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Shooting for the Sun

A feasibility assessment of Lebanon’s renewable electricity targets

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Abstract

Most electricity in Lebanon is produced by burning fossil fuels, which produces more than one half of domestic greenhouse gas emissions, and the state-owned electricity companies are unable to meet the demand. To increase the country's generation capacity and simultaneously combat the effects of climate change, the government aims to produce 30% of its electricity from renewables by 2030. It is however not clear whether this ambitious aim is feasible. This research aims to assess the feasibility of Lebanon's renewable energy targets and identify options for increasing this feasibility. The thesis first explores what mechanisms and processes enable and constrain the achievement of Lebanon's renewable electricity targets through a structured comparison of techno-economic, socio-technical and political factors. It then investigates how Lebanon's experience with renewable electricity deployment and the trajectory of renewable electricity growth necessary for achieving their targets compare with the historical experience of renewable electricity deployment in other countries that succeeded in rapidly and widely deploying renewable energy using growth modeling. Lastly, recommendations are given on how to increase the feasibility of achieving Lebanon's renewable electricity targets. The thesis shows that Lebanon has sufficient geophysical potential to reach these targets but that its solar target of 3 GW is highly ambitious and faces numerous challenges in its accomplishment pertaining to the current political and financial situation, institutional and regulatory limitations, and poor infrastructure. To achieve this target, Lebanon would need to develop its solar power sector as fast, if not faster than the world's front-runners, which generally have much higher technological and institutional capacities. This thesis argues that energy security imperatives together with strong demand growth and import dependency provide strong incentives for the rapid expansion of solar power in Lebanon. Such expansion can be enabled by electricity market liberalization and attracting international investors and developers through stable support schemes, making Lebanon's renewable electricity targets more feasible.

Keywords: Lebanon, feasibility assessment, growth modeling, renewable electricity, energy transition.

Executive Summary

There is a shortage of electricity in Lebanon forcing households and businesses to rely on private diesel generators as the state-owned utilities cannot satisfy the growing demand. Furthermore, most electricity is produced from fossil fuels so that the electricity sector is responsible for more than half of national emissions. Because these fuels are 100% imported while electricity is sold at tariffs below its actual cost, the power sector is also responsible for half of the national debt. To increase the country's generation capacity and reduce greenhouse gas emissions, as well as decrease the national debt, the government aims to produce 30% of electricity from renewables by 2030. A sustainable energy transition could both raise the quality of life in Lebanon and also support the government in overcoming the current political and financial crises.

This research aims to assess the feasibility of Lebanon's renewable electricity targets and identify options for increasing this feasibility. To achieve this aim, the thesis addresses the following research questions:

1. What are the renewable electricity targets in Lebanon and what are the mechanisms and processes which enable and constrain the achievement of these targets?

2. How does Lebanon's experience with renewable electricity deployment and the trajectory of renewable electricity growth necessary for achieving their targets compare with the historical experience of renewable electricity deployment in other countries that succeeded in rapidly and widely deploying renewable energy?

3. What can be done to increase the feasibility of achieving Lebanon's renewable electricity targets?

The first question defines the targets analyzed and provides deeper insight into the current electricity system and resource potentials in Lebanon and how these impact the feasibility of achieving their targets, through literature and documentary review. This will then be compared to the targets and implemented strategies, as well as contextual factors pertaining to the techno-economic, socio-economic and political context in four selected case study countries, conducting a focused, structured comparison. The second question compares the growth of renewable electricity of selected case study countries with the growth projected and the growth necessary to achieve Lebanon's electricity targets, utilizing growth modeling based on historic data, hence providing observations on the feasibility of achieving these targets. This is based on the assumption that what was feasible in the past (in other countries) may be feasible in the future (may also be feasible in Lebanon). The third question provides recommendations on how the feasibility of achieving Lebanon's targets can be increased, based on the results identified by the first two questions.

By 2030, Lebanon aims to install 3 GW of solar power, of which 0.5 GW should come from decentralized installations, 1 GW of wind power, and 0.6 GW of hydro. On the one hand, Wind and hydro power targets seem to be within reach when compared to the already installed and planned 0.7 GW of wind and 0.58 GW of hydro. On the other hand, however, the solar target is ambitious since by 2018 only 0.06 GW of solar has been installed, which represents 0.39% of the total electricity generated in the country and 1 GW in projects currently in progress.

The kind of growth of solar power Lebanon wants to achieve has not been achieved in any other country so far. Only two countries, Germany and Spain, had achieved 0.3% solar share earlier than 12 years ago and neither of those has been able to reach 16-17% share – something that Lebanon aspires to do – within this time frame. However, solar technology is rapidly getting cheaper and more effective, and sunnier rapidly growing economies might be able to grow faster than Germany and Spain. For example, Chile is currently exactly on track with the kind of growth Lebanon wants to achieve, indicating that achieving its target is not impossible. To achieve its target, Lebanon needs to follow the growth that Chile has accomplished so far.

There are several mechanisms and processes that could enable Lebanon to achieve its targets, including the high incentives for an energy transition due to the need for energy security and the prospect of domestic economic activity and job creation. Additionally, Lebanon has abundant solar resources, which, possibly in combination with newly found natural gas, could power the whole country, eliminating the need for expensive imported fossil fuels. Lastly, Lebanon is already party to multiple bilateral and multilateral agreements to combat climate change, which gives them access to a variety of technical and financial resources for the adoption of renewable electricity.

There are however also several constraints Lebanon must overcome to increase the share of renewable electricity. It currently faces high political instability due to the regional Middle East crisis, the currency collapse, and the government crisis escalated by the explosion in Beirut harbor in August 2020. Its current institutions may not be able to formulate and carry out policies needed to achieve the targets. Finally, the current state monopoly on electricity production, distribution, and generation may present a significant barrier to the adoption of renewables, there is little interaction with the private sector and low levels of innovation. Political instability, weak institutions, state-dominated market structure complicate state-led investments and deter private investments in the electricity sector.

To increase the feasibility of Lebanon's power target this thesis recommends to:

1. **Let electricity tariffs reflect real costs** – This would ensure profitability and attract private investors as well as reduce the financial burden on the government freeing funds for other necessary measures.

2. **Liberalize electricity market** – Following Chile's example, the electricity market should be liberalized and allow private actors to produce electricity and feed it into the national grid.

3. **Provide subsidies or other incentives for solar power –** The attractiveness of investment in solar power in Lebanon for pioneering investors could be increased by subsidies (e.g. tax breaks or preferential loans). As the domestic market develops and investors gain more confidence, subsidies can be gradually reduced to reduce the financial burden on the state.

4. **Reduce risks for investors** – Providing a regulatory framework that reduces risks for investors may encourage investment in renewables in Lebanon, increasing renewables adoption.

5. **Participate in international cooperation** – Take advantage of resources and knowledge exchange provided through international cooperation and organizations, including international targets and action plans on how to achieve them.

6. **Promote innovation and research** – Increased promotion of innovation and research could benefit the increased adoption of renewables and a resilient and sustainable electricity supply that is less vulnerable to conflicts, instability, or other disruptions.

7. **Adapt the legal framework to allow for bottom-up initiatives** – The legal framework should be adapted to allow for bottom-up initiatives, such as through a net-metering scheme, the continuation of low-interest loans for decentralized solar solutions, or energy communities, to encourage private households to participate in the increased adoption of renewable energy applications.

The target Lebanon wants to achieve is highly ambitious, even in a stable economy and political system. It would require Lebanon to perform better than almost any country has in the past. The current political and financial crises, as well as the outdated legal system constraining the Lebanese energy market present large barriers to the achievement of their renewable electricity targets. The recommendations of this thesis provide guideposts on how to overcome these constraints, using strategies that have worked in countries with similar contexts.

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Abbreviations

BRSS	Beirut River Solar Snake
BDL	Banque du Liban
EDL	Electricité du Liban
ERA	Electricity Regulatory Authority
EOI	Expression of interest
GDP	Gross domestic product
IAM	Integrated assessment method
IEA	International Energy Agency
IRENA	International Renewable Energy Agency
LCEC	Lebanese Center for Energy Conservation

LCPS	Lebanese Center for Policy Studies
LPA	Lebanese Petroleum Administration
M(o)EW	Ministry of Energy and Water
MW	Megawatt
MWp	Megawatt peak
NECP	National Energy and Climate Plan
NREAP	National Renewable Energy Action Plan
PV	Photovoltaics
RE	Renewable energy
RSS	Residual Sum of Squares
UNDP	United Nations Development Program
UNIDO	United Nations Industrial Development Organization
WTP	Willingness to pay

1 Introduction

An uninterrupted supply of energy is a fundamental requirement for a flourishing economy, a functioning industry, and ultimately a good quality of life (Moore & Collins, 2019). Among countries that struggle to provide this to their industry and its citizens is Lebanon. Though according to the IEA 100% of its citizens have access to electricity (International Energy Agency, 2020), the day-to-day life in Lebanon paints a different picture. Formally, Electricité du Liban (EDL), Lebanon's government agency, reporting to the Ministry of Energy and Water (MoEW) should provide all electricity (Moore & Collins, 2019). In practice, however, the majority of electricity produced comes from private diesel generators, leaving electricity production up to private households. Hence there is a large gap between the amount of electricity supplied and what the population demands. In 2018, Electricité du Liban (EDL) was able to provide only 47% of the total energy demand and power outages were recorded to be between three to 17 hours a day (Moore & Collins, 2019). Additionally, Lebanon's electricity sector is responsible for 53% of the country's greenhouse gas emissions and imported fossil fuels are the sources for 98% of energy production (Moore & Collins, 2019).

As Lebanon does not have its own oil reserves and is still relying so heavily on oil products, it has to import almost the entirety of its energy sources. This distinguishes the country from other countries in the region of the Middle East, which usually rely on their own oil reserves, increasing the incentive to switch to domestic energy production. Due to subsidies for the electricity sector and low, inefficient tariffs not reflecting current electricity prices, the electricity sector presents an immense financial burden for the country, in 2017 operating at a loss of 1.4 billion USD (Moore & Collins, 2019) and making up more than half of Lebanon's national debt (Ahmad et al., 2020). And it is not just a financial burden for the state. Most households are forced to pay two electricity bills – one for electricity from the grid and one for the operation of the diesel generators, making up a significant portion of the already slim household income (Chams, 2020).

Despite the fact that Lebanon's energy provision to its citizens is lacking, it is also going through one of the worst political and economic crises in its history. Sparked by the population's dissatisfaction with the government and its engagement in widespread corruption, the crisis has been worsened through the rapid devaluation of the Lebanese Lira at the beginning of 2020, the recent COVID crisis further weakening the economy, and the explosion in Beirut's harbor, further exposing the government's inability to adequately protect and provide for its citizens (Bizri et al., 2020).

To increase the country's generation capacity and simultaneously combat the effects of climate change, in 2016 the government implemented a target to reach 12% energy generation through renewable energy sources such as hydroelectric, solar, and wind power, as well as biomass, by 2020 (Moore & Collins, 2019). Though this target was not reached, the government has subsequently established a more ambitious plan to reach 30% by 2030 (IRENA, 2020), possibly motivated by international pressures to transition to more sustainable energy systems. Lebanon is a signatory to the Paris Agreement, has ratified it in March 2019, and is also part of the Climate Vulnerable Forum, a group of countries highly vulnerable to the effects of climate change (Ministry of Environment, 2021). A sustainable energy transition could provide Lebanon and especially its citizens with an array of benefits, such as a lower dependence on imports and fluctuating oil prices, energy security and a domestic energy industry and subsequent job creation, as well as a significant decrease in greenhouse gas emissions, contributing to a mitigation of the effects of climate change. Not only does the strategy have the potential to raise the quality of life in Lebanon, but it can also support the government in overcoming current crises, making its feasibility all the more vital for the country's future.

1.1 Problem definition

There is a shortage of electricity in Lebanon forcing households and businesses to rely on private diesel generators as the state-owned utilities cannot satisfy the growing demand. Furthermore, most electricity is produced from fossil fuels so that the electricity sector is responsible for more than half of national emissions. Because these fuels are 100% imported while electricity is sold at tariffs below its actual cost, the power sector is also responsible for half of the national debt. To increase the country's generation capacity and reduce greenhouse gas emissions, as well as decrease the national debt, the government aims to produce 30% of electricity from renewables by 2030. A sustainable energy transition could both raise the quality of life in Lebanon and also support the government in overcoming the current political and financial crises.

Considering the immense challenges Lebanon faces, the feasibility of reaching its renewable energy targets is uncertain. Given the poor understanding of the feasibility of renewable energy targets, both national stakeholders and the international community are uncertain of whether to wholeheartedly support it and if so how, especially considering the current crises and the recently updated targets for 2030. Assessing the feasibility of Lebanon's renewable energy targets not only identifies challenges in their feasibility and how to overcome them but may also provide useful insights for other developing countries that are aiming to address their energy challenges through renewable electricity.

Though energy transitions and their feasibility have been assessed in other contexts, none have been applied to the context of Lebanon. IRENA (2020), Moore & Collins (2019) and Ibrahim et al. (2013) have all assessed the current RE status in Lebanon, have identified potential barriers and drivers for increasing the share of RE in Lebanon, as well as recommendations on institutional changes and policies. These assessments have not been in relation to specific targets, however, in the case of Moore & Collins (2019) and Ibrahim et al. (2013). In the case of IRENA (2020), targets set in course of the NREAP 2016-2020 for 2030 have been assessed and reiterated, using their REmap method, that have also been adopted by the Lebanese government for the NREAP 2021-2025. However, the feasibility of these targets has not been assessed in relation to the international feasibility space of increasing the share of RE, especially compared to successful growth trajectories achieved in other countries.

1.2 Aim and Research Questions

This research aims to assess the feasibility of Lebanon's renewable electricity targets and identify options for increasing this feasibility. To achieve this aim, the thesis addresses the following research questions:

1. What are the renewable electricity targets in Lebanon and what are the mechanisms and processes which enable and constrain the achievement of these targets?
2. How does Lebanon's experience with renewable electricity deployment and the trajectory of renewable electricity growth necessary for achieving their targets compare with the historical experience of renewable electricity deployment in other countries that succeeded in rapidly and widely deploying renewable energy?

3. What can be done to increase the feasibility of achieving Lebanon's renewable electricity targets?

RQ 1 defines the targets analyzed and provides deeper insight into the current electricity system and resource potentials in Lebanon and how these impact the feasibility of achieving their targets, through literature and documentary review, as well as energy and socio-economic statistics. RQ2 compares the growth of renewable electricity of selected case study countries with the growth projected and the growth necessary to achieve Lebanon's electricity targets, utilizing growth modeling based on historic data, hence providing observations on the feasibility of achieving these targets. This is based on the assumption that what was feasible in the past (in other countries) may be feasible in the future (may also be feasible in Lebanon). RQ3 provides recommendations on how the feasibility of achieving Lebanon's targets can be increased, based on the results from RQ1 and RQ2.

1.3 Scope and Delimitations

The focus of this thesis' empirical study is the national electricity system in Lebanon, including energy generation and distribution, which will be compared to renewable energy generation in countries systematically selected for the relevance of their experience with renewable electricity. Particular focus is put on its solar electricity target, as hydro and wind targets are less ambitious and may be achieved more easily, due to projects already in progress. Lebanon was chosen as the focus of this study because of its high potential and incentive for a transition to renewable energy sources, its highly ambitious renewable energy target for 2030, and the multifaceted challenges it faces currently.

Lebanon's solar electricity target will be compared with the growth trajectories and targets in Chile, Greece, Israel, and Vietnam, including a comparative analysis of their contextual factors. Additionally, in order to compare Lebanon's targeted growth to the wider realm of feasibility, the solar growth trajectory of 62 countries that have developed a significant share of solar power of their total electricity generation. This will not include contextual factors and will only focus on electricity generation data.

Concerning the temporal scope of the study, historical developments in the electricity system of Lebanon will be investigated from the 1920s to today and fit growth models will be based on historical data from 2010 to 2019 for the case study countries (2018 for Lebanon, as there is no data available for 2019) and project electricity growth in Lebanon to 2030, the year in which the targets should be reached. Limitations of the set time frame are that models are based on a shorter time frame of historic data, due to the only recent expansion of renewables in Lebanon and therefore limited availability of historic data.

1.4 Ethical considerations

The research design has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee. There is no external organization or anyone else involved in the research for my thesis that may be in a position to unduly influence the analysis and subsequently the conclusions. All empirical data collected will be stored on my personal computer. Any sensitive information, which will most likely include name, contact details, and place of employment of stakeholders providing data or information, will only be stored digitally with the participants' consent and will not be published.

It is recognized that some websites encountered during the research process have only been available in Arabic, Lebanon's official language, which the author is not fluent in. It was therefore ensured that any translation was as accurate as possible and was proofread by an Arabic native speaker.

Furthermore, the author acknowledges the strained relationship between the Lebanese and Israeli governments (Schweikle, 2020) and by no means considers this study a political statement for either side of the conflict, as this is an objective study solemnly on renewable energy adoption in Lebanon. Israel was chosen as a case study purely for its geographical location, similar resource availabilities, and advancing renewable energy policies, to provide unique learnings on how to increase the adoption of renewable energy in Lebanon.

1.5 Audience

There are two intended audiences of this research. On the one hand, the findings can be of use to policy makers and non-governmental organizations supporting renewable energy uptake in Lebanon, providing important insights into increasing its targets' feasibility and the transition to a renewable electricity system. On the other hand, it provides a method of assessing the feasibility of a renewable energy transition strategy in a developing country in crisis that may apply to other contexts, therefore also addressing academic audiences.

1.6 Disposition

Chapter 1 introduces the problem of the feasibility of Lebanon's renewable energy targets for 2030, especially in relation to what has been historically achieved by other countries. It then defines the overall aim and research questions, followed by the scope, ethical considerations, and audience of this study.

Chapter 2 reviews academic literature concerning energy transitions, technology diffusion, and feasibility assessments, as well as previously identified drivers and barriers of RE adoption in Lebanon and recommendations on how to improve its energy system.

Chapter 3 describes the analytical framework and research design of this study, as well as methods for data collection and analysis.

Chapter 4 presents the findings of this study. The first part describes the current state of the electricity system in Lebanon, the energy resources available, and their targets for 2030. It then outlines the current electricity generation by source, the policies in place, and future targets for the case study countries. The second part documents the results of the growth models and feasibility frontier and the resulting implications for the feasibility of Lebanon's solar targets. Lastly, the third part compares techno-economic, socio-technical, and political contextual factors in the case study countries and Lebanon.

Chapter 5 discusses the main findings and their implications for the feasibility of Lebanon's targets, identifying enablers and constraints to its achievement and relevant differences in growth trajectories between Lebanon's solar target and the case study countries. It furthermore provides recommendations on increasing the feasibility of Lebanon's targets and reflects upon the methodological limitations of this study.

Chapter 6 provides a summary of the main findings of this study, describes the implications of these for non-academic audiences, and identifies areas for further research.

2 Literature Review

This section first presents relevant theories and concepts pertaining to the feasibility of energy transitions, including what energy transitions entail, how this relates to technology diffusion, and how feasibility has been previously assessed. This is followed by drivers and barriers previously identified in the literature for Lebanon's energy transition, as well as policy, infrastructure, and financial recommendations given.

2.1 Feasibility of energy transitions

2.1.1 Energy transitions

According to Grubler et al. (2016, p. 18), energy transitions entail *"a change in the state of an energy system, as opposed to a change in an individual energy technology or fuel source."*. The Lebanese government wants to transform their energy system from relying almost solemnly on oil products, to include more renewable energy sources, such as wind and solar power, and aspire to operate a more renewable energy system in the future, therefore transitioning to a more renewable energy system. This requires a change in three distinct elements of an energy system, namely the energy flows and markets (techno-economic factors), the energy technologies employed and the socio-technical context they are entrenched in (socio-technical factors), as well as the political framework defining relevant policies and how these are implemented (political factors) (Cherp et al., 2018). Similarly, Cantarero (2020) has defined three pillars necessary for every energy transition, including technology, society, and policies/institutions.

2.1.2 Technology diffusion

For an energy transition to happen, energy technologies in their socio-technological context need to change and innovative technologies, such as renewable energy technologies like solar PV and wind turbines, need to "diffuse" in the energy system, called technology diffusion (Grubb et al., 2020; Cherp et al., in press). This tends to happen in three phases, the formative phase, the growth phase, and the saturation phase, and can be visualized by a logistic function, also known as the S-curve, shown in Figure 1. This is characterized by relatively slow and gradual growth in the beginning, when the technology starts to emerge in the market (formative phase), followed by exponential growth as the new technology becomes more established (growth phase). The transition from the formative to the growth phase is marked through the "take-off" when an innovative niche technology starts to penetrate the socio-technical regime and can expand exponentially with diminishing need for support from political institutions for example. Cherp et al. (in press) define this point as $T_{1\%}$, as they consider the take-off to be when the relevant technology makes up 1% of the total energy supply. Eventually, a slow down in growth happens, as the penetration of the technology in the market stabilizes and reaches saturation of the market eventually (saturation phase).

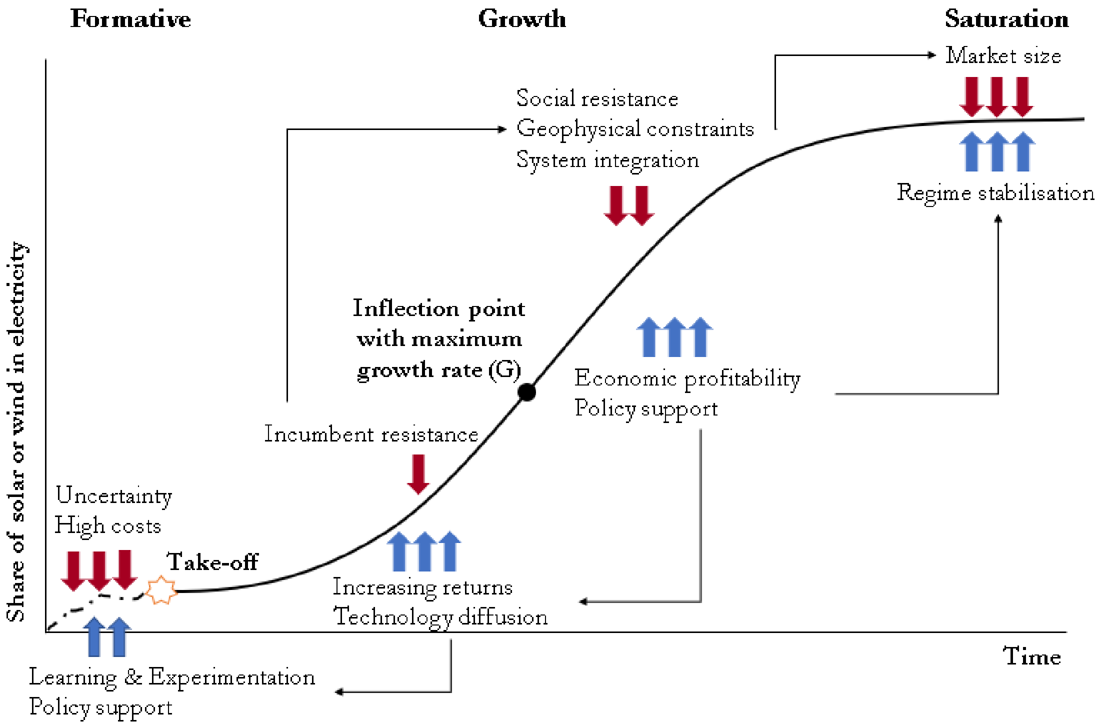

Figure 1: S-curve showing the phases of renewable electricity adoption, adapted from Cherp et al. (in press).

2.1.3 Feasibility

In principle, feasibility means how likely something is to work out. Majone (1975, p. 261) says *"a policy is said to be feasible insofar as it satisfies all the constraints of the problem which it tries to solve"*, meaning that anything not under the control of the policymaker that could have an impact on the policy results needs to be considered and overcome to successfully reach the policy goals. Jewell & Cherp (2019) divided (political) feasibility into the questions of "feasibility of what?", "feasibility when and where" and "feasibility for whom", indicating that when analyzing feasibility, it is important to define what you are analyzing, in what context, and what actors will be involved.

Assessing the feasibility of energy transitions

Among methods used in academic literature to assess energy transitions are an analytical hierarchy process methodology (Karatayev et al., 2016), a four-pillar approach, including justice, democracy and citizenship, energy security, and environmental sustainability (Cantarero, 2020), a combination of four transition frameworks (Batinge et al., 2019), including transition management, socio-technical transition, innovation systems, and strategic niche management and a comparative analysis of electricity transitions (Cherp et al., 2017).

The analytical hierarchy process used by Karatayev et al. (2016) to assess the energy transition in Kazakhstan represents a technique for organizing and analyzing decisions in complex environments, using mathematics and psychology to divide a problem into a hierarchy of criteria according to a numerical prioritization. This produces different alternatives and their probability. It represents a rational framework to weigh alternatives against each other and this case to define the most realistic, as well as a beneficial energy transition strategy for Kazakhstan.

The four-pillar approach developed by Cantarero (2020) includes four dimensions to assess a country's energy transition progress:

- Justice, including access to modern cooking fuels, electricity access, female school enrolment in secondary school, and access to information.
- Democracy and citizenship, including participation in democratic processes, civic ownership, the number of green jobs available, "prosumer" legislation like net-metering or feed-in tariffs, available support schemes, and the amount of energy produced by private households.
- Energy security, including the energy use per capita, the amount of energy used per unit of GDP, the share of renewable energy in total generation, average electricity prices, and net import dependency.
- Environmental sustainability, including emissions per capita and unit of GDP, as well as the ecological footprint.

Batinge (2019) draws from four transition frameworks to develop a sustainable energy transition framework for unmet electricity markets:

- Transition management, based on the assumption that transitions from one energy source to another need to be governed (managed), especially in developing countries.
- Multi-level perspective/socio-technical transition, based on the assumption that existing regimes are challenged by niche technologies and in conjunction with landscape pressures these are increasingly adopted and eventually become the new regime technology.
- Innovation systems, based on the assumption that having these systems in place accelerates the innovation diffusion process, through knowledge transfer and learning.
- Strategic niche management, based on the assumption that governments need to nurture niche technologies, for example through subsidies, tariffs, or other market-based instruments.

Cherp et al. (2017) conducted a comparative analysis of the electricity transition of Germany and Japan, considering techno-economic, political, and socio-technical processes, in order to understand the different energy transition trajectories and provide an interdisciplinary approach to assessing energy transitions.

Though all authors have addressed how to assess energy transitions and what factors are important for an energy transition to happen, none of them explicitly address the feasibility of these in terms of the growth necessary to achieve these energy transitions, the time it takes to complete it, historical evidence of successful adoption of renewable energy or the consideration of existing growth trajectories.

Wilson et al. (2012) first analyzed the future capacity growth of energy technologies, meaning how much can energy technologies feasibly grow in the future, based on historical growth data and found that they show "*a consistent relationship between how much a technology's cumulative installed capacity grows and how long this growth takes*" (Wilson et al., 2012, p.381). Applied to future trajectories of growth of renewable energy technology, they found that it also offers a consistent relationship, meaning a suitable predictor of growth, though currently still predicting conservative growth compared to historical evidence, as there were still limited data points available (Wilson et al., 2012).

Based on these findings and on the assumption that what has been feasible in the past should be feasible in the future, Cherp et al. (in press) developed a method to evaluate the feasibility of energy transitions based on historical evidence and existing trajectories, comparing renewable energy technology growth across different countries. Grubler et al. (2016, p. 18) defined conditions for such comparative analyses, as they emphasize the importance of defining the same parameters for all case study subjects, to ensure you are comparing like with like instead of "*apples-to-oranges*". This plays into the notion that comparisons need to be done between similar contexts and consistently defined and normalized parameters.

Learnings from energy transition assessments

The Literature has provided several learnings important for the feasibility of a (relatively fast) energy transition:

1. **Low Complexity**: According to Grubler et al. (2016), rapid energy transitions share the common conditions of a low degree of complexity (meaning one technology is easily replaced by another), knowledge spillover from these technologies being implemented in close markets, and high tangible benefits for adopters. Hence, the more steps there are to take in an energy transition, and the more complicated it is, the slower the energy transition will be.

2. **Resources**: As reported by Cherp et al. (2017), energy technology regimes are stronger when they are based on domestic sources and involve new construction, as both of these mean energy security and job creation and therefore benefits for the domestic economy. Cantarero (2020) found that resource exhaustion must be considered as well in the energy transition, meaning the number of available resources (resource potential) needs to be considered, agreeing that energy transitions should be based on domestic resources and their availability.

3. **Supporting Policies**: Cantarero (2020) also found that there is a strong requirement for supporting policies that encourage a strong energy market, through investment incentives and revenue opportunities, meaning market-based policy instruments.

4. **Political interests**: Cherp et al. (2017) found that political interests are important for faster energy transitions, as the more important the adoption of renewable energy is to a government, the faster it will grow, but that also the inclusion of incumbent regimes matters, creating a strong support base.

2.2 Feasibility of rapid expansion of renewables in Lebanon

2.2.1 Drivers and barriers for successful implementation

There were several drivers and barriers identified by the literature, both for the Lebanese context and for energy transitions in developing countries in general. Factors that could be beneficial for reaching renewable electricity targets in Lebanon successfully include the following:

1. **Geographic suitability** – Lebanon is geographically well suited and possesses ample solar resources, as well as some more limited wind and hydro potential. Having an average of 300 days of sunshine with 8 to 9 hours of sun a year, solar power has the capacity to cover almost 50% of Lebanon's energy demand (Ibrahim et al., 2013;

Moore & Collins, 2019). Additionally, suitable wind speeds at the top of Lebanon's many mountains can complement solar power, as the wind blows when the sun does not shine (Ibrahim et al., 2013), though the landscape limits the possibility of larger wind farms.

2. **Willingness to pay (WTP)** – As current electricity costs are unbearably high, mainly due to the forced use of private generators, citizens are willing to pay for renewable alternatives, as long as they are at least at the same cost or cheaper, also considering the added benefit that after the initial investment, no fuel expenses are needed (Moore & Collins, 2019). This is based on a study conducted by the UNDP in 2015 on Lebanese consumers' WTP for renewable energy solutions.

3. **Improving trade balance** – Moore & Collins (2019) and Ibrahim et al. (2013) have estimated major cost savings in switching to renewables, mainly because the country would significantly decrease the amount of oil products imported, improving the external trade balance and reducing the costs to EDL.

4. **Local industry and jobs** – Producing renewable electricity locally would mean the creation of a currently lacking domestic energy industry, creating jobs in manufacturing, construction, maintenance, and operation of renewable energy plants. This is a strong incentive for the government and Lebanese citizens to support a transition to renewable energy (Moore & Collins, 2019; Ibrahim et al. 2013).

5. **National financing scheme** – Low-interest loans for renewable energy applications and energy efficiency have already yielded some successes during NREAP 2016-2020, having financed more than 938 projects as of March and having the potential to remain successful in the future (Moore & Collins, 2019). This has also been identified as one of the drivers for energy transitions in developing countries by Vanegas Cantarero (2020). However, as the financial situation is getting worse with the current political and financial crisis and the deflation of the Lebanese Lira it is unclear whether this program can be continued at the same level.

However, Lebanon is also facing an array of barriers that could hinder the successful fulfillment of its targets:

1. **Low electricity tariffs** – As mentioned, tariffs do not represent real costs at the moment, meaning there is low competition in the energy sector and large financial losses (Ibrahim et al., 2013; Moore & Collins, 2019; IRENA, 2020). Tariffs have not been adjusted since 1994 (Ahmad et al., 2020).

2. **Low institutional capacity** – Generally, a lack of data and research has existed in Lebanon, especially concerning energy generation data and the costs and benefits of RE (Ibrahim et al., 2013), due to a lack of infrastructure for monitoring energy data. This has also been identified as one of the barriers for energy transitions in developing countries by Vanegas Cantarero (2020) and was highlighted during the collaborative study between the MEW and IRENA in 2020, which states that "*Lebanon faces difficulties in compiling energy data and therefore is yet to generate a complete energy balance.*" (IRENA, 2020, p. 5)

3. **Lack of awareness** – There is a lack of awareness the renewable alternatives are an option, especially among those that could benefit the most. (Ibrahim et al., 2013). This has also been identified as one of the barriers to the energy transition in Kazakhstan by Karatayev (2016).

4. **EDL monopoly** – As the EDL is the only entity permitted to produce, transmit or distribute energy in Lebanon, it is obstructing the private sector from entering the energy sector, therefore inhibiting the creation of a functioning electricity market, presenting a large barrier to a capital-intensive technology such as RE (Ibrahim et al., 2013; Moore & Collins, 2019; IRENA, 2020).

5. **Poor infrastructure** – Not only are production plants (mostly hydro) deteriorating and decreasing steadily in efficiency, due to a lack of maintenance but also the grid is in bad shape, causing losses during distribution of up to 16.5% (Ibrahim et al., 2013; Moore & Collins, 2019; IRENA, 2020) and including illegal connections to the grid and other non-technical losses, 37.5% (IRENA, 2020). This has also been identified as one of the barriers to energy transitions in developing countries by Vanegas Cantarero (2020) and Karatayev (2016).

6. **Economic crisis** – The current economic crisis and the depletion of the Lebanese lira, the rising black market taking over currency exchanges, and the declining economy further worsened by the COVID crisis (Bizri et al., 2020) could endanger any planned investments in increasing the share of RE (Moore & Collins, 2019).

7. **Political crisis** – The current political crisis peaking in August 2020 with the explosion in Beirut harbor that has already forced the prime minister to step down and will likely cause further turmoil in the future, as well as wide-spread corruption creating an unstable political climate potentially endangering the legitimacy, financing, and effectiveness of any programs implemented by the government. Additionally, illegitimate elections and the involvement of religious groups in the government system mean a lack of accountability through elections (Moore & Collins, 2019)

2.2.2 Recommendations for increasing share of RE

The literature contains several recommendations on how to reform the electricity system in Lebanon and increase the share of renewable electricity. These concern institutions and regulations, regarding the infrastructure, technology, and human resources, and financing mechanisms and investments.

Institutional & Regulatory Recommendations

1. **Subsidy and tariff reform** – There is a consensus in the literature that subsidies for electricity generation from oil products should be reduced and electricity tariffs should be increased, to match the real cost of producing electricity and decrease the financial pressure on the electricity sector, relieving national debt (IRENA, 2020; Ibrahim et al., 2013; Moore & Collins, 2019). Higher tariffs can also make renewable electricity more profitable and thus attract more investments in the sector.

2. **Independent regulatory authority** – IRENA (2020) recommends the institution of an independent regulatory authority to act as an access point for the private sector

and regulate a standardized licensing process for RE projects, which is a recommendation also given by Ibrahim et al. (2013). This authority (ERA) has already been adopted into law by the Lebanese government but has not been established yet.

3. **Consistent legal framework for RE** – Currently there is a variety of laws governing certain aspects of renewable energy generation, which is why IRENA (2020) recommends instituting a new law that clearly defines the role of renewable energy and provides a consistent legal framework for the sector.

4. **Net metering and feed-in schemes.** IRENA (2020) recommends a net metering scheme while Ibrahim et al. (2018) recommend instituting a feed-in tariff. Both recommendations aim to compensate prosumers who feed electricity back into the grid from decentralized RE installations.

5. **Mandatory RE inclusion in new construction** – To increase the adoption of decentralized renewable energy solutions, Ibrahim et al. (2013) recommend adopting a mandate for RE inclusion for all new construction into law.

6. **Reduced taxes on RE products** – Both Ibrahim et al. (2013) and Moore & Collins recommend reducing taxes on RE products to promote their adoption, suggesting to cut import taxes and income taxes respectively.

7. **Encourage private sector investments** – There is a consensus that regulations need to be adapted to encourage the involvement of the private sector in electricity production in Lebanon, especially through investments (IRENA, 2020; Ibrahim et al., 2013; Moore & Collins, 2019).

Technology, Infrastructure & Human Capital Recommendations

1. **Improvement of the grid & integration of RE** – To cut losses and be able to provide an uninterrupted electricity supply, the grid needs to be updated and improved (IRENA, 2020; Ibrahim et al., 2013; Moore & Collins, 2019). Additionally, to ensure that RE applications can be connected to the grid, IRENA (2020) and Ibrahim et al. (2013) suggest an impact assessment to identify and overcome technological limitations, as well as the usage of smart meters for improved monitoring of the system (IRENA, 2020).

2. **Maintenance** – To be able to take advantage of existing generation capacity and ensure continued operation of already established hydro plants, Ibrahim et al. (2013) recommend the implementation of computerized maintenance management systems, as well as planned maintenance programs.

3. **Grid connection with neighboring countries** – For a facilitated import and export of (renewable) electricity, Ibrahim et al. (2013) recommend expanding the grid and connecting it to neighboring countries, such as Syria, Jordan, Egypt, or Turkey.

4. **Capacity building & human resource development** – IRENA (2020) and Moore & Collins (2019) recommend instituting programs for capacity building and continued training to ensure a highly qualified workforce for the electricity sector and lay the foundation for expanding the domestic electricity market, for which a qualified domestic workforce is required.

Financing Recommendations

1. **Modernize billing process** – As many uncollected bills make up part of the financial deficit EDL faces, Ibrahim et al. (2013) suggest modernizing and automate the billing process, making it more efficient and leaving less room for error.

2. **Bundled RE projects** – To reduce the risk of RE projects, IRENA (2020) recommends bundling smaller RE projects, to reduce transaction costs of single projects, increase confidence in the completion of the project and reduce the financial risk.

3. **Facilitate access to financing and risk mitigation schemes** – To encourage a wider number of RE projects and investments, IRENA (2020) recommends improving EDLs creditworthiness, through the subsidy and tariff reform, as well as taking advantage of risk mitigation instruments provided by IRENA.

4. **Standardize requirements in the bidding process** – To streamline the process for power purchasing agreements, IRENA (2020) suggests standardizing the documentation requirements for bidders in the bidding process and provide transparent information about auctions, which are currently not publicly available, facilitating the process for bidders.

2.3 Implications of prior research for this study

The literature shows that the adoption of renewable energy technology is a complex, non-linear process influenced by a variety of global and national contextual factors. This means that in assessing the feasibility of renewables growth, it cannot simply be assumed that the existing trends apply to every context, as the individual mechanisms that accelerate and constrain the deployment of renewables in every unique context need to be understood. The literature stresses that the organization of electricity markets, the capacity of key state and non-state actors as well as favorable policies, geophysical potential, and technology readiness can affect the feasibility of renewables deployment. While there is significant literature with general theories of energy transitions and emerging literature on feasibility assessment, there are virtually no studies on the feasibility of specific natural targets using insights from both transition studies and technology diffusion theories. In particular, despite several assessments of the electricity sector in Lebanon, there has not been a focused analysis of the feasibility of government targets. This provides the niche for this thesis.

3 Methodology

3.1 Analytical Framework

As defined in section 2.1.3, every feasibility framework should include a characterization of what is being analyzed, in what context, and what actors are involved, following the questions defined by Jewell & Cherp (2019), "what, where and for whom?".

3.1.1 Feasibility of what?

The feasibility assessment will focus on the renewable electricity targets set for 2030 and the strategy outlined to reach these. Here two main questions need to be answered to assess the targets' feasibility. The first is what needs to happen to achieve the targets? This includes the construction of wind and solar parks, maintenance, repair, and improvement of the current grid infrastructure, fostering of a local electricity market with domestic production, a complete regulatory reform, including policies that will support the adoption of more RE, like feed-in tariffs and low-interest loans and investments to finance the construction, purchase of technologies and equipment, etc.

The second is how fast do renewable energy technologies and in particular solar energy have to grow to reach the targets set for 2030. Here it is not only interesting to see what is technically possible but also how the targets compare to this, whether they are set adequately, too ambitious, or not ambitious enough. This can be achieved using integrated assessment methods (IAMs), modeling the growth of RE technologies in Lebanon, such as mentioned as useful to (partially) assess energy transitions in Jewell & Cherp (2019), Cherp et al. (2018), Vinichenko (2018) and Grubb et al. (2020). But because these methods do not consider factors beyond neoclassical economics and technological assumptions (Vinichenko, 2018), multiple criteria and assessment methods are needed to include socio-technical and political factors in the overall feasibility assessment.

3.1.2 Feasibility when and where?

The feasibility assessment will focus on the national strategy in Lebanon to reach the defined targets by 2030, specifically looking at the time frame between 2010 and 2030, using historical data for growth modeling and analysis. Here it is particularly interesting to investigate if similar growth of RE has been successfully implemented before in similar techno-economic, socio-technical and political contexts, according to the meta-theoretical framework defined by Cherp et al. (2018). The techno-economic context includes factors pertaining to energy resources, demand for electricity and infrastructure of the electricity system. The socio-economic context includes factors regarding the performance of the innovation system and technology diffusion. The political context includes factors regarding state goals, political interests and institutions and capacities.

3.1.3 Feasibility for whom?

The final dimension of feasibility includes who it is feasible for to achieve, so who is going to participate in achieving these targets. According to the strategy, it will primarily be the government and its financial institutions participating (IRENA, 2020). Concerning necessary investments for the projects up until now and in the course of the NREAP 2016-2020, investments have come from the government, Lebanese banks providing low-interest loans for RE projects (IRENA, 2020), and to a small extent from foreign investors such as the Japanese government for solar rooftops for schools (Tsagas, 2018). As most funding is currently expected to come from the government, this could potentially pose a problem for the current strategy, as since the financial crisis beginning of 2020 banks have run out of foreign and domestic currency, even temporarily denying Lebanese citizens access to their own money (Bizri et al., 2020). In light of this, it could be unrealistic to assume that they will still be able to provide low-interest loans for example.

New investors could either come from foreign investors, just as they have successfully implemented projects in Egypt (Vinichenko, 2018) or from the private sector. According to Grubb et al. (2020), the private sector is the main driver for energy transitions, and centralized (state-owned) utility companies, such as EDL in Lebanon usually present a barrier more than a driver to a successful transition. For the private sector to be able to participate, a legal framework and institutional reform are necessary (Ibrahim et al., 2013; Moore & Collins, 2019; IRENA, 2020).

3.2 Method

To answer the research questions, an inductive logic of inquiry has been followed, guided by the ontology of causal mechanisms and the epistemological assumptions of critical realism. This follows the belief that a combination of underlying mechanisms can explain observable phenomena and that these can be studied through empirical analysis. This combination of ontological and epistemological assumptions favors the use of specific research methods, also including (comparative) case studies, justifying the use of a comparative longitudinal case study for this thesis.

This thesis aims to assess the feasibility of Lebanon's renewable electricity targets. The main approach for this assessment will be comparing these targets with renewable electricity trajectories in other countries which are further advanced along the growth curves as well as with the emerging renewable energy trajectories in Lebanon itself. The choice of conducting a comparative longitudinal case study is based on the assumption that what was feasible in the past (in other countries) may be feasible in the future (may also be feasible in Lebanon). Therefore, analyzing what has supported the implementation of an increased share of RE in other countries may give an indication of the feasibility of Lebanon's RE targets, considering whether these identified conditions are given there or not, and may help predict its outcome. The criteria on which the selection of countries is based is explained in section 3.3.

The comparative cases will be selected considering the requirements of the structured, focused comparison approach (George & Bennett, 2005). This is a comparison based on distinct questions posed to each of the selected case studies and structured so as to focus on distinct features of the historical context comparable across case studies (George & Bennett, 2005). For this thesis, key features of the cases will be the parameters of growth models in Lebanon and the countries selected for comparison.

The comparative analysis will help identify which factors are drivers for the adoption of RE and which could present potential barriers. The presence of these (or lack thereof) in Lebanon should then provide an indication of whether it is then feasible to execute their strategy in the next ten years. It will furthermore show the growth rate in other countries compared to the growth rate that Lebanon needs to achieve its targets for 2030 and whether or not this expected/planned growth rate is realistic (feasible). Lastly, it will provide an insight into constraints to achieving Lebanon's electricity targets and what can be improved upon to increase the feasibility of these.

The last section in this chapter (3.4) describes the methods of data collection. RQ1 will be answered through literature & documentary review, using a synthesis matrix- To answer RQ2, several growth models are fitted to the empirical data on solar power deployment for Lebanon and the case study countries (in case of Lebanon also to targets). I subsequently compare the parameters of these growth models, especially the maximum growth rate at the inflection point of the S-curve in different countries. Here the focus is put on solar energy, as the other renewable resources for electricity generation (wind and hydro) have comparatively lower targets for 2030, and projects underway already indicate that reaching these targets will be feasible, while the target for solar power is set significantly higher. This comparison is the main indicator of the feasibility of the required growth in Lebanon. I will then use a structured comparison of techno-economic, socio-technical and political indicators (contextual factors) to analyze underlying causes for growth / non-growth of RE. The growth models are discussed in sections 3.4.1 and 3.4.2 and the analysis of the contextual factors in 3.4.3. It should also be mentioned that RQ3 is answered by synthesizing and interpreting the material obtained and analyzed within RQ1 and RQ2.

3.3 Selection of case study countries

The countries that have been selected as case studies are listed in Table 1. The selection of comparative countries to assess the feasibility of Lebanon's targets is based on three criteria:

1. Comparable potentials for solar power.

2. Growth of solar power should have passed the formative stage, defined as over 0.3% of total energy supply.

3. Case studies should be on the rim or periphery of technological adoption, as early adopters likely come from a different context and will therefore be less comparable to the Lebanese situation, which lies on the periphery of renewable energy adoption (Europe, the US, and Japan). (Jewell & Cherp, 2019).

Table 1: Case Studies chosen for comparative study. (IEA, 2021a; ESMAP, 2020)

Country	**Criteria 1** Average solar potentials in kWh/m2/day (theoretical [t] & practical [p] in kWh/kWp)	**Criteria 2** Share of Solar of total electricity supply in 2019 (2018 for Lebanon and Vietnam)	**Criteria 3** Location vis-à-vis core of technology adoption
Chile	5.72 [t], 5.36 [p]	7.76 % Solar	Rim
Greece	4.45 [t], 4.14 [p]	8.12 % Solar	Rim
Israel	5.75 [t], 5.08 [p]	3.64 % Solar	Rim
Vietnam	4.25 [t], 3.55 [p]	0% Solar	Periphery
Lebanon	5.36 [t], 4.83 [t]	0.32 % Solar	Periphery

Though Vietnam has not generated a significant amount of solar power in 2018, it has enormously increased its installed capacity in the last two years and therefore qualifies as a case study country. More on the current electricity situation in all four case study countries can be found in section 4.2.

3.4 Data Collection & Analysis

The data collection methods used to answer each research question, what type of data was collected, and from what sources, as well as the data analysis methods, are listed in Table 2. The data analysis methods for RQ 2 are further explained below.

Table 2: Data collection & analysis methods per research question.

RQ	Method	Data collected	Sources	Data analysis method
RQ 1	Literature Review Documentary Review Energy and socio-economic statistics	• Status of energy system in Lebanon & case study countries • Resource potentials • RE targets • Policy plans • Demographic data	LUBcat, Google Scholar, recommended readings, World Bank Data, government websites	Synthesis matrix
RQ 2	Energy statistics	• Historic data on electricity generation by source for Lebanon & case study countries • Historic data on solar electricity generation for all countries surpassing 0.3% solar of total generation • Techno-economic, socio-technical and political factors for Lebanon and case study countries	IEA, IRENA, government websites	Growth model, feasibility frontier, synthesis matrix for contextual factors
RQ 3	Literature Review	• Policy measures successfully implemented in case study countries	LUBcat, Google Scholar, recommended readings	Synthesis matrix

3.4.1 Growth Models

As described in section 2.1.2, the diffusion (growth) of a renewable energy technology happens in three phases – the formative, the growth, and the saturation phase. These phases can be used to model the development of diffusion in different countries, which makes the comparison of cross-national differences in the diffusion possible, without being distorted by external factors such as population size or size of the energy system.

The growth phases are represented by an S-curve. The moment the renewable technology has reached 1% of the total electricity supply (or another predefined level) is characterized as the "takeoff" year and serves as the starting point of the growth model, defined as $T_{1\%}$ by Cherp et al. (in press). Though Lebanon has not reached 1% yet, in 2018 the share of renewable energy in the total electricity supply started to increase exponentially, which is why this will serve as the "take-off" point for the analysis, at 0.3%, to be able to model its growth. The time it takes a country to go from 10% RE to 90%, when the saturation phase is reached, is defined as Δt and gives an indication of the speed of energy transition. For the logistic curve, it approximately equals the time it takes to grow from 1% to 50% of the electricity share. The inflection point of the graph, when the growth rate is at its maximum is described as t_0 and the maximum growth rate achieved is denoted as G. Finally, the maximum share of total electricity supply that can be reached with this technology, the asymptote of the function, is described as L and the inflection point can also be represented as L/2 for the logistic model. Many different types of functions can be used to model the shape of the S-curve and which function best approximates the shape of the S-curve and thus the growth of each technology best differs from country to country.

For this analysis, the focus is on three growth models that perform particularly well in this approximation. In theory, the growth can also be modeled using a linear function. However, this function is not able to represent the differing growth rates at different phases and will therefore not produce an accurate representation of the technology diffusion in Lebanon or the case studies. Hence it will not produce results that give an indication of the feasibility of Lebanon's solar electricity target and will be excluded from the analysis in this thesis. The remaining functions used in the analysis are described in the following sections.

<u>Gompertz model</u>

$$f(t) = Le^{-e^{-k(t-t_0)}}$$

Equation 1: Gompertz model function (Cherp et al., in press).

Equation 1 represents the formula for the Gompertz model, where L represents the maximum share of total electricity supply (the asymptote), k the constant growth rate and t_0 the point in time when growth is at its maximum. The historic data on electricity generation can be used to calculate the values for each variable.

<u>Logistic model</u>

$$f(t) = \frac{L}{1 + e^{-k(t-t_0)}}$$

Equation 2: Logistic growth function (Cherp et al., in press).

Equation 2 represents the formula for the logistic function, where again, L represents the maximum share of total electricity supply (the asymptote), k the constant growth rate and t_0 the point in time when growth is at its maximum. The historic data on electricity generation can be used to calculate the values for each variable. This is the function most frequently used to model growth of newer technologies (Cherp et al., in press).

Exponential function

$$f(t) \approx 1\% \times e^{k(t-T_{1\%})}$$

Equation 3: Exponential growth function (Cherp et al., in press).

Execution using R

To calculate and graphically depict the above-explained models, the statistical programming language R will be used, to produce fitted growth curves that model the growth of solar power in Lebanon and the chosen case study countries. The code for the models was taken from Github (Vinichenko, 2021) and adjusted to the data set of this study.

Output of the model

Table 3: Output of growth models in R (Cherp et al., in press; Barone, 2021).

Variable	Name	Meaning
Fit	Fitted model	Shows the model that was fitted (G – Gompertz, S – Logistic, E – Exponential).
L	Saturation level	The growth ceiling (asymptote) of the model in % of the total energy system, meaning the saturation level (only applicable to S and G models, E has no growth ceiling).
TMax	Maximum growth year	The year when the maximum growth rate G is achieved, the inflection point of the S-curve (only applicable to S and G models, E has no maximum growth rate).
K	Growth constant	Year-on-year growth rate (measured in year^{-1}) at the beginning of the logistic and Gompertz curves and the exponential curve. In the S and G models, it is inversely proportional to dT.

dT, years	Delta T	The time (in years) it takes to grow from 10% to 90% of the saturation level L (only applicable to S and G models).
G	Maximum growth rate	The maximum growth rate at TMax in % of electricity supply in this year (only applicable to S and G models).
Maturity	Maturity	% of the saturation level achieved by the fitted curve in the last year of the time series data (only applicable to S and G models) For the logistic model, it gives an indication of whether growth is accelerating (<50%), stable (50-90%), or stalling (>90%).
RSS	Relative residual sum of squares	Value of 1 or above, indicating the amount of variance in a data set or model and the lower the value is, the more statistically accurate a model can be interpreted. Therefore, the lowest RSS value indicates the best fitting model to the time series.

Normalization

For the models to be comparable between Lebanon and other countries, the historic data used for the functions needs to be normalized to the total amount of electricity produced. The choice of year to use for the normalization can affect the results and must thus be consistent across case studies. For the growth models, the year of the maximum growth rate (T_{max}) of the best fitting model was chosen as the normalization year, which is 2016 for Chile, 2012 for Greece, and 2015 for Israel. For Lebanon, the best fitting model suggests 2028 as T_{max} and since data for that year does not exist yet, 2018 was chosen as the year of normalization, based on the second-best fitting model. All values are therefore expressed as percentage of the total electricity system.

3.4.2 Feasibility Frontier

A feasibility frontier compiles historic data on growth trajectories and shows graphically what maximum growth rates can be achieved after take-off, based on global maximum growth rates per year. To compare the feasibility of Lebanon's forecasted solar growth to growth that has been achieved globally, a feasibility frontier will be created, using historic solar electricity generation data from all countries that have surpassed the defined take-off point, in this case, 0.3%. These values will again be normalized, to account for differing sizes in electricity systems. All countries were normalized to 2010, as this is the starting point of the analysis and the first year of electricity generation from solar power in Lebanon. The results will be represented graphically, using Microsoft Excel, to depict the growth in the share of total electricity generation over time, starting from the take-off point), creating a "feasibility frontier" of what is possible to achieve in that time frame. Lebanon's anticipated growth will then be added (normalized), from 2015 to 2018 using historical data (data before 2015 is too small to be significant for graphical representation) to the target it wants to achieve by 2030, making its feasibility visually comparable to what has already been attained in other countries around the world.

3.4.3 Contextual factors

To analyze the feasibility of Lebanon's renewable energy strategy, a comparative longitudinal case study will be conducted to compare growth rates of RE and how these are affected by contextual factors defined in the meta-theoretical framework by Cherp et al. (2018). This will also be used to answer RQ1, to identify what mechanisms and processes enable and constrain Lebanon's energy transition strategy and consequently the feasibility of reaching their targets. The framework combines techno-economic, socio-technical, and political factors, drawing from multiple disciplines, such as economics, political science, sociology, and energy systems analysis, and provides interdisciplinary guiding principles for my analysis. Factors that are included in the framework can be found in the appendix [Appendix A]. For each overarching factor, several indicators have been identified and are explained in the appendix [Appendix B].

4 Results

4.1 Electricity in Lebanon

4.1.1 Current Electricity Situation

In 2018, the last year with available data, 98.01% of the electricity supply in Lebanon was sourced from oil products, 0.35% from solar and wind, and 1.64% from hydropower (IEA, 2021a). Data on exact electricity generation by source for 2019 and 2020 is currently not available, but Moore & Collins (2019) estimate that the share of renewable electricity currently lies between 4 and 6%, mainly due to hydropower. Considering the 12% renewable electricity target established for 2020 in the National Renewable Energy Action Plan in 2016 (NREAP 2016-2020), Lebanon most likely has not been able to reach its goal on time. However, there are a considerable amount of projects in the pipeline involving the construction of solar, wind, and hydropower plants that are supposed to be in operation within the next years (IRENA, 2020). The planned generation capacity created through these projects can be seen in Table 4. An overview of ongoing and completed solar and wind projects can be found in Appendix C and D.

Table 4: NREAP 2016-2020 targets, contracted capacity, projects in progress, 2030 targets, and potential generation capacity in Lebanon (IRENA, 2020).

Source	Target 2020	Contracted capacity 2020	Projects in progress	Target 2030	Potential
Solar power (PV)	150 MWp	2 MWp	1030 MWp	3000 MWp	87 636 MWp
Hydro power	331.5 MW	N.A.	300 MW	601 MW	855 – 960 MW
Wind power	200 MW	200-220 MW	500 MW	1000 MW	1500 MW

There is a significant gap between electricity supplied by the government and electricity demanded by Lebanese consumers, leading to power outages and the need for supplementing through private diesel generators. This issue has persisted for so long that owning private generators to make up for the gap in supply has been normalized – housing projects are usually always built with a space for a private diesel generator and if you are moving into a new complex, you automatically have to buy into the often community-owned generators (Moore & Collins, 2019). Owning and operating the generators comes at a much higher cost to the population and the increasing number of illegal connections to these is further straining the already dire financial situation. However, as they already represent a decentralized electricity supply, it could serve as supplement to the implementation of solar PVs on rooftops, as these are further developed.

Additional to the problems Lebanon is facing in its electricity sector, it is also going through one of the worst political and financial crises in its history. Protests, sparked by the population's dissatisfaction with the government and its engagement in widespread corruption, started in

October 2019 (Bizri et al., 2020). The Lebanese Lira plummeted at the beginning of 2020, due to a shortage of local and foreign currency, leading to a large increase in unemployment and an increase in mass protests against the failings of the government. This also meant that the country did not have any resources to support the economy or the healthcare system when the COVID-19 pandemic hit the country in early spring of 2020 and the debt to GDP ratio is expected to rise to 160% by the end of 2020. Forced and planned power outages increased to up to 20 hours without electricity per day, due to rationing of the energy supply, also impacting the education system that was supposed to shift to online learning, similar to the rest of the world at the time. To make matters worse, the explosion in Beirut's harbor in August 2020 further exposed the government's inability to adequately protect and provide for its citizens, also increasing the pressure on the government.

Lebanon's location at the Eastern Mediterranean Sea and the fact that more than 85% of Lebanon's population live in urban areas along the coast, makes this country particularly vulnerable to the sea level and temperature rise resulting from climate change (USAID, 2016). The USAID (2016) estimates the damages resulting from climate change to amount to around US$140 Million by 2040, due to flooded coastal areas, loss of tourist hotspots, beaches, and ski resorts (as the amount of snow is also declining), decreasing water supply and deteriorating water quality, as well as decreasing agricultural productivity. Hence Lebanon should have a large incentive to mitigate and prevent the effects of climate change.

4.1.2 Actors involved in Electricity generation and distribution

In Table 5, a summary of all governmental actors involved in electricity generation, transport, transmission, and distribution, including their functions, are listed.

Table 5: Actors involved in electricity generation and distribution Lebanon, adapted from IRENA (2020) and Ahmad et al. (2020).

Actor	Function
Ministry of Energy and Water (MEW)	Responsible for the governance of the energy sector, including proposal of laws for the electricity sector and electrical interconnection agreements with other countries.
Lebanese Centre for Energy Conservation (LCEC)	Part of MEW, determines action plans and the national strategies for energy efficiency and renewable energy deployment.
Electricité Du Liban (EDL)	Publicly owned utility company, controlling 90% of the electricity market and the only company allowed to transmit and distribute electricity to end-users. Is responsible for the regulation of the electricity sector.
Electricity Regulatory Authority (ERA)	Not established yet (political reasons), but meant to set conditions for acquisition of permits relating to production, transportation, and distribution of energy.

Council of Ministers	Reviews majority of decisions made by the MEW and exercises ERA's responsibilities for now.
Central Bank of Lebanon (BDL)	Initiated and is executing NEEREA, which is a program for low-interest loans funding green energy projects.
Ministry of Finance	Responsible for subventions to EDL to cover financial losses.
Litani River Authority	Responsible for maintenance and operation of Lebanon's hydro plants.
Private electricity concession holders	In selected areas, private distributors buy electricity from EDL and distribute it to consumers.
Private diesel generator operators	Supply electricity from private diesel generators to households during EDL power outages, mostly unregulated by the government and their activities are technically not legal.

4.1.3 Resources

Natural Gas

The history of natural gas in Lebanon first started in 1947, shortly after their independence from the French mandate in 1943, when the government started to drill wells across the country looking for natural gas. This was however abandoned again in 1967, as the extraction was deemed too expensive. In 1993, the first 2D seismic survey mapping out potential gas and oil deposits underneath the earth's surface along Lebanon's shores was performed and more surveys in 2D and 3D were conducted in the years after, discovering large gas deposits across the sea shelf off its coast. In 2012, the first strategic environmental assessment for offshore petroleum extraction was conducted, meant to assess environmental and social effects of commencing oil and gas activities as a first step to holding licensing rounds for drilling in 2013. Soon after, the Lebanese Petroleum Administration was founded, responsible for the offshore petroleum sector in Lebanon. In 2018, the first exploration and production agreements were signed and in 2020, after an offshore environmental impact assessment study was successfully completed, drilling of the first well, going 4,076 m below sea level was concluded. However, the chance of actually finding a gas deposit within the first well is less than 30% and gas has not been extracted as of now and natural gas has not been used to generate electricity so far. (LPA, 2021).

The estimation of offshore gas and oil potentials in Lebanon varies significantly, with values for gas ranging from 25.4 trillion cubic feet (tcf, the US standard of measuring volume of natural gas), estimated by a Norwegian company after conducting a 3D seismic survey, to 30 tcf, the initial estimation by the government, to 95.5 tcf, estimated by the Minister of Energy in 2013 (LCPS, 2015). Here it is important to note however that no exploratory drilling was conducted to confirm the highest estimated value (LCPS, 2015). In comparison, Israel, a neighboring country that has been increasingly relying on natural gas as electricity source, with 64% of its electricity generated from natural gas in 2019 (IEA, 2021a) and is planning to further expand this in the future has an estimated potential of 75 tcf (Israel Ministry of Energy, 2016). Israel's energy system is over three times larger than that of Lebanon (IEA, 2021a) and so are their gas reserves, meaning their natural gas potential is comparable even at the lowest estimate of 25.4 tcf.

As Lebanon is currently suffering a shortage in electricity supply and large amounts of debt accumulated partially through financing its energy sector, replacing the more expensive imported oil, with cheaper (and in the future domestically produced natural gas, in the long run, should increase generation capacity and reduce the financial burden on the government. The infrastructure for producing electricity from natural gas already exists in Lebanon. However, new plants built specifically to burn natural gas have been run on oil so far, as there have been problems with importing natural gas due to regional crises. According to LCEC and MEW, this should change by mid-2021, at which time natural gas should be imported to replace oil until domestic reserves can be extracted. (IRENA, 2020)

According to the Lebanese center for policy studies, "*a long history of paralysis in the decision-making process due to the sectarian nature of the political system and long delays in the implementation of a suitable legal and regulatory framework, constrains Lebanon's prospects for short-term development of gas reserves, taking the time period for possible Lebanese gas developments further into the mid-2020s.*" (LCPS, 2015, p. 2). This confirms the need to import natural gas to replace oil for the time being, but nevertheless, hopes for domestic natural gas production and potentially even exporting to other countries are held high and the LCPS confirms the high potential natural gas has for the electricity sector (LCPS, 2015).

Solar

Electricity production from solar power in Lebanon started in 2010 with 1 GWh generated and gradually increased to 68 GWh in 2018 (IEA, 2021a). Though estimation of solar power potential varies, there is a consensus, that solar power has the highest potential for energy generation from a renewable source in Lebanon. The MEW estimates the solar potential to be around 87 000 MW, while IRENA estimated it to be 183 615 MW in 2020, more than twice the value given by the government in the NREAP 2016 – 2020 (IRENA, 2020). Even solar farms with the lower estimation of 87 000 MW could replace Lebanon's entire electricity system almost three times, which had an installed capacity of 3248.37 MW in 2018 (IRENA, 2020) and could provide more than double the amount of electricity demanded (Moore & Collins, 2019). The installed capacity of solar power in 2018 was 58.37 MW, of which only 2 MW come from a centralized solar power plant, while the rest comes from decentralized solar PV panels, mostly attached to roofs or powering street lamps (IRENA, 2020). A full overview of all centralized and decentralized solar projects, completed and ongoing, can be found in the appendix [Appendix C].

The first centralized solar installation was the Beirut snake project, also known as the Beirut River Solar Snake (BRSS. Procured in 2013 with a call for an expression of interest (EOI) and constructed from 2014 to 2015, it first consisted of solar panels covering an area of around one hectare of the Beirut river, with an installed capacity of 1 MWp, in phase 1, which were connected to the grid in September 2015 (LCEC, 2020). The successful implementation of this project led to another tender launched by the LCEC and the MEW in 2018, calling for bids for an additional 7 MWp[1] installed capacity, that could even be extended to 9 MWp, according to the LCEC (2020). Another 1 MWp solar farm was installed by the Zahrani Oil Installations in 2014, increasing the total installed capacity from centralized solar to 2 MW.

The target of 3000 MW installed capacity for 2030, shown in Table 4, of which 500 MW should be decentralized and 1500 MW centralized, should be reached through the continuation of tenders for the procurement of centralized installations and low-interest loans from BDL, the national bank, for decentralized rooftop installations.

Wind

Due to Lebanon's mostly mountainous terrain, space for onshore wind farms is limited and the potential for electricity is around 1500 MW (Ibrahim et al., 2013; IRENA, 2020). The first wind farm, the Akkar wind farm with an installed capacity of 200 to 220 MW, was procured through an auction in 2013 and has been in operation since 2014. Until 2030, an additional 800 MW of generation capacity should be installed to reach the target of 1000 MW, promoted through the continued use of auctions for procurement (IRENA, 2020). A second auction round has already been held in 2018, initially to contract 200 to 400 additional MW in capacity but resulting in bids for around 4000 MW wind farms across Lebanon, but most concentrated in Akkar (IRENA, 2020). As part of that, the first private-public Power Purchase Agreement has been signed between Sustainable Akkar and the Lebanese government, to provide 82.5 MW of power to the local population in Akkar through wind power by 2021 (Sustainable Akkar, 2021). More information on ongoing wind projects can be found in the appendix [Appendix D].

Hydro

As in most countries, hydropower was the first renewable energy source to be in use in Lebanon and the first hydro plant was installed in 1924 in the Kadisha Valley. In the following 40 years, 13 plants were added all around the country (IRENA, 2020) and in 1976, at the peak of electricity production from hydro energy, about 70% of overall electricity generated was sourced from hydro plants (Moore & Collins, 2019). Over the years, however, the lack of maintenance and low contracted prices led to neglected, inefficient plants and a drop in overall supply (IRENA, 2020), leading to only about 2% of electricity coming from hydropower in 2018 (IEA, 2021a).

In 2018, there was an installed capacity of 286 MW, but an effective capacity of only 88 MW, meaning only 31% of the installed capacity could be used (IRENA, 2020). The most inefficient hydro plant lies in the Litani hydropower plant, with an installed capacity of 199 MW, but an effective capacity of only 47 MW in 2018, about 24% of the installed capacity (IRENA, 2020). Because a lot of the plants are in such bad shape, they are currently almost exclusively used for agriculture irrigation, instead of electricity production.

As shown in Table 4, the production of electricity from hydropower should be increased to 601 MW by 2030. This is planned to be achieved through the repair and maintenance of old plants, as well as the construction of new plants and some micro installments (IRENA, 2020). However, the potential for hydropower in Lebanon is limited, lying at around 855 to 960 MW

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[1] MWp stands for Mega Watt peak and describes the power output of a photovoltaic system assuming sunshine per square meter is at its peak. Because of varying levels of sunshine throughout the day, the power output fluctuates as well and therefore MWp is needed to be able to accurately measure power output. (Solar Bay, 2020)

(IRENA, 2020), and additionally, the decreasing frequency of precipitation and increasing frequency of droughts caused by climate change will increasingly affect Lebanon's freshwater reserves (USAID, 2016).

Furthermore, several increases in installed capacity are conditioned to building new dams (Ibrahim et al., 2013), which has been highly controversial in the past years. A recent example is the Bisri dam that was supposed to be constructed by 2024, with $474 Million in funding from the World Bank. The World Bank withdrew its funding from the project in September 2020, after heavy protests by local activists setting up camp at the construction site, a national campaign to protect the Bisri Valley, and a public petition to cancel the project by the Lebanon Eco Movement since 2018. Building the dam would have meant harm to the environment and destruction of cultural heritage, as well as safety concerns for the local community (Bretton Woods Project, 2020).

4.1.4 Renewable Electricity Targets

In 2018, in anticipation of the end of NREAP 2016-2020, a new target was set for 2030, to reach 30% renewable energy (IRENA, 2020). The NREAP 2021-2025 outlining the new strategy and specific policy measures, as well as technology-specific targets, was supposed to be released at the end of 2019, but likely due to the political and financial crises, as well as the COVID-19 pandemic, the release has been delayed and has not been made publicly available yet as of May 2021. Through communication with the LCEC, it could however be confirmed that the NREAP 2021-2025 will be following the technology-specific target recommendations given by IRENA in 2020, in their renewable energy outlook report. These can be found in Table 4.

According to the case developed by IRENA (2020) in cooperation with the Lebanese government, of those 30% renewable energy to be achieved in 2030, 52% should come from solar power, 22.5% from wind, and 17% from hydropower. This means that in 2030, 15.6% of total electricity production should come from solar power, 6.75% from wind power, and 5.1% from hydropower, showing that the focus is put on increasing installed solar power generation capacity.

4.2 Renewable Electricity Use and Targets in Case-study Countries

This section presents the individual renewable electricity use and targets in place in the respective case study countries, including policies implemented and why the advancement of solar power generation capacity has been successful, to further understand the drivers of growth of renewables.

4.2.1 Chile

Chile is a presidential democracy, located in South America with a population of almost 19 Million people (World Bank Data, 2021e). Chile is seen as a front-runner concerning renewable energy deployment in developing countries and is "*one of the first subsidy-free large markets, where renewable energy projects can compete directly with other conventional sources*" (Nasirov et al., 2018, p. 3). In 2019, 45% of electricity generated came from renewable sources, as depicted in Table 6, with around 26% from hydro, 8% from solar, and 6% from wind power. The target set for 2025 to generate 20% electricity from renewable sources (Nasirov et al., 2018) has already been surpassed by more than double the anticipated amount and targets have been set at 60% by 2035 and 70% by 2050 (Simsek et al., 2019).

Table 6: Electricity generation by source in Chile 2019 (IEA, 2021a).

Electricity source	Generation 2019 (GWh)	Percentage of generation (%)
Solar PV	6 304	7.76
Hydro	20 874	25.71
Geothermal	202	0.25
Biofuels	4 351	5.36
Wind	4 809	5.92
Natural Gas	15 128	18.63
Coal	26 494	32.63
Oil	3 033	3.74
Waste	-	0
Other sources	-	0
Total	**81 195**	**100**

Nasirov et al. (2018) attribute this advancement in renewable energy deployment to favorable market conditions and an attractive investment climate, as well as the successful implementation of an extensive policy mix. Policy measures currently in place promoting the expansion of renewable energy sources (Simsek et al., 2019) include (but are not limited to) the following:

- Quota obligation for renewable energy in electric utility
- Auctions for the competitive procurement of energy projects
- Net metering (for small, private, renewable electricity installations)
- Priority grid access for renewable electricity
- Fiscal incentives for rural areas in electricity production
- Carbon tax
- Subsidies for disaster affected regions

Instead of providing feed-in tariffs to kick-start the growth of renewables, Chile focused on fostering a competitive market and the involvement of the private sector (Nasirov et al., 2018). This was done through competitive auction design, adapting to the needs of renewables to enable them to compete against conventional energy sources, as for example through the adaption of time blocks for bidding. These were switched from 24-hour blocks to several blocks throughout the day, enabling renewables like solar, which produce most electricity during the day to compete with generation from fossil fuels or coal (Nasirov et al., 2018).

4.2.2 Greece

Greece is a parliamentary democracy, located in Europe and part of the European Union, with a population of around 10.7 Million people (World Bank Data, 2021e). In 2019, around 35% of electricity generated came from renewable sources, as depicted in Table 7, with around 15% from wind, 8% from solar, and 8% from hydropower. During the formation of their national energy and climate plan (NECP), a target was set to increase this number to 61% by 2030 (Ministry of the Environment and Energy, 2019), focusing especially on increasing the share of solar and wind power and overall a share of renewable energy of 35%. This was deemed "sufficiently ambitious" by the European Commission (2020) during an assessment of their NECP.

Table 7: Electricity generation by source in Greece 2019 (IEA, 2021a).

Electricity source	Generation 2019 (GWh)	Percentage of generation (%)
Solar PV	3 961	8.12
Hydro	4 059	8.32
Geothermal	-	0
Biofuels	1 579	3.24
Wind	7 278	14.93
Natural Gas	16 303	33.44
Coal	10 805	22.16
Oil	4 471	9.17
Waste	286	0.59
Other sources	18	0.04
Total	**48 760**	**100**

Policy measures planned to promote the share of renewable electricity (Ministry of the Environment and Energy, 2019) include (but are not limited to):

- Implementation of competitive procedures for commercially mature renewable energy technologies
- Quotas for share of renewable electricity
- Continuation of support schemes for renewable energy installations & technologies
- Support for innovation projects
- Continuation of net metering scheme
- Support for energy communities through specialized financing tools

- Adaptation of electricity market to accommodate participation of decentralized energy schemes
- Financing models to speed up deployment of transmission and distribution infrastructure

A main contributing factor to their successful strategy was the implementation of generous feed-in tariffs at the beginning of their renewables adoption (Papadimitriou, 2014). Later, this was replaced by a competitive auction design and supported by the ease of administrative processes, such as obtaining licenses (Psaropoulos, 2020). Another contributing factor was their membership in the EU, as according to Psaropoulos (2020), their commitment to the EU's target of being carbon neutral by 2050 was another important driver.

4.2.3 Israel

Israel is a parliamentary democracy, located in the Middle East in Asia and bordering Lebanon in the North, with a population of around 9 Million people (World Bank Data, 2021e). As it is located in the same area as Lebanon, it has very similar resources available, namely an abundance of natural gas in offshore reservoirs and ample solar power, due to its position in the "*solar sunbelt*" (Hamed & Bressler, 2019, p. 383), with one of the highest rates of solar radiation in the world. In 2019, only 4.04% of electricity generated came from renewable sources, as depicted in Table 8, with most of that generated from solar power. However, generation from solar power has been increasing exponentially in the past 10 years and as the most viable renewable energy source for Israel, it constitutes a major part of their renewable energy strategy (Hamed & Bressler, 2019; Eitan, 2021).

Table 8: Electricity generation by source in Israel 2019 (IEA, 2021a).

Electricity source	Generation 2019 (GWh)	Percentage of generation (%)
Solar PV	2 597	3.62
Hydro	-	0
Geothermal	-	0
Biofuels	-	0
Wind	302	0.42
Natural Gas	46 028	64.17
Coal	21 983	30.65
Oil	654	0.91
Waste	-	0
Other sources	159	0.22
Total	**71 723**	**100**

Policy measures currently instituted to promote the share of renewable electricity (Hamed & Bressler, 2019) include (but are not limited to):

- Subsidies for electricity generation from wind and solar PV
- Tariffs promoting large-scale solar energy
- Incentives for entrepreneurs to build RE power plants with installed capacities bigger than 500 MW (faster land approval process)
- Tax benefits and policies supporting research and development
- Net metering for private consumers (up to 400 MW capacity)
- Auctions for the competitive procurement of solar power plants

Israel's successful expansion of renewables is based on a history of research and innovation in renewable energy technology and the build-up of a domestic renewable energy market, with over 270 smart and RE companies currently operating in Israel (Hamed & Bressler, 2019).

4.2.4 Vietnam

Vietnam is a one-party, communist state, located in South-East Asia, with a population of around 97 Million people (World Bank Data, 2021e). In 2018, the last year with complete available electricity generation data, 35.18% of total electricity generation came from renewable sources, as seen in Table 9, of which 34.92% were produced from hydropower and the remaining 0.26% from wind and biomass. According to Do & Burke (2021), in 2018 Vietnam had 86 MWp of installed solar power generation capacity, but evidently, no significant amount of electricity had been produced yet, considering the large size of their electricity system of 240,917 GWh of generated electricity in 2018, more than eleven times the amount produced in Lebanon. However, within two years, Vietnam managed to reach an installed solar power generation capacity of 16,500 MW at the end of 2020, generating 10.6 TWh of electricity from solar, which makes up about 4% of total electricity generation (Do & Burke, 2021). 48% of that was generated from decentralized rooftop solar installations (Do & Burke, 2021). This greatly surpasses their goal of 850 MW installed generation capacity from solar by 2020 (Do & Burke, 2021) and as they have exceeded the amount of solar capacity installed in Malaysia and Thailand, they now have the highest installed generation capacity from solar in Southeast Asia (Nguyen, 2021). Vietnam wants to double its power generation capacity by 2030 and 29% of that electricity should be generated from wind and solar power (Do & Burke, 2021). In August 2020, an additional 23 GW of planned solar and wind power projects had already been approved (Dimitrova, 2020). Electricity production from hydro on the other hand should be discouraged going forward, making up only 18% of the target installed capacity in 2030 (Nguyen, 2021).

Table 9: Electricity generation by source in Vietnam 2018 (IEA, 2021a).

Electricity source	Generation 2018 (GWh)	Percentage of generation (%)
Solar PV	-	0
Hydro	84 125	34.92
Geothermal	-	0

Biofuels	126	0.05
Wind	497	0.21
Natural Gas	41 729	17.32
Coal	114 182	47.39
Oil	258	0.11
Waste	-	0
Other sources	-	0
Total	**240 917**	**100**

Policy measures currently instituted and planned for the future to promote the share of renewable electricity (Nguyen, 2021; Do & Burke, 2021) include (but are not limited to):

- Feed-in tariffs at above market price
- Income tax exemptions for utility-scale investors
- Lease payment for land use exemptions for utility-scale investors
- Planned auctions for developers not qualifying for feed-in tariff scheme
- Planned direct power purchase agreements making the sale and delivery of electricity to corporate consumers possible without including the state-owned utility provider
- Increased research into smart grids and Industry 4.0 technology

The major driver for the incredibly fast renewables adoption over the last two years was the generous feed-in tariff, guaranteeing above-market prices for renewable energy and attracting a large amount of investors (Nguyen, 2021; Do & Burke, 2021). Generally, encouraging investment from the private sector is seen as a priority and is the reason why the government currently plans to allow the private sector to invest in transmission lines to connect their plants directly to the main grid, without going through the national utility company (Do & Burke, 2021). Another important factor is the fostering of domestic solar PV production, stemming from the government's aim to enhance self-sufficient energy production (Do et al., 2020).

4.3 Feasibility assessment

The feasibility assessment is focused solemnly on solar. This is because the targets for hydro and wind power, as defined in previous sections, will be relatively easy to reach, considering projects to reach their target are already in the pipeline, 10 years before it should be reached. The solar target however is more ambitious and therefore the feasibility of reaching this necessitates further investigation.

To assess the feasibility of the growth of solar power in Lebanon and particularly the feasibility of reaching their target of 3000 MW installed capacity set for 2030, several growth models have been fitted to historic electricity generation data from Lebanon, as well as case study countries. This is followed by the construction of a feasibility frontier, assessing global growth of solar in countries that have surpassed the "take-off" threshold, defined before as 0.3% of total electricity generation. This is an indication of what is possible within this time frame, regardless of context. Finally, techno-economic, socio-technical, and political factors in the case study countries will be compared to Lebanon, to give an indication of what factors enable vs constrain the increased adoption of renewables in countries with similar contexts.

4.3.1 Growth Models

Figure 2 shows the Gompertz (G) and Logistic (S) solar power growth curves for Chile (S.CHL), Greece (S.GRC), Israel (S.ISR), and Lebanon (S.LBN), as well as the Exponential (E) model for Lebanon, fit to historic data from 2010 to 2019 (2018 in the case of Lebanon), which was normalized to total electricity generation at Tmax. The individual growth models and their variables are explained in section 3.4.1. The exponential model was excluded for the case study countries because they are at a later stage in the technology diffusion process compared to Lebanon and the exponential model can no longer represent real growth accurately. The closer a country comes to its saturation phase and ultimately maximum levels of solar power as part of total electricity generation (the asymptote), the less accurate the exponential model becomes, as it is most accurate in the early stages when growth accelerates. At the inflection point, growth stops accelerating and the exponential model is no longer suitable to model growth precisely, growth is no longer exponential after the inflection point (Cherp et al., in press). The inflection point of each model gives an indication of maximum growth rates that have been achieved in each country, represented by the variable 'G' and in what year that occurred, represented by the variable 'T_{max}'(Cherp et al., in press). If this has occurred in the past, growth rates are near-linear or slowing down. If this point will occur in the future, growth is still accelerating.

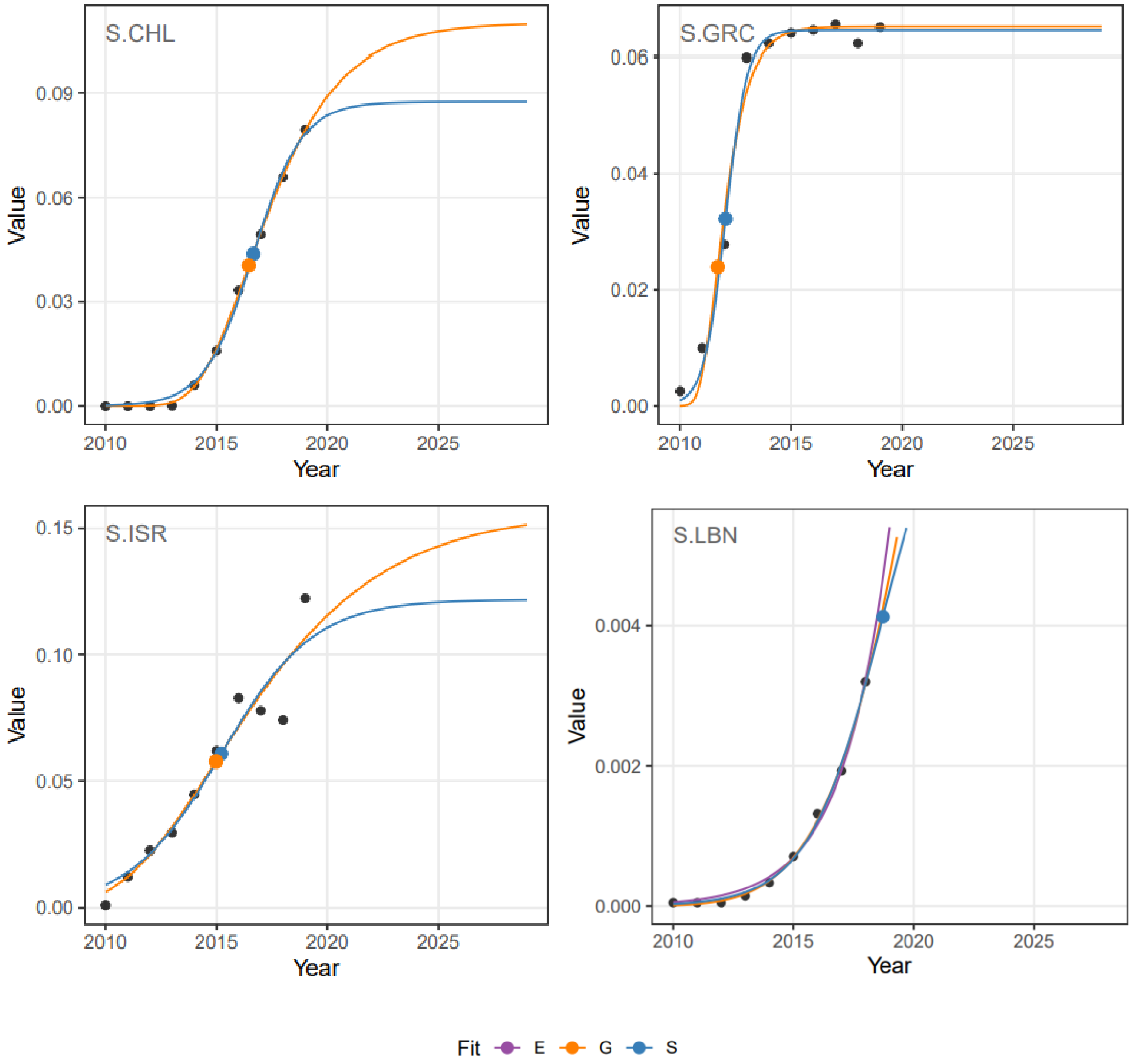

Figure 2: Solar growth models case study countries and Lebanon (2010-2030).

Using the models in Figure 2, it can be estimated what phase of deployment of solar power each country has reached, depending on the best fitting model. This is supported by the calculations made in R, where the model that fits best for each country has the value of the residual sum of squares (RSS) closest to one and the maturity, showing what percentage of the saturation level has been achieved.

Chile's growth in solar power is best modeled through the Gompertz model (G), with an RSS of 1, as seen in Table 10. It has passed the inflection point in 2016 and reached 72% of the saturation level, given by the maturity rate. Growth rates are stable, indicating that Chile's solar growth is currently in the growth phase. The value of dT shows a projection of a growth phase of 7 years. Likewise, Israel's growth in solar power is also best modeled through the Gompertz model (G), with an RSS of 1.08. It has passed the inflection point in 2015 and reached 68% of the saturation level. Growth rates are stable and indicate that Israel's solar growth is also currently in the growth phase. dT shows a growth phase of 13 years, indicating slower growth than in Chile. Greece's growth in solar power is best modeled through the Logistic model (S), with an RSS of 1. It has passed the inflection point in 2012 and reached 100% of the saturation level, given by the maturity rate, showing that growth rates are stalling. This indicates that Greece's solar growth is currently in the saturation phase and dT shows that growth from 10% to 90% happened within two years, a significantly shorter time span than in Chile and Israel. Lebanon's growth in solar power is best modeled through the Gompertz model (G), with an RSS of 1, but all three models are closely overlapping at these early stages of technology diffusion. It has not yet passed the inflection point and reached only 3% of the saturation level. Growth rates are accelerating and indicate that Lebanon's solar growth is currently at the beginning of the growth phase. The estimation of dT is not reliable before the inflection point is reached and therefore the duration of Lebanon's growth cannot be projected yet.

Table 10: Solar growth model parameters Lebanon and case study countries, G and L normalized to total electricity supply.

Country	Fit	L	TMax	K	dT, years	G	Maturity	RSS
Chile	G	11%	2016	0.44	7.00	1.8%	72%	1.00
	S	9%	2017	0.91	4.81	2.0%	89%	7.85
Greece	G	7%	2012	1.29	2.40	3.1%	100%	2.38
	S	6%	2012	2.03	2.16	3.3%	100%	1.00
Israel	G	16%	2015	0.24	13.12	1.4%	68%	1.09
	S	12%	2015	0.48	9.13	1.5%	86%	1.22
Lebanon	E	-	-	0.51	-	-	-	2.37
	G	10%	2028	0.12	25.04	0.4%	3%	1.00
	S	1%	2019	0.65	6.76	0.1%	38%	1.37
Lebanon incl. target	E	-	-	0.34	-	-	-	12.81
	G	-	-	-	-	-	-	-
	S	18%	2025	0.52	8.47	2.4%	90%	1.01

As mentioned, the variable G describes the maximum growth rate each country has experienced, during the year Tmax (the inflection point). Growth rates decline after that point. Table 10 shows that Lebanon's maximum growth rate modeled by the best fitting Gompertz model, based on the historic growth of solar in Lebanon, that should occur in 2028 is almost a third of what was modeled for Israel, a fourth of Chile, and a sixth of Greece. In contrast, the estimated maximum level of deployment of solar power (represented by the asymptote 'L') in Lebanon is comparable to Chile, at 10% vs 11% and higher than that of Greece at 6%, only surpassed by that of Israel at 16%. This indicates that although solar power deployment in Lebanon will eventually reach similar levels to the case study countries, growth will happen a lot slower. However, estimation of the saturation level is not reliable before the inflection point has been reached and should be interpreted with care.

Figure 3 shows the modeled growth necessary to reach the target for 2030. the target was converted to 3495.24 GWh generated in the year 2030, using the solar capacity factor of 13.3%, based on solar capacity in Lebanon in 2018, which equals to 16.46% of total electricity generation normalized at Tmax (2018). The Gompertz model did not produce a meaningful outcome, meaning that this model is not suited to model the aspired growth and was therefore excluded from the analysis. In this case, the logistic model (S) was most fitting in representing the growth necessary to reach the target in 2030, with an RSS value of 1.01, shown in Table 10.

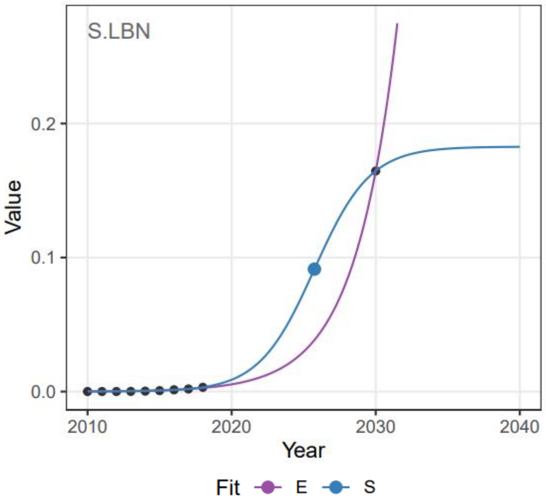

Figure 3: Solar growth model Lebanon, including 2030 target.

Table 10 shows that if the target is included in the model, the inflection point would happen in 2025, with a maximum growth rate of 2.4%. This is more than five times the maximum growth rate of 0.44% predicted by the models based solemnly on historic data without the target, shown in Table 10, and surpasses that of Chile and Israel. Hence growth would need to happen faster than what is currently predicted based on historic growth to reach the target of 16.46%.

4.3.2 Projected Growth Lebanon

Figure 4 and Figure 5 represent the projected growth of solar power in Lebanon, from 2015 to 2030, using both the Gompertz model and the Logistic model and the results from the model in R, as well as the aspired growth based on the solar target of 3000 MW and the assumption that G is reached in 2019 and growth is constant until 2030. Again the target was converted to 3495.24 GWh generated in the year 2030. Figure 4 represents solar power generation values in GWh and Figure 5 represents values as percentage of total electricity generated in 2018, based on historic electricity generation data from 2010 to 2018. The target normalized to electricity generation in 2018 is 16.45% solar power. Data for both figures can be found in the appendix [Appendix E].

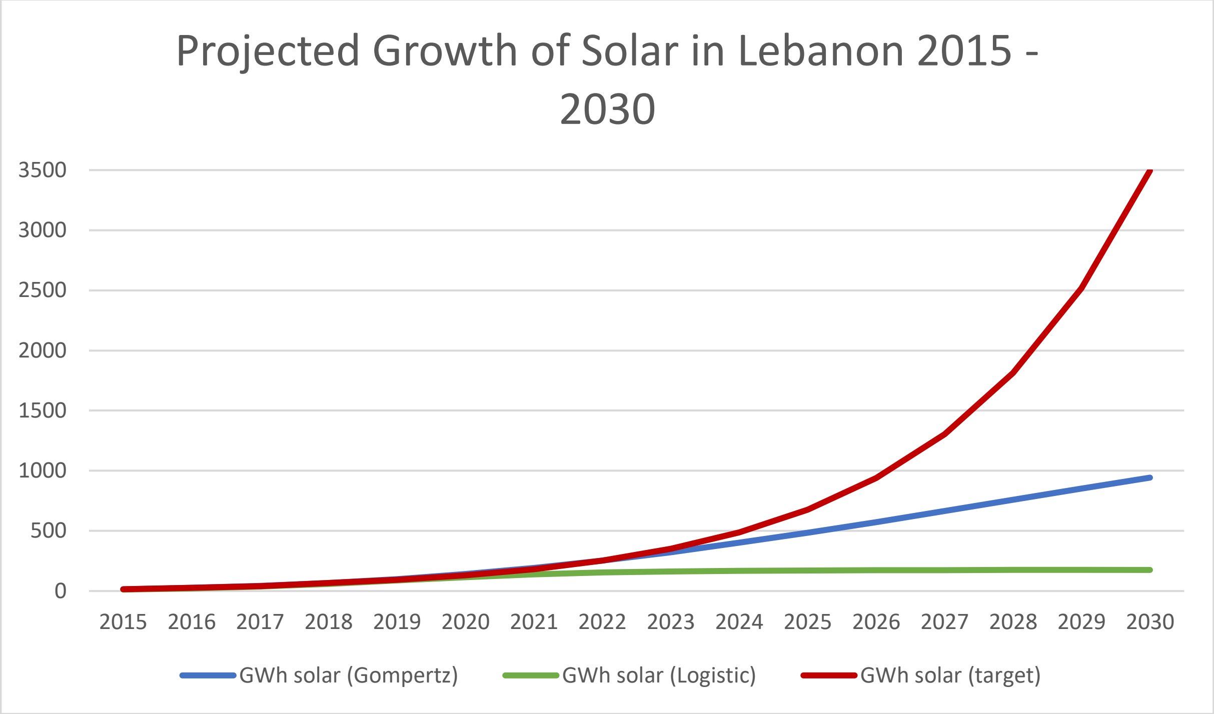

Figure 4: Projected growth of solar in Lebanon (2015-2030) and target.

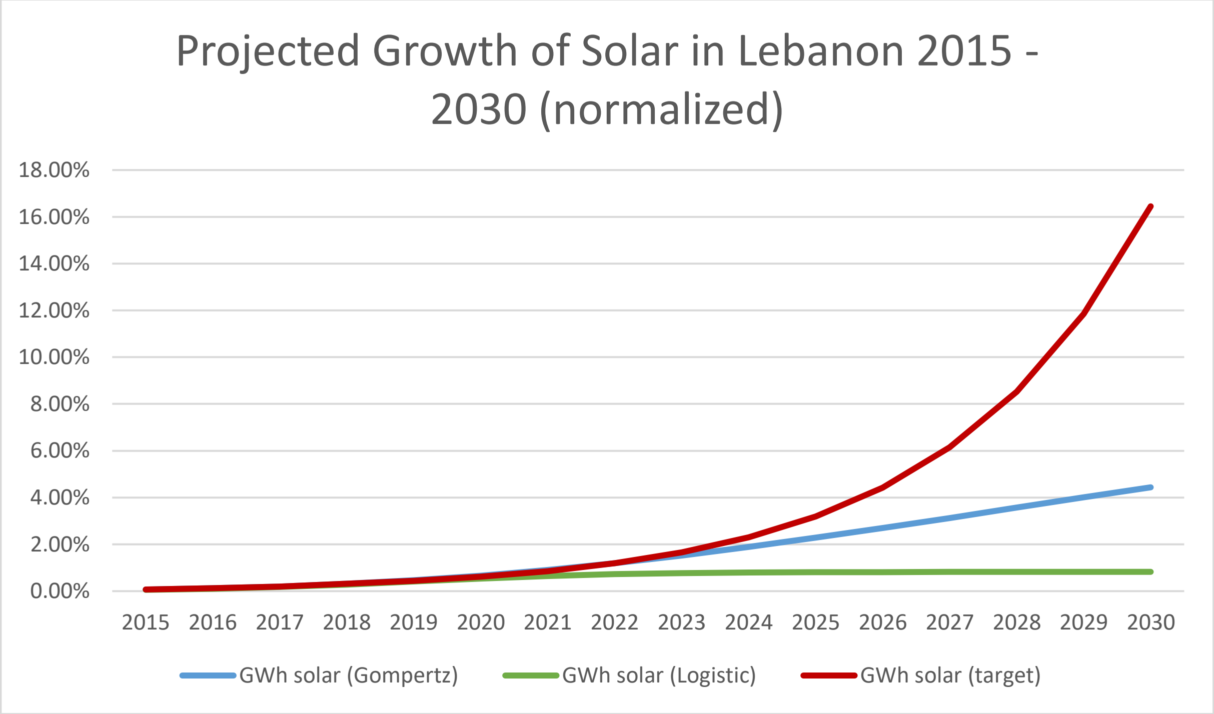

Figure 5: Projected growth of solar in Lebanon (2015-2030) and target (normalized).

As seen in Figure 4 and Figure 5, following historic growth trajectories, the logistic model projects that by 2030 solar power would reach 0.82% of the electricity generation in 2018, which would mean about 175 GWh, with an average annual growth rate of 22%. The Gompertz model estimates solar power to reach 4.44% of electricity generated in 2018, meaning about 943 GWh, with an average annual growth rate of 34%. In contrast, to reach the target of 16.45% (or 3495.24 GWh), solar power would need to grow an average of 44% growth annually.

This means that the logistic model projects growth to reach only 0.5% of the targeted growth and the Gompertz model to reach only 27% of the target. To reach the target, the average annual growth rate would need to double from the logistic model's prediction and increase by a third from the Gompertz model's prediction. Since these models are based on historic data and growth trajectories, this likely means that in order reach such an ambitious target, measures must be implemented to greatly accelerate growth.

4.3.3 Feasibility frontier

Figure 6 represents the global growth of solar in countries that have surpassed the "take-off" threshold, defined as 0.3% of total electricity generation, which includes 62 countries, based on historic data from 1983 to 2019. Values are normalized to total electricity generation in 2010, to be able to compare values across differently sized electricity systems. The complete data table, including the countries included, can be found in the appendix [Appendix F].

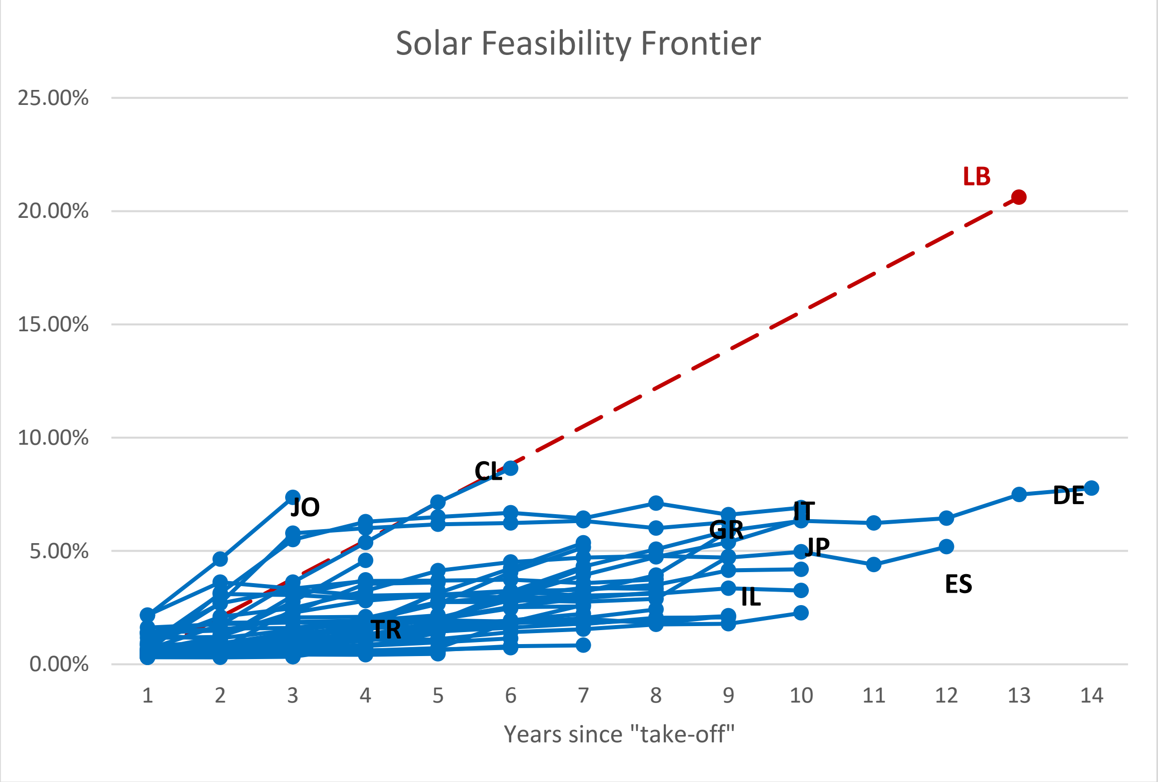

Figure 6: Feasibility frontier of solar growth, as percentage of total electricity generation per country in 2010.

The blue lines show the share of solar power of total electricity generation achieved in a given year after take-off for each country. From this, we can see that share of solar power has been growing in Germany the longest since reaching the take-off point, namely for 14 years and it has reached a share of around 7.7% of electricity generation in 2010 in 2019. In the comparative case study countries Greece and Israel, the share of solar power has been growing simultaneously since the take-off point in 2010 for 9 years and have reached 6.28% and 4.75% of electricity generation in 2010 respectively. The solar power take-off point in Chile happened later, in 2014, but it has achieved 8.65% of electricity generated in 2010, the highest value in the data set.

The red dotted line represents the growth Lebanon would have to achieve, to reach its target. Again the target of 3000 MW solar power in 2030 was converted to 3495.24 GWh generated in the year 2030, using the solar capacity factor of 13.3%, based on solar capacity in Lebanon in 2018. Normalized to electricity generated in 2010, this represents 22.23%, meaning that they would have to grow to 21.83% solar power of electricity generated in 2010, from 0.4% to 22.23% within 12 years.

Comparing this to the growth that Spain and Germany, the only two countries that have surpassed 12 years of solar growth since take-off, have achieved within 12 years, from 0.89% to 5.19% and from 0.36% to 7.77% respectively, Lebanon's target seems highly ambitious. However, Chile's growth since the take-off point is running parallel to Lebanon's target curve, indicating that it may not be impossible if Lebanon were to follow the same growth as Chile. Hence, the feasibility frontier indicates that reaching their solar target in 2030 is challenging, considering the current state of knowledge, but it is too early to draw definitive conclusions solemnly from this graph, as the renewable energy technology of solar PV is not mature enough yet and not enough long-term data from other countries exists.

4.4 Contextual factors

To further understand the context in which the case study countries have successfully increased the share of electricity generated from renewable electricity and how it enabled or constrained this development, techno-economic, socio-technical and political factors are analyzed in a structured comparison, following the meta-theoretical framework by Cherp et al. (2018). Factors included in the analysis can be found in the appendix [Appendix C]. To support this analysis, various indicators have been chosen, as seen in Table 11. The composition of these indicators is further explained in the appendix [Appendix E].

Table 11: Contextual indicators in Lebanon and case study countries (various sources).

Indicator	Chile	Greece	Israel	Vietnam	Lebanon
Techno-economic Indicators					
Net energy imports 2019/ 2018 in Mtoe	29.2	19.4	16.3	23.6	8.6
Average solar potentials in kWh/m2/day (theoretical [t] & practical [p] in kWh/kWp)	5.72 [t], 5.36 [p]	4.45 [t], 4.14 [p]	5.75 [t], 5.08 [p]	4.25 [t], 3.55 [p]	5.36 [t], 4.83 [p]
Population growth 2019 in annual %	1.2	-0.1	1.9	1.0	0.1

GDP per capita 2019 in current USD	14,897	19,581	43,589	2,715	7,584
GDP growth 2019 in annual %	1.1	1.9	3.5	7.0	-6.7
Electricity intensity 2018 in kWh per USD GDP	0.28	0.24	0.18	0.98	0.39
Socio-technical Indicators					
Global Innovation Index 2020 (Rank out of 131)	54	43	13	42	87
Political Indicators					
Quality of democracy 2020 (0-10)	8.28	7.39	7.84	2.94	4.16
Corruption Perception Index 2020 (0-100)	67	50	60	34	25
World Press Freedom Index 2021 (Rank out of 180)	54	70	86	175	107
Political Stability Index 2019 (-2.5 to 2.5)	0.21	0.29	-0.78	0.13	-1.64

4.4.1 Techno-economic factors

Resources

The case study countries of Chile, Vietnam, and Israel were all highly import dependant on oil products and coal before advancing renewable energy adoption and together with Greece they still import more energy than they export, as seen in Table 11 where all countries have significantly positive net energy import balances. This was cited as one of the major drivers for transitioning to a higher share in renewable energy (Nasirov et al., 2018; Hamed & Bressler, 2019). Lebanon is also highly import dependant, with 98% of its electricity produced from oil products, and presents a major financial burden for the country. None of them have significant domestic oil resources, but abundant renewable resources, especially solar, as seen by the relatively high solar irradiance values in Table 11.

Lebanon and Israel do have significant natural gas resources, which Israel is already exploiting and has replaced a large amount of electricity produced from imported coal (58.5% in 2010 vs. 30.7% in 2019) with domestically produced natural gas (37.5% in 2010 vs. 64.17% in 2019) and almost eliminating electricity produced from oil (3.7% in 2010 vs. 0.9% in 2019) (IEA, 2021a). However, this does not prevent Israel from also developing solar power, as an intermittent energy source requires dispatchable electricity, which is easily provided by gas-fired plants, for balancing the electricity supply. Therefore gas resources might encourage rather than discourage the deployment of solar. In addition, countries with significant gas resources might be interested in preserving those for exports, rather than for domestic electricity production, to produce additional government revenue.

Demand

Electricity demand has been driving concerns for energy security in Chile, Israel, Vietnam, and Lebanon, as the population is growing, seen by the positive annual population growth in Table 11 and in Greece, Israel, and especially Vietnam, a growing economy, as seen by GDP per capita growth in Table 11. In Vietnam, demand for electricity is expected to double from current values by 2050 (Do & Burke, 2021).

Electricity intensity gives further insight into the energy intensity of the economy and while it indicates that Israel is operating in a relatively low energy intensity economy compared to the other case study countries, Chile and Greece are not far behind, but Lebanon needs more than double the amount of electricity for one USD of GDP and Vietnam needs more than five times the amount of Israel for one USD of GDP, meaning it is a highly energy-intensive economy with a high demand for electricity.

Infrastructure

Infrastructure has been cited as a major challenge for all case study countries, as well as Lebanon, especially pertaining to the grid. According to Psaropoulos (2020), Greece's grid infrastructure is "*stuck in the 1980s*", Vietnam's grid is overwhelmed with the intermittent solar power in the south of the country and deals with faulty transmission lines (Nguyen, 2021), Chile struggles with providing renewable energy applications access to national transmission lines (Nasirov et al., 2018), Israel's transmission lines are overloaded through the addition of renewables to the grid (Navon et al., 2020) and Lebanon deals with major transmission losses of up to 16.5% due to the bad shape the national grid is in and up to 37.5% including non-technical losses (IRENA, 2020).

The case study countries have already implemented policies to improve their infrastructure, with Chile investing in updating and merging national grid lines (Nasirov et al., 2018) and Vietnam and Israel increasing research into implementing and in the case of Isreal expanding smart grid infrastructure with the implementation of the Israeli Smart Energy Association in 2011 (Nguyen, 2021; ISEA, 2011).

4.4.2 Socio-technical factors

Innovation systems

The Global Innovation Index (GII) gives insight into the innovation performance of 131 countries, including factors regarding the political environment, education, infrastructure, and business sophistication (Dutta et al., 2020). According to the ranking order of the GII seen in Table 11, Israel is part of the global front-runners in innovation, placing 13th of 131 countries. It has over 270 companies and start-ups working to research and advance renewable energy technologies in the country and evidently has a well-functioning innovation system in place. Vietnam places 42nd, Vietnam 43rd, and Chile 54th, all three relatively close to each other and still in the top 40% of global innovation. Lebanon, on the other hand, lags behind, placing 87th, in the bottom 40% of global innovation.

Technology diffusion

Chile and Israel are OECD members, placing them at the rim of most technologies. Greece is a member of the EU, the core of technology adoption for solar energy, and can also be classified as being on the rim. Within these organizations, there are multiple trade links and mechanisms for knowledge and policy diffusion. Vietnam, though not part of OECD or the EU, is close to China, the "secondary core" of technology adoption, as it produces the majority of solar panels distributed globally (Jaganmohan, 2021b). This places Vietnam at the "secondary rim" or periphery of solar technology adoption. Lebanon is on the periphery of renewable technology adoption and both Lebanon and Vietnam can be classified as late-comers, with the share of renewable electricity only really taking off in 2018.

The possibility to export electricity in the future is given in all countries and can be another incentive to increase domestic electricity generation.

4.4.3 Political factors

States goals

Chile, Israel, Vietnam, and Lebanon are all mainly driven by the need for energy security (Nasirov et al., 2018; Do & Burke, 2021; Hamed & Bressler, 2019) and their import dependence. Chile and Israel have both had unreliable trade partners in Argentina and Egypt in the past, due to political instability, from which they previously imported natural gas and oil products, increasing the need for domestic energy production. Climate mitigation also plays a role in driving the adoption of renewable energy forward, as the countries face international and national pressures, such as Greece committing to the EU target of being climate neutral by 2050 (Psaropoulos, 2020) and Vietnam facing growing public pressure for cleaner air (Do & Burke, 2021).

Political interests

Party ideologies of ruling parties differ widely in the case study countries, from the far left in Vietnam, being a one-party communist state and following a Marxist-Leninist ideology, to Chile and Greece that are presidential and parliamentary democracies following a central-right ideology to Israel, that is a parliamentary democracy ruled by a central-right to right party. Lebanon on the other hand is a confessionalist parliamentary democracy, where most parties are organized by religious groups and the highest offices are reserved proportionally for representatives from different religious communities. Party ideology is based on sectarian interests and usually, single candidates form a group with peers from the same religious group rather than a certain political ideology. The country is ruled by a large coalition representing all religious groups (Badaan et al., 2020). No special interest groups that were lobbying successfully against the adoption of renewable energy in any of the case study countries or Lebanon were identified.

Institutions and capacities

Israel's GDP per capita, shown in Table 11, is almost six times as high as that of Lebanon, at 43,589 USD per capita vs. 7,584 USD per capita and more than double that of Greece and Chile, which still have significantly more economic resources available per capita than Lebanon (World Bank Data, 2021). The outlier is Vietnam, which has successfully been increasing the share of renewable electricity, even though GDP per capita is only a third of that of Lebanon at 2,715 USD per capita (World Bank Data, 2021).

The Quality of Democracy Index evaluates 165 countries on factors relating to the electoral process and party pluralism, civil liberties, the functioning of the government, political participation, and the political countries and gives a score out of 100 (The Economist Intelligence Unit, 2020). Based on that score, a country can be classified as a full democracy, a flawed democracy, a hybrid regime, or an authoritarian regime and gives an indication of how much influence a population has on their government and the accountability of their actions.

As seen in Table 11, Chile scored highest out of the case study countries, and Lebanon, with a score of 8.28 and is classified as a full democracy, performing well in all categories besides political participation, where it received 6.67 out of 10 points. Israel and Greece are classified as flawed democracies, with scores of 7.84 and 7.39. Israel scores especially lower in the category of civil liberties, with a value of 5.59 and Greece performs worst in the functioning of government, with a score of 5.21 and political participation at 6.11. Lebanon is classified as a hybrid regime, with a score of 4.16, performing particularly badly in the functioning of government at 1.5 and electoral process and pluralism at 3.5. Vietnam is classified as an authoritarian regime, with a score of 2.76, performing particularly badly in electoral process and pluralism with a score of 0, civil liberties, with a score of 2.35, and functioning of government with a score of 2.86.

In Lebanon and Vietnam, perception of corruption according to the Corruption Perception Index is particularly concerning, at values of 25 and 34 out of 100 respectively, meaning that most likely the country has to deal with rent-seeking officials pursuing primarily their own interests instead of the citizen's interests (Transparency International, 2020). That, in addition to the limited freedom of press indication by the World Press Freedom Index where Lebanon ranks in place 107 out of 180 and Vietnam 175 out of 180, indicates that there is likely little accountability for the government's actions within the country.

While Greece, Chile, and Vietnam all seem to be experiencing moderate political stability at positive values for the Political Stability Index, Israel and Lebanon are perceived to be relatively unstable, with values of -0.78 and -1.64 respectively. This means that the threat of an overthrow of the government through violent or unconstitutional actions, international conflict, acts of terrorism or violent demonstrations is high (The Global Economy, 2019), reflecting the tensions in the region and the recent political crisis.

All countries are signatories to the Paris Agreement and multiple other international agreements for climate change and have access to international resources to advance renewable energy adoption, as for example those offered by IRENA.

4.4.4 Summary

Table 12 provides a summary of the contextual factors identified in section 4.4. Classifications such as "High", "Moderate" and "Low" are based on the indicators in Table 11.

Table 12: Summary of contextual factors in Lebanon and case study countries.

Indicator	Chile	Greece	Israel	Vietnam	Lebanon
Techno-economic Indicators					
Net energy imports	Importer	Importer	Importer	Importer	Importer
Average solar potentials	High	High	High	High	High
Population growth	Positive	Negative	Positive	Positive	Positive
GDP per capita	Moderate	Moderate	High	Low	Low
GDP growth	Small Decline	Moderate Growth	Moderate Growth	Large Growth	Large Decline
Electricity intensity	Low	Low	Low	High	Moderate
Socio-technical Indicators					
Innovation performance	Moderate	Moderate	High	Moderate	Low
Political Indicators					
Quality of democracy	Full democracy	Faulty democracy	Faulty democracy	Authoritarian regime	Hybrid regime
Corruption Perception	Moderate	Moderate	Moderate	High	High
Press Freedom	High	Moderate	Moderate	Very Low	Low
Political Stability	Stable	Stable	Instable	Stable	Instable

5 Discussion

5.1 Implications of the study results

5.1.1 Enablers and constraints to achieving the targets

This section answers the first research question of what the renewable electricity targets in Lebanon and the mechanisms and processes which enable and constrain the achievement of these targets are.

The renewable electricity targets are to reach 3000 MWp of installed solar power generation capacity, of which 500 MWp should be decentralized, 601 MW of installed hydropower generation capacity, and 1000 MW of installed wind power generation capacity. The installed capacity of hydropower in 2020 and the projects in progress make up 586 MW, meaning they only need to contract another 12 MW. The contracted capacity of wind power and projects in progress make up 700 MW, meaning they need to contract another 300 MW, and considering that the government received bids for over 1000 MW at the last wind power auction, the achievement of their target seems rather feasible. Therefore the main concern is the feasibility of achieving the solar power target of 3 GW installed by 2030.

The comparison of Lebanon with other countries has revealed several processes and mechanisms that can enable Lebanon's achievement of its solar target, but also those that constrain it.

Processes and mechanisms that enable Lebanon's renewable energy strategy include:

1. **High incentives for expanding domestic electricity generation** – As Lebanon is currently only servicing about 63% of its electricity demand and about half of their national debt comes from their electricity sector through the import of oil products and low electricity tariffs that do not reflect the real cost, energy security, and import dependence are major driving factors to transition to renewable electricity and subsequently a domestic energy market. These have also been the driving factors for increased renewable electricity adoption in Chile, Israel, and Vietnam.

2. **Prospect of domestic market and job creation** – Since Lebanon is currently in a deep financial crisis after the collapse of the Lebanese Lira, the country could immensely profit from the creation of a domestic energy market and increased job opportunities.

3. **Resource abundance** – Lebanon has ample solar resources, like the case study countries that have managed to increase their solar power generation. Together with their natural gas resources can support the creation of a domestic energy market, instead of an energy market based on imported oil products. Additionally, solar power has the potential to power the whole electricity system and close the demand gap, giving a high incentive to increase its installed generation capacity.

4. **International cooperation** – Lebanon is signatory to the Paris agreement and part of multiple bilateral and multilateral agreements for climate change mitigation. This gives Lebanon access to multiple knowledge exchange platforms and resources, such as the Open Solar Contracts developed by IRENA, that provide a template for governments to

standardize contractual agreements for power purchasing agreements, or their online Climate Investment Platform that pairs developers, lenders, and investors with fitting guarantees, decreasing the risk of renewable energy investments (IRENA, 2020). Greece has especially profited from international cooperation in the past, as it is a member of the European Union and although Lebanon is not, it can still take advantage of other international resources available.

Factors 1, 2, and 3 are in line with drivers identified in the literature review by previous studies, including a domestic energy industry and creating jobs improving the trade balance and geographic suitability (IRENA, 2020; Moore & Collins, 2019; Ibrahim et al. 2013).

Processes and mechanisms that constrain Lebanon's renewable energy strategy include:

1. **Political instability** – The political situation in Lebanon is deeply unstable. Not only because of the general political instability in the Middle Eastern region but also due to the current political financial crises. In Chile especially, part of the reason their strategy has been successful in increasing renewable electricity so far is that its political climate is relatively stable and has demonstrated clear decision-making and consistent policies. This presents a low-risk environment for investors and therefore encourages investment in the country and its renewable energy projects. Investing in Lebanon during the current situation may present a high risk to investors, discouraging investment.

2. **Poor quality of institutions** – Lebanon's political institutions do not function well nor are they based on sound electoral processes or public accountability, as demonstrated by the low Quality of Democracy Index, World Freedom of Press Index, and the Corruption Perception Index. This makes it difficult to formulate and implement sound policies. Poor quality of institutions together with political instability presents a serious deterrent to investors. In contrast, Chile and Israel have performed rather well in the above-mentioned indices and have so far managed to consistently implement their policies. However, Vietnam has a similarly poor performance in these indices but has still managed to successfully contract 16,500 MWp of solar power within two years, though doubt about their ability to maintain this accelerated growth due to low institutional capacity remains (Nguyen, 2021).

3. **Lack of financial means** – As mentioned, Lebanon is currently in the worst financial crisis of its history, with the collapse of the Lebanese Lira beginning of 2020. Significant financial means are needed for essential subsidies and tariffs to kick-start growth, as have been responsible for the accelerated growth of solar in Greece and Vietnam. Lebanon may not have access to these, especially considering that a significant power supplier had to cut off their supply to Lebanon because the government had not paid them for their services for over 18 months, representing around 17% of their installed generation capacity (BBC News, 2021).

4. **Poor infrastructure** – The Lebanese grid is in a poor state, currently responsible for up to 16.5% technical losses and an additional 21% of losses through illegal connections. Grid infrastructure is one of the biggest problems for renewables adoption in Chile, Greece, and Vietnam, and intermittent renewables even overload a modern grid like that of Israel, requiring significant investments in updating transmission lines and installing smart grids to

better monitor loads. Investing in the grid is just as important as investing in renewable energy applications to be able to transmit it, requiring additional funds.

5. **Little interaction with private sector** – As EDL has a state monopoly on electricity production, transmission, and distribution, there is little interaction with the private sector and any electricity generated by private actors is bought from EDL to be transmitted and sold at electricity tariffs that do not represent the real cost of producing it. This presents an unattractive investment environment. Chile has liberalized its electricity market and managed to attract investors and developers in auctions designed for renewables to compete directly with conventional sources, without having to use generous feed-in tariffs or subsidies such as in Greece or Vietnam.

6. **Low levels of innovation** – Compared to the case study countries and especially Israel, Lebanon has relatively low levels of innovation according to the GII. Innovation and research have played a big role in the development of the Israeli domestic electricity market, with currently over 270 domestic start-ups and companies working to advance renewable electricity in Israel.

Factors 1, 2, 3, 4, and 5 are in line with barriers identified in the literature review by previous studies. This includes the poor infrastructure, the current political and financial crisis, low institutional capacity, and the fact that the state has a monopoly on electricity generation (IRENA, 2020; Moore & Collins, 2019; Ibrahim et al., 2013; Karatayev, 2016; Cantarero, 2020, Bizri et al., 2020).

5.1.2 Lebanon's projected growth compared to case study countries

This section answers the second research question of how Lebanon's experience with renewable electricity deployment and the trajectory of renewable electricity growth necessary for achieving their targets compares with the historical experience of renewable electricity deployment in other countries.

Lebanon is currently at the beginning of the growth phase of solar power, still exhibiting accelerating growth. Israel and Chile are exhibiting stable growth and have passed the inflection point, signaling that they are in the middle of the growth phase. Greece's growth is slowing down and is therefore approaching the end of the growth phase, nearing the saturation phase. Vietnam could not be modeled, as growth of solar has only started in 2018 and the time series data is too short to fit a growth model to it, but the growth clearly experienced acceleration in 2019 to 2020.

Comparing maximum growth rates of the best fitting models of the case study countries with that of Lebanon based on current growth trajectories, Lebanon's maximum growth rate is 0.4% of the national electricity supply, while those of Chile and Israel are 1.8% and 1.4% respectively and Greece has a maximum growth rate of 3.3% (although it is important to note here that growth in Greece was only maintained for a couple of years). Considering the maximum growth rate the model estimates necessary to reach the target in 2030 for Lebanon, growth would need to multiply six-fold to be able to achieve it and would have to trump that of Chile and Israel. Looking then at the growth estimated through the projected growth from Gompertz and logistic model vs the growth necessary to reach the target, the models estimate that Lebanon would reach 943 GWh and 175 GWh respectively in 2030, not even a third of the growth they want to achieve.

The feasibility frontier shows that the kind of growth Lebanon wants to achieve, has not been achieved anywhere so far, signaling the solar target set is highly ambitious. However, solar power is still a relatively new renewable energy technology and there are only two countries that have been increasing the share of solar power for 12 years or longer since reaching 0.3% of total electricity generation, which represents the time span Lebanon has to go from 0.3% of their total electricity generation to reach their target. Chile, which has had its take-off point six years prior to the latest available data point has so far exhibited exactly the kind of growth Lebanon wants to achieve, indicating that in order to achieve its target, Lebanon needs to follow the growth that Chile is accomplishing.

Lebanon will most likely need a lot of government support in the beginning, as in Vietnam or Greece, which have implemented generous feed-in tariffs above market price to encourage investment, or the strong involvement of the private sector as in Chile, to make renewable energy competitive with conventional resources, which is challenging given the extremely low electricity tariffs in Lebanon and the state monopoly on electricity production, transmission, and distribution.

This is in line with the previous literature which identifies significant obstacles to renewable electricity targets in Lebanon. However, the thesis quantifies this challenge signaling a large level of ambition.

5.2 Recommendations for increasing the feasibility of Lebanon's solar power target

Considering the many factors that constrain the achievement of Lebanon's renewable electricity targets, and the fact that no other country has achieved that kind of growth within 12 years so far, tremendous effort will be needed to reach them by 2030. To increase the feasibility of reaching these targets, several recommendations have been identified considering existing challenges, as well as successfully implemented measures in the case study countries that have advanced the adoption of renewable energy, answering the third research question of how to increase the feasibility of reaching Lebanon's electricity targets.

1. **Let electricity tariffs reflect real costs** – This would ensure profitability and attract private investors as well as reduce the financial burden on the government freeing funds for other necessary measures.

2. **Liberalize electricity market** – Following Chile's example, the electricity market should be liberalized and allow private actors to produce electricity and feed it into the national grid.

3. **Provide subsidies or other incentives for solar power –** The attractiveness of investment in solar power in Lebanon for pioneering investors could be increased by subsidies (e.g. tax breaks or preferential loans). As the domestic market develops and investors gain more confidence, subsidies can be gradually reduced to reduce the financial burden on the state.

4. **Reduce risks for investors** – Providing a regulatory framework that reduces risks for investors may encourage investment in renewables in Lebanon, increasing renewables adoption. This includes:
    - Long contract times, such as implemented in the auction design in Chile, to increase the running time and pay-out of the renewables project.

   - An eased administrative process as established in Greece or Vietnam, with eased access to licenses and land for renewable energy plants.
   - Implementing mechanisms to encourage a fast project implementation, such as in Greece, where investors that do not start the project within a certain time frame can lose the contract.
   - Provide import or income tax exemptions, such as in Vietnam and Chile or land-lease exemptions as in Vietnam, to decrease costs for investors.
   - Guarantee prioritized access to the grid, as implemented in Chile, to provide investors with the security that their renewable energy plants will be able to operate without delays.

5. **Participate in international cooperation** – Take advantage of resources and knowledge exchange provided through international cooperation and organizations, including international targets and action plans on how to achieve them.

6. **Promote innovation and research** – Increased promotion of innovation systems and research could benefit the increased adoption of renewables and an electricity supply that is less vulnerable to consequences of conflict. Measures that would build up a domestic innovation system include:
   - Focus on developing technology domestically and implement domestic solar panel manufacturing, to decrease the dependence on technology import.
   - Continue and expand cooperation with academic institutions specialized in renewable energy adoption, with a focus on those familiar with the Lebanese context.

7. **Adapt the legal framework to allow for bottom-up initiatives** – The legal framework should be adapted to allow for bottom-up initiatives, such as through a net-metering scheme, the continuation of low-interest loans for decentralized solar solutions, or energy communities, to encourage private households to participate in the increased adoption of renewable energy applications.
   - A net-metering scheme would allow prosumers to feed electricity back into the grid at market price, giving private households an incentive to produce their own electricity and provide what is not consumed back to the grid, increasing generation supply.
   - The continuation of low-interest loans reduces the barrier to purchasing renewable energy applications for private households, as it eliminates the need for large capital investment, allowing more actors to participate.
   - Energy communities empower local communities to organize and govern a local energy system based on renewable energy sources and allow for electricity generation independent of the national energy grid and private diesel generators. This however requires the legalization of independent electricity generation and a regulatory framework to govern these activities.

It is recognized that not all recommendations can or should be implemented. It merely provides a portfolio of actions the Lebanese government can undertake to increase renewable electricity generation, considering their individual context and what has worked well in the case study countries. These recommendations are in line with recommendations previously identified by the literature, including an electricity tariff reform, reduced taxes for RE applications, encouragement of private investments, and the adaptation of the legal framework to accommodate RE adoption (IRENA, 2020; Moore & Collins, 2019; Ibrahim et al., 2013).

5.3 Limitations of the study

5.3.1 Feasibility assessment

The methods for assessing the feasibility of energy transitions are only emerging. Due to the nature and scope of this study, only one recently proposed method is used. It is important to note however that other methods of assessing feasibility may yield different results and no feasibility assessment can produce a definitive answer of whether something is feasible or not. It will only produce an estimation of how feasible or infeasible the assessed target seems from the current standpoint, but it cannot predict the future.

This feasibility assessment is analyzing historical data and growth trajectories from other countries and comparing them to Lebanon, to determine whether or not the growth that Lebanon wants to achieve has been achieved in other countries with similar contexts. Though we can not say with certainty whether their growth trajectories are applicable to future developments in Lebanon, looking at what has been feasible in similar contexts in the past can give an indication of what may be possible in the future.

5.3.2 Growth models

There are many growth models and this study is limited to three. Limitations relevant to the chosen growth models include that exponential models have become less relevant concerning renewables and logistic growth models presume symmetry on either side of the inflection point, as opposed to other growth models that assume asymmetry and often higher saturation levels, as well as a longer time span to transition (Cherp et al., in press).

Additionally, Gompertz and logistic models keep growth conservative, as they are based on assumptions of stable markets and technologies. The maximum growth rate G cannot be calculated accurately until the inflection point is reached, which at the time of this study, Lebanon has not, and saturation levels are even less accurate. It is therefore important to keep this in mind when interpreting the results of the models, acknowledging that Lebanon is still in the early stages of the growth phase and predictions made at this point in time are not definitive.

Choosing a year of normalization for the growth models also presents a limitation, as the year chosen may affect the results. Choosing an earlier year in the growth stages will make growth in renewables appear larger relative to total generation, assuming that the electricity system grows over the years while choosing a later year will make growth appear smaller relative to total generation, assuming again that the electricity system grows over the years. Another option to normalize is to normalize generation to the total generation each year. This, however, makes renewable growth in fast-expanding electricity systems seem smaller than in a more steadily growing electricity market, potentially favoring developed countries that usually exhibit more moderate growth in electricity systems compared to developing countries that have more rapidly growing economies for example. Therefore, the choice of normalization year can affect how the results are perceived.

Another limitation regarding the growth models was the conversion of the target from MWp to GWh, so as to fit the unit of measurement to the available time-series data, which was recorded in GWh of electricity generated in a year. To convert the target from MWp to GWh generated in a year, the value had to be multiplied by the hours of a year and the solar capacity factor, divided by a thousand to convert MWh to GWh. The solar capacity factor was based on the difference between the installed solar power generation capacity in MW (so how much it would be able to produce at peak capacity) and the GWh generated in 2018 (how much it actually produced), returning a solar capacity factor of 13.3%. Considering that the global average solar capacity has been steadily increasing from about 14% in 2010 to 18% in 2019 (Jaganmohan, 2021a), it may be a limitation to assume that the solar capacity factor will be the same in 2030. However, if it were to increase, it would make the target even more ambitious, meaning that it would not change the results of the study but rather emphasize it.

5.3.3 Data & Resource availability

The lack of data and resource availability also presented limitations for this study. The last year of available electricity generation data is 2018, as opposed to 2019 for the case study countries of Greece, Chile, and Israel, and electricity tariff data was not easily obtainable. Public availability of information to determine enablers and constraints was also lacking and meant that factors like solar auction prices could not be considered in the analysis.

Additionally, the NREAP 2021-2025 was supposed to be published beginning of 2020, but its publication has been delayed, most likely due to the political crisis & COVID. Through communication with the Lebanese Ministry of Energy and Water, it was conveyed that the plans will not be publicly available before mid-2021, which meant that the exact policy plans could not be taken into account for this analysis and was limited to the targets, as well as policy measures implemented in the past.

6 Conclusions

In Lebanon, the majority of electricity comes from private diesel generators, and electricity production is mostly up to private households, due to a large gap in the amount of electricity supplied by the government and the amount demanded by Lebanese households, industry, and other sectors. The electricity the government does provide is mostly produced from fossil fuels and the electricity sector is responsible for more than half of national emissions and because these fuels are 100% imported but sold at electricity tariffs below the actual cost, also half of national debt. To increase the country's generation capacity and simultaneously combat the effects of climate change, as well as decrease the national deficit, the government now wants to reach 30% renewable energy production by 2030. A sustainable energy transition could not only have the potential to raise the quality of life in Lebanon but can also support the government in overcoming current political and financial crises, making it all the more vital that they achieve their target.

The technology-specific targets to reach 30% renewable energy by 2030 are 3000 MWp of installed solar power generation capacity, of which 500 MWp should come from decentralized solar PV installations, 1000 MW of installed wind power generation capacity, and 601 MW of installed hydropower generation capacity. This thesis aims to systematically investigate the feasibility of these targets.

The kind of growth Lebanon wants to achieve, has not been achieved in any other country so far, signaling the solar target set is highly ambitious. However, solar power is still a relatively new renewable energy technology and there are only two countries that have been increasing the share of solar power for 12 years or longer since reaching 0.3% of total electricity generation, which represents the time span Lebanon has to go from 0.3% of their total electricity generation to reach their target. Chile has so far exhibited exactly the kind of growth Lebanon wants to achieve, indicating that achieving its target is not impossible. To achieve its target, Lebanon needs to follow the growth that Chile has accomplished so far.

There are several measures and processes in place that could be enablers for Lebanon to achieve its targets, including the high incentives for an energy transition due to the need for energy security and the prospect of a domestic market and job creation. Additionally, Lebanon has abundant solar resources, which, likely in combination with domestic natural gas, could power the whole country, eliminating the need for expensive imported fossil fuels for electricity production. Lastly, Lebanon is already party to multiple bilateral and multilateral agreements to combat climate change, which gives them access to a variety of resources useful for the adoption of renewable electricity.

There are however also several constraints Lebanon must overcome to increase the share of renewable electricity. It currently faces high political instability, both due to political instability in the region and inside the country, due to the current political crisis and their current institutions may not be able to carry out consistent policy measures needed to achieve their targets, especially considering that it has not been possible to form a new government since that last one had to step down after the explosion in Beirut harbor in August 2020. Additionally, because of the current financial crisis and the collapse of the Lebanese Lira, the necessary financial means to update existing infrastructure that is currently in bad shape and invest in new renewable electricity applications may not be available. Finally, the current state monopoly on electricity production, distribution, and generation may present a significant barrier to the adoption of renewables, there is little interaction with the private sector and low levels of innovation.

6.1 Practical and policy implications and recommendations for non-academic audiences

The target Lebanon wants to achieve is highly ambitious, even in a stable economy and political system. The current political and financial crises, as well as the outdated legal system surrounding the Lebanese energy market present large barriers to the achievement of their renewable electricity targets. Though hydro and wind targets may well be achievable, due to projects already in progress, based on this research a tremendous effort will be necessary to achieve their solar target, considering it requires them to perform better than any country has in the past. The recommendations given in section 5.2 should provide a guide on how to overcome the identified constraints, using strategies that have worked in countries with similar contexts and enabling factors.

To increase the feasibility of their target several recommendations have been identified and the most important step is to let current electricity tariffs reflect the real cost of electricity, to encourage investment in the country, and decrease the financial burden on the government. Secondly, it is important to liberalize the electricity market and allow private actors to come in, increasingly decreasing the burden on the government, as has been part of the successful adoption of increasing renewables in Chile. To further attract investors to the Lebanese electricity market, generous feed-in tariffs as Greece and Vietnam have implemented would be beneficial for an increase in the share of renewable electricity. It is also important however to reduce risks for investors, through measures like long contracts, a guarantee scheme, prioritized access to the grid and land-lease and tax exemptions, as well as to increasingly promote innovation and research in the country. Lebanon's government should also take advantage of the vast number of resources available through international cooperation, such as those offered by IRENA. Lastly, the legal framework should be adapted to accommodate for bottom-up solutions, such as energy communities, to allow them to legally operate and empower its citizens to actively participate in the energy transition.

Generalized recommendations that can be identified from this study for late-adopters planning on increasing the share of renewable electricity are as follows:

1. **Learn from front-runner countries** – policy measures and instruments like international cooperation, market liberalization, the protection of investors, and generous subsidies have generally been driving factors in increasing the share of renewable electricity. Adapted to the context of the individual country and its institutional and regulatory framework

2. **Collect data & make it available** – The more data there is available, the easier it is to identify issues in the system and provide recommendations on how to overcome them. Consistent monitoring and transparency are therefore important factors in advancing renewable electricity adoption.

3. **Set attainable targets** – Though ambitious targets are important to drive forward the adoption of renewables, they should be attainable considering the individual contexts and clear paths to their achievement need to be set. Ratcheting up ambition is not enough to achieve ambitious targets.

4. **Consider multiple avenues for decarbonization** – For a successful energy transition, multiple avenues for decarbonization should be considered, including measures like energy efficiency or alternative fuel sources.

6.2 Recommendations for future research

To define distinct steps towards an institutional and regulatory reform that would promote the adoption of renewable electricity in Lebanon, in-depth knowledge of the political and legal system is required, which was deemed outside of the scope of this study. It is therefore recommended to conduct further research regarding specific laws and regulations, as well as institutional structures and how they need to be adapted, as well as how that will impact the Lebanese energy market. Additionally, as the exact policy measures and institutional changes the government wants to undertake to reach their targets for 2030, in the form of the NREAP 2021-2025, were not publicly available yet at the time of this study, these should be taken into consideration once they are published and compared against the policy measures that have led to the successful increase in the share of renewables in the case study countries.

Furthermore, since this study has focused solemnly on Lebanon's electricity system, additional research could be conducted into other decarbonization alternatives, such as energy efficiency measures or alternative fuels, to combat the effects of climate change that will have likely have a proportionally large impact on Lebanon and its coastal cities.

Lastly, as large amounts of investments in renewable energy infrastructure, Lebanon's grid, and government support for renewable energy adoption in form of subsidies or tariffs, will be necessary, further research should be undertaken to define the exact investments needed for the plan to be achieved, where these investments will come from and how to make the Lebanese energy market more attractive for (foreign) investors.

Bibliography

Ahmad, A., McCulloch, N., Al-Masri, M., & Ayoub, M. (2020). From dysfunctional to functional corruption: The politics of reform in Lebanon's electricity sector. Anti-Corruption Evidence SOAS Consortium. https://www.aub.edu.lb/ifi/Documents/publications/working_papers/2020-2021/20201218_from_dysfunctional_to_functional_corruption_working_paper.pdf

Badaan, V., Richa, R., & Jost, J. T. (2020). Ideological justification of the sectarian political system in Lebanon. Current Opinion in Psychology, 32, 138–145. https://doi.org/10.1016/j.copsyc.2019.07.033

Barone, A. (2021, April 30). How Residual Sum of Squares (RSS) Works. Investopedia. https://www.investopedia.com/terms/r/residual-sum-of-squares.asp

Batinge, B., Musango, J. K., & Brent, A. C. (2019). Sustainable energy transition framework for unmet electricity markets. Energy Policy, 129, 1090–1099. https://doi.org/10.1016/j.enpol.2019.03.016

BBC News. (2021, May 14). Lebanon: Karpowership shuts down electricity supply. BBC News. https://www.bbc.com/news/world-middle-east-57112611

Bizri, A. R., Khachfe, H. H., Fares, M. Y., & Musharrafieh, U. (2020). COVID-19 Pandemic: An Insult Over Injury for Lebanon. Journal of Community Health. https://doi.org/10.1007/s10900-020-00884-y

Bretton Woods Project. (2020, December 10). World Bank cancels Bisri dam project in Lebanon after years of community resistance. Bretton Woods Project. https://www.brettonwoodsproject.org/2020/12/world-bank-cancels-bisri-dam-project-in-lebanon-after-years-of-community-resistance/

Chams, D. (2020, October 8). Kein Geld, kein Strom, keine Zukunft. Le Monde diplomatique. https://monde-diplomatique.de/artikel/!5716900

Cherp, A., Vinichenko, V., Jewell, J., Brutschin, E., & Sovacool, B. (2018). Integrating techno-economic, socio-technical and political perspectives on national energy transitions: A meta-theoretical framework. Energy Research & Social Science, 37, 175–190. https://doi.org/10.1016/j.erss.2017.09.015

Cherp, A., Vinichenko, V., Jewell, J., Suzuki, M., & Antal, M. (2017). Comparing electricity transitions: A historical analysis of nuclear, wind and solar power in Germany and Japan. Energy Policy, 101, 612–628. https://doi.org/10.1016/j.enpol.2016.10.044

Cherp, A., Vinichenko, V., Tosun, J., Gordon, J., & Jewell, J. (in press). National growth dynamics of wind and solar power compared to the growth required for global climate targets. Nature Energy.

Dimitrova, A. (2020, September 7). Vietnam adds 4 GWp of solar plants in Q2 2019. Renewables Now. https://renewablesnow.com/news/vietnam-adds-4-gwp-of-solar-plants-in-q2-2019-712625/

Do, T. N., & Burke, P. J. (2021). ISEAS Perspective 2021 Archives. ISEAS-Yusof Ishak Institute, 28(2021). https://www.think-asia.org/bitstream/handle/11540/13293/ISEAS_Perspective_2021_28.pdf?sequence=1

Do, T. N., Burke, P. J., Baldwin, K. G. H., & Nguyen, C. T. (2020). Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. Energy Policy, 144, 111561. https://doi.org/10.1016/j.enpol.2020.111561

Dutta, S., Lanvin, B., & Wunsch-Vincent, S. (2020). Global Innovation Index 2020—Who Will Finance Innovation? (No. 13). https://www.globalinnovationindex.org/gii-2020-report#

Eitan, A. (2021). Promoting Renewable Energy to Cope with Climate Change—Policy Discourse in Israel. Sustainability, 13(6), 3170. https://doi.org/10.3390/su13063170

ESMAP. (2020). Global Photovoltaic Power Potential by Country. Global Solar Atlas. https://globalsolaratlas.info/global-pv-potential-study

European Commission. (2020). Assessment of the final national energy and climate plan of Greece. https://ec.europa.eu/energy/sites/ener/files/documents/staff_working_document_assessment_necp_greece.pdf

George, A. L., & Bennett, A. (2005). Case studies and theory development in the social sciences. MIT Press.

Grubb, M., Drummond, P., & Hughes, N. (2020). The Shape and Pace of Change in the Electricity Transition: Sectoral dynamics and indicators of progress (p. 40). UCL Institute for Sustainable Resources.

Grubler, A., Wilson, C., & Nemet, G. (2016). Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions. Energy Research & Social Science, 22, 18–25. https://doi.org/10.1016/j.erss.2016.08.015

Hamed, T. A., & Bressler, L. (2019). Energy security in Israel and Jordan: The role of renewable energy sources. Renewable Energy, 135, 378–389. https://doi.org/10.1016/j.renene.2018.12.036

Ibrahim, O., Fardoun, F., Younes, R., & Louahlia-Gualous, H. (2013). Energy status in Lebanon and electricity generation reform plan based on cost and pollution optimization. Renewable and Sustainable Energy Reviews, 20, 255–278. https://doi.org/10.1016/j.rser.2012.11.014

IEA. (2021a). Electricity generation by source. IEA. https://www.iea.org/data-and-statistics/data-browser/?country=WORLD&fuel=Energy%20supply&indicator=ElecGenByFuel

IEA. (2021b). Net energy imports. IEA. https://www.iea.org/data-and-statistics/data-browser/?country=WORLD&fuel=Imports%2Fexports&indicator=NetImports

International Energy Agency. (2020). Access to electricity – SDG7: Data and Projections – Analysis. IEA. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity

IRENA. (2020). Renewable Energy Outlook: Lebanon. International Renewable Energy Agency.

ISEA. (2017). Smart Energy Solutions | Israel | ISEA. https://www.isea.org.il

Israeli Ministry of Energy. (2016). Israeli Gas Opportunities. https://www.energy-sea.gov.il/English-Site/Pages/News%20And%20Media/ISRAELI%20GAS%20OPPORTUNITIES.pdf

Jaganmohan, M. (2021a, January 27). Solar PV capacity factor globally 2019. Statista. https://www.statista.com/statistics/799330/global-solar-pv-installation-cost-per-kilowatt/

Jaganmohan, M. (2021b, February 2). Regional distribution of solar module production. Statista. https://www.statista.com/statistics/668749/regional-distribution-of-solar-pv-module-manufacturing/

Jewell, J., & Cherp, A. (2019). On the political feasibility of climate change mitigation pathways: Is it too late to keep warming below 1.5°C? Wiley Interdisciplinary Reviews: Climate Change, 11(1). https://doi.org/10.1002/wcc.621

Karatayev, M., Hall, S., Kalyuzhnova, Y., & Clarke, M. L. (2016). Renewable energy technology uptake in Kazakhstan: Policy drivers and barriers in a transitional economy. Renewable and Sustainable Energy Reviews, 66, 120–136. https://doi.org/10.1016/j.rser.2016.07.057

LCEC. (2020). Beirut River Solar Snake Report—The Dawn of the Solar Market in Lebanon (p. 52). https://lcec.org.lb/sites/default/files/2021-02/BRSS%20Report.pdf

LCPS. (2015). Lebanon's Gas Trading Options. https://www.lcps-lebanon.org/publications/1453981980-fattouh-katiri_for_web.pdf

LPA. (2021). Oil and Gas|Major Developments. Lebanese Petroleum Administration. https://www.lpa.gov.lb/english/oil-amp-gas/major-developments

Majone, G. (1975). On the notion of political feasibility. European Journal of Political Research, 3(3), 259–274. https://doi.org/10.1111/j.1475-6765.1975.tb00780.x

Ministry of Environment. (2021). Negotiations | Climate Change Lebanon. Climate Change. http://climatechange.moe.gov.lb//negotiations

Ministry of the Environment and Energy. (2019). National Energy and Climate Plan for the Hellenic Republic. https://ec.europa.eu/energy/sites/ener/files/el_final_necp_main_en.pdf

Moore, H. L., & Collins, H. (2019). Decentralised renewable energy and prosperity for Lebanon. Energy Policy, 137, 111102. https://doi.org/10.1016/j.enpol.2019.111102

Nasirov, S., Agostini, C., Silva, C., & Caceres, G. (2018). Renewable energy transition: A market-driven solution for the energy and environmental concerns in Chile. Clean Technologies and Environmental Policy, 20(1), 3–12. https://doi.org/10.1007/s10098-017-1434-x

Navon, A., Kulbekov, P., Dolev, S., Yehuda, G., & Levron, Y. (2020). Integration of distributed renewable energy sources in Israel: Transmission congestion challenges and policy recommendations. Energy Policy, 140, 111412. https://doi.org/10.1016/j.enpol.2020.111412

Nguyen, J. (2021, March 8). Vietnam's Solar Industry: Bright Prospects for Investors. Vietnam Briefing News. https://www.vietnam-briefing.com/news/vietnams-solar-industry-bright-prospects-investors.html/

RSF. (2021). 2021 World Press Freedom Index | RSF. Reporters Without Borders. https://rsf.org/en/ranking

Schweikle, S. (2020, October 21). Lebanese divided over hopes for wider peace with Israel | DW | 21.10.2020. Deutsche Welle. https://www.dw.com/en/lebanon-israel-relations-beirut/a-55345009

Simsek, Y., Lorca, Á., Urmee, T., Bahri, P. A., & Escobar, R. (2019). Review and assessment of energy policy developments in Chile. Energy Policy, 127, 87–101. https://doi.org/10.1016/j.enpol.2018.11.058

Solar Bay. (2020, June 7). Understanding How Solar Power Is Measured [Solar Bay]. https://solarbay.com.au/portfolio-item/understanding-how-solar-power-is-measured/

Sustainable Akkar. (2021). Project History—Sustainable Akkar. http://www.sustainableakkar.com/project-history

The Economist Intelligence Unit. (2020). Democracy Index 2020—In sickness and in health? The Economist. https://www.eiu.com/n/campaigns/democracy-index-2020/

The Global Economy. (2019). Political stability by country, around the world. The Global Economy. https://www.theglobaleconomy.com/rankings/wb_political_stability/

Transparency International. (2020). 2020—Corruption Perceptions Index. Transparency.Org. https://www.transparency.org/en/cpi/2020

Tsagas, I. (2018, October 5). Beirut Energy Forum: Lebanon's solar PV takes off – pv magazine International. PV Magazine. https://www.pv-magazine.com/2018/10/05/beirut-energy-forum-lebanons-solar-pv-takes-off/

USAID. (2016). Climate Risk Profile Lebanon. https://www.climatelinks.org/sites/default/files/asset/document/2016_USAID_Climate%20Risk%20Profile_Lebanon_2.pdf

Vadim Vinichenko. (2018). Mechanisms of energy transitions: National cases and the worldwide uptake of wind and solar power [Doctoral dissertation]. Department of Environmental Sciences and Policy, Central European University.

Vadim Vinichenko. (2021). Code for the article Cherp, A., Vinichenko, V., Tosun, J., Gordon, J., and Jewell J. 'Historical trajectories of solar and wind growth map a feasibility space for 1.5°C and 2°C pathways' [R]. poletresearch. https://github.com/poletresearch/RES_article (Original work published 2021)

Vanegas Cantarero, M. M. (2020). Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. Energy Research & Social Science, 70, 101716. https://doi.org/10.1016/j.erss.2020.101716

Wilson, C., Grubler, A., Bauer, N., Krey, V., & Riahi, K. (2013). Future capacity growth of energy technologies: Are scenarios consistent with historical evidence? Climatic Change, 118(2), 381–395. https://doi.org/10.1007/s10584-012-0618-y

World Bank Data. (2021a). GDP (current US$) | Data. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD

World Bank Data. (2021b). GDP growth (annual %) | Data. https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

World Bank Data. (2021c). GDP per capita (current US$)—Vietnam, Chile, Greece, Israel, Lebanon | Data. https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?locations=VN-CL-GR-IL-LB

World Bank Data. (2021d). Population growth (annual %)—Vietnam, Chile, Greece, Israel, Lebanon | Data. https://data.worldbank.org/indicator/SP.POP.GROW?locations=VN-CL-GR-IL-LB

World Bank Data. (2021e). Population, total | Data. https://data.worldbank.org/indicator/SP.POP.TOTL

Appendix

Appendix A – Factors Meta-theoretical Framework

Adapted from Cherp et al. (2018)

Techno-economic

Resources:
- Fossil fuel types, resources, reserves
- Import and export of fuels and carriers
- Type and potential of renewable resources

Demand:
- Types and scale of energy uses
- Energy intensity
- Factors driving demand growth and decline

Infrastructure:
- Existing infrastructure for extraction, transportation, conversion, and use

Socio-technical

Innovation systems:
- Presence and structure of national, sectoral, and technological innovation systems
- Performance of innovation systems

Technology diffusion:
- Location on core/periphery of technology
- Possibilities for technology export

Political

State goals:
- Type of state goals
- Factors affecting state goals

Political interests:
- Special interests (e.g. industrial lobbies)
- Party ideologies and organized social movements

Institutions and capacities:
- State capacity e.g. economic and other resources, political stability
- Institutional arrangements, e.g. varieties of capitalism party system, government system
- International processes, e.g. policy diffusion, international agreements

Appendix B – Contextual indicators

The following table is a description of the contextual indicators used in section 4.4.

Indicator	Description	Source
Net energy imports	Net energy imports describes the net amount of energy imported in Mtoe (imports minus exports). A positive value means the country exports more than it imports and vice versa.	(IEA, 2021b)
Average solar potentials	Average solar potentials, given in kWh/m²/day describe the average potential of solar power in kWh per m² and day and are given both for theoretical and practical potential.	(ESMAP, 2020)
Population growth	Population growth in % shows the annual growth of the population.	(World Bank Data, 2021d)
GDP per capita	GDP per capita, measured in current USD, shows the gross domestic product normalized to population size.	(World Bank Data, 2021c)
GDP growth	GDP growth, measured in %, shows the annual growth of the gross domestic product.	(World Bank Data, 2021b)
Electricity intensity	Electricity intensity is calculated by dividing total electricity generation in kWh by real GDP in current USD of the same year and gives an indication of how energy-intense the economy is. The higher the electricity intensity, the more electricity the economy uses to produce one USD of output.	(IEA, 2021a; World Bank Data, 2021a)
Innovation performance	The Global Innovation Index ranks 131 by their innovation performance, considering innovation inputs and outputs. Innovation inputs include institutions, human capital and research, infrastructure, and market and business sophistication. Innovation outputs include knowledge and technology outputs and creative outputs. The score that ranks each country is the average of input and output.	(Dutta et al., 2020)

Indicator	Description	Source
Quality of democracy	The Quality of democracy index scores 167 countries according to 60 indicators summarized in five categories: electoral process and pluralism, civil liberties, functioning of government, political participation, and political culture, condensing it into a score between 0 and 10. Countries that receive a score greater than 8 are classified as full democracies, a score between 6 and 8 are flawed democracies, a score between 4 and 6 are hybrid regimes and any score under or equal to 4 is an authoritarian regime.	(The Economist Intelligence Unit, 2020)
Corruption Perception Index	The Corruption Perception Index ranks 180 countries according to public perception of corruption on a scale of 0 to 100, where 100 is no corruption and 0 is highly corrupt. It is based on the opinion of experts and businesspeople.	(Transparency International, 2020)
World Press Freedom Index	The World Press Freedom Index is based on a survey filled out by journalists in 180 countries around the world, evaluating pluralism, media independence, media environment and self-censorship, legislative framework, transparency, and the quality of the infrastructure that supports the production of news and information. This is then compiled into a score from 0 to 100, with 100 being the worst and 0 the best score.	(RSF, 2021)
Political Stability Index	The Political Stability Index is a composite index of multiple indices, showing the perception of how probable a destabilization or overthrow of the government through violence or unconstitutional means seems (also includes politically motivated terrorism, social unrest, international tensions, violent demonstrations among others). It gives each country a score between -2.5 and 2.5, with positive numbers indicating perception of a stable political system and vice versa.	(The Global Economy, 2019)

Appendix C – Solar Power Projects Lebanon

Adapted from IRENA (2020), LCEC (2020) and Tsagas (2018).

Project	**D/ C**	**Procurement**	**Contracted capacity**	**Time frame**	**Investors**	**Developers**	**Location**
River Solar Snake (BRSS) Phase 1	C	EPC Model	1.08 MWp	2013 (procurement initiation) 2014 (construction) 2016 (handover to EDL)	LCEC / MEW	LCEC / MEW	Beirut
Zahrani Oil Installations	C	N/A	1 MWp	2014	N/A	N/A	Zahrani (south Lebanon)
BRSS Phase 2	C	Auction	7 MWp (could be extended to 10 MWp)	2018 (procuremept initiation) 2020 (commission of project)	LCEC / MEW	LCEC / MEW	Beirut
Solar rooftop for 113 schools	D	Auction	Expected at around 600 KW	2018 (start of bidding process)	Japanese government grant	Japanese government (coordinate bidding process) Ministry of Education Lebanon	All across Lebanon
Beirut Sea Port (rooftop of silos)	D	Auction	200 KW	2018 (start of bidding process)	N/A	LCEC / MEW	Beirut harbor

Project	D/C	Procurement	Contracted capacity	Time frame	Investors	Developers	Location
12 solar farms	C	Auction	10 – 15 MW	2017 (first auction) 2019 (conclusion of first evaluation phase of bidders)	LCEC / MEW	LCEC / MEW	4 main regions (North and Akkar, South and Nabatieh, Bekaa and Hermel, Mount Lebanon)
3 utility scale solar farms plus storage	C	Auction	300 MWp (100 MWp each) -> bids for 4 268 MWp Storage capacity of 70 MWh	2018 (start of bidding process)	LCEC / MEW	LCEC / MEW	All across Lebanon
24 solar farms	C	Auction	240 – 360 MWp	2020 (planned start of bids)	LCEC / MEW	LCEC / MEW	All across Lebanon
PVs on 10 public buildings	D	N/A	1.56 MW	Some already installed, some under evaluation or bid preparation	LCEC / MEW	LCEC / MEW	Public buildings across Lebanon
Public street lighting systems with PV	D	N/A	1.2 MWp	Installed	MEW	MEW	All across Lebanon
Street lighting poles (private) and PV pumping	D	N/A	1.4 MWp	Installed	Council for Development and Reconstruction	CDR	Baalbek

Appendix D – Wind Power Projects Lebanon

Adapted from IRENA (2020) and Sustainable Akkar (2021).

Project	Procurement	Contracted capacity	Time frame	Location
Akkar wind farms	Auction	200 – 220 MW	2013 (auction) 2021 (planned start of generation)	Akkar
Second Wind auction round	Auction	200 – 400 MW (bids for around 4000 MW)	2018 (auction)	All across Lebanon (most in Akkar)

Appendix E – Growth projection data

	Target projection			Gompertz model				Logistic model			
Year	**GWh as % (normalized)**	**Growth rate**	**GWh**	**Years after Tmax**	**GWh as % (normalized)**	**Growth rate**	**GWh**	**Years after Tmax**	**GWh as % (normalized)**	**Growth rate**	**GWh**
2015	0.07%	-	15.0	-13	0.07%	-	14.4	-4	0.06%	-	12.1
2016	0.13%	87%	28.0	-12	0.12%	78%	25.7	-3	0.10%	80%	21.9
2017	0.19%	46%	40.7	-11	0.20%	66%	42.7	-2	0.18%	72%	37.6
2018	0.32%	67%	68.0	-10	0.31%	57%	66.9	-1	0.28%	60%	60.2
2019	0.44%	39%	94.5	-9	0.47%	49%	99.5	0	0.41%	46%	87.7
2020	0.62%	39%	131.2	-8	0.67%	42%	141.4	1	0.54%	31%	115.2
2021	0.86%	39%	182.1	-7	0.91%	36%	192.9	2	0.65%	20%	137.8
2022	1.19%	39%	252.9	-6	1.19%	32%	253.8	3	0.72%	11%	153.5
2023	1.65%	39%	351.2	-5	1.52%	27%	323.5	4	0.77%	6%	163.3
2024	2.30%	39%	487.6	-4	1.89%	24%	400.9	5	0.79%	3%	168.9
2025	3.19%	39%	677.1	-3	2.28%	21%	484.7	6	0.81%	2%	171.9
2026	4.43%	39%	940.2	-2	2.70%	18%	573.2	7	0.82%	1%	173.6
2027	6.14%	39%	1305.5	-1	3.13%	16%	664.8	8	0.82%	1%	174.5
2028	8.53%	39%	1812.8	0	3.57%	14%	757.9	9	0.82%	0%	174.9
2029	11.85%	39%	2517.2	1	4.01%	12%	851.1	10	0.82%	0%	175.2
2030	16.45%	39%	3495.2	2	4.44%	11%	942.9	11	0.82%	0%	175.3

Appendix F – Feasibility Frontier Data

Country	Years after take-off													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Lebanon	0.40%	-	-	-	-	-	-	-	-	-	-	-	-	-
Algeria	0.83%	0.95%	-	-	-	-	-	-	-	-	-	-	-	-
Argentina	0.58%	-	-	-	-	-	-	-	-	-	-	-	-	-
Australia	0.55%	0.92%	1.38%	1.59%	1.99%	2.46%	3.20%	3.93%	5.88%	-	-	-	-	-
Austria	0.48%	0.89%	1.12%	1.33%	1.56%	1.80%	2.04%	2.42%	-	-	-	-	-	-
Bangladesh	0.33%	0.39%	0.44%	0.50%	0.55%	-	-	-	-	-	-	-	-	-
Belarus	0.47%	0.48%	-	-	-	-	-	-	-	-	-	-	-	-
Belgium	0.59%	1.24%	2.28%	2.81%	3.07%	3.25%	3.29%	3.51%	4.15%	4.19%	-	-	-	-
Brazil	0.57%	1.09%	-	-	-	-	-	-	-	-	-	-	-	-
Bulgaria	2.17%	3.63%	3.34%	3.68%	3.69%	3.74%	3.58%	3.74%	-	-	-	-	-	-
Canada	0.37%	0.50%	0.70%	0.62%	0.66%	0.73%	-	-	-	-	-	-	-	-
Chile	0.66%	1.73%	3.62%	5.37%	7.16%	8.65%	-	-	-	-	-	-	-	-
China	0.37%	0.70%	1.07%	1.80%	3.14%	4.24%	5.36%	-	-	-	-	-	-	-
Costa Rica	0.57%	0.78%	-	-	-	-	-	-	-	-	-	-	-	-
Croatia	0.32%	0.37%	0.44%	0.42%	0.46%	-	-	-	-	-	-	-	-	-
Cuba	0.34%	0.83%	-	-	-	-	-	-	-	-	-	-	-	-
Czechia	0.88%	3.10%	3.05%	2.89%	3.02%	3.22%	3.03%	3.12%	3.35%	3.25%	-	-	-	-
Denmark	1.37%	1.58%	1.60%	1.97%	1.99%	2.53%	2.55%	-	-	-	-	-	-	-
Dominican Republic	0.45%	0.83%	1.37%	-	-	-	-	-	-	-	-	-	-	-
Egypt	0.40%	0.37%	0.37%	-	-	-	-	-	-	-	-	-	-	-
Ethiopia	0.35%	0.37%	0.34%	-	-	-	-	-	-	-	-	-	-	-
France	0.44%	0.83%	0.97%	1.20%	1.45%	1.62%	1.80%	1.98%	2.13%	-	-	-	-	-
Germany	0.36%	0.50%	0.72%	1.08%	1.92%	3.20%	4.31%	5.07%	5.89%	6.33%	6.23%	6.44%	7.48%	7.77%
Greece	0.97%	2.69%	5.78%	6.01%	6.18%	6.23%	6.33%	6.01%	6.28%	-	-	-	-	-
Guatemala	1.42%	1.82%	1.88%	1.93%	2.16%	-	-	-	-	-	-	-	-	-
Hungary	0.33%	0.57%	0.82%	1.46%	3.26%	-	-	-	-	-	-	-	-	-
India	0.42%	0.59%	1.06%	1.92%	2.66%	4.05%	5.16%	-	-	-	-	-	-	-
Israel	0.35%	0.68%	0.90%	1.54%	2.04%	2.83%	2.77%	2.88%	4.75%	-	-	-	-	-
Italy	0.56%	3.15%	5.50%	6.30%	6.50%	6.69%	6.45%	7.11%	6.61%	6.91%	-	-	-	-
Japan	0.30%	0.42%	0.57%	1.11%	1.97%	2.99%	3.93%	4.73%	5.38%	6.37%	-	-	-	-
Jordan	2.15%	4.64%	7.36%	-	-	-	-	-	-	-	-	-	-	-
Kazakhstan	0.41%	-	-	-	-	-	-	-	-	-	-	-	-	-
Kenya	0.37%	0.66%	0.68%	0.81%	0.96%	1.14%	-	-	-	-	-	-	-	-
Lithuania	0.41%	0.67%	0.67%	0.60%	0.62%	0.79%	0.83%	-	-	-	-	-	-	-
Malaysia	0.43%	-	-	-	-	-	-	-	-	-	-	-	-	-
Mexico	0.40%	0.68%	2.40%	-	-	-	-	-	-	-	-	-	-	-
Morocco	1.16%	1.20%	2.76%	4.59%	-	-	-	-	-	-	-	-	-	-
Netherlands	0.34%	0.59%	0.91%	1.31%	1.81%	3.03%	4.23%	-	-	-	-	-	-	-
Pakistan	0.44%	0.69%	0.79%	-	-	-	-	-	-	-	-	-	-	-
Peru	0.49%	0.50%	0.58%	0.60%	0.72%	1.88%	1.92%	-	-	-	-	-	-	-
Philippines	1.62%	1.77%	1.84%	1.84%	-	-	-	-	-	-	-	-	-	-
Poland	0.45%	-	-	-	-	-	-	-	-	-	-	-	-	-
Portugal	0.37%	0.50%	0.70%	0.85%	1.11%	1.41%	1.55%	1.76%	1.79%	2.26%	-	-	-	-
Romania	0.70%	2.69%	3.30%	3.03%	3.09%	2.95%	2.96%	-	-	-	-	-	-	-
Singapore	0.31%	0.38%	0.51%	0.73%	-	-	-	-	-	-	-	-	-	-
Slovakia	1.39%	1.49%	2.06%	2.09%	1.78%	1.87%	1.78%	2.05%	2.07%	-	-	-	-	-
Slovenia	0.46%	1.15%	1.52%	1.82%	1.94%	1.89%	2.01%	1.80%	2.14%	-	-	-	-	-
South Africa	0.41%	0.86%	1.21%	1.58%	1.71%	1.93%	-	-	-	-	-	-	-	-
South Korea	0.32%	0.51%	0.80%	1.03%	1.42%	1.85%	2.62%	-	-	-	-	-	-	-
Spain	0.89%	2.09%	2.48%	3.24%	4.13%	4.52%	4.72%	4.78%	4.70%	4.96%	4.39%	5.19%	-	-
Sri Lanka	1.31%	1.08%	-	-	-	-	-	-	-	-	-	-	-	-
Sweden	0.44%	-	-	-	-	-	-	-	-	-	-	-	-	-
Switzerland	0.45%	0.75%	1.26%	1.68%	2.00%	2.53%	2.92%	3.17%	-	-	-	-	-	-
Taiwan	0.36%	0.46%	0.69%	1.12%	1.70%	-	-	-	-	-	-	-	-	-
Thailand	0.65%	0.84%	1.44%	2.04%	2.75%	2.75%	3.14%	-	-	-	-	-	-	-
Tunisia	0.41%	0.68%	0.84%	1.09%	1.09%	-	-	-	-	-	-	-	-	-
Turkey	0.41%	1.12%	3.03%	3.72%	-	-	-	-	-	-	-	-	-	-
Ukraine	0.30%	0.59%	0.53%	-	-	-	-	-	-	-	-	-	-	-
United Arab Emirates	0.31%	0.31%	0.33%	0.78%	1.39%	-	-	-	-	-	-	-	-	-
United Kingdom	0.35%	0.53%	1.06%	1.97%	2.73%	3.01%	3.37%	3.32%	-	-	-	-	-	-
United States of America	0.36%	0.59%	0.81%	1.15%	1.62%	1.94%	2.23%	-	-	-	-	-	-	-
Uruguay	0.42%	1.29%	2.29%	3.55%	3.61%	-	-	-	-	-	-	-	-	-