucial issue, which is significantly influenced by the psychological, contextual, and personal factors affecting public acceptance. This study aims to determine the personal and psychological determinants that influence the public's knowledge of and attitudes and behavioral intentions toward solar energy use in the power sector in urban and rural areas in Yemen. In this study, the people's behavioral intentions are evaluated by measuring their willingness to pay, willingness to change the currently used electricity source during power outages, and willingness to invest in the feed-in tariff (FiT. Under the Rural Electrification Policy Statement (REPS) (approved in July 2008), the vision to implement a rural electrification program was introduced. This, in turn, allowed for the development of more off-grid projects in rural areas and focused on the use of community and consumer-based service providers (Ajlan et al., 2016; The World Bank, 2009). Within this framework, a large number of Solar Home Systems (SHS) have been installed in off-grid areas.

In June 2009, the government approved the National Strategy for Renewable Energy and Energy Efficiency that aimed to increase the RE share in the electricity mix and to decrease the total expenditure on diesel fuel. The RE targets for grid electricity were divided into three different scenarios:

1) the high scenario projected a share of 20% renewables in the generation mix by 2025 (3,467 GWh);
2) the baseline scenario, which was publicly announced in official governmental events, targeted a 15% RE share in the power sector by 2025 (2,600 GWh); and
3) the low market penetration scenario foresaw a share of 10% renewables in the generation mix by 2025 (1,733 GWh).

The off-grid targets for the respective scenarios were set as follows:

1) in the high scenario, 160,000 rural households (65% of the identified market potential) should be electrified with PV systems until 2025, with a total installed capacity of approximately 8 MWp;
2) in the baseline scenario, 110,000 rural households (45% of the identified market potential) should be electrified with PV systems until 2025, with a total installed capacity of approximately 5.5 MWp; and
3) in the low market penetration scenario, 60,000 rural households (25% of the identified market potential) should be electrified with PV systems until 2025, with a total installed capacity of approximately 2.5 MWp.

The grid-based RE targets for the baseline scenario are summarised in Table 4-1 for each individual technology. These are the most common targets raised in government speeches and official events.

Table 4-1
**Targets of the National Strategy for Renewable Energy**

| Energy source | Target (MW) |
|---|---|
| **Wind** | 400 |
| **Landfill gas** | 6 |
| **Geothermal** | 160 |

(Source: data based on expert interviews)

For the heating sector, the National Strategy for Renewable Energy and Energy Efficiency highlighted the utilisation of solar water heaters. The following were the most important targets:

1) in the high scenario, 300,000 units, which represent 60% of the market potential, shall be installed until 2025, saving around 686 GWh;
2) in the baseline scenario, 200,000 units, which represent 40% of the market potential, shall be installed until 2025, saving around 457 GWh; and
3) in the low scenario, 100,000 units, which represent 20% of the market potential, shall be installed until 2025, saving around 229 GWh.

Furthermore, the National Strategy for Renewable Energy and Energy Efficiency intended to facilitate investments from the private sector to create a regulatory office (Electricity Sector Regulatory Board) and a new authority (Rural Electrification Authority). However, due to the ongoing civil war, these targets currently seem out of reach.

Prior to this strategy, a power sector reform strategy was approved in 2001. This strategy aimed at separating generation, transmission, and distribution. It also planned to create an independent regulatory agency to enhance the competition in the generation sector. Its other objectives included transforming the PEC into a corporate facility, introducing unbundled electricity tariffs, and privatising electricity businesses (ibid.). These goals, however, have not yet been implemented.

The Ex-Minister of Electricity Mustafa Bahran promoted the Bahran Vision 20/20. This vision concentrated on energy market restructuring, regulations, and policies, aiming to increase the total electricity production up to 20 GW by the end of 2020. The use of gas, wind, geothermal, and CSP were proposed to diversify the electricty mix. This vision, nevertheless, has not been approved by the Yemeni government.

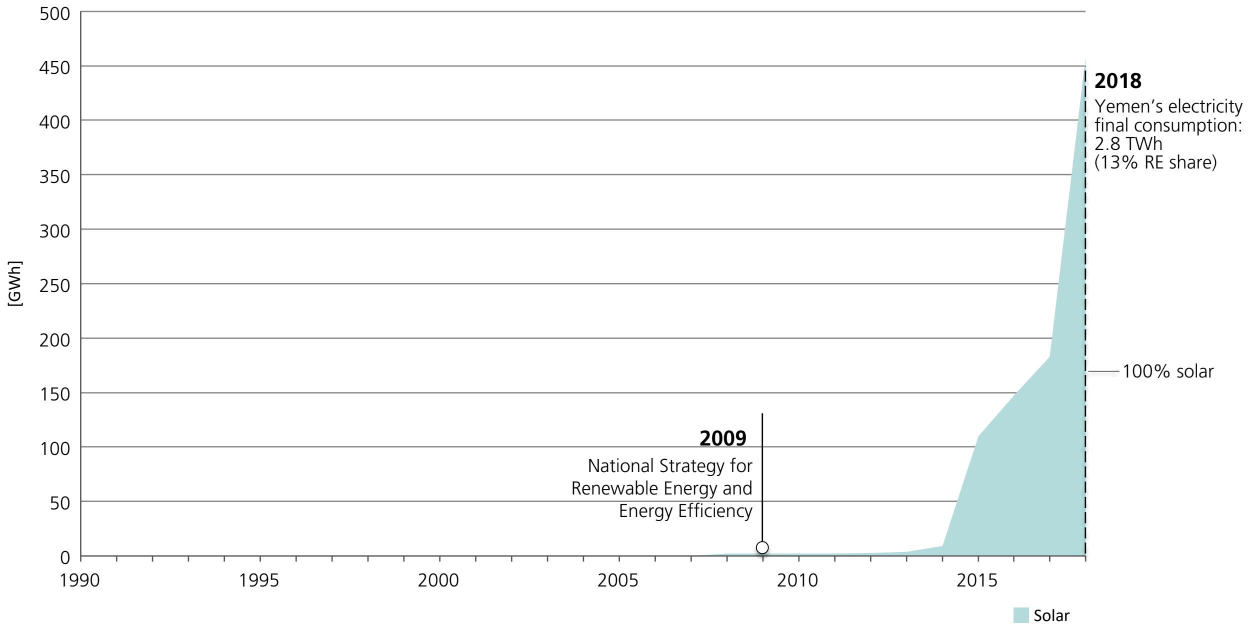
Fig. 4-7 depicts the introduction of the described energy policy measures and the renewable electricity generation by year. The graph shows that the policy measures did not impact the growth in solar energy use. In fact, the growth occurred mainly due to the circumstances that evolved during the war, which created a need for alternative electricity sources. Fig. 4-7 illustrates that solar PV systems became reliable sources of energy during the conflict and began to be widely applied by Yemeni households and farmers.

In summary, the Yemeni government seems incapable to increase the deployment of REs, as the war has led to a severe dysfunction of the institutional arrangement. However, the military conflict has contributed to the wide use of solar energy out of necessity, seeing as other sources were short in supply, expensive, or unavailable. The implementation of solar energy seems, therefore, to be needs-driven rather than politically motivated. Yet, so far, there are no large-scale projects, the overall share of solar energy in the mix remains low, and there is no regulatory framework in place. Accordingly, renewables still hold only a niche position in Yemen. Therefore, Yemen can be classified as being in a pre-phase of the MENA phase model.

**Fossil Fuel Sector**

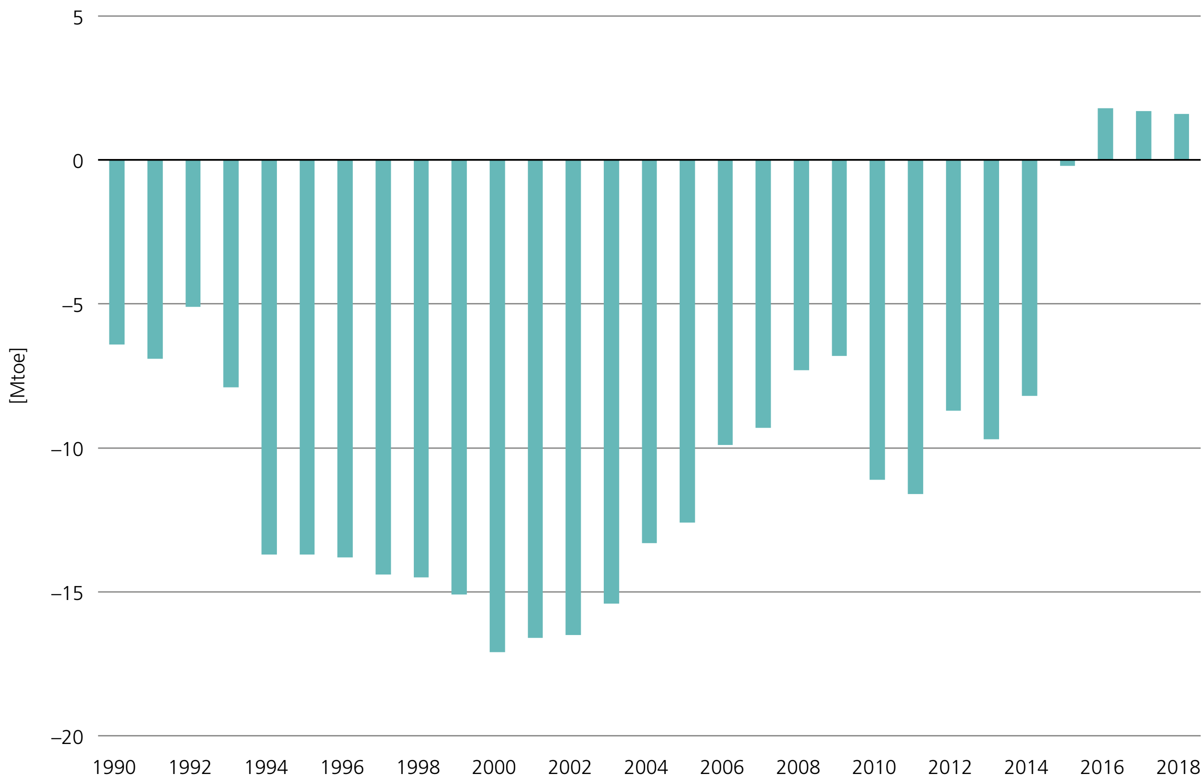
The oil and gas sector in Yemen is mainly run by the state and includes oil production, refining, and distribution (Atamanov, 2017). Private companies take part in the upstream oil exploration and production activities as well as in the filling and distribution of liquefied petroleum gas (LPG) bottles and petroleum products. Prior to the war, Yemen's economy was largely dependent on the revenues from the declining oil sector, which accounted for 27% of the Gross Domestic Product (GDP), 50% of the national budget revenue, and 70% of exports (Republic of Yemen, 2015). As a result of annual budget shortfalls, the government tried to diversify the economic structure with the support of an International Monetary Fund (IMF) program. Fuel subsidies reductions were one of the measures taken within this reform. Fig. 4-8 shows that Yemen had been a net energy exporter until

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




Source: data based on IEA (2020a)

Figure 4-8
**Net Energy Imports (in Mtoe), Yemen 1990–2018**




Source: data based on IEA (2020a)

2015. From 2016 to 2018, however, it had become largely dependent on energy imports, as the domestic structures in the oil sector were critically affected by the war. Yet, according to official data through expert interviews, Yemen still possesses gas reserves of about 18 trillion cubic metres, and its oil reserves amount to nearly 10.4 billion barrels.

Since the electricity grid network has been severely affected by the military conflict, many households have turned to diesel generators and private diesel grids (Ansari et al., 2019). The shortage of the fuel has led to an organised black market for selling diesel fuel at high prices. Simultaneously, the Yemen Oil Products Distribution Company (YOPDC) recorded 77% less fuel sales in 2015 (Almohamadi, 2021). Although the fuel availability improved by 2016, frequent production disruptions and sabotage attacks still occur, with a particularly frequency recorded in the second half of 2019 (ibid.).

The military conflict has also been severely affecting the fossil fuel sector. Many oil companies and operators have halted their production activities due to hostile attacks on the infrastructure; only a few companies started operating again. Due to these reasons, there has been only little resistance from the gas and oil lobby against the renewables transition. According to Yemeni experts, the energy transition plans of Yemeni gas importing countries, such as South Korea, will have only a limited effect on Yemen. Instead, they regard this development as an opportunity for Yemen to retain gas for local consumption, local development, and electricity generation. This would mean that gas will remain an important pillar in Yemen's energy strategy in the long term and that the transition to a RE-based system is likely to take a longer period of time.

**Infrastructure**

The Yemeni electricity grid is currently unable to meet the demand, and it is unstable, resulting (as previously mentioned) in frequent load shedding. Since 2018, Yemen's transmission network has consisted of one main 132 kV grid, as shown in Fig. 4-9. The Marib gas power plant is connected to the main grid via a 400 kV double circuit transmission line (Sufian, 2019). There are plans to connect Marib to the 132 kV substation at Dhamar with a 400 kV line. There are several smaller grids in Yemen's central eastern area, while around Sada, north of Sana'a, isolated networks are established that are not connected to the main transmission network (ibid.). Before the war, several projects were developed to expand the grid within Yemen. For instance, the following grid extension projects were planned: Amran-Bajil (Hodeidah), through Hajjah and Al-Qanawis (Hodeidah) as well as Dhamar-Aden, through Yarim (Ibb) and Al-Houban (Taiz) (Almohamadi, 2021). However, these projects have been suspended due to the military conflict. To most of the Houthi-controlled zones, in particular Hajjah, Sadah, and Amran, no electricity is delivered from the public grid. Although the Marib gas power plant is located close to these Houthi-controlled areas, the power supply is currently interrupted (Ansari et al., 2019).

As stated previously, electricity in Yemen is mainly produced by oil-fired power plants. Around 684 MW capacity run on diesel, 495 MW of the capacity are steam turbines, and 340 MW are gas-fired power plants (Sufian, 2019). The voltages of the electrical power plants range between 10.5 kV and 15 kV, and they increase in the substations to transmission levels of 33 kV, 132 kV, or 400 kV (ibid.). Electricity is normally transmitted via 33 kV to the demand centres, while the distribution network uses 11 kV voltage levels.

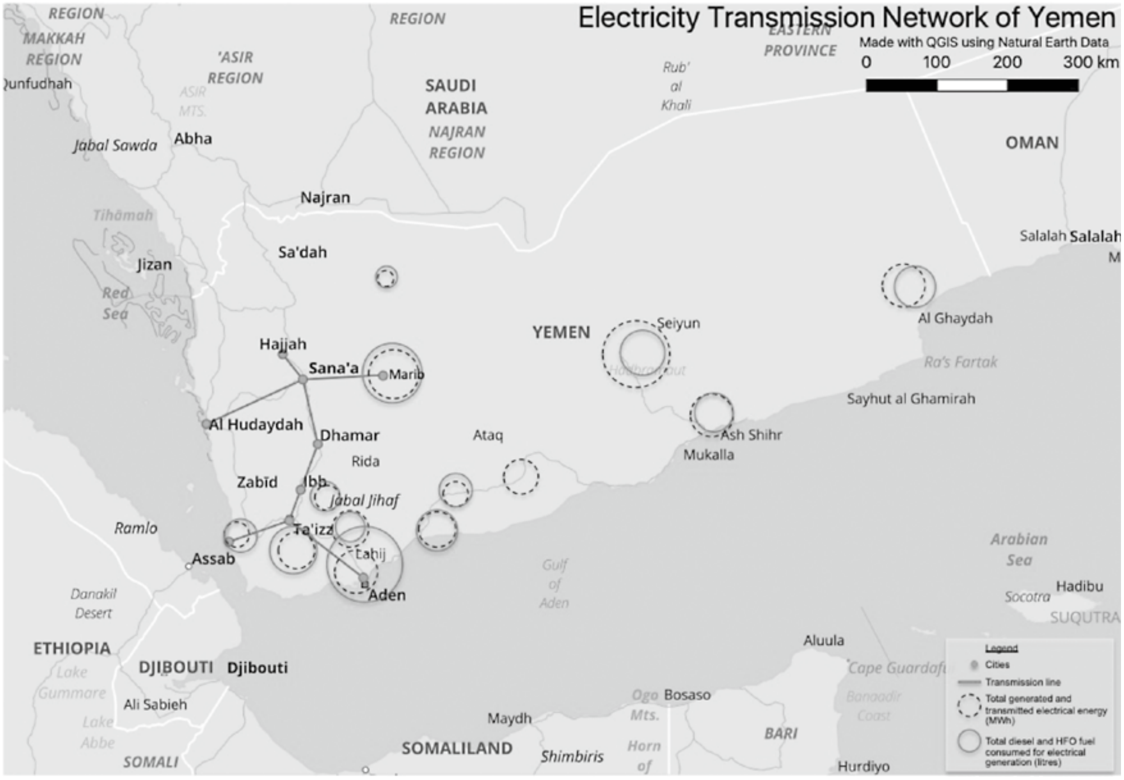
Yemen's electrical transmission grid has large energy losses in the distribution network and in the transmission network due to old and inefficient grid lines. As a consequence of the damage caused during the war, electricity from operational power plants cannot always be transmitted to the grid. Thus, most of the connected areas remain undersupplied. Other reasons for the high electricity losses are the lack of service and maintenance, lack of public investment, and electricity theft (Ansari et al., 2019). Prior to the war in 2012, more than 40% of the generated electricity was lost, and the technical and non-technical losses of the distribution sector amounted to 36% or 2,329.1 GWh (Almohamadi, 2021). Significant losses are recorded in Sana'a, Aden, Hodeidah, and Hadhramout Al-Sahel. The generation sector was responsible for around 5.5% of losses.

Fig. 4-9 depicts Yemen's 132 kV electricity transmission network, the locations of the total generated and transmitted electrical energy, and the total diesel and HFO fuel consumed for generation within the whole territory for the year 2018. The size of the circles corresponds to the scale of consumption.

Before the war, the grid was evaluated as adequate to accommodate about 120 MW of wind power. However, in its current condition, the grid could only integrate small quantities of fluctuant renewables. According to experts, it will be essential to conduct independent grid integration studies for each newly planned renewable power plant. A study by Al-Ashwal et al. (2016) analyses the possibilities of integrating residential PV systems into the local grids. Although the initial results show that the integration of these systems is possible, the study concludes that the biggest challenge for the integration will be the lack of measurements and control devices. Missing standards and codes that clarify the connection mechanism to the grid to avoid instability as well as the allowed PV capacity add to this challenge. Moreover, the outdated control system of the national grid poses a barrier to the integration of larger renewable capacities. Furthermore, according to experts, there is a significant lack of qualified staff that can appropriately manage those technical challenges. Especially in the field of grid infrastructure, skilled workers are absent. Nevertheless, interviewed experts believe that up to 20% of electricity generated from RE sources, such as wind and solar, could potentially be integrated into the grid by 2025.

In summary, the transmission infrastructure in Yemen does not provide sufficient capacity to meet the demand. Future rebuilding and extension efforts should directly be designed in a way that allow for the integration of large-scale inter-

Figure 4-9
**Electricity Transmission Network of Yemen Showing Areas of Total Generated Electrical Energy and Consumed Fuels**




Source: own creation, data based on Energydata (2017a); Sufian (2019)

mittent renewables into the grid. Simultaneously, efforts must be taken to address the shortage of qualified and skilled staff in Yemen. Accordingly, the current state of the electricity infrastructure in Yemen can be classified as being in a pre-phase level of the MENA phase model.

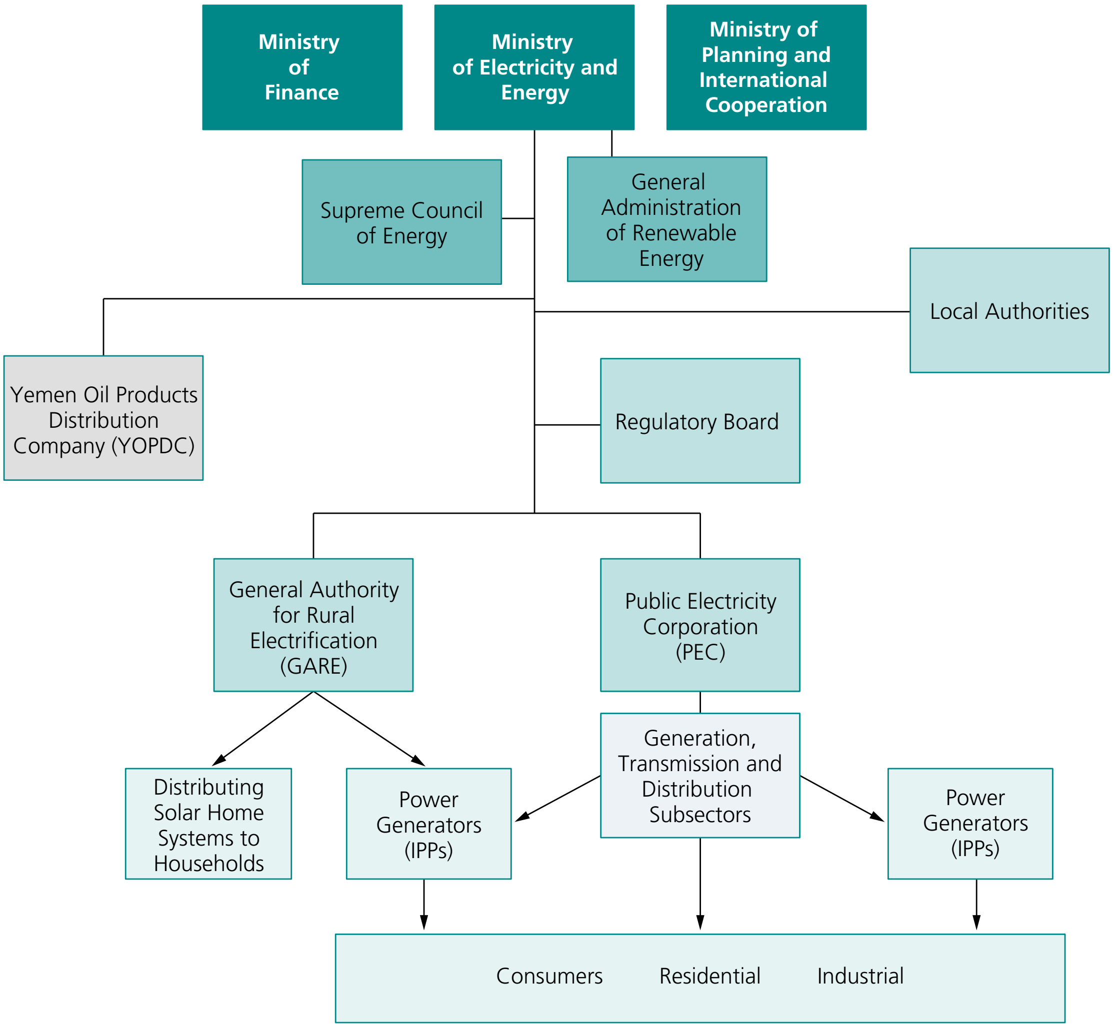
### Institutions and Governance

The electricity sector in Yemen is organised by the Ministry of Electricity and Energy (MoEE). The MoEE sets policy and strategic plans, grants licenses, and is responsible for decision-making (Hadwan & Alkholidi, 2016; Sufian, 2019). The electricity generation, transmission, and distribution is run by PEC, which belongs to the MoEE (Rawea & Urooj, 2018). PEC is supposed to have financial and administrative independence, and it oversees the collection of electricity bills. However, the poor commercial performance has left PEC largely dependent on government financial allocations for investments as well as operational costs (Almohamadi, 2021). While urban retail sales are also handled by PEC, rural retail sales are managed by the General Authority for Rural Electrification (GARE) under the Electricity Act No. 1 of 2009 (Sufian, 2019). GARE is responsible for providing electricity services in rural areas. The tariffs are set by the Electricity Sector Regulatory Boards that also monitor the industrial sector's compliance with regulations (Sufian, 2019). This Board was intended to function as a temporary agency until an independent regulatory authority would be established (Almohamadi, 2021). However, due to the war the authority was not created. Furthermore, several other governmental entities are involved in the energy sector, such as the Supreme Council for Energy. Prior to the war, this Council reviewed and set strategies and policies for the electricity sector and consisted of the Yemeni Minister of Electricity and Energy, Minister of Planning and International Cooperation, Minister of Finance, Minister of Oil and Mineral Resources, and the Cabinet Secretary. For example, the setting of electricity tariffs was approved by the Prime Minister only after the Council of Ministers agreed to it. Another important entity in the energy sector is the General Corporation for Oil, Gas and Mineral Resources (GCOGMR), which manages industry contracts and is responsible for crude oil exports. Several state-owned subsidiaries belong to GCOGMR: Yemen Oil Company (YOC), Yemen Refining Company (YRC), Petroleum Exploration and Production Authority (PEPA), Yemen Gas Company (YGC), Yemen LNG Company (YLNGC), YOPDC, General Department of Crude Oil Marketing, and Safer E&P Operations Company (Almohamadi, 2021). YOPDC supplies the power plants with fuels at a subsidised price, in coordination with the Ministry of Finance (ibid.). The body that supervises the oil and gas sector is the Ministry of Oil and Mineral Resources (MOM).

Fig. 4-10 depicts the institutional framework of the electricity and energy market in Yemen.

Prior to the war, Yemen's electricity sector was vertically structured, which is very typical for the Middle East. However, issuing Electricity Law No. 1 in 2009 was an important step taken to restructure the electricity sector. The law also

Figure 4-10
**Electricity Market Structure with Relevant Authorities and Companies**



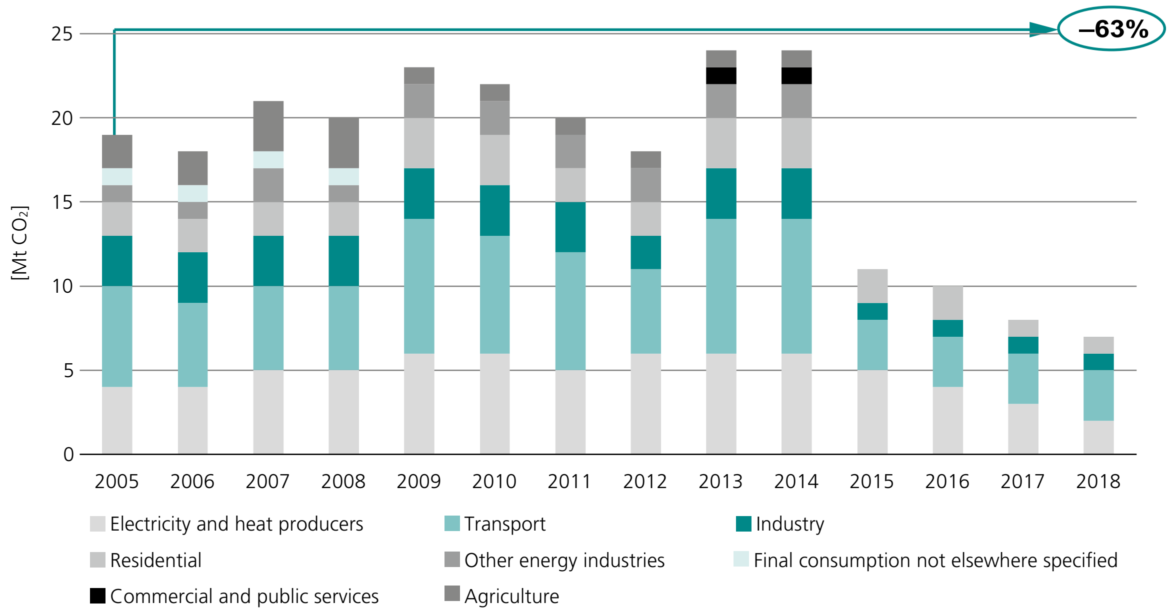

Source: own creation, data based on Almohamadi (2021); Sufian (2019)

introduced a new division, namely the »General Administration of Renewable Energy« to support the transition of the energy sector towards renewables. The planned formation of an independent regulatory authority to separate electricity generation and distribution was another milestone. However, as previously mentioned, the implementation of an independent regulatory authority has not yet been realised. At the beginning of the war, the institutional framework became dysfunctional, and the initially planned liberalisation efforts have still not been implemented. Based on the current state, Yemen is still in the pre-transition stage towards RE according to the applied phase model.

### Energy Market and Economy

The tariffs in the existing public network are based on an increasing block tariff (IBT) system that charges a higher price per kWh for higher energy consumption levels (Atamanov, 2017). The average price tariff is approximately YER 23.14 or USD-cent 10.75/kWh, which represents a value far below the production cost (Sufian, 2019). In addition, the electricity pricing is divided into different categories with different tariffs. The categories are: urban households, rural households, small commercial sector, large commercial sector, hotels, agriculture, large industry, cement factories, public water pumping, and governmental buildings. Four cost blocks exist for urban households: for up to 200 kWh costs USD-cent 2.8/kWh, up to 350 kWh amounts to USD-cent 4.2/kWh, up to 700 kWh costs USD-cent 12/kWh, and consumption over 700 kWh monthly implies a cost of USD-cent 8.8/kWh. In contrast, there are two cost categories for rural households: for up to 100 kWh costs USD-cent 4.2/kWh and for more than 100 kWh costs USD-cent 8.8/kWh. The tariffs for commercial entities, hotels, the agricultural sector, industry, cement factories, public water pumping, and governmental buildings vary between USD-cent 12 and 16 (Sufian, 2019). These electricity tariffs are only implemented in the governorates that are under the Yemeni government's control, as the electricity is still heavily subsidised by the Ministry of Electricity. The northern governorates that are under the control of the Houthis lifted electricity subsidies, which, in turn, led to an increase in the tariff in these areas. However, the tariff has been established according to the climate and economic condition in each city. For example,

Figure 4-11
**$CO_2$ Emissions by Sector (in Mt $CO_2$), Yemen 2005–2018**




Source: data based on IEA (2020a)

the current tariff in hot and low-income cities, such as Hodeidah, is YER 70/kWh (around USD-cent 11), in Al-Jawf is YER 130/kWh (around USD-cent 21), while in Sana'a is YER 225/kWh (around USD-cent 37.5).

As the public network cannot cover the demand, electricity is also provided by private actors (Al-Saidi, 2020b). For instance, on the neighbourhood level, private electricity vendors, particularly in major cities (such as Sana'a), use diesel generators more than 100 kW-capacity to sell electricity to households. Although the tariff for this option is almost 10 times the average price for supply from the public grid, many private customers opt for this model in order to secure their electricity supply. For example, they use it to run agricultural water pumps, supply commercial shops, and to run other appliances necessary to meet the basic needs (ibid.). This electricity model is also controlled by the Houthi-administrated government but has several drawbacks, as it depends on the availability of fuel and is subject to price fluctuations on the market (Al-Saidi, 2020b).

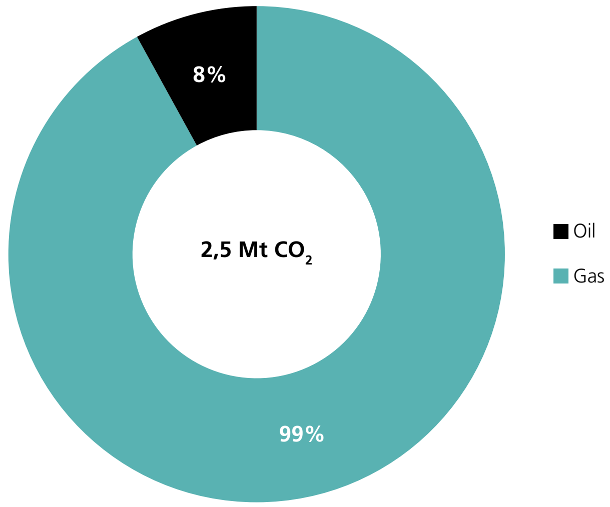
Fuel prices are currently about 70% of the international level, as they are still subsidised by the government. Along with the decline in oil revenues and additional fuel shortages, the government adopted a policy of gradual subsidy lifting (Sufian, 2019). Between 1995 and 2021, the prices increased by 130% on average. The prices for commodities, such as gasoline, diesel, and kerosene, gradually increased as well, aiming to fully remove the subsidies at a later stage (ibid.). As a result, the state expenditures on subsidies fell from 14% of GDP in 2008 to 7.2% in 2013. Yet, the gradual increase in fuel prices resulted in violent protests that led the government to partially reverse the reforms (Atamanov, 2017). However, the subsidies mainly benefit the rich and create incentives for smuggling, corruption, and inefficiencies that still heavily impact the fiscal situation of the state. Although in 1996 a Social Welfare Fund (SWF) was established to support the poorest and most vulnerable groups in Yemen, the SWF compensated the impact of the subsidies reform only in a limited way (ibid.). According to experts, the northern governorates that are under the control of the Houthis have recently lifted electricity subsidies, while the electricity rates in the governorates under the Yemeni government control are still heavily subsidised.

In summary, the state-subsidised energy prices have long been a burden on the fiscal sustainability of the Yemeni state. The subsidy reforms that started before the war failed to achieve the intended goal to close the gap between domestic and international fuel prices (Atamanov, 2017). These subsidies for fossil fuels are also an obstacle to an efficient energy transition. The assessment that Yemen is in a pre-phase of the transition to REs is, thus, confirmed.

### $CO_2$ Emissions

In 2018, a total of 7 Mt $CO_2$ were emitted in Yemen, which is 63% less than the amount in 2005, and 71% less than the amount in 2014, the year before the military conflict started. This decline has been driven by the war-induced slump in fossil fuel power generation, the disruption of economic activities, and the reduction in transport due to fuel shortages. Energy-based $CO_2$ emissions and, in general, GHG emissions are dominated by the energy sector. The majority of the emissions were caused by fossil fuel combustion for electricity generation and transportation, while industry and residential sectors contributed between 30–40% to the overall emissions (Fig. 4-11). Within the electricity and heat production, oil resources, such as diesel, HFO, and LFO (e.g. kerosene), contributed more than 90%

Figure 4-12
**$CO_2$ Emissions from Electricity and Heat Generation by Energy Source (in Mt $CO_2$), Yemen 2018**




Source: data based on IEA (2020a))

to the $CO_2$ emissions, while the remainder was caused by natural gas. Fig. 4-12 illustrates the resulting emissions from heat and electricity generation by source for 2018.

Although the country's contribution to the global GHG emissions is quite minimal, Yemen is highly vulnerable to climate change related impacts (Republic of Yemen, 2015). In the Intended Nationally Determined Contributions (INDCs), which were drafted in the year 2015 and have not yet been converted to Nationally Determined Contributions (NDCs), Yemen intends to reduce its GHG emissions by 14% compared to the business-as-usual scenario by 2030 (ibid.). This represents an estimated total cumulative GHG emissions reduction of around 35 Mt $CO_2$ from 2020 until 2030. The unconditional target without international support is 1%.

In summary, Yemen's INDCs aimed to reduce GHG emissions by 2030, and emissions are, in fact, decreasing. However, this decrease is attributed to the political circumstances rather than to policy strategies or measurements, which are widely lacking. Given that the energy sector is responsible for the largest share of emissions, reconstruction efforts should be directed at reducing GHG emissions. In this regard, RE sources could largely contribute to achieving the INDCs target.

### Efficiency

Yemen does possess energy efficiency strategies with concrete measures and plans, but they are largely limited to the energy sector. In its INDCs, Yemen seeks to increase the energy efficiency in the energy sector by 15% until 2025 (Republic of Yemen, 2015). The efficiency measures are planned to address power generation, transmission, and distribution. A great emphasis is placed on the use of natural gas in the power sector. New installed generation capacities are planned to be efficient combined-cycle gas turbines (CCGTs) for the central power supply, while the decentralised power supply is intended to include combined heat and power (CHP) generation systems that record efficiencies of more than 80% (ibid.). The use of RE sources for power generation and for industrial and agricultural purposes has also been promoted. For instance, the widespread use of solar water heaters has been endorsed. Furthermore, the INDCs foresees the improvement of the energy use efficiency in the transportation sector. However, concrete targets have not been given.

The Ministry of Electricity in Sana'a has also taken significant measures to improve energy efficiency. For example, it passed a law in 2019 requiring governmental facilities and streets to use economic light-emitting diode (LED) lamps and solar lighting systems.

On a household level, many people have rationalised their electricity consumption, seeing as the electricity tariffs have increased. In line with this development, awareness of more energy efficient electrical household devices has been raised among the people.

The assessment of the steps taken by Yemen in the field of energy efficiency shows that the issue is generally understood as an important part of energy sector management. Accordingly, Yemen developed initial energy efficiency targets before the war but without quantifying them or setting a concrete timetable. Moreover, the war prevented the implementation of the targets. On the household level, people mainly rationalise their electricity use for money-saving purposes rather than for environmentally friendly reasons. Based on this information, energy efficiency in Yemen is underdeveloped, which reinforces the classification of the country in the pre-stage of the energy transition model.

### Society

The population in Yemen suffers greatly from energy shortages and rising energy costs, which contribute to the ongoing humanitarian crisis in the country. Due to this energy shortage, the use of solar energy sources has gained importance. Accordingly, public awareness of REs has considerably increased (Ajlan et al., 2016). For instance, solar energy is, in general, positively received by the people, who are willing to adopt this technology for their own residential use. People have become familiar with terms like watt, watt hour, LED, and energy efficiency, seeing as they have switched to less-energy intensive devices to save energy and costs. While in urban areas knowledge about RE and solar energy is mainly communicated through education, people in rural areas often become aware about the topic through personal observation and experience (Baharoon et al., 2016). In addition, people in urban areas are less likely to know about other renewable technologies, such as CSP or wind power, whereas in rural areas knowledge about solar heaters and PV systems is often limited. Therefore, several authors suggest increasing knowledge through targeted education, specific training, and awareness-raising campaigns, both at the household level and among financial institutions and government agencies. This, in turn, would support the implementation of REs (Ajlan et al., 2016).

However, low quality standards of solar energy systems that have been sold in Yemen pose a huge barrier to increasing the use of solar energy (Ansari et al., 2019). Furthermore, there is a lack of qualified personnel, as hardly any trainings are offered to prepare technicians and engineers. As a result, non-specialised or unskilled staff members often take the responsibility for the planning, installation, and maintenance of solar systems. Most of the solar systems register a performance drop after a couple of months, or it happens that the systems are undersized, which, in turn, limits the entire system's performance (ibid.). The incorrect sizing of the PV systems and the low quality of the PV components has led to households being unsatisfied with their solar. This has damaged the reputation of this technology (ibid.).

Another factor that also leads to mistrust towards renewable technologies is the high level of corruption (Ansari et al., 2019). The patronage network, which includes government actors, encourages monopolisation, and this raises local prices. In the solar energy sector, this structure has caused wholesale prices to increase and import bottlenecks to occur (ibid.). According to Ansari et al. (2019), solar energy profit margins can exceed 300%. Furthermore, bribery is widespread, and permits and levies are sometimes arbitrarily issued by local authorities.

Overall, Yemen has no established institutions to raise awareness about REs. Public knowledge is mainly shaped by people's own experiences with solar energy. Bribery and corruption increase costs for households and hinder a faster diffusion of REs. Due to the lack of specialised training institutions, employees in the solar energy sector often have limited skills that affect the sector's performance and people's trust in the technology. This underpins the classification of Yemen in the pre-stage level of the energy transition according to the applied phase model.

**Summary of the Landscape and System Level Developments**

In summary, the Yemeni energy sector faces several major challenges. On the landscape level, the political instability and armed conflict affect the whole energy system, at least in the short term. They will most likely influence the country's energy development in the long term as well. Prior to the war, there was a lack of policies and legal frameworks in the form of laws and regulations for the deployment of REs. These were also still not developed in the years that followed the war. Due to the desolate economic situation, there is hardly any funding available for REs in Yemen. Even before the war, energy subsidies placed a heavy burden on the national budget that there was little leeway for the promotion of REs.

On the system level, the high dependency on diesel represents a great burden for households due to the inconsistent supply, the costs, and the effects on health and the environment. Technical obstacles to the development of the energy sector include high electricity losses due to old and inefficient infrastructure, transmission, and distribution networks, which were destroyed by violent attacks. Unskilled personnel and difficulties in collecting electricity bills constitute further challenges. Many systems are designed and installed by unqualified staff, which can lead to poor performance and a short lifespan of these systems. As a result, solar energy develops a poor reputation and people lose confidence in the technology. Yet, the current level of public acceptance for RE, particularly PV and solar heating, is very high. These technologies have helped people to meet their electricity and hot water demand, following the deterioration of the public energy supply since the start of the war in 2015. Accordingly, most solar applications are found in households or small businesses and are sold and installed by the private sector. Therefore, Yemen presents a very exceptional case of a »microscale driven adaptation« (Al-Saidi, 2020b) in the Middle East, where energy development is mostly organised in a highly centralised manner.

The COVID-19 pandemic did not have a large influence on the current energy demand and supply in Yemen, as there has been no serious lockdown in the country. However, according to experts, the pandemic was the major reason for several delays of large-scale solar projects that have been planned by the Ministry of Electricity in Aden.

In summary, the energy transformation in Yemen is hampered by the consequences of the war but also by structures that already existed before the war. These factors have led to supply shortages that exacerbated the humanitarian crisis. They have also caused bottlenecks in the expansion of RE production.

Table 4-2 summarises the current trends and goals of the energy transition according to relevant indicators for Yemen.

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

| Category | Indicator | 2005 | 2010 | 2015 | 2018 | 2020 | 2030 | 2050 |
|---|---|---|---|---|---|---|---|---|
| **Carbon Emissions (Compared to 1990)** | $CO_2$ emissions per unit of GDP | +150% | +136% | +97% | N/A | N/A | – | – |
| | $CO_2$ emissions per capita | +80% | +100% | –20% | –40% | N/A | | |
| **RE** | Installed and planned capacity (MW) | N/A | 1 | 290 | 1,090 | 1,650 | | – |
| | Share in final energy use | 0.9% | 1% | 2.4% | N/A | N/A | | – |
| | Share in electricity mix (existing and planned) | 0% | 0.02% | 1.75% | 12.7% | N/A | | – |
| **Efficiency** | Total primary energy supply (TPES) (compared to 1990) | +162.5% | +211.2% | +52.6% | +31.5% | N/A | – | – |
| | Energy intensity of primary energy (compared to 1990) | +22.9% | +22% | –21% | N/A | N/A | – | – |
| | Total energy supply (TES) per capita (compared to 1990) | +50% | +50% | –50% | –50% | N/A | – | – |
| | Electricity consumption per capita (compared to 1990) | +100% | +200% | +100% | +0% | N/A | – | – |
| | Fossil fuel subsidies (share of GDP) | N/A | 7.15% (2013) | 0.7% | N/A | N/A | | |
| **Buildings** | Residential final electricity consumption (compared to 1990) | +120.5% | +269.2% | +80.8% | +94.9% | N/A | – | – |
| **Transport (Compared to 1990)** | Total final energy consumption (compared to 1990) | +36.5% | +73.4% | –25.5% | –36.4% | N/A | – | – |
| | $CO_2$ emissions in transport sector (compared to 1990) | +50% | +75% | –25% | –25% | N/A | – | – |
| **Industry** | Carbon intensity of industry consumption (compared to 1995) | –1.8% | +3.6% | +5.8% | +6.6% | N/A | – | – |
| | Value added (share of GDP) | 49% | 43.8% | 36.4% | 35.6% | 40.6% (2019) | – | – |
| **Supply Security** | LNG exports (compared to 2009) | N/A | +1,275% | +375% | N/A | N/A | – | – |
| | Oil products imports (compared to 1990) | –80.2% | N/A | N/A | N/A | N/A | – | – |
| | Crude oil exports (compared to 1990) | +114.2% | +72.3% | +6.6% | –94.8% | N/A | – | – |
| | Electricity access by population proportion | 56% | 73.7% | 71% | 62% | N/A | – | – |
| | Oil reserves (compared to 1999) | +45% | +50% | +50% | +50% | +50% | – | – |
| | Gas reserves (compared to 1999) | +50% | +50% | +50% | +50% | +50% | – | – |
| **Investments** | Decarbonisation investments (USD million) | N/A | N/A | N/A | 0.0062 (2017) | N/A | – | – |
| **Socio-economy** | Population | | | | 29,161,922 (2019) | – | – | |
| | Population growth | 2.8% | 2.8% | 2.6% | 2.4% | 2.3% (2019) | – | – |
| | Urbanisation rate | 28.9% | 31.8% | 34.8% | 36% (2017) | N/A | – | – |
| | GDP growth | 5.6% | 7.7% | –27.9% | 0.7% | 2.1% (2019) | – | – |
| | Oil rents (value of GDP) | 43% | 22% | 2% | 2.6% | N/A | – | – |
| **Water** | Level of water stress | 169.8% | 169.8% | N/A | N/A | N/A | – | – |

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

### 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). However, Yemen displays very limited progress in almost all relevant dimensions: supply, demand, infrastructure, markets, economy, and society.

#### Renewable Energy

Before the military conflict, the government planned to install grid-connected large-scale RE projects, including solar thermal, solar PV, geothermal, and wind power plants. The target was for the share of renewables in the electricity generation mix to reach 15% or 2,600 GWh by 2025. In other words, the plan included a 6 MW power station using landfill gas, a large-scale wind farm in Mokha in the west of Yemen that should have been constructed between 2014–2019 (Republic of Yemen, 2015), and PV power plants in a tender scheme based on the build-own-operate-transfer (BOOT) model (MoEE, 2021). Currently, however, mainly PV projects are being discussed, such as:

1) 10 MW-capacity PV power plant with storage in Sada planned by the Ministry of Electricity
2) 7 PV power plants with a total capacity of 96 MW planned by the Ministry of Electricity in Aden: Lahj city PV plant, 30 MW; Al-Dhalaa PV plant, 5MW; Hadramoot Al-Waadi PV plant, 7MW; Aden PV plant, 10MW; Abyan PV plant, 20MW; Loadder / Moddyah PV plant, 15MW; and Al-Mahara PV plant, 10MW
3) 2 PV power plants in Hadhramaut with storage and a capacity of 50 MW each that are planned by the local authority in the governorate

The solar PV projects, for which tender rounds have been announced, are planned to be added in the governmental controlled areas between 2022 and 2023. However, due to the instability of the political situation and partly because of the global pandemic, large-scale power infrastructural projects have been suspended or severely delayed. Moreover, the lack of skilled staff is a major challenge for the further deployment of solar energy and poses the risk of stagnation in the sector.

#### Grid Expansion

Prior to the war, Yemen planned to integrate its electrical grid with several neighbouring countries. For instance, in 2007, there were plans to establish a grid interconnection from Yemen to Saudi Arabia with a capacity between 500 MW and 1,000 MW (Ansari et al., 2019). The interconnector would have been 416 km long, consisting of a 400 kV double-circuit alternating current (AC) line and an AC/ direct current (DC) converter station in order to convert Saudi Arabia's 60 Hz electric system to the 50 Hz electric system in Yemen. Although PEC developed investment plans for the interconnections, funding for these projects was lacking and none of them have been realised yet (ibid.).

Another plan was being developed that involved the establishment of an electrical high voltage direct current (HVDC) connection from Ethiopia via Djibouti to Yemen (Sufian, 2019). The aim would be for Yemen to obtain electrical energy from a hydropower plant in southern Ethiopia, which is still under construction.

#### Electric Vehicles (EVs)

As mentioned in section 4.1.1, the government in Sana'a introduced a customs exemptions law (May 2020) that is applied to all components and products related to RE, including EVs. This provides an opportunity for traders to import EVs to the Yemeni market at lower costs. In addition, the constant scarcity of petrol and the rise in its prices are prompting people to seek alternative means of transport that do not rely on fossil fuels, such as petrol, diesel, and gas. However, infrastructure for charging EVs does not yet exist, and electricity supply is unreliable. The few EV users charge their vehicles in their homes using either solar power systems or electricity from diesel generators.

### 4.1.3 Necessary Steps for Achieving the Next Phase

Fossil fuels, particularly oil, are the predominant sources of energy in Yemen. RE, besides small-scale decentralised solar energy, still plays a minor role in the energy system. Legal and market regulations for renewables are widely lacking and the implementation of large-scale projects has been hampered by the political instability. Moreover, the grid infrastructure is largely destroyed or damaged, and the remaining grid is inefficient and outdated, restricting the future connection of large-scale RE power plants. Without peace and major reconstruction efforts, the extension of renewables-based energy systems on a large-scale will likely remain limited in the coming years. Therefore, the recommended measures highly depend on the development of the political situation in Yemen (Almohamadi, 2021). In any case, the development of the RE sector must be addressed at different levels, including in the areas of law, administration, regulation, policy making, capacity building, and financing. These areas are briefly outlined below.

**Legal Framework**

To support a successful development of the RE sector in Yemen, it is highly important to improve the political and legal frameworks. In order to accelerate large-scale RE projects, clear procedures and legislations are essential to build investor confidence, especially following the years of instability in Yemen. The electricity law from 2010 can serve as a basis for establishing further developments and concretisations. On a small-scale level, it will be crucial to develop regulations that foster the import of high quality PV products to increase consumer confidence in these systems. Furthermore, control instances are needed to form quality standards or certifications. On the technical side, laws must be drafted and implemented to regulate local grid codes and requirements for the installation of PV systems on buildings. These laws would also manage energy efficiency measures. To identify the most suitable options for its regulatory development, Yemen could first analyse best practices and exchange with peers from countries in the region where these advancements have already been implemented.

**Institutions and Governance**

Strategy development along with structural and institutional reforms are needed to put Yemen on a sustainable post-war growth path. However, apart from the outdated National Strategy on Renewable Energy and Energy Efficiency from 2009, no other strategies exist in Yemen, and this strategy has not been put into practice as result of the ongoing military conflict. Strategic visions, such as the Mustafa Bahran Vision 20/20, have been developed but have also not been realised. Thus, as a first step, Yemen must develop an energy strategy that should aim to achieve diversification, sustainability, and social and economic development. The strategy ought to set quantified targets and indicators to measure these goals for RE and energy efficiency. Moreover, Yemen must formulate plans to initiate the reform of the power sector. This would unbundle electricity generation, transmission, and distribution. By establishing an independent energy regulatory authority, the sector could become more competitive, and the investment environment could be improved. The next step would be to resume the activities of GARE in order to enhance the service provision in rural areas (Almohamadi, 2021). The creation of financial institutions and mechanisms are also crucial in order to finance small and large-scale energy project investments. A state support and incentive programme for small solar plants should be implemented to cushion the effects of the subsidy reforms and to meet the urgent need for electricity for the economic reconstruction. Lastly, strengthening the cooperation and coordination between different agencies will help to support the RE sector development. To achieve this, exchange formats between the various institutions under the leadership of the Ministry of Energy could be established as an initial measure. This procedure would create a multifaceted understanding of the challenges and opportunities of REs in Yemen.

**Electricity Sector**

In the electricity sector, subsidy reforms are needed to create a level playing field for REs. This also requires a reform of electricity tariffs to ensure that generation and operating costs are covered in the future to achieve a reliable supply of electricity in the long term. In view of the humanitarian crisis in Yemen, these reforms must be carefully administered in order to not further burden the population. Yemen's first step could be conducting a comprehensive stakeholder consultation in order to establish a tariff structure that is fair and consistent. This would support the most vulnerable members of the society, and it would also allow for economic development.

**Infrastructure**

Improving and expanding grid capacity is key to integrating REs and ensuring a reliable energy supply in the long term. Post-war reconstruction should, therefore, be directly designed in such a way that the grid can accommodate RE in the future. For example, the voltage level must be improved to ensure a disturbance-free power supply, seeing as frequent overloads lead to technical losses. Yemen could also continue implementing interconnection projects with neighbouring countries, which could help meet the country's electricity needs as an initial stage. These projects could later serve as flexibility options and pathways to export electricity. Moreover, analyses are required to assess and quantify the need for RE storage options, as peak demand in Yemen occurs in the evening hours after sunset. In addition, the decentralisation of electricity generation has, indeed, already began with the use of solar energy in households. However, it must be further promoted, as this can directly reduce vulnerability to fossil fuel price fluctuations and is less susceptible to attacks and damages compared to centralised infrastructures (Al-Saidi, 2020b). Research should also be conducted on the optimal mix between centralised and decentralised renewable power generation, and concrete targets and subsequent support mechanisms should be developed for both sectors. Overall, it is necessary to build central power plants that cover the demand of electricity across the country. Simultaneously, RE plants should be developed to reduce the country's dependence on fuel (especially diesel) imports.

**Capacity Building and Sector Performance**

A sustained transition will depend on qualified and trained staff in all sectors. Therefore, the Ministry of Electricity should support the establishment of institutionalised qualification measures in the RE sector that match international standards (Ansari et al., 2019). This should include all qualification levels from vocational training for technical installation and maintenance services to applied engineering programs at universities. The creation of dedicated capacity and competence training centres could be a first step in this direction (Ansari et al., 2019). For the small-scale solar energy sector, special trainings for technicians and engineers must be offered that target the dimensioning, installation, and maintenance of solar energy systems. This will support technical teams to prepare adequately for installing high quality solar energy systems. Furthermore, measures that enhance the governance and managerial skills of PEC will be key to enhance the sector's performance. For instance, technical staff that knows how to prepare technical and legal documents, apply regulations, develop PPAs, or conduct feasibility studies for RE will be needed (ibid.). Exchange programs with operators in other countries that have higher shares of renewables should be initiated. Moreover, measures such as staff reviews and performance and financial audits should be taken by third parties. These actions could help to achieve capacity building.

## 4.2 OUTLOOK FOR THE NEXT PHASES OF THE TRANSITION PROCESS

The war has made it extremely difficult for Yemen to adequately exploit its renewable potential. Other MENA countries have not faced such a situation. From the analysis, it is evident that Yemen's energy transition in recent years is mainly conflict-driven. As result of the war, people no longer have access to many sources of energy. Thus, they have resorted to using solar energy to meet their basic electricity needs. Solar PV has been widely implemented not only in households but also in the agricultural sector. For instance, the solar water pumps have become the most prominent technology at country-scale. The same holds true for health facilities, hotels, and educational entities that rely on secure solar energy. Although there is huge potential for RE, Yemen lacks a comprehensive strategy. So far, no large-scale RE projects have been implemented due to the political instability and the absence of laws and regulations. The lack of a legal framework has been unanimously mentioned by the interviewed experts as a major challenge. This highlights the need to develop policies and legislations to promote the successful reconstruction of the electricity sector in Yemen, including the RE sector.

While most of the experts interviewed agreed on the need to advance the energy transition towards renewables, they also pointed to other challenges, such as the dominant role that fossil fuels play and the long-standing patronage politics that hinder the path of the energy transition in Yemen. However, the falling cost and advances of RE technologies offer a valuable opportunity to solve the chronic issue of the electricity crisis. Adopting these technologies has become the better and less expensive option for generating electricity and heating water compared to using conventional technologies. Besides these internal factors, external events such as the COVID-19 pandemic have affected the renewable development in the last two years, resulting in the delay of solar energy projects in the governorate of Aden.

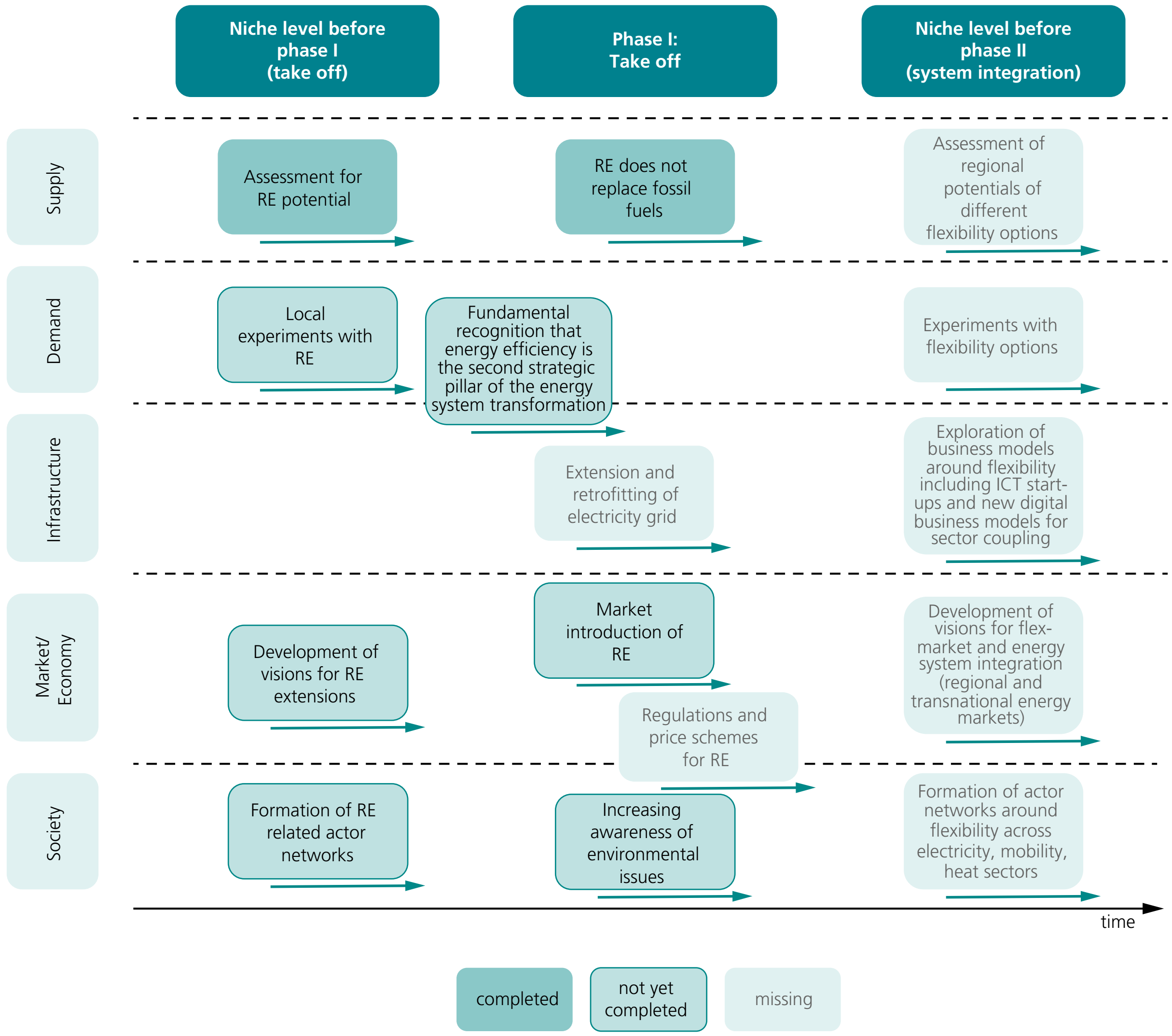
For the future development of the energy system, the different political ideologies in the north and south need to be considered. Since energy security and stability of the electricity supply are major concerns both in the north and south of Yemen, policymakers need to understand that renewables can offer benefits to both parties on an economic and social scale. It will be more beneficial to rebuild a state-wide connected energy supply system rather than fragmented systems in the north and south of Yemen.

While the need to secure the national energy supply is a strong driver to the greater deployment of renewables, domestic natural gas is also becoming more relevant for Yemen's energy strategy. The energy transition plans of the countries buying Yemen's natural gas will, according to experts, influence Yemen's energy strategy. In other words, Yemen could use the gas domestically instead of selling it below market value under existing contracts. However, given the global decarbonisation efforts and the resulting decline in demand for fossil fuels, Yemen would be well advised not to delay the transition to RE sources. This energy transition can help Yemen to develop new economic sectors and can provide it with future export opportunities.

To ensure that these opportunities are made available to a wide range of the population, citizens and communities should become an integral part of the energy planning process. The current development of RE in Yemen is »community-driven and self-organised« (Al-Saidi, 2020b), which is a good starting point, even though the current development is far from being a best-case model. In addition, research and development (R&D) will be essential for the creation of local value chains, and this must be supported financially. One way to fund RE research, but also to support RE programmes and incentives, could be the establishment of a RE fund fed by a defined share of oil and gas revenues.

Against this backdrop, a long-term and conflict-resilient approach, which considers the entire energy system and long-term objectives of a transition towards fully renewables-based energy system, is needed. Yemen's policymakers must understand that the early adoption of RE systems represents multiple benefits; in the short term it would increase the energy supply, while in the long term it would present an opportunity for economic development. Fig. 4-13 summarises Yemen's current status in the energy system transition and provides with an outlook on the following steps.

Figure 4-13
**Overview of Yemen's Status in the Energy System Transition Model**



# 5

# CONCLUSIONS AND OUTLOOK

A clear understanding and a 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 Yemen 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, characteristics of the MENA region, and the specific Yemen context.

The model, which includes four phases (»Take-off RE«, »System Integration«, »PtF/G«, and »Towards 100% Renewables«), was applied to analyse and determine where Yemen stands in terms of its energy transition towards renewables. The application of the model also provides the basis for the development of a roadmap detailing the steps needed to proceed on this path. The analysis has shown that Yemen's so-called »solar revolution« is conflict-driven and limited to small-scale decentralised applications of solar energy. The drivers for Yemen to shift to a sustainable energy system are predominantly the need to secure a reliable and affordable electricity supply as well as cost-benefit-opportunities in the long-term economic development. Despite the drop in renewable technology costs, the current pathway towards renewables seems to be challenging for Yemen due to the country's political instability, the lack of strategies, legislations and regulations, and the widespread patronage in the administration.

Yet, renewables represent a long-term sustainable perspective for Yemen, as they offer an opportunity for an energy transition while also rebuilding the energy system after the war. To seize this opportunity, Yemen needs to increase its ambition, improve the framework conditions for renewables, and raise the awareness of its benefits. This includes the need to unbundle the electricity sector. Likewise, energy efficiency efforts must be increased. In particular, this requires capacity and skills building to ensure that the strategies can be successfully implemented on a broader scale.

While the energy transition in Yemen is still at the earliest stage and the upscaling of renewables faces many challenges, the country would be well advised to establish a more sustainable energy system that will benefit its population in the short and long term. The results along the transition phase model towards 100% renewables can stimulate and support the discussion about Yemen's future energy system. This is achieved by providing an overarching guiding vision for the energy transition and the development of appropriate policy strategies.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| AC | Alternating current |
| BOOT | Build-own-operate-transfer |
| CCGT | Combined-cycle gas turbine |
| CCS | Carbon capture and storage |
| CCU | Carbon capture and use |
| CHP | Combined heat and power |
| CNG | Compressed natural gas |
| COVID-19 | Coronavirus disease 2019 |
| CSP | Concentrated solar power |
| DC | Direct current |
| DSM | Demand-side management |
| ERRY | Enhanced Rural Resilience in Yemen |
| EU | European Union |
| EV | Electric vehicle |
| FAO | Food and Agriculture Organisation |
| FiT | Feed-in tariff |
| GARE | General Authority for Rural Electrification |
| GCOGMR | General Corporation for Oil, Gas and Mineral Resources |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas |
| HFO | Heavy Fuel Oil |
| HVDC | High Voltage Direct Current |
| IBT | Increasing block tariff |
| ICT | Information and communication technologies |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| IMF | International Monetary Fund |
| INDC | Intended Nationally Determined Contribution |
| IPP | Independent Power Producer |
| IRENA | International Renewable Energy Agency |
| LED | Light-emitting diode |
| LFO | Light fuel oil |
| LNG | Liquefied natural gas |
| LPG | Liquefied petroleum gas |
| MENA | Middle East and North Africa |
| MLP | Multi-level perspective |
| MoEE | Ministry of Electricity and Energy |
| MOM | Ministry of Oil and Mineral Resources |
| MoU | Memorandum of Understanding |
| NDC | Nationally Determined Contribution |
| PEC | Public Electricity Corporation |
| PEPA | Petroleum Exploration and Production Authority |
| PPA | Power Purchase Agreement |
| PtF | Power-to-fuel |
| PtG | Power-to-gas |
| PtX | Power-to-X |
| PV | Photovoltaic |
| R&D | Research and Development |
| RE | Renewable Energy |
| REPS | Rural Electrification Policy Statement |
| SHS | Solar Home Systems |
| SWF | Social Welfare Fund |
| USD | US-Dollar |
| YGC | Yemen Gas Company |
| YLNGC | Yemen LNG Company |
| YOC | Yemen Oil Company |
| YOPDC | Yemen Oil Products Distribution Company |
| YRC | Yemen Refining Company |

## LIST OF UNITS AND SYMBOLS

| | |
|---|---|
| % | Percent |
| $CO_2$ | Carbon dioxide |
| GW | Gigawatt |
| GWh | Gigawatt hour |
| Hz | Hertz |
| kgoe | Kilogramme of oil equivalent |
| ktoe | Kilotonne of oil equivalent |
| kV | Kilo Volt |
| kW | Kilowatt |
| kWh | Kilowatt hour |
| $m^3$ | Cubic metre |
| m/s | Metre per second |
| Mt | Megatonne |
| Mtoe | Millions of tonnes of oil equivalent |
| MVA | Megavolt-ampere |
| MW | Megawatt |

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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 YEMEN'S ENERGY SYSTEM

## Development of a Phase Model

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 (RE) transition in MENA countries has been developed and applied to the country case of Yemen. It is designed to support the strategy development and governance of the energy transition and to serve as a guide for decision makers.

The transition towards REs is still at a quite early stage in Yemen. The military conflict has prevented the implementation of most of the planned large-scale renewable projects. The political instability, the high dependence on fossil fuels, and poor administrative performance are the most pressing concerns for Yemen's electricity sector. At an operational level, Yemen requires a total retrofit of the electricity infrastructure and needs to expand its overall capacity while improving its efficiencies.

Despite these challenges, rebuilding the energy system after the political turmoil and the subsequent violent conflicts could offer Yemen the capability to transition towards renewables. This will provide short-term and long-term opportunities and avoid stranded investments in fossil-fuel capacities.

The priority is to improve the framework conditions for RE in Yemen, starting with the development of a long-term strategy up to 2030 and beyond. Also, an appropriate and transparent legislation must be created. Furthermore, based on the legislation, clear regulations for REs must be introduced, and a realistic timeframe for expansion must be established in order to promote acceptance and market development on a large scale.

The results of the analysis along the transition phase model towards 100% RE are intended to stimulate and support the discussion on Yemen'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://yemen.fes.de/**
**https://mena.fes.de/topics/climate-and-energy**

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