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The Lebanese Electricity Sector: A Novel Polycentric Design

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Cover Image: Jounieh right at the outskirts of Lebanon's capital, Beirut. An electricity power plant can be seen at the periphery of the image. Source: aboutleb.com (2019).

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The Lebanese Electricity Sector: A Novel Polycentric Design

A New Perspective for the Lebanese Electricity Sector

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Housam Hammoud
Delft, April 2019.

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Executive Summary

The Lebanese electricity sector suffers from immense reliability problems that cause power outages to be a daily routine to the Lebanese consumer. Power rationing is used by the state-owned monopoly, i.e. Electricite du Liban (EdL), to distribute the limited amount of energy capacity to consumers, and power outages varies between 3 to 12 hours a day depending on the region of the country. Several energy reform policies have failed to be implemented and transform the sector into a well-functioning one, and this is mainly attributed to the political-sectarian system of the country (confessionalism). Therefore, thesis attempts to reform the Lebanese electricity sector using a novel approach based on polycentricity, which is able to surpass the political system in the country as well as taking into account the societal and economic need in Lebanon. The following main research question was put forth to provide guidance for the thesis:

"What polycentric governance structure(s) would constitute an acceptable arrangement for a hybrid electricity sector for the case of Lebanon?"

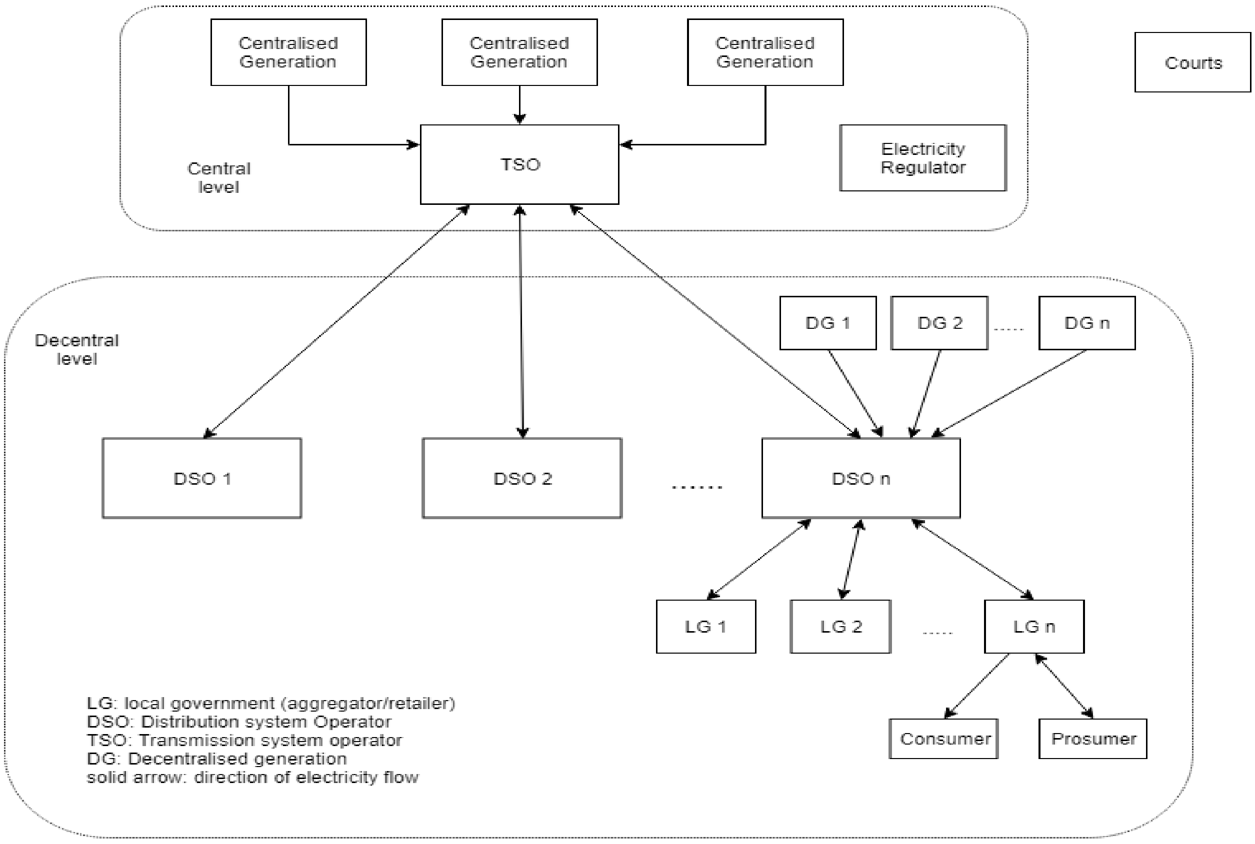
To achieve its objective, the thesis builds a design framework that follows sequential steps, and relies on literature and expert interviews to achieve the steps of the framework. The Literature proved to be the most important aspect to create the Polycentric Market Design Framework (PMDF). Whereas the interviews were instrumental in designing the Lebanese polycentric electricity sector, and validating the design. Information on designing came from interviews of category one, while validation came from interviews from category 2 (Table. 1). Validation looked into whether the designed structure is acceptable for Lebanon, and whether it can circumvent the political, social, and technical challenges that are facing the electricity sector.

Building the theoretical framework for the thesis mainly relied on three building blocks. The first block is polycentricity which mostly relied on studies done V. Ostrom and Aligica and Tarko. Polycentric indicators, extracted from the "Logical Structure of Polycentricity" framework, were utilised as constraints for designing the sector. The second block, i.e. the modes of organisation block, relied on studies by Ménard and Shirley (2008), Provan and Kenis (2008), and Scholten (2013) for information. This block was important in forming the relations between the different layers (actors) of the polycentric structure. The final major block, i.e. market design variables, was taken from a study conducted by Littlechild (2003). Along with the second block, the third block was utilised as the tactics to design and build the framework. The thesis understands designing a polycentric electricity sector as a market design exercise, and thus chose to stress more on the market aspects (modes of organisation and market design variables). However, the thesis does not neglect the important role and influence of the technical (system) dimension, and the need to ensure the reliability of the electricity sector. Thus, the study states that safeguarding the technical functions of the system is a constraint when designing the market aspects. This was achieved by making sure that actors have incentives to execute the technical functions that are assigned to them.

The theoretical framework created by this thesis is named the "Polycentric Market Design Framework" (PMDF). It includes seven steps for designing a polycentric electricity sector, and those steps are used to design the Lebanese sector. The steps can be summarised as follows, and they are found in section 2.6:

1. Start with designing the conceptual general structure of a polycentric electricity sector.
2. Investigate and decide on the relevant actors with respect to the case in hand.
3. Select the geographical jurisdiction for the centres, i.e. the DSO's and its accompanying actors.
4. Investigate and decide on the mode of organisation that will govern the relation between the different layers in the polycentric structure.
5. Make a choice on which of the remaining market design variables are relevant to your case.
6. Select the market option per market variable.
7. Create a conceptual framework that describes the pathway towards achieving the new electricity sector design.

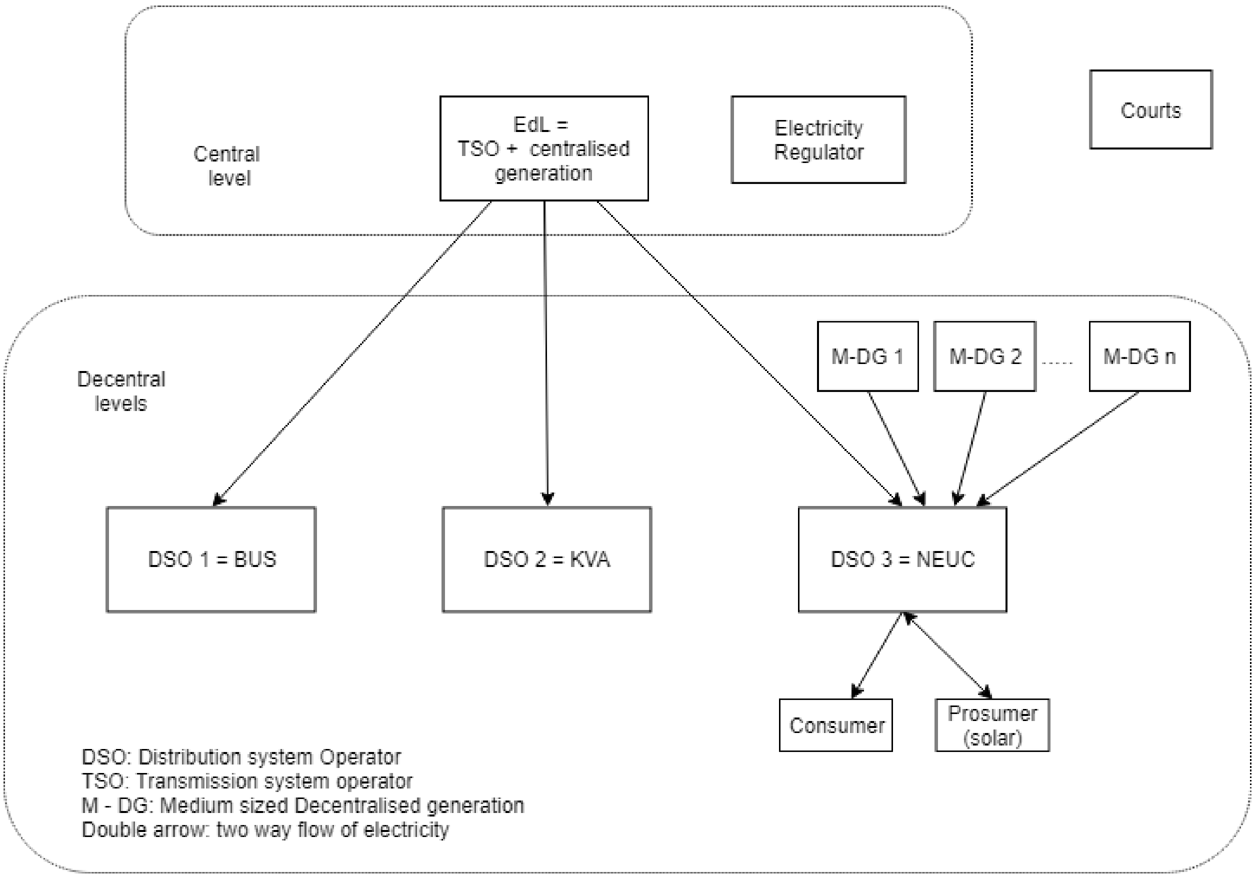
The conceptual (general) structure of a polycentric electricity sector, i.e. step 1 of the PMDF, which is the basis for design is presented below. This structure was developed through a combining the concepts taken from polycentric indicators, a general structure of polycentricity (figure. 6), and retail-competition market model of the electricity sector.



The thesis moves on to present the contextual attributes of the Lebanese electricity sector (institutional, and physical), as well as economic and socio-political context of the country. Interesting findings shows that Lebanon's electricity sector have the initial base of developing a polycentric electricity sector. For example, the distribution network is already split into three regions, where each region's operation and management were handed over by concessions to private companies, named distribution service providers (DSPs). The sectarian-political system of Lebanon which effects decision-making and enhance political bigotry amongst parties, gives a compelling reason for Lebanon to go ahead with this division.

Next, the thesis applies the PMDF to design the Lebanese polycentric hybrid electricity sector. The design calls for more decision-making power and autonomy to be handed to each distribution service provider, and thus turning each into a "market" distribution system operator (DSO). This is achieved by allowing decentralised generation to be connected to the distribution network. An auctioning mechanism named the Contract Deferral Scheme (CDS) was selected to provide the methodology to select decentralised generation, and demand side management. This classifies the market model at the decentral level of the polycentric structure as a single-buyer model, where only the DSO holds the power to buy generated electricity and sell it to consumers/prosumers. Therefore, each DSO acts as the retailer in its respective region, and no possibility of retail competition would exist in Lebanon. Consumers also have the possibility to turn into prosumers by producing electricity through solar power and sending it back to the grid (two-way flow of power). This is achieved through the currently existing incentives, i.e. net-metering. The jurisdiction of each DSO is based on figure. 11, which ensures socio-political approval, technical applicability, and optimum economic benefit (number of consumers, area covered…. etc.), and besides this jurisdiction is already in place which ensures the acceptability by the decision-makers in the government. The DSO's ownership model remain as the current model depicts, i.e. concessions to private entities. However, eventually the concessions over operation and management is handed to legally unbundled state-owned distribution firms. On another note, incentivising the decentralised generators to connect at the optimum location played an important role in increasing the efficiency of the design. Therefore, the thesis chose to utilise shallow connection charges and locational based incentive mechanism for the Distribution network use of system (DNuS). At the central level of the structure, EdL kept its transmission and centralised generation ownership and duties. Thus, the market model at the central level would remain vertically integrated. However, a regulator was added at the central level to oversee the ongoing operations and activities in the whole electricity sector. Another important piece of the jigsaw in the proposed design was to select the balancing mechanism to control and coordinate between the DSO and the transmission system operator (TSO), i.e. EdL. This was achieved through the devolution principle, which separated balancing responsibilities between DSO and TSO with respect to each network. The principle asks the DSO to pay the TSO for the balancing cost caused by that DSO at the transmission line.

The following figure, shows the final structure/shape of the Lebanese polycentric hybrid electricity sector.



The design above was deemed acceptable by both the political system as well as the public in Lebanon. On one hand, handing over some market power to DSOs, having a balanced relation between the DSO and the TSO, and dividing the distribution network through regional division could end political bigotry between the various factions of the Lebanese parties. On the other hand, the public would be willing to accept the design because it is solving the reliability issue of the sector at a probable lower cumulative price than the current situation, where currently consumers are paying two electricity bills, i.e. one from EdL and another from independent energy providers (illegal diesel generators). It also ensures that consumers are able to produce cheap solar power to mitigate part of the electricity bill. In addition, the design was able to mitigate the technical bottlenecks which are found at the transmission level, giving this design the potential of being much cheaper for the Lebanese government when compared to the latest Lebanese energy policy of Bassil (2010).

Aside from the main conclusion which stated that the design polycentric structure would be acceptable for the Lebanese case, the study arrived at a set of other conclusions and recommendations. The following gives a set of the conclusion and recommendation found in chapter 6&7:

- A novel approach to design the electricity market was created through the "Polycentric Market Design Framework", and the study concluded that the PMDF could be generalised for other cases when designing polycentric electricity structures. This also along with the conceptual structure of a polycentric electricity sector can be generalisable to serve the purpose of designing other cases.
- An investigation on the possible negative effects of the polycentric design on the Lebanese society, and whither it leads to reinforcing sectarian conflicts or reinforcing social capital. If the former is found to be true, the author believes that such a design should not be implemented in Lebanon.
- Future research to check whether the existing Lebanese DSPs are able to change their business model into a market DSO.
- Future research should be made on the way to implement polycentric design for Lebanon the seventh step of the Polycentric Market Design Framework, which calls for finding out how to implement the design. This step was not achieved in this study.
- Investigating the investment level needed by the Lebanese government to apply the proposed design, and compare it with the one proposed in the latest energy policy (Bassil, 2010).
- Investigate whether there is a possibility for local governments, i.e. municipalities, in Lebanon to play a role in the proposed electricity sector. A proposition is to have municipal boards to monitor the activities of the DSOs, which would bring more involvement to the communities in the electricity sector. Such monitoring could be utilised in order to make sure that the interest of prosumers and consumers are safeguarded, and would serve as a second mechanism to safeguard consumers interests. This second mechanism would be advised to interact and coordinate with the first monitoring entity, i.e. the regulator.

- It is believed that the set of polycentric indicators that describes attributes of a polycentric energy infrastructure is better suited to the electricity sector than the more comprehensive indicators found in the Logical Structure of Polycentricity framework.
- A research could be done to investigate the possibility of further dividing the fifth and sixth steps in the PMDF into more steps. The logic would be to investigate which of the variables presented in these two steps should be selected prior to the other.
- The technical functions of the electricity sector were treated as constraints, i.e. the need to safeguard them by allocating the execution responsibility to relevant actors. However, the PMDF does not clearly show this aspect, which is natural since it's a market design framework. Nonetheless, to further develop the PMDF research could focus on integrating the need to safeguard the technical functions in the PMDF steps.
- Investigating whether the PMDF methodology could be utilised for other electricity market design models, i.e. other than polycentric.

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1. Introduction

1.1. Problem introduction

This thesis studies the Lebanese electricity sector and sheds light on a new design perspective in an effort to overcome the immense reliability problems that the sector suffers from. The electricity sector has not fully recovered ever since the civil war ended in 1990, with power outages and electricity rationing becoming a daily routine in Lebanon (Verdeil, 2016). Electricity rationing varies depending on the region; for example, Beirut (capital) is subjected to daily outages that averages at around 3 hours, while other areas suffer from 12 to 16 hours of daily power outages (Verdeil, 2016). This is accompanied with many failed attempts by the Lebanese government to transform the sector into an efficient and reliable infrastructure. Most notable attempts were the relatively recent official reform policies which date back to 2006, 2008, and 2010. However, none of these policies were implemented, and this is mainly attributed to the barriers exerted by the political sphere on decision-making (Ibrahim et. al, 2013).

To understand the unique situation surrounding the decay in the Lebanese electricity sector, it is important to get an overview of how policymaking or decision-making in the state is done. The decision-making process can be described as "politicised", in which politics interfere in every aspect of decision and policy-making (Khodr and Hasbani, 2013). Policymaking in Lebanon is well engraved in the sectarian socio-political system of Lebanon. Political parties represent their respective sects (e.g. Christian Maronite, Christian Orthodox, Sunni, Shiite…etc.), and through these sectarian ties they can manipulate and gain the public's approval towards decisions and policies. They also use regional's and international's support to foster their political agendas (Khodr and Hasbani, 2013). In addition, unanimous decision-making is of extreme importance between all political parties that form the government, where diverging ideologies and objectives are clearly visible. This is intensified by the fact that in the Lebanese government the notion of opposition vs. ruling parties does not exist, and this comes from the need to represent all sects in the government; this leads to the continuous representation of the same major political parties in the government. The need to represent all sects in the government is mainly attributed to maintaining the balance between each other, and it is feared that misrepresenting one would ultimately lead to misrepresenting of others. Such a political paradigm makes any decision-making in Lebanon very difficult and a highly complex process that casts a shadow over possibilities to achieve fast and eloquent results.

This continuous struggle in decision-making is clearly reflected in the Lebanese electricity sector, which suffers from negligence, mismanagement, and corruption. Despite massive investments after the civil war (1975-1990), electricity provision has never fully recovered and was also worsened by the 2006 Israeli bombings (Verdeil, 2016). Electricity production, transmission, and distribution fall under a state-owned monopoly labelled Electricite du Liban (EdL). EdL is overseen by the Ministry of Energy and Water (MoEW), while other ministries including the Ministry of Finance (MoF), and the Ministry of Environment (MoENV) play various roles in the electricity sector (Khodr and Hasbani, 2013). EdL was created in 1964 following the nationalisation of the electricity sector by the mandate n.16878, and EdL is currently providing only 60% of the country's demand. The other 40% of the country's demand is compensated through three main strategies, which are used to cope with the power outages. First strategy is the purchase of a diesel generator by a single consumer; second, is the collective purchase of a larger generator for a block or a residential building by consumers; and third, which is the most common strategy is the subscription to an independent energy provider (IEP), which mainly produce through decentralised diesel generators (Ghanem, 2018). However, IEPs are not legally protected, in which organisational mechanisms do not exist to organise their work.

The literature on the Lebanese electricity sector was extensively studied, thus allowing this study an opportunity to address one of the identified gaps. The investigated articles could be categorised into three categories, with the first category addressing the current situation of the sector and the barriers that hinder its development (Ghanem, 2018; Verdeil, 2016; Ibrahim et. al, 2013; Khodr and Hasbani, 2013; Fardoun et. al, 2012; Ruble and Nader, 2011). The second category includes studies that mainly focused on future energy scenarios and their implications from a technical and economic perspective (Dagher and Ruble, 2011; El-Fadel et. al, 2010; Ibrahim et. al, 2013). The literature of the third and final category paid attention to integrating renewable energy in the electricity generation mix, where limitation and barriers for developing the minimal-existence of renewable energy generation is discussed (Khoury et. al, 2016; El-Jamal et. al, 2014; Kinab and El Khoury, 2012; Dagher and Ruble, 2010; El-Fadel et. al, 2003). A commonality amongst the studied literature is that they don't delve into the governance aspects of the electricity sector. It was clear from reading the articles that not much effort has been made to investigate and propose new governance solutions to reform the Lebanese electricity sector and bypass the political challenges. The existing studies mainly tackle the generation side of the sector without tackling the current structure of the market (Ibrahim et.al, 2013; Fardoun et. al, 2012; Dagher and Ruble, 2011), which has proven to be an ineffective market within the Lebanese political context (Ruble and Nader, 2011). Ignoring the political and environmental context might lead to wrong recommendations and conclusions, and therefore favouring centralised solutions that might be optimal from an economic and technical perspective alone. Given the very strong influence of the unique political situation in Lebanon, an unconventional and an innovative governance to the sector is needed.

1.2. The way Forward

Given the Lebanese situation, i.e. having legal centralised generation on one hand, and “illegal” decentralised generation on the other, as well as the complex socio-political structure of the country. The thesis investigates a sector reform solution that can overcome the political complexion of the country through combining centralised and decentralised generation in a unified governance structure. Therefore, this section sheds light on a number of studies that provide the direction this thesis should delve into.

The current restructuring or reform model for the electricity was developed around three decades ago when energy systems were considerably different than today’s or the future energy systems (Conejo and Sioshansi, 2018). The authors argue that electricity markets are reaching something of a breaking point due to the structural changes in the architecture of the electric power systems in two major ways. On one hand, the supply side of the market is relying less and less on centralised dispatchable generation sources, and is shifting towards weather-dependent renewable energy which is expected to increase drastically in the future. On the other hand, the demand side is experiencing new technologies that make it no longer static and inflexible. Therefore, the authors argue that a rethinking of the market design and ways to govern the sector is needed. Funcke and Bauknecht (2016), study the electricity topology of Germany and state that disagreements amongst actors can be found when it comes deciding whether the infrastructure should lean towards decentralised or centralised generation. Their study concludes that when it comes to deciding whether the market should choose centralised or decentralised there is no black or white decision, which means that the market doesn’t have to stick to one paradigm. It should instead seek to combine both generation technologies through a unified governance structure.

An interesting and unconventional description of the electricity infrastructure comes from Künneke and Finger (2009) and Goldthau (2014), where the authors identify the infrastructure as a common pool problem (Künneke and Finger, 2009; and Goldthau, 2014). Ostrom, Gardner, and Walker (1994), defines a case as a common pool when “excluding potential appropriators or limiting appropriations rights of existing users is nontrivial (but not necessarily impossible) and the yield of the resource system is subtractable”. Therefore, a common pool resource can be described as rivalrous but non-excludable. Künneke and Finger (2009), explain that infrastructures, e.g. energy, are nonexcludable resources for three important reasons. First, due to the vast geographical area that the network covers, and thus making it very difficult to monitor. Second, even if it would be technically possible to monitor the infrastructure, political motives may hinder the possibility of excluding consumers from using it. Third, for users who have already entered the network, it might be impossible to quite determine the services they’re claiming from the network. The authors continue to explain that infrastructures are open access services and it is impossible to individually assign the benefits among consumers, which results in consumers exploiting the benefits at the expense of others without contemplating the economic or technical effects on the network. Thus, Künneke and Finger conclude that infrastructures are considered rivalrous services, and categorizes them as common pool resources. The same sentiment is shared by Goldthau (2014), where the author describes the energy infrastructure as non-excludable and rivalrous since consumers have almost unlimited access to it, and in turn the resource (energy) is limited, which might lead to its destructive overuse.

Repeated findings of empirical research done on common pool problems successfully challenge the conventional theory that perceives those who are directly affected, as helpless and cannot take actions (Ostrom, 2010). Participants are able to prove that through tough efforts the community would successfully achieve collective benefits, and that is why Ostrom calls for polycentric governance of common pool problems. Andersson and Ostrom (2008) proves through comparing case studies that polycentric governance for decentralised natural resources, forests (socio-ecological system), is a better fit than decentralised governance. However, limited studies linking the concept of polycentric governance with the energy/electricity infrastructure exist. Goldthau (2014), calls for a polycentric governance for the sector, in which it can provide solutions at multiple levels (centralised and decentralised), and therefore allowing for higher integration of decentralised generation options. Another interesting study conducted by Sovacool (2011) explored four case studies in Denmark, Brazil, Bangladesh, and China that had various degrees of polycentric governance implemented in different energy related sectors. The study concluded that polycentrism was able to promote “equity, inclusivity, information (distribution of data), accountability, organisational multiplicity, and adaptability” (Sovacool, 2011, p. 3840). However, the limited amount of studies that discuss polycentricity in energy infrastructure mostly discuss the importance of polycentrism and its added value to energy infrastructure governance (Goldthau, 2014; Sovacool,2011), except a study conducted by Cayford and Scholten (2014), which discusses the viability of polycentrism towards self-governance in community energy systems.

Given the above explained problem, and taking the Lebanese electricity sector as the centre stage for the study, the thesis investigates a new design for the electricity sector. The thesis looks beyond the 'standard model' for sector reform, in which it takes inspiration from the success of polycentric governance in the field of socio-ecological systems and tries to apply in the socio-technical field (energy infrastructure). In an effort to come up with a unified governance structure for centralised and decentralised generation, the study believes that polycentric governance can be a solution to a hybrid (centralised and decentralised generation) electricity sector in Lebanon. The study relies on design methods from the electricity market design, which is developed from the integration of three theories, i.e. micro-economics (Neoclassical economic theory), institutional economics, and industrial organisation (Scholten and Künneke, 2016). As well as the concept of polycentricity, which was introduced to governance studies by Vincent and Elinor Ostrom (Aligica and Tarko, 2012).

1.3. Objectives & Main Research Question

Following the above discussion, the objective of the thesis is to explore possible polycentric governance structures for a hybrid electricity sector in Lebanon.

Therefore, the main research question for this thesis is:

What polycentric governance structure(s) would constitute an acceptable arrangement for a hybrid electricity sector for the case of Lebanon?

The term "acceptable" is of significance to this thesis, in which it is attributed to being acceptable by both the political regime and the public's eye. For the political regime, the design should be able to bypass the previous bottlenecks that lead to other policies not being implemented, i.e. sectarianism. As for the public's opinion, the design should end the unreliability of the electricity sector whilst providing consumers with lower end prices when compared to the current situation.

To be able to answer the above main research question four sub questions were formulated:

a. Sub-question one: *What are the necessary steps to design a polycentric hybrid electricity sector?*
b. Sub-question two: *What is the current organisation of the Lebanese electricity sector? And what are the context peculiarities of the country?*
c. Sub-question three: *What is a possible design for the polycentric hybrid electricity sector in Lebanon?*
d. Sub-question four: *Is the proposed polycentric design acceptable in the current Lebanese situation? And what are the bottlenecks to achieve that?*

1.4. Scientific and Practical Relevance

As stated above, even though polycentric approaches have received a lot of attention in studies of common pool problems in socio-ecological systems, literature has failed to extensively investigate the energy infrastructure from a polycentric angle, despite the fact that it shares lots of characteristics with the definition of a common pool problem (Künneke and Finger, 2009). Thus, the thesis is trying to assist in bridging the identified gap and explore how would a polycentric governance structure look for the electricity sector in the specific context of Lebanon. therefore, there is a possibility that the theoretical framework used in this thesis could be generalised for other similar cases. The other added value of this thesis is studying the Lebanese context and proposing a governance solution to its struggling electricity sector, thus opening a new field of study for further researchers to explore. From a practical point of view, this study might be seen as the stepping stone for finding a solution for the Lebanese electricity sector, that suffers from immense political, regulatory, and technical problems.

1.5. Research Design

This section briefly explains the logic and the major design blocks this thesis will utilise to come up with an answer to the main research question. Three major blocks, i.e. polycentricity, modes of organisation, and market design variables constitute the pillars for designing the polycentric hybrid electricity market of Lebanon. A fourth block, which is the technical aspects of the electricity sector is considered as a constraint to designing the sector. A fifth and important block is the Lebanese context (physical, economical, institutional, and political), which is not necessarily reflected in the design process, but it provides context and base for designing the sector.

This thesis mainly relies on the studies of V. Ostrom (1999) and Aligica and Tarko (2012) to subtract information about polycentricity, and utilises the "Logical Structure of Polycentricity" (LSP) framework designed by Aligica and Tarko to withdraw the attributes and indicators of polycentricity. The Logical Structure of Polycentricity (LSP) framework is used to setup the constraints that distinguish the modes of organisation, and the options of the market design variables which creates a polycentric electricity sector. The modes of organisation block rely on studies by Ménard and Shirley (2008), Provan and Kenis (2008), and Scholten (2013) for information. This block is important to form the relations between the different layers (actors) of the polycentric structure (fig. 6). The final major block, i.e. market design variables, is taken from a study conducted by Littlechild (2003), which is also adapted by Correljé and de Vries (2008, p. 76). Linking these three major design blocks will be done through the institutional framework designed by Williamson (2000), which was adapted to the energy infrastructure by Scholten and Künneke (2016) and de Vries (2017) will be utilised.

1.5.1. Linkage Framework and Case study

Based on the author's understanding of the polycentric literature (Ostrom et. al, 1961; Ostrom, 1999), polycentricity is applicable to the market side of a sector, rather than to its technical dimension; this is visible through the attributes and indicators of polycentricity. Thus, the thesis chooses to stress more on the market design aspect of the electricity sector, rather than system (technical) design. However, the thesis does not neglect the influence of the technical (system) dimension, and the need to ensure the reliability of the electricity sector. Thus, the study assumes that safeguarding the technical functions of the system is a constraint when designing the market aspects.

As shown in Fig. 1, the Lebanese context will influence the indicators/attributes chosen from the LSP framework, the modes of organisation, and the choices taken when it comes to the market design variables. Polycentricity and system design, will impose certain constraints on both the modes of organisation and the market design options, where actual sector design will take place. On a simpler note, polycentricity will be used as the broad strategy to create the structure of the sector, while modes of organisation and market design variables will be used as the tactics to design and build the sector. The final outcome should be the green block, i.e. the polycentric hybrid electricity sector in Lebanon.

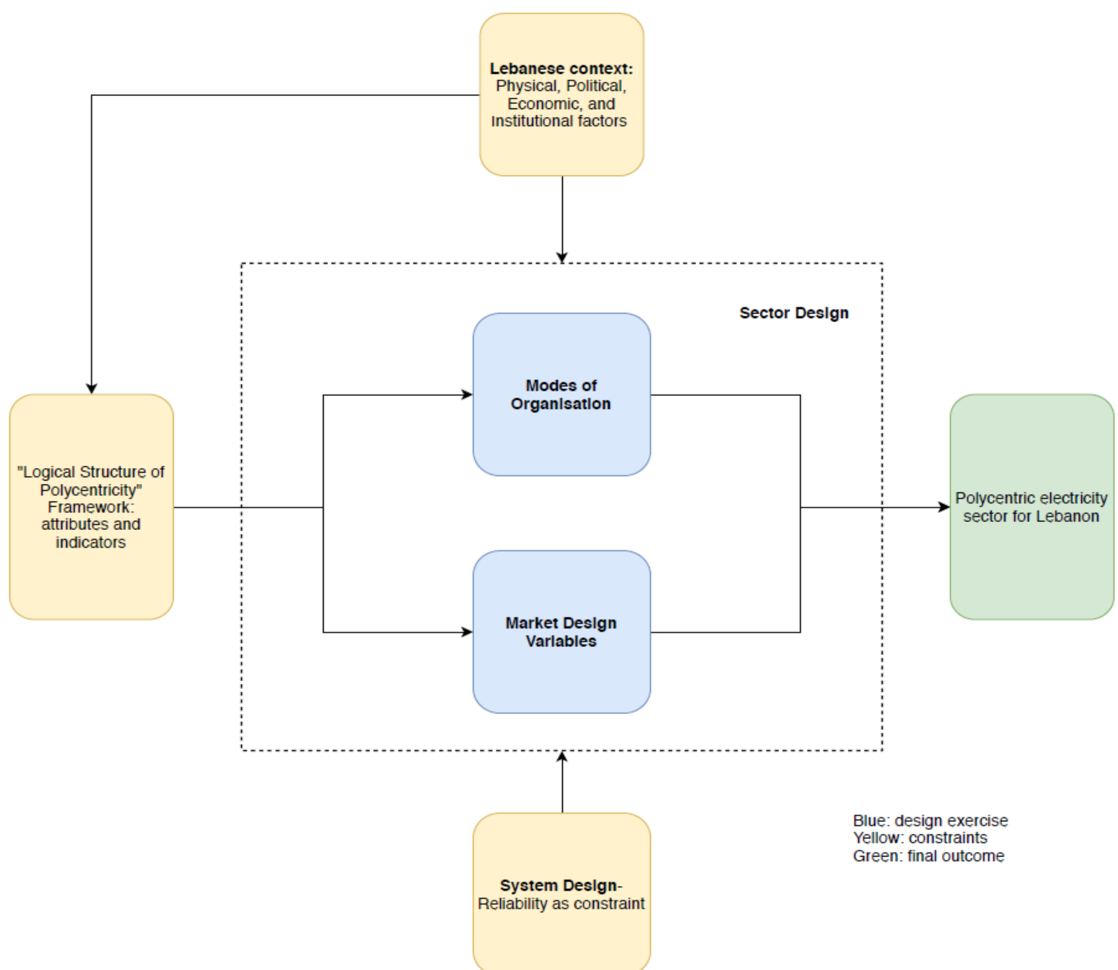

Figure 1: Basis for the Design framework of a polycentric governance structure

1.6. Methodology

This section is dedicated to explaining the pathway and methodology chosen by the researcher to arrive at the final results. The section is divided into three subsections; the first subsection introduces the four research sub-questions along with the needed steps to arrive at their respective answers, and discusses the method(s) used for each one. The aim of these four research questions is to attain the final answer for the main research question (section 1.3), in which each of the question's contribution is highlighted below. The second subsection introduces the interviews conducted for the study, and explains their relevance to the chapters of the thesis. The third subsection presents the structure of the thesis through a flow diagram.

1.6.1. Sub-Research Questions and Data Collection

<u>Sub-question one</u>: *What are the necessary steps to design a polycentric hybrid electricity sector?*

The aim of this research sub-question is to develop the necessary theoretical steps to design the polycentric electricity sector in Lebanon. In order to achieve that main objective, several aspects must be investigated and the following steps summarise the aspects to be investigated:

a. The electricity sector along with its technical functions.
b. The concept of polycentricity, along with its attributes/indicators, where the general notion of polycentricity is linked with the electricity sector.
c. The modes of organisation, which are responsible to define the relations between the different levels of a polycentric structure.
d. The market design variables, with their respective options.
e. Coming up with the framework which integrates the aspects needed to design a polycentric electricity sector. This framework will be a series of steps that shows the designer the pathway to design the polycentric sector.

The main method used to collect data for this question was desk research and literature review. The search began by looking through search engines for relevant articles, books, and grey literature. The search engines used were: Science Direct, Google, Google Scholar, Scopus, and TU Delft Library (online and physical books). The keywords that were used to conduct the search included, but were not limited to "polycentricity", "electricity/energy market design", "hybrid governance", "modes of governance" "critical functions", "unbundling", "access regulations", and "reform". The relevance of the literature found was identified based on their abstract and keywords used, and was completely read when deemed relevant. Looking at cited literature in relevant articles was also insightful, as well as exploring recommended articles from the search engines after downloading an article.

<u>Sub-question two</u>: *What is the current organisation of the Lebanese electricity sector? And what are the context peculiarities of the country?*

The expected results from this sub-question are a set of contextual findings that serve the purpose of being input for the polycentric sector design. The path to answer the above question would have to pass through the following:

a. Studying the current institutional and regulations that govern the electricity sector.
b. Investigating the generation, transmission, distribution, and consumption portfolio of the Lebanese electricity sector.
c. Inspecting the social, political, and economic context of Lebanon.

The method used to investigate and come up with a conclusion about all the above objectives was done through desk research, and Lebanese `interviews. The keywords that were used to conduct the search included, but were not limited to, "Lebanon", "electricity/energy market", "political economy", "energy policy". In addition, some information for the Lebanese context, e.g. generation portfolio or the updated situation of renewable energy sources, were acquired while conducting interviews with Lebanese experts/stakeholders, e.g. Prof. Raymond Ghajar and Mr. Ali Ismail.

<u>Sub-question three</u>: *What is a possible design for the polycentric hybrid electricity sector in Lebanon?*

The aim of this question is to design the polycentric structure for the hybrid electricity sector in Lebanon. The chapter follows the steps given by the theoretical framework in chapter two. The final structure should be able to surpass the Lebanese contextual constraints (e.g. political) and consider the objectives, goals, and requirements of the country.

To answer the above question, the chapter uses the results of sub-question one and two, along with semi-structured interviews with experts. The information from the first two sub-questions provides the background and base to start the design, whereas interviews with experts are responsible to provide answers for the modes of organisation, and the market design variables to complete the design.

<u>Sub-question four</u>: *Is the proposed polycentric design acceptable in the current Lebanese situation? And what are the bottlenecks to achieve that?*

Two objectives the above sub-question aims to achieve. The first is to assess whether the proposed design can be implemented in the current Lebanese situation. The second objective is to indicate the bottlenecks that might hinder the implementation of the design(s).

To achieve the two objectives, semi-structured interviews will be conducted with Lebanese electricity stakeholders/experts, and a Lebanese lawyer.

1.6.2. Interview Methodology & List of Interviewees

The strategy in selecting the interviewees for this thesis was based on the knowledge and perceived added value of the interviewees towards the findings of this thesis. The author decided to interview experts that are mainly knowledgeable in the fields of electricity market design, and the Lebanese electricity sector. Information from experts who have knowledge in market design was used to design the proposed polycentric electricity sector, while experts in the Lebanese sector were interviewed to validate the design, check its feasibility, and acquire some information on the Lebanese electricity sector.

Based on the above-mentioned needs, the interviewees could be divided into two categories, (i) experts that provided information and input to design the sector, and (ii) experts/stakeholders that validated the design and provided other important information. Some of the experts, i.e. three Lebanese experts, are categorised into both categories, since they were able to provide information in certain aspects of the design and validate other aspects. The importance of this categorisation is that interviewees of category one will only be used in the design chapter (fourth chapter) to answer the third research sub-question. However, the interviewees belonging to the second category will mainly be utilised to provide/validate information on the Lebanese situation (chapter 3) and to answer the fourth sub-question, i.e. chapter five. The list of interviewees is provided in the table below (alphabetical order), and the total number of interviewees are 12:

Interviewee number	Expert Name	Category	Institution	Position	Relevant Expertise
1	Bhagwat, Pradyumna Dr. M.Sc.	1	Florence School of Regulation	Research Fellow	Energy policy and regulation
2	Bhagwat, Swetha M.Sc.	1	Florence School of Regulation	Research Associate	Technology, policy & regulation, finance and business development in the renewable energy sector.
3	De Vries, Laurens Dr. ir.	1	Delft University of Technology	Associate Professor	Electricity market design
4	Ghajar, Raymond Prof. dr.	1 & 2	Lebanese American University. Ministry of Energy & Water	Dean, School of Engineering. Senior Energy Advisor at MoEW	Electricity utility restructuring (Lebanese situation)
5	Hammoud, Sami M.L.	2	Private office	Lawyer	Lebanese constitution and judiciary system
6	Ibrahim, Oussam Dr. M.Sc.	2	Lebanese University	Lecturer	Research in the Lebanese electricity sector
7	Ismail, Ali M.Sc.	1 & 2	Electricite du Liban (EdL)	Head of Dispatch Centre	Technical knowledge of the Lebanese sector
8	Jamasb, Tooraj Prof. dr.	1	Durham University – United Kingdom	Chair in Energy Economics, and Co-Director at the Durham Energy Institute	Energy sector reform and market liberalisation (developing countries)
9	Khazzaka, Raymond	2	Private sector	Independent Energy Provider	The sector of Diesel Generators in Lebanon
10	Mortada, Sorina Dr. M.Sc.	2	Lebanese Centre for Energy Conservation. Lebanese University	- Technical Consultant. - Associate Professor	Renewable energy in Lebanon
11	Mubarak, Sameh	1 & 2	World Bank	Senior Energy Specialist. Energy Extractives Global Practice, MENA region.	Electricity sector reform in Lebanon
12	Yorke-Smith, Neil Dr.	1	Delft University of Technology	Associate Professor	Socio-Technical Algorithmics and knowledge in the Lebanese case

Table 1: List of interviewed experts

All experts were approached to conduct a one-hour interview. Following the consent for conducting the interviews, a brief text explaining the aim of the thesis and the objective of the interview was sent to the interviewees that belonged to the first category (Appendix B). This was done to accelerate the interview and prepare the interviewee for the topics to be discussed. It was deemed unnecessary to send the explanation to interviewees listed in the second category due to their prior knowledge in the Lebanese situation. Most of the interviews were performed face-to-face, except two interviews, with Prof. Tooraj Jamasb and a conference interview with Dr. Pradyumna Bhagwat & M.Sc. Swetha Bhagwat, which were realised through Skype (video call).

All conducted interviews were semi-structured; however, interviews with non-Lebanese experts was more structured than that with Lebanese experts. The explanation sent, and the need to answer questions related to market design variables and modes of organization between the polycentric levels steered the interviewer to ask specific questions to the interviewee. These interviews started with a short, i.e. 10 minutes, introduction explaining the Lebanese context (political and electricity sector), and then proceeded to the specific questions. The main objectives of these interviews were to gather opinions and information relating to the structure of the design, i.e. levels in the polycentric structure (figure. 8), the organisational relation between the different levels (e.g. TSO, DSO, decentralised generation, users) in the structure, vertical unbundling, the ownership problem, and the position of the electricity regulator.

Whereas interviews with Lebanese experts, especially those that specifically belong to the second category, started with open questions relating to their expertise. For example, Dr. Sorina Mortada was asked about the current situation of renewable energy in Lebanon and whether decentralised generation could help the Lebanese sector. Towards the end of the interviews, the structure of the design was presented and the interviewees' opinions were taken with regards to the acceptability of the design in the Lebanese context. Only the interview with M.L. Sami Hammoud (lawyer) which is categorised in the second group was done with no open questions, in which the interviewee was asked specific questions relating to the availability of the pre-conditions for a successful polycentric governance in the electricity sector. Summaries of the conducted interviews could be found in Appendix C.

1.6.3. Structure of the Thesis

The figure below shows the research flow diagram. The discussion and reflection chapter will be responsible to reflect on the decisions made mainly in chapters two, four, and five. Discussion should cover the decisions made when it comes to the decision on selecting the relevant modes of organisation, the market design options, and the applicability of polycentricity in general to the Lebanese context. Reflection should shed light on the topics that could not be covered for any given reason, and how that might have altered the findings. The chapter must also discuss the possibility of generalising the polycentric structure to other cases.

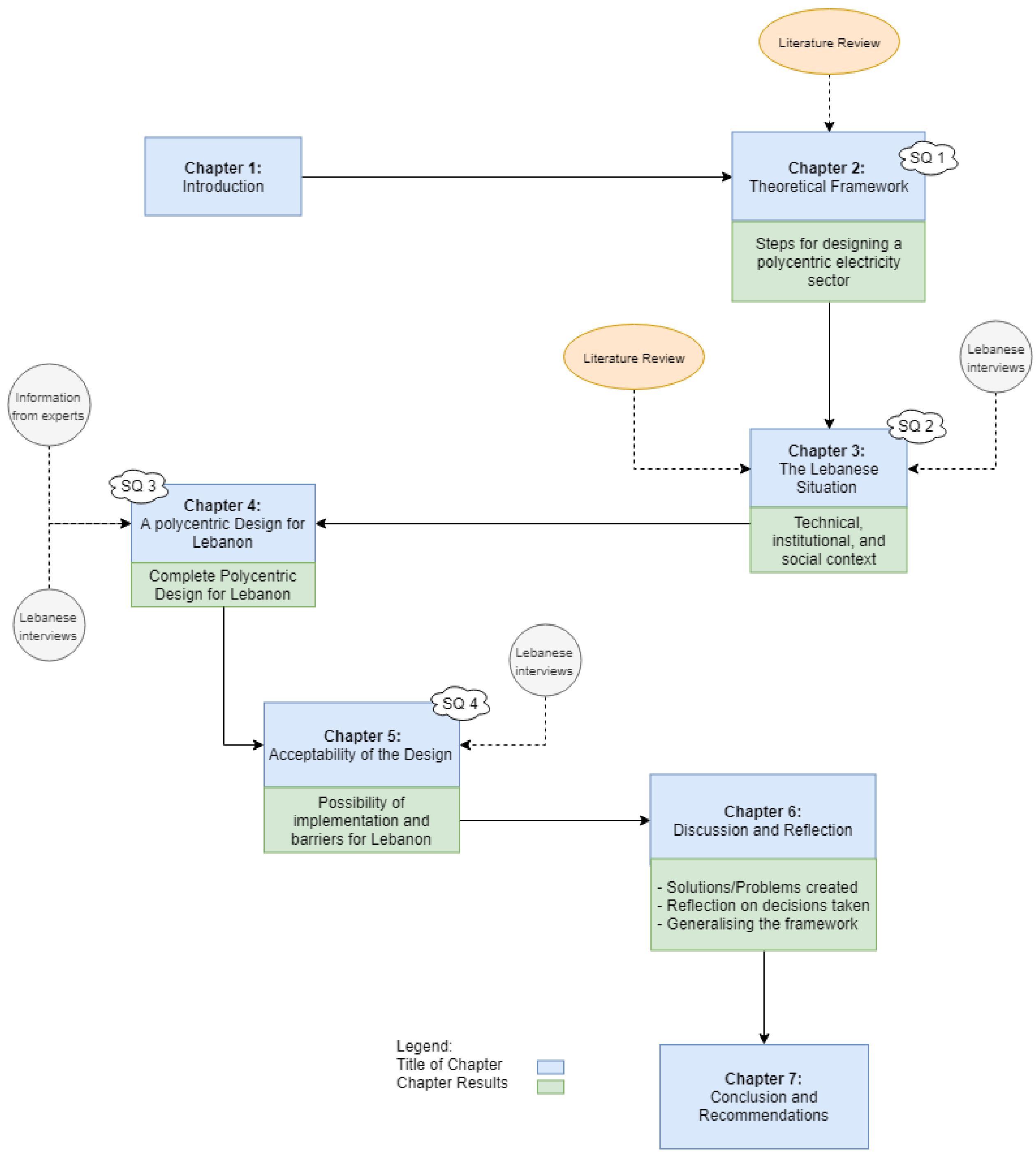

Figure 2: Research Flow Diagram

2. Theoretical Framework

This chapter aims to explain the framework and the pathway that this thesis takes to analyse and draw up conclusions for the study. The chapter has 6 sections, and these sections have four objectives. The first section serves the first objective, which is to present the electricity sector along with its definitions and main attributes. The second section serves the second objective, and that is to indicate the scope of design for the thesis and to link the three blocks, i.e. polycentricity, modes of organisation, and market design variables, that form the pillars of designing the polycentric market design framework. The third, fourth, and fifth section serves the third objective, which is to present and discuss the theories and design aspects involved in this thesis. The sixth and final section indicate how designing will take place, which is translated into a "Polycentric Market Design Framework" that provides the theoretical steps for designing a polycentric hybrid electricity sector.

The chapter starts with explanations concerning the electricity sector, where both the technical and institutional aspects of the sector are discussed. This section is followed by indicating the level of analysis of the three blocks, where the institutional framework of Williamson (2000) is used to link the design aspects used in the thesis. The third section discusses the main theory that this thesis applies to the electricity sector, i.e. Polycentricity. The section introduces the concept of polycentricity and its structure, identifies the preconditions for polycentricity in markets as defined by V. Ostrom (1999), and then it pinpoints the attributes and indicators of polycentricity as shown in the "Logical Structure of Polycentricity" framework created by Aligica and Tarko (2012). The chapter moves on to explain polycentricity within the electricity infrastructure, and introduces the concept of market in a polycentric structure. The fourth section identifies four general modes of organisation in a market, where modes of organisation are utilised to describe the relations between the various layers (actors) in the polycentric structure. The fifth section of the chapter serves the notion of the detailed variable of the electricity market design, in which thirteen design variables are explained along with their respective design options. The market design variables and their options serve as the detailed tactics to operationalise the strategy which is taken form polycentricity. The final section provides the necessary steps for designing a polycentric electricity sector.

2.1. The Electricity Sector

This section has three objectives to serve, the first objective is to explain the different aspects of the electricity sector and how does this thesis portray the infrastructure. The second objective is to present the functions that the electricity infrastructure must attain. The third objective is to serve as a point of reference for explaining the Lebanese electricity sector in chapter three. The section is divided into three subsections, the first subsection defines the electricity infrastructure. The second subsection reviews the institutional/market side of the electricity sector, and explores the different market models of the sector. The third subsection identifies and explains the physical aspects of the sector, along with the technical functions that must be safeguarded while designing the sector.

2.1.1. The Electricity Sector as a Socio-Technical System

According to literature (Goldthau, 2014; Scholten, 2013; Loorbach et al., 2010; and Smith et al., 2005), the electricity infrastructure fits the definition of a socio-technical system. This definition helps the study understand that the electricity infrastructure is actually embedded in its surrounding, i.e. its society. According to Fuenfschilling and Truffer (2014), a socio-technical system is characterised by the interdependence and "co-evolution" of the social structures, such as culture, customs, policies, institutions…. etc., and technology or physical material, which would ultimately lead to achieving a stable and a functioning societal service. It is important to understand the nature of how technologies tend to shape and co-evolve with social structure, and according to Fuenfschilling and Binz (2018) the dominant feature of the interaction and the major end product is the rationality and the rules of the game which govern the entire system (e.g. energy infrastructure). This definition indicates that when addressing the complex issue of the electricity sector, which in this case is the design of a new structure for the Lebanese electricity sector, both technical and institutional/market aspects of the sector must be considered.

2.1.2. The Market Side

Historically, i.e. pre-liberalisation era, the electricity sector was a state-owned vertically integrated monopoly (Jamasb et. al, 2017). The sector could be described as centrally governed with centralised thermal generation technologies being the major source of energy. Since the 1980s, and more rapidly in the 1990s the former governance model has been subjected to restructuring with market-oriented reforms. In general, reforms focused on transforming the sector from a state owned vertically integrated monopoly to private ownership, having lots of competition, and regulated by the government. Jamasb et. al (2017) labelled the reform model as the "textbook or standard model", in which it was first implemented in Chile in 1982, and it involves the following seven steps, (i) corporatisation of the state-owned enterprise, (ii) passing of sector regulations for liberalisation, (iii) establishing of an independent regulator, (iv) vertical unbundling of the main functions of the sector, (v) inventive regulation of the network, (vi) formation of wholesale and retail markets, and (vii) privatisation through selling state assets to the private sector. Figure. 3, shows the electricity value chain before and after liberalisation. However, according to Jamasb et. al (2017), even though the reforms were able to increase the technical efficiency of the sector, macroeconomic benefits were hard to spot and they did not trickle down to consumers.

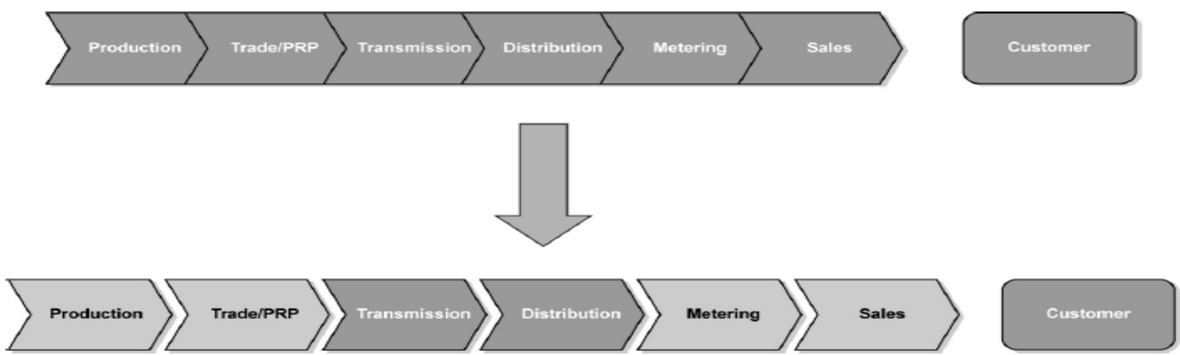

Figure 3: The electricity infrastructure value chain, pre- and post-liberalisation. Source: Finger et al. (2005, p. 245).

Even with the presence of the above "standard model" reform, there is divergence in the design and the final structure of the electricity market between different countries, which is accompanied by different success rates when it comes to achieving the objectives of reform (Jamasb, 2006). The divergence in the market design, i.e. being somewhere between the old monopolistic vertically integrated state and perfect competition, was attributed by Correljé and de Vries (2008) to a set of exogenous factors; those include physical, economic, and institutional factors, which determine the context of the restructuring process.

Literature studied the different market models (Hunt and Shuttleworth, 1996; Correljé and de Vries, 2008; de Vries, 2007; Nagayama, 2009; de Vries, 2017; Eberhard and Godinho, 2017), and all the market models in the mentioned literature adopted the models developed by Hunt and Shuttleworth (1996). Therefore, this thesis adopts and lists the same market models, which are:

a. Vertical Integrated model: which was the pre-liberalisation model of combining all the value chain in one entity.

b. The Single Buyer model: it is the most limited model amongst the new models when it comes to introducing competition to the sector. The power purchasing authority, i.e. normally the former monopolist, is solely responsible to buy generated power. Minimal competition exists at the generation level, where new capacities are allocated to independent power producers (IPPs) based on long-term contracts.
c. Wholesale Competition model: the power purchasing authority is simply removed. Vertical unbundling between the operator of the transmission lines, generation takes place, and distribution lines; the transmission operator becomes independent of other activities. To make this model successful, there needs to be a sufficient number of independent distribution companies for effective competition. However, retail is not unbundled from distribution, where sales remain a monopoly and integrated with its respective distribution company.
d. Retail Competition model: the post-liberalisation value chain in figure. 3 represents this model. The difference between this model and wholesale competition model is the unbundling of sale/retail from distribution companies and introducing competition at this level. Therefore, consumers are able to choose from where to purchase their electricity, and thus competitive markets exists at both retail and wholesale levels.

Appendix A, shows three figures to depict the three market models. As the figure below (Fig. 4) shows, the extreme case of the retail model requires the highest level of unbundling that currently exists, while the other extreme, i.e. vertical integration, vertical unbundling does not exist. It is important to mention that with competition entering into the electricity sector, the transmission and distribution grids are typically organised as regulated monopolies where competition is not possible at these levels (Künneke and Finger, 2007).

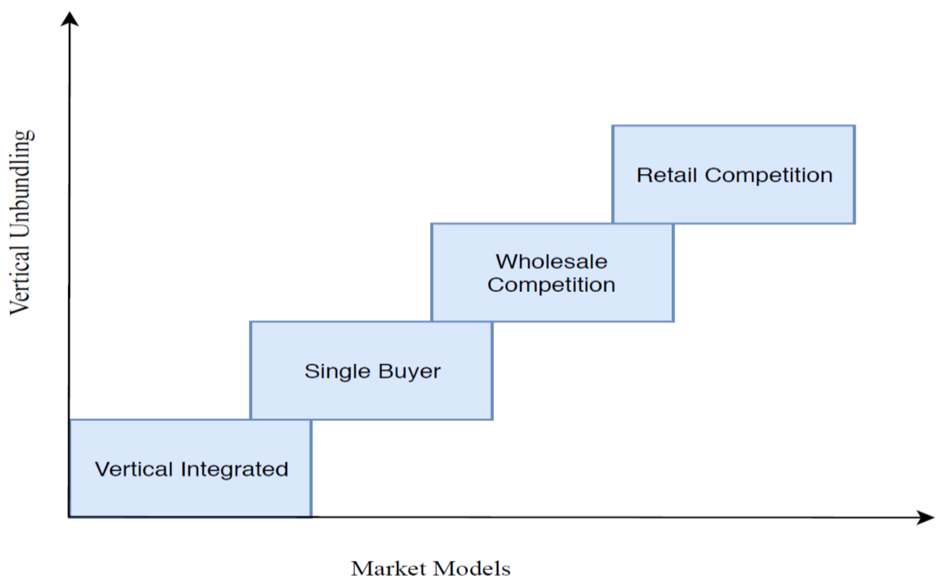

Figure 4: Degree of vertical unbundling for various markets. Adapted from: de Vries (2017)

2.1.3. The Technical System and its Functions

From a technical point of view, and for both eras, i.e. pre- and post-liberalisation, there was no major change in the physical layer and its respective sections (Finger et al., 2005). The physical layer can be divided into production (generation), transmission, distribution, and load (consumption). The following gives a brief explanation of each physical section:

A. Generation/Production: this aspect entails the generation of electricity power through different energy sources. Generation can be divided into centralised and decentralised generation. Centralised generation is defined as technologies that are connected to the transmission grid (Bouffard and Kirschen, 2008; Funcke and Bauknecht, 2016). While decentralised generation is defined as electricity generation source(s) that are connected either directly to the consumer side or to the distribution grid (Bauknecht and Brunekreeft, 2008; Karger and Hennings, 2009; Funcke and Bauknecht, 2016). Traditionally, electricity generation relied on large centralised power plants, with the primary fuels coming from natural gas, oil, coal, hydropower and uranium. With the advancement of technology, new generation methods entered the market, mainly renewable energy sources, which include wind, solar, biomass, geothermal…etc. Large wind and solar parks are usually connected to transmission lines, while small and medium production is connected to distribution lines (Finger et al., 2005).

   Literature compared and named the advantages and disadvantages of both generation systems. According to Goldthau (2014), and Bouffard and Kirschen (2008), decentralised generation reduce costs for transmission systems, provides efficiency gains, lower grid losses, reduces the impact of terrorist attacks, and incentivise the penetration of renewable energy. It also enhances the resilience of the grid, since the grid would be less susceptible to the grand failures of a centralised system. A decentralised system is also more innovative than the centralised system, since producers and operators are more inclined to be specialised and find tailored solutions that consider their contextual settings (physical and economic). Advantages of centralised generation include their flexibility and controllability, in which conventional generation (fossil fuels) that constitute the bulk of centralised generation provide those two characteristics through decreasing or increasing their output in a relatively easy way compared to renewable energy (Funcke and Bauknecht, 2016). Allan et. al (2015) also identifies the effect of economies of scale as an advantage for centralised generation (thermal technologies), but this encompasses a higher investment risk due to the possibility of overcapacity, which can be mitigated by relying more on smaller decentralised options (Bouffard and Kirschen, 2008).
B. Transmission and Distribution lines: the electricity network (grid) consists of two parts, the transmission and distribution grid. The transmission grid transmits the bulk of the power from centralised generation to the distribution grid through substations, it also provides energy to large consumers (industries) at high voltage levels. While the distribution grid receives most of the energy through the substations and is responsible to provide energy to small consumers at low/medium voltage levels.
C. Load: there exists two kinds of load (consumption), either small consumers, e.g. households and offices, connected to the distribution grid, or large consumers, e.g. industries, connected to the transmission grid (de Vries, 2017).

The engineers who are responsible to design the technical system of the electricity sector think of it in terms of the performance of the system, which is translated into the reliability and robustness of the system (Scholten and Künneke, 2016). According to Künneke and Finger (2007), the technical reliability of an infrastructure should be considered as a prerequisite for realising the economic and socio-political goals of the sector. The reliability of the sector means the ability of the system to perform its functions in usual, hostile, and/or unexpected conditions. Achieving the reliability of the system is done through safeguarding the technical functions of the system (Künneke and Finger, 2007), and this is considered to be a condition for designing the polycentric hybrid electricity sector in Lebanon. This study adopts the technical functions from studies by de Vries (2007), and Künneke & Finger (2007). Table 1. provides an indication of the technical functions along with a respective timescale within which they can be achieved.

Technical Function	Timescale
Generation: - Operation - Investment - Maintenance scheduling	 - Real time - Lead time in several year, and life cycle in decades - 1 year to 3 years
System Operation: - Scheduling generation - Balancing - Black start capability - Maintaining operating reserves	 - Hours before real time - Real time - Real time (availability), months/years (Investment) - Days, months
Transmission network management: - Voltage control - Congestion management - Network investment	 - Real time - Day-ahead to multi-year solution - Years in lead time, and decades in life cycle
Distribution network management: - Operation - Voltage control - Network investment - Congestion management	 - Real time - Real time - Years in lead time, and decades in life cycle - Day-ahead to multiyear solution.
Interoperability:	- years

Table 2: Technical Functions of an Electricity Sector (adapted from: De vries, 2007; and Künneke & Finger, 2007)

In order to safeguard the above technical functions, it is necessary to allocate the "rights of use" or right of control over each function with its underlying elements and to allocate the right mode of organisation to manage the function. In a vertically integrated industry, the right of control and planning was all done by the monopoly; however, liberalisation has put an end to this. The timescale of each function affects the mode of organisation for the function, e.g. an authoritative approach is needed for functions of real-time timescales. As for long-term timescale functions, planning and a collaborative approach between the concerned actors can safeguard the function (de Vries, 2007). Therefore, it is important to make sure that at the end of the design exercise, all of these technical functions have been allocated to the right actors with the right organisational approach.

2.2. Level of Analysis

The objective of this section is to identify and explore the design levels this thesis is delving into. To achieve that, the design level of each of the three blocks, i.e. polycentricity, modes of organisation, and market design variables, must be identified. Identifying their design levels helps in linking them together, and explaining the benefit of each one of the blocks with respect to the final design of the polycentric hybrid electricity sector in Lebanon. Therefore, the study uses the four-layer model of Williamson (2000) that was adapted by both Scholten and Künneke (2016), and by de Vries (2017) for the energy infrastructure. The framework distinguishes four different levels of institutions and makes an interrelation between its levels.

Figure. 5, relies on the four-layer model from de Vries (2017) and pinpoints where each block fits. Starting with the concept of polycentricity, it clearly resides in layer 2a. Polycentricity as depicted by V. Ostrom and the rest of the scholars is a concept that explains a social and political system for the society, in which it can be implemented in the judiciary, constitutional, political, and market systems (Ostrom, 1999). The second block which discusses modes of organisation between the different levels of a polycentric structure is situated in layer 3. According to Scholten and Künneke (2016), an integral part of layer 3 is the design for coordination between actors involved in the sector, e.g. spot markets, long-term contracts…etc. this is also shown in de Vries (2017), in the "inter-firm" category of the "Governance" layer (third). When it comes to the third block that discusses the market design variables, thirteen different variables encompass this block which are given by Littlechild (2003) and adopted by Correljé and de Vries (2008). These thirteen variables are:

1. Determining the degree of market opening
2. The pace of market opening
3. Competition policies and horizontal unbundling
4. Network unbundling
5. Public, private, collective, and commons ownership
6. Congestion management method
7. Arrangements with neighbouring networks and interconnector congestion management
8. Balancing mechanism
9. Network regulation for tariffs and access conditions
10. Wholesale and end-user price regulation
11. Capacity mechanism
12. Position of regulator; and
13. Integrated vs. decentralised market

Those 13 variables could be linked to two layers in figure. 5, it actually depends on which variable we are discussing. For example, variables one, two, four, and eleven discuss the formal institutions of the sector and thus belong to layer 2b (de Vries, 2017). While variables five, eight, nine, twelve, and thirteen clearly belong to the third layer (Governance).

Now that we have identified where does each block fit in the institutional framework, it is easy to make the link and reason why these blocks are so important for the end result of the thesis. As Williamson (2000) depicts, the solid arrow that connects the higher level with the lower one indicates that the higher level imposes certain constraints on the succeeding lower level. Therefore, polycentricity and its attributes pose constraints on both market design variables and modes of organisation. At the same time, market design variables that belong to layer 2b pose constraints on both modes of organisation and market design variables that belong to layer 3.

The key contribution of the modes of organisation block in this thesis is to capture the way to govern the relations between the actors or the different levels of the polycentric structure (figure. 6). Therefore, it is necessary to pinpoint which of the polycentric attributes/indicators give the necessary constraint in order to choose the valid mode(s) of organisation for polycentricity. This logic also applies to choosing the right design options per market design variable. However, choosing the market design option is not only constrained by polycentric attributes/indicators. According to Correljé and de Vries (2008), the existing economic, institutional, and technical/physical conditions in a country pose certain constraints on choosing a market design option. The market design variables play the important role of actually designing the details of the electricity sector, and solving all the variables should result in the final outcome of the design.

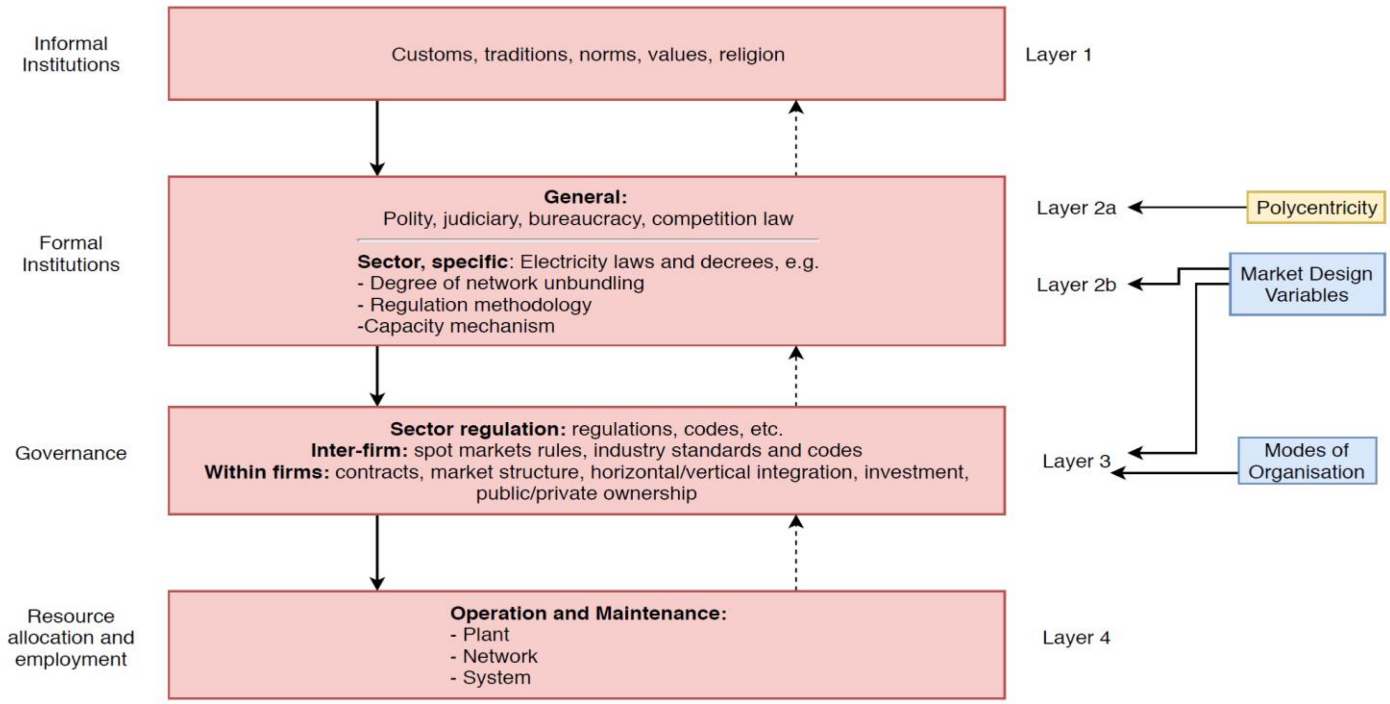

Figure 5: The four-layer model by Williamson (1998), adapted by de Vries (2017, slide.47&48)

Accordingly, this thesis does not look at ways to design the concept of polycentricity, it merely tries to convey the lessons learned, attributes, and design aspects of polycentricity to the electricity sector in Lebanon. Therefore, guided by the attributes and aspects of polycentricity and in order to change the sector into a polycentric sector, aspects in layer two and three should be changed and designed. Those design changes in layers two and three should, in turn, makes sure that the technical functions of the system are safeguarded.

2.3. Polycentricity

This section is divided into five subsections, the first introduces the concept of polycentricity and its structure. The second subsection discusses the preconditions of polycentricity in markets as indicated by V. Ostrom (1999), and comes up with the conclusion that they will not be utilised for design aspects or in-depth analysis in this study. The third subsection discusses the attributes and indicators of polycentricity, where the aim is to identify the framework that lays the path to achieve a polycentric structure. The Logical Structure of Polycentricity (LSP) framework serves two functions, first it will be utilised as a constraint to select the modes of organisation that govern the relation between the different decision-making levels in a polycentric structure. Second, when designing the market of the sector, the LSP framework will also be used as the strategic guidelines for choosing the best market design option per design variable. The fourth subsection discusses polycentricity in the energy/electricity infrastructure, where the polycentric attributes found in the LSP framework are linked to that which are found in the electricity sector. The subsection also comes up with a general structure of how a polycentric hybrid electricity sector would look like. The fifth and final subsection introduces the concept of a market within polycentricity, which was identified by V. Ostrom et al. (1961) as a quasi-market.

2.3.1. The Concept of Polycentricity

The foremost concept that this thesis is building on is polycentricity, which was first envisaged by Michael Polanyi and later introduced to governance studies by Vincent and Elinor Ostrom (Aligica and Tarko, 2012). V. Ostrom, Tiebout, and Warren (1961, p. 831), describe polycentricity in the following manner:

> *Polycentric connotes many centers of decision making that are formally independent of each other. Whether they actually function independently, or instead constitute an interdependent system of relations, is an empirical question in particular cases. To the extent that they take each other into account in competitive relationships, enter into various contractual and cooperative undertakings or have recourse to central mechanisms to resolve conflicts, the various political jurisdictions in a metropolitan area may function in a coherent manner with consistent and predictable patterns of interacting behavior. To the extent that this is so, they may be said to function as a "system".*

What we can understand from the above definition is that polycentric systems are characterised by multiple levels and/or centres of governing authorities rather than a centralised one. The independence between the bodies give them the ability to set up rules and norms within their own jurisdiction, that is mostly based on their contextual settings and prior learnings (Ostrom, 2010). An important aspect of this concept is that larger units, e.g. centralised regulator, may intervene to resolve problems associated with "local tyrants, non-contributors, or inappropriate discrimination", and can even incentivise new innovations (Ostrom, 2010). The other important governance entity in is the unit termed "local government", which is a formal governmental unit at the regional, municipal, or local community level (Andersson and Ostrom, 2008). The figure below gives an example of how Andersson and Ostrom pictured polycentric governance for decentralised resources. This figure will serve as base for designing the polycentric electricity sector in Lebanon.

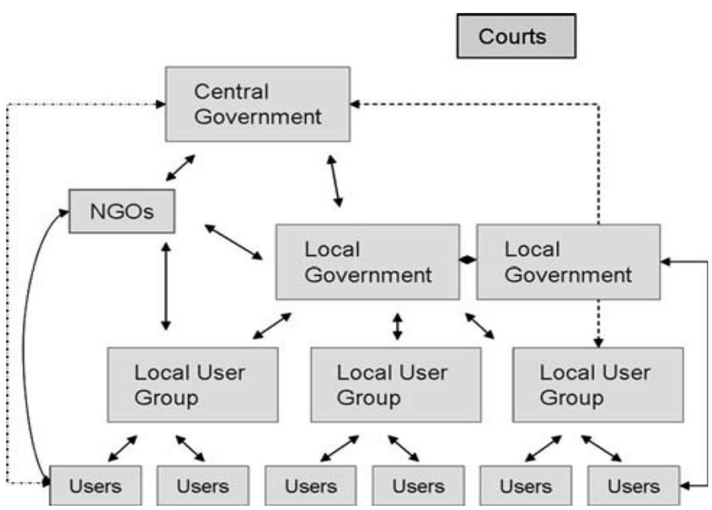

Figure 6: The conceptual model of decentralized resource governance from a polycentric perspective. Source: Andersson and Ostrom (2008, p. 78).

2.3.2. Polycentric Preconditions

Before delving into the attributes and indicators of polycentricity, it is important to discuss the pre-conditions for a successful polycentric governance. Now, for polycentricity to exist in a public service economy it necessitates its existence in the following sectors beforehand (V. Ostrom, 1999):

a. Polycentricity in Judicial Decision Making

b. Polycentricity in Constitutional Rule; and
c. Polycentricity in the Selection of Political Leadership and in the Organisation of Political Coalitions

However, a contradiction seems to exist between the assumption that these preconditions need to exist and what was stated earlier by Ostrom in the same chapter. The contradiction resides in Ostrom noting that a predominantly monocentric governing system does not exclude the existence of elements of a polycentric organisation within the system, and vice versa. Ostrom states that the possibility of existence of a system depends on conceptualising the important defining characteristics of that system for that particular sector in mind, and indicating the logical conditions that need to be met for keeping the system working in an efficient manner. Thus, elements of both systems can be theoretically combined if they lead to an efficient and well-functioning system. Aligica and Tarko (2012) saw these pre-conditions as "conjectures" that are not proven yet, in which they state that "If one accepts the hypothesis of the existence of such a systemic logic, one may visualize the entire social system shaped by underlying currents originating in pulsating polycentric domains." This means that if those pre-conditions do exist, then one can see the entire social system being shaped in a polycentric manner, which would contradict the earlier statement that a monocentric system could co-exist with a polycentric one. Delving deeper into these three preconditions would mean that the study needs to shift its focus to another domain and probe into other aspects, which is beyond the timeframe given and the scope of the study. However, in the discussion chapter the existence of these preconditions will be discussed based on interviews made with Lebanese lawyers. This does not mean that an in-depth inquiry will take place, it is only a means to carve a pathway for another study to take, which might deem this topic interesting; thus, investigating these aspects and coming up with a final conclusion about their existence and the possibility of implementing polycentricity in these sectors can be carried out in another study.

2.3.3. The Logical Structure of Polycentricity Framework

In his efforts to explain polycentricity, Ostrom (1999) states that "spontaneity" is an element that relates to the polycentric governance. For Ostrom "spontaneity" meant that modes of organisation within the system can be self-organising or self-generating, so that actors will be incentivised to establish appropriate relationship amongst each other. To achieve spontaneity, self-organising tendencies should show up at three levels of ordered relations. Ostrom refers to them as levels while Aligica and Tarko (2012) referred to them as attributes or conditions when building their LSP framework, and those attributes formed the second level in their framework, in which the first level was "polycentricity". This thesis treats them as Aligica and Tarko did, i.e. attributes of polycentricity, and follows the naming set by the same study. The attributes are:

a. **Multiplicity of decision centres**: is studied with respect to the ability of forming autonomous decision-making centres/layers, and the presence of common/shared goals.
b. **Institutional/cultural framework (overarching system of rules)**: this attribute is analysed with respect to the "jurisdiction" of decision centres, the involvement of the *individuals* in designing the overarching rules, the usefulness of the rules (related to incentives), and the nature of decision-making mechanisms within the centres.
   It is important to note that in complicated markets, e.g. advanced technology markets (electricity sector), Ostrom meant by an individual as a group of incentivised individuals that group together and form a firm. Thus, the viability of the polycentric system depends on whether individuals can be grouped and whether their respective firms have free entrance to the market to engage in trade.
c. **The existence of a spontaneous social order**: this attribute seeks "evolutionary competition" amongst the decision centres, in which the elements of entry, exit, and information are decided upon.

The third level in the framework contains the indicators that make polycentricity more operational and practical (figure. 7). The indicators specify the different dimensions of each attribute, and are the ones to be used as constraints to select the modes of organisation further on or to guide the path of market design. The indicators can be divided into two categories, the first category includes the indicators that are found in all polycentric cases (Aligica and Tarko,2012), which are:

a. *Active exercise of diverse opinions* (P1): ideas are actually implemented by at least one decision centre and not only proposed.
b. *Autonomous decision making* (P2): the different governing entities in the system can make operational decisions autonomously from the higher levels.
c. *Incentive compatibility, alignment between rules and incentives* (P3): if the alignment between rules and incentive does not exist, polycentricity is bound to fail, which would lead to violent anarchy.

The second category constitutes the rest of the indicators that make polycentricity variable from one case to another. For those indicators, two or three options (Fig. 10) exist to choose from when designing the governance structure, and decisions would have to be made based on the empirics of the case. According to Aligica and Tarko (2012), the listed options A1, B1, C2, D3, E2, F2, and G2 makes the polycentric system more susceptible to failure and fall towards either a monocentric system or chaos. However, empirics still play the major role in choosing whether to go for example with A1 or A2. For example, when dealing with the "Rule Design", i.e. C, for designing the market regulations for an electricity sector, it might be undesirable to choose C1 over C2, since C1 would enhance market power for the actors involved.

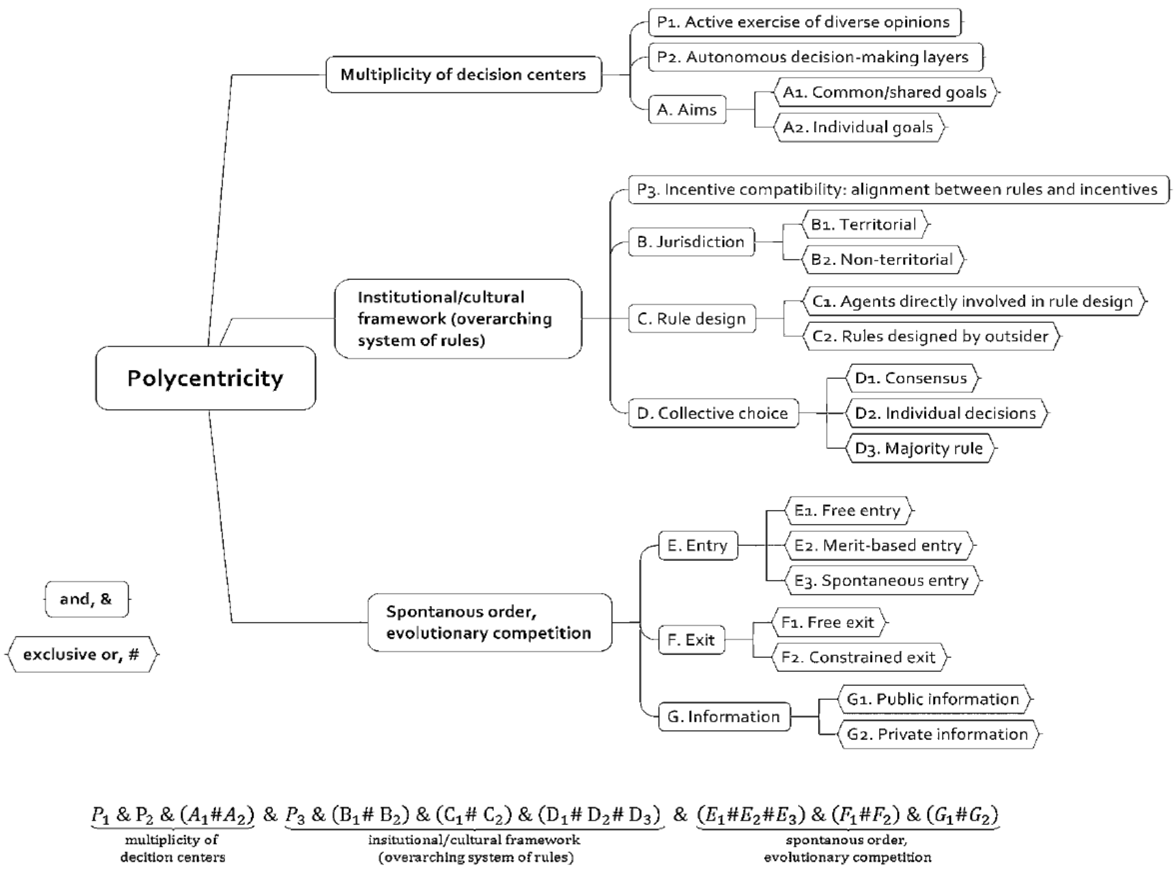

Figure 7: Logical Structure of Polycentricity. Source: Aligica and Tarko (2012, p. 257).

2.3.4. Polycentricity in the Electricity Sector

This subsection is divided into two parts, where it aims to introduce polycentricity to the electricity sector. The first part identifies the indicators that define an effective polycentric structure in an energy infrastructure, and then compares those indicators to the ones found in the LSP framework. The second part introduces a general structure of a polycentric electricity sector, which is derived from figure. 6, the polycentric indicators, and actors found in a liberalised electricity sector that follows the retail-competition model.

2.3.4.1. Polycentric Indicators in Energy Infrastructure

In a study conducted by Sovacool (2011), a polycentric form of governance for energy infrastructures is described as constituting multiple scales, different mechanisms of control, and multiple actors. The author identifies multiple scales as having multiple layers of governance, i.e. at the global, national, regional, and local level. The different mechanisms of control (modes of governance) are decentralised and local policies, centralised command and control regulations, and the free market. As for multiple actors Sovacool (2011) states that the sector must include corporates, government institutions, civil society, and individuals (households). In his study, the author investigated four successful polycentric cases and found a common set of variables that gave an inclination towards more effective polycentric energy governance. These six variables are discussed below, and are linked to the indicators in the LSP framework:

a. Equity: makes sure of the equivalence between cost and benefit, and ensure alignment between rules and incentives (economic). This is ***<u>P3</u>*** in LSP.
b. Inclusivity: this means the active participation and involvement of diverse stakeholders, from local actors (e.g. municipalities) to central governments, and inhabitants. This is ***<u>P1</u>*** in LSP.
c. Information monitoring: encouraging sharing of information and feedbacks amongst stakeholders and distribution of data. This is ***<u>G</u>*** in LSP
d. Accountability: local governments and users should be accountable for their actions along with the central government both sides should bear part of the cost together. Graduated sanctions should exist to enforce rules and discipline noncompliance. This is ***<u>P1</u>*** in LSP.
e. Organisational multiplicity: multiple decision-makers that are organised either in parallel (centres) or levels. This is ***<u>P2</u>*** in LSP
f. Adaptability and flexibility: conflict resolution mechanism is put in place to respond to challenges and unanticipated circumstances. This variable more or less describes one of the key importance and the uniqueness of polycentricity, which according to E. Ostrom (1998) provides opportunities to users and local governments to innovate and intervene to correct "maldistribution" of outcomes. In addition to that V. Ostrom et al. (1961) state that an integral part of polycentricity is having "*recourse to central mechanisms to resolve conflicts*"; therefore, ensuring adaptability and flexibility.

The above variables and their description show that they are an integral part of the general attributes and indicators of polycentricity, and they are well depicted in the LSP framework. The way Sovacool portrays polycentricity in the energy sector is compatible with polycentricity in general, and does not pose any contradictions with how V. Ostrom and other studies depicts it. However, the six variables derived by Sovacool are mostly linked to the fixed indicators found in all polycentric structures, i.e. P1, P2, and P3, derived by Aligica and Tarko, and to the notion of a centralised conflict resolution mechanism that is stated by V. Ostrom and E. Ostrom. Therefore, this thesis concludes that those fixed indicators along with the need for a conflict resolution mechanism are the core polycentric indicators that contribute in designing the general structure of a polycentric electricity sector. These indicators specify that the structure of the electricity sector should constitute multiple decision-making levels (layers), with each layer exercising some degree of autonomy and giving it the ability to implement its opinions, with incentive compatibility at all layers in the structure, and with the necessity for protection through a conflict resolution mechanism for the different layers in the structure, e.g. users (consumers in electricity sector) from local tyranny.

Utilising the above indicators to contribute in constructing the structure of a polycentric electricity sector is compatible with the logic presented in the level of analysis in section 2.2., where it was indicated that polycentricity (layer 2a) impose certain constraints on the aspects of electricity market design (e.g. structure of the sector). In addition, the fixed indicators of polycentricity (P1, P2, P3) will be utilised as constraints to identify the relevant modes of organisation that can govern the relation between the various layers in a polycentric structure.

The rest of the mentioned indicators in the LSP framework, i.e. second category, along with the Ps will be also be used in the upcoming section. Their usage will either be of importance to design, e.g. indicator B, or of importance to check whether the final design of the Lebanese electricity sector is compatible to those indicators.

2.3.4.2. General Structure of a Polycentric Electricity Sector

Forming the structure was a result of combining the structure given by Andersson and Ostrom (figure.6), the above identified polycentric indicators, and the actors found in an electricity sector that follows the retail-competition market model. The reason behind choosing the actors based on the retail-competition model is the inclusivity and the widest possible number of actors in this model. The decision on whether to integrate some actors into one, e.g. DSO and LGs, comes later when designing the sector for the specific case (Lebanon). Decisions are based on the need to abide by the identified polycentric indicators, and the context of the case.

To be able to apply the polycentric indicator that asks for the creation of multiple decision-making levels (layers), it is necessary to unbundle transmission from distribution in the electricity sector. However, the nature of unbundling, i.e. legal, accounting, or ownership, cannot be identified at this level of analysis in the study. Unbundling the two important components in the electricity value chain allows us to create multiple centres in the sector, where the Transmission System Operator (TSO) along with the centralised generation would constitute the main players that replace the entity of the “central government” from figure. 6, and represent the Central Level in the electricity sector (figure. 8). On the lower level, comes the Distribution System Operator (DSO) which is the main player in the Decentral level (fig. 8), and it replaces the “Local Government” stakeholder from figure. 6. Decentralised generation at the DSO level gives each of the centres some degree of autonomy and the ability to exercise their own opinions. Local governments, i.e. municipalities, can play two roles in this structure, (i) they can play the role of retailers and compete amongst each other, or (ii) they can take the role of aggregators to provide demand response services and act as intermediaries between the DSO and prosumers. The need for retailers or aggregators is determined per context, e.g. the technical need and ability of the system for local governments (LG) to act as aggregators to combine and control electricity produced by households. The idea of having local governments as retailers/aggregators comes from the believe that local governments can interact and connect with its local citizens in an efficient manner. Another important actor in this structure is the prosumer, for this structure it is desirable for consumers to switch into prosumers who are incentivised to generate electricity power. Being able to produce power gives some degree of autonomy to that player, and creates and interdependency between prosumers and the layer above them, i.e. LG or DSO.

Figure. 8 shows the resulting structure, where the central government in figure. 6 is represented here by the centralised generation, TSO, and electricity regulator. Assigning the electricity regulator’s position can change depending on the final design; this is the case if the designer chooses to opt for a regulator at the regional/local level instead of a national regulator. However, given the nature of the regulator’s job in a liberalised electricity sector, one can deduce that along with the courts the electricity regulator plays the role of resolving/preventing possible conflicts that might arise between the different actors in the sector. This important role for the regulator leads us to recommend its position to be at the national, i.e. centralised, level.

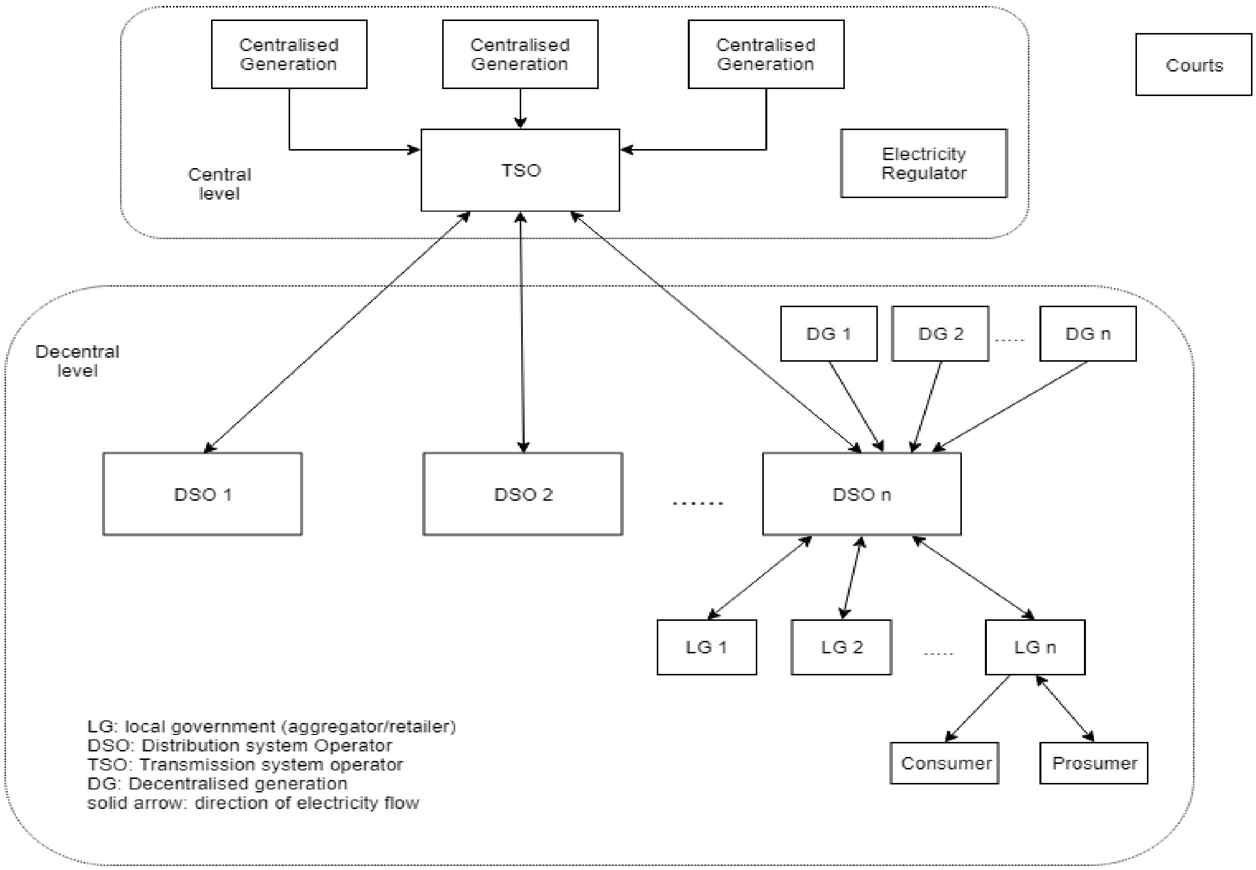

Figure 8: Polycentric structure of a hybrid electricity sector

2.3.5. Towards a polycentric Market

As Ostrom et al. (1961) put it, a market's performance in a polycentric structure can be evaluated with respect to the patterns of cooperation, competition, and conflict that might occur between its units. For the cooperation aspect, the authors simply state that cooperative arrangements pose no difficult challenge for the polycentric system, in which contractual arrangements should suffice. The authors mostly stress on the competition and the conflict dimensions, in which they propose the quasi-market option for the provision of public goods or services. A quasi-market is defined as an organisationally designed and supervised internal market (Dubois and Contandriopoulos, 2015). This concept can be used for creating markets within the jurisdiction of each of the centres that are part of the polycentric electricity sector. However, this option is efficient to goods that can be successfully provisioned within the jurisdiction of the entity providing the goods; thus, ensuring the absence of spill-overs, i.e. freeriding by adjacent entities. The possibility of competition would exist at the level of the good's production, i.e. electricity. This means that provision is separated from production in a quasi-market, and public control at the provisional level is maintained (Ostrom et al., 1961). Within the above structure (figure. 8), a quasi-market would belong to a jurisdiction governed by a DSO; the DSO or Local Government would be the provider of the goods (electricity), and production (centralised/decentralised generation) would be separated from provision.

2.4. Modes of Organisation

Modes of organisation is an integral factor in this thesis, where they are seen as the tool to govern the relation between the different actors in the polycentric structure of an electricity sector. Two objectives are of importance to this section, first is to introduce the general modes of organisation. Second is to identify the organisation modes that fit the concept of polycentricity.

According to Provan and Kenis (2008), forms of organisation are needed for goal-oriented organisational networks. For the authors, a network constitutes multiple autonomous organisations (actors) that work together to achieve individualistic and collective goals. Organisation in such networks, e.g. electricity sector, constitutes the use of structures of authority as well as collaboration and institutions to allocate rights of use and to coordinate and manage joint actions across the whole network (Common and Acevedo, 2006; Provan and Kenis, 2008). According to Provan and Kenis (2008) and Scholten (2013), organisation entails two aspects, (i) the division of responsibilities amongst the actors involved within the network (system), (ii) the form of interaction and the relation between the actors within the network, i.e. the "mechanisms of coordination". This study combines both aspects of organisation as proposed by Provan and Kenis (2008), in which the electricity sector is a socio-technical system (network) whose organisation include the structured relationships between the various actors, which have certain responsibilities towards the network.

Organisational structures vary from centralised forms to completely decentral operations (Scholten, 2013). In order to capture the various modes/structures of governance, this thesis opted to investigate the works of Ménard and Shirley (2008), Provan and Kenis (2008), and Scholten (2013); four modes of governance could be distinguished from the above studies:

a. **Vertical integration**: where a single firm integrates all property rights which include all transaction costs for production and provision of goods. In electricity infrastructures, a single entity takes responsibility for the entire value chain, i.e. production, transmission, distribution, and retail, and coordinates all the technical operations within the same organisation. This is the current case of the Lebanese electricity sector.
b. **Lead organisation**: this mode of governance happens often when there is a single powerful buyer/supplier/funder and several other smaller and weaker firms. Key network activities and coordination happen through a single powerful entity, which acts as a lead organisation. The network leader provides administrative services and facilitates activities for the other weaker organisations in order to align their goals and serve the end goal of the network. In a liberalised electricity sector, the role played by the transmission system operator can be labelled as the lead actor (Scholten, 2013).
c. **Participant-governed (common operation)**: this mode of governance is accomplished through network members themselves with no separate central governance entity. Members within the network have autonomy when it comes to executing their responsibilities (technical). However, meetings between representatives of the members occur at a regular basis, where collective decisions regarding network activities are taken. Coordination between the network member can also be established through an agreed upon formal administrative entity. Power over the network is more or less symmetrical between the members, with some differences occurring due to the size, capabilities, and performance of each organisation. An example within the energy infrastructure is the community-based self-governance that relies on local renewable energy (Scholten, 2013).
d. **Incidental coordination**: this fourth mode of governance organises the sector in a completely decentral fashion, in which the network members coordinate or interact occasionally only when

necessary. Bilateral contracts between entities are usually sufficient for these interactions (Scholten, 2013).

After explaining the above four governance modes, both “Lead organisation” and “Participant” modes come closest to the concept of hybrid arrangements as defined by Ménard (2008). The concept of hybrid arrangements is defined as a set of autonomous organisations/entities that participate in a set of arranged agreements to do business together to achieve a certain end goal. Three characteristics define hybrid arrangements, (i) pooling of some resources, (ii) rational contracting that link resources and activities amongst members, and (iii) existence of competition amongst members of the network (Ménard, 2008). Pooling of resources doesn’t mean that property rights are not distinct, but it means that the property right holders should be committed to collaborate and interact together within one system. This is achieved through agreed upon structures (rational contracting). The characteristics and definition of hybrid arrangements comes can be closely associated with the definitions of both “Lead organisation” and “Participant” modes of governance. Thus, both modes of governance can be categorised as hybrid governance.

The definition of hybrid arrangements, and the three fixed indicators of polycentricity (P1, P2, &P3) match together; in which it is clear to see that both the chosen governance modes call for the exercise of autonomous decision-making organisations. Hybrid arrangements, i.e. lead and participant modes, call for active exercise of opinion through their modes of collaboration and interaction that happens amongst the network members. However, a quick comparison between “lead” and “participant” mode shows that the attribute P1 (active exercise of decision-making) can be better associated with the participant mode. As for the attribute P2, i.e. autonomous decision-making layers, lead and participant modes equally represent this attribute within their structure. The third indicator (P3), incentive vs. rule compatibility should be present in both governance modes for the members to come into an agreement on their respective roles. However, if we look at another important aspect of polycentricity, i.e. the presence of larger units to intervene in the system when deemed necessary, e.g. presence of “local tyrants” or “non-contributors” (E. Ostrom, 2010); the lead mode of orgnisation matches this aspect better than the participant mode. Therefore, this study accepts that both modes of organisation can represent the concept of polycentricity.

2.5. Market Design Variables

The objective of this section is to present the market design variables along with the respective design options that are utilised as the tactical options to achieve the final design of the polycentric hybrid electricity sector (figure. 8). The following design variables, are taken from the study of Littlechild (2003), whereas the design options per step are taken from studies by de Vries (2007), Correljé and de Vries (2008), Bauknecht and Brunekreeft (2008), de Vries et al. (2010), and Bell and Gill (2018).

We start with “Determining the degree of market opening” which discusses the degree of competition and openness of the market. This is achieved through unbundling in the electricity value chain. Options for this step are:

a. Corporatisation of the state-owned monopoly, i.e. EdL for this case.
b. Single buyer model
c. Wholesale market model
d. Retail market model

Determining the degree of market opening in a polycentric structure should be done on two levels, i.e. at the Central level and the Decentral levels (fig. 8). The final result of the sector does not have to strictly abide with the above-mentioned models. This is due to the usage of the concept of polycentricity (multiple levels). A possibility that would defy the above models would be keeping the TSO and centralised generation part of the monopoly, while introducing competition at the decentralised generation, i.e. at the DSO level.

Second step is the "pace of market opening", for this design step the Correlje and de Vries (2008) state that two options exist, either to be a leader or a follower vis-a-vis neighbouring country. For this thesis, the decision would concern lots, i.e. should the new design be implemented for the entire country at once, or should the reform start with one lot as a pilot, and if that is the case which lot should be selected as the starting point.

Next is the "network unbundling" step. According to de Vries et al. (2010), network unbundling influences the incentives and independence of network managers to provide equal environments for network users. Options for unbundling are accounting, legal, or ownership unbundling (de Vries, 2007). Decisions in this thesis needs to be taken at the following levels:

a. Unbundling of transmission from centralised generation.
b. Unbundling of DSOs from decentralised production.

Fourth step is "integrated vs. decentralised market". Two options exist for this step, either integrated or decentralised markets. An integrated market signifies that congestion management (step 6) is integrated into the market clearing, e.g. nodal pricing, whereas a decentralised market assumes that market clearing is separated from congestion and the system operator would handle the congestion in a given area.

The fifth step is deciding upon the "balancing mechanism" strategy. However, if the market is integrated (step 4), then a balancing mechanism is not needed (de Vries et al., 2010).
Sixth step is "Congestion management method". The design options for this step are:

a. Nodal pricing (integrated market)
b. Counter trading
c. Re-dispatching
d. Explicit auctions
e. Market splitting

Seventh step is congestion management at the interconnection, i.e. with neighbouring countries. Same options as the above step could be listed. However, Syria, which is the only country Lebanon has an interconnector with, is currently in turmoil. In addition, Syria's current electricity sector is a vertically integrated monopoly, and at the present no electricity is being traded between the two countries.

Eighth step is the ownership issue. Four options for ownership can be found in the literature, private, public, public private partnership (PPT), or commons ownership. When it comes to ownership four important decisions would have to be taken:

b. Ownership of DSO.
c. Ownership of TSO.
d. Ownership of centralised generation.
e. Ownership of decentralised electricity production.

Ninth step is "Network regulation of network tariffs and access conditions". This is linked to the incentives given to either TSO and DSOs. An inappropriate distribution of risk between actors will act as hinderance to achieving the objective of low-cost electricity system (Bell and Gill, 2018), as well as culminating to a chaotic polycentric sector (Aligica and Tarko, 2012). The main concern in this thesis is the incentives and network regulation for the DSO. The risk of under- or over-investment in distribution network capacity is placed on the DSOs, and thus proper incentives should be given to ensure its alignment with risks. Prior to According to Bauknecht and Brunekreeft (2008), three principles should apply when devising incentives for the DSO:

a. DSO should not be punished if there is high decentralised penetration in the network, which might lead to higher network costs. Otherwise it would lead DSOs to becomes opposed to decentralised generation.
b. DSOs should be given the opportunity to make profits for new DG connections (positive incentive).
c. The type of technology of decentralised generation connections is exogenous to the decisions taken by the DSO. But the DSO will have an influence on the costs of connections and the necessary reinforcements due to decentralised generation.

The tenth step is “Wholesale and end-user price regulations”. This is aimed at protecting consumers from volatile and high prices; however, there exists a trade-off between the interest of consumers and investment incentives for generators to cover demand. As discussed in the 2010 energy policy by Bassil (2010), a solution could be to provide subsidies by the government to low income households.

The eleventh step to decide upon is the “capacity mechanism” issue. However, if retail competition does not exist, then this step is not required (de Vries, 2007). This means that retail companies have a static customer number, and long-term contracts would be sufficient to achieve sufficient generation (de Vries, 2007). When retail competition does exist, one of the following capacity mechanisms could be used (de Vries et al., 2010):

a. Capacity payments
b. Strategic reserve
c. Operating reserves pricing
d. Capacity requirements
e. Reliability contracts
f. Bilateral reliability contracts; or
g. Capacity subscriptions

The twelfth step to be solved is the “position of regulator”. According to de Vries et al. (2010), the regulator’s position could be at the local, provincial, national or supranational level. For a polycentric structure, the position would either be at the national (Central) or Decentral level. However, it was recommended above for a polycentric structure to have the regulator at the central level. This choice has value when it comes to the relation between the regulator and the regulated industry, e.g. network operators and power generators. It also influences the regulator’s degree of specificity and generality when it comes to solving regulatory problems.

The Final design variable is “competition policy and horizontal unbundling”. This variable serves the purpose to decide on the kind of competition law utilised to regulate the sector. Two options reside for this step, either a sector regulation law that targets the sector alone, or to make the competition in the sector follow the general competition law of the country. Both approaches must have an ex-ante component for solving sector characteristics or prescribing behaviour of the various actors, and an ex-post component for mitigating abuse of market power.

2.6. The Polycentric Market Design Framework

This section presents the “Polycentric Market Design Framework” (PMDF), which gives the necessary steps for designing a polycentric hybrid electricity sector. It also explains the chronological logic of the steps, which are in line with the level of analysis presented in section 2.2. Those below steps form the structure for this thesis to design the Lebanese polycentric electricity sector, and were determined from the above-discussed sections:

1. Start with the general structure of a polycentric electricity sector (figure. 8), which was derived from figure. 6, polycentric indicators, and the actors found in the retail-competition model of an electricity sector.
2. Investigate and decide on the relevant actors with respect to the case in hand, e.g. Lebanon in this study. The decision is based on the context needs of the case, i.e. socio-political, economic, and technical. This step ultimately decides the shape of the sector, and answers the first market design variable, i.e. the "degree of market opening".
3. Select the geographical jurisdiction of each of the centres, i.e. the DSO's and its accompanying actors (DGs and LGs). This matches the indicator B1 in the Logical Structure of Polycentricity (LSP) framework. The jurisdiction should take into consideration the existing technical system and the socio-political aspects of the country.
4. Investigate and decide on the mode of organisation that will govern the relation between the different levels in the polycentric structure. The choice is limited to either the "lead organisation model" or the "participant-governed". Once again, the decision is based on the context of the case.
5. Make a choice on which of the remaining market design variables are relevant to your case. The choice will depend on a couple of prior decisions:
    - The shape of the polycentric structure, i.e. actors involved (step 2).
    - The mode of organisation selected to govern relations amongst actors (step 4), and
    - The level of analysis the study deems necessary, i.e. "Formal Institutions" with/without the "Governance" level (fig. 5).
6. Select the market option per market variable. Each selection is constrained by the context of your case and the previous decisions made in the above steps.
7. Create a conceptual framework that describes the pathway towards achieving the new electricity sector design.

The above steps give a clear pathway for designing a polycentric hybrid electricity sector. Taking a closer look at the level of analysis presented in section 2.2 and the above sequential steps leads us to make some comparisons, in which the following could be identified:

- The first step is already established in this chapter, it relies on the polycentric indicators and retail-competition model to establish the general structure of a polycentric structure. This step uses indicators from level 2a (figure. 5) and establishes the general structure found in layer 2b, those indicators are actually responsible, as previously explained, for the unbundling of transmission from distribution (layer 2b).
- The second and third step in the above sequential model investigates and decides on the case specific actors and their respective jurisdictions in the sector. These decisions still reside in layer 2b, and are actually deciding on the market design variable called "degree of market opening".
- The fourth step, i.e. modes of organisation between actors, is listed in the third layer (figure. 5). Thus, the sequential steps move on from layer 2b to layer 3; this level of analysis also continues in the fifth and sixth step, where for example choices regarding the "access regulation", "balancing mechanism", or "ownership" are done.
- The final step in the above sequential model is not linked to designing the sector, it is about creating a framework or pathway to establish/implement the design. In this step, the decision-maker has to decide on which aspect of the design has priority over the other. For example, establishing the regulator might be deemed the first step to reform the market and implement the design.

Therefore, we can conclude that the above sequential model is in line with the four-layer model developed by Williamson (1998) and adapted by de Vries (2017).

3. The Lebanese case

This chapter investigates the Lebanese electricity sector along with the peculiarities of the country that affects directly or indirectly the current state and outcome of the electricity sector. The chapter is divided into three sections; the first section discusses the Lebanese electricity sector, in which it's subdivided into two subsections which introduces all the relevant institutional and market dimensions of the sector, and the physical layout of the sector. The second section investigates the socio-political, and economic context of Lebanon, where certain examples are given to show how the Lebanese context is affecting the electricity sector and vice versa. The third and final section of the chapter identifies the set of peculiarities from the Lebanese situation; those peculiarities are taken from sections one and two, and must be taken into account when designing the polycentric hybrid electricity sector.

3.1. The Lebanese Electricity Sector

This section discusses all the relevant issues of the Lebanese electricity sector, i.e. institutional and physical. The section is divided into two subsections, the first will discuss the market context of the sector. In this subsection, the institutional structure of the sector will be discussed, followed by the tariff structure, and finishing with the latest reform policy. The second subsection will discuss the physical parts of the infrastructure, which include the generation and load portfolio, and the grid characteristics.

3.1.1. The Lebanese Electricity Market

The importance of this subsection for designing the new polycentric hybrid electricity sector resides in first explaining the current institutional structure and regulations that would come into play when designing the polycentric structure. Second part of this subsection is important to show three things, (i) the effect of the low tariffs on the economic situation (subsidies), (ii) the rigid tariff structure that EdL is using, and (iii) the difference between EdL's electricity tariffs and the ones from Independent Energy Producers (IEP's). These three aspects show that the current tariff situation must change when designing the new sector.

3.1.1.1. Institutional Structure

The electricity sector in Lebanon follows the pre-reform market structure, i.e. vertical integrated model (Ghanem, 2018). Formal electricity is provided through the publicly owned company Electricity of Lebanon (EDL- Electricite´ du Liban), which owns most of the formal generation, transmission, distribution, and sale. The rest, i.e. 10% of generation, comes from concessions that sell their production to EdL (Ibrahim et al., 2013). Concessions include hydropower plants owned by The Litanti River Authority (public company), Ibrahim River plant, and Al Bared River plant, both of which are private; in addition, concessions for components that come after transmission in the electricity value-chain (figure. 3) are allocated (concessions) to private companies in three cities, Zahle, Jbeil, and Bhamdoun; with Zahle's concession coming to an end at the end of 2018 (Alieh, 2017). Furthermore in 2012, operations and management of the distribution network have been handed to private companies (Booz&Co, 2012).

The history of electricity in Lebanon dates back to 1907, with the first concession given to a hydropower plant. Table. 1, summarises the major regulations that are linked to the electricity sector in Lebanon. Several turning points are important to mention, in which these regulations left their mark on the current situation of the infrastructure. The first turning point is the 1923 regulation which introduced electricity to the Lebanese households in the capital Beirut; this turning point allowed for the first grid to be established and thus starting the age of electricity in Lebanon. The second important turning point is the 1964 Law No. 16878, which created the public company EdL and gave it the authority for generation, transmission, distribution, and sale. This law followed the 1954 law (nationalisation law), which paved the way for creating EdL. This law is still valid to the current time, in which EdL still holds authority on the formal produced, transmitted, distributed, and sold power. The third turning point is the 1995 law, this law was after the end of the Lebanese civil war (1975-1990), which wreaked havoc to the electricity infrastructure (Verdeil, 2016). The law allowed EdL to invest up to $1.26 billion to the infrastructure (generation and the grid) under the name of "Power Sector Master Plan'' that lasted till 2002, in the intention of rehabilitating the sector and bringing it up to the needed demand level (Ibrahim et al., 2013). However, this plan turned out to be a major failure and demand still exceeded supply, which is the case to the very moment with daily rationing still existing. The fourth turning point is the Law No. 462, the main attributes of the law can be summarised into (i) vertical unbundling of generation from transmission, (ii) vertical unbundling of transmission from distribution, (iii) distribution and sale are kept vertically integrated, (iv) the creation of the electricity regulator, (v) privatisation and introduction of competition at the generation level, and (vi) allowing privatisation to take place at the distribution (sale) level. The new law clearly tried to transform the electricity sector from a vertically integrated sector into a sector that follows the "Wholesale Competition" market model. However, this law was never implemented and the sector remained vertically integrated and owned by EdL (Verdeil, 2016).

YEAR	LAWS / DESCRIPTION
1907	First concession granted to private company, Ibrahim River
1923	Concession for the private company "Tramways et Eclairage de Beyrouth" to construct tramways and lighten the city of Beirut
1924-1936	"Kadisha" private company was granted concessions for the entire value chain of electricity in villages of North Lebanon
1954	• Nationalisation of the Beirut Electricity Company • Creation of the electricity and transport public authorities • Creating the National office of Litani river (ONL), which is responsible (till nowadays) for the main hydropower plant in Lebanon (public company).
1964	Law No. 16878, establishing EdL as a public company, which was given the responsibility of the electricity value chain for the country
1985	Nationalisation of the Kadisha Electricity Company
1995	• Nationalising the "Ibrahim River" hydropower plant • Handing over $1.29 billion to EdL for investments in the electricity infrastructure
1996	Law No. 621, to allow the expansion of the 220kv transmission lines
1997	Law No. 632, penal law against illegal connections and theft. Up to imprisonment
2000	Law No. 228, privatisation law that covers conditions and procedures
2002	Law No. 462, new electricity law for reforming the sector (NOT Implemented till now)
2006	Law No. 775, granting the council of minister temporal authority to give permits and licenses for new generation capacity (IPP). It is being renewed ever since 2006.
2011	EdL decision (No. 135) and not law in parliament. Net Metering to incentivise solar energy production at the consumer level.

Table 3: Overview of the important regulations for the Lebanese electricity sector. Sources: EdL (2011) and Ibrahim et al. (2013).

As for renewable energy sources, some incentives exist for the Lebanese consumers to invest in solar panels. According to interviewee 10, the incentives are:

a. Subsidised loans, i.e. 0.75%, for consumers to invest in solar (governmental subsidies).
b. Tax exemptions (customs) on solar panels and inverters, but not on batteries.

c. Grants, e.g. UNDP and EU.
d. Net-metering regulation, which entails the following: consumers are made prosumers. At the end of the year, any surcharge of electricity produced by the prosumer is nullified; whereas if the surcharge is for the benefit of EdL, then the prosumer has to pay the difference for EdL.

All the above institutional and regulatory description applies to the "formal" electricity value chain that is provided by EdL. As mentioned above, the "Power Sector Master Plan" failed to achieve its main objective of meeting the electricity demand of the country. Therefore, consumers were pushed to rely on other "informal" sources of electricity. According to Ghanem (2018), the strategies that consumers went after were:

a. Purchase of diesel generators by a single household
b. Collective purchase of a diesel generator by residents of a building/block
c. Subscription to an independent energy provider (IEP)

Majority of the Lebanese households chose the third option, i.e. IEP, due to financial reasons. Competition between IEPs does not exist, where each IEPs monopolise a certain geographical area within the larger city or village (Ghanem, 2018). However, the IEPs generated power is not connected to the national grid, i.e. controlled by EdL, they have their own distribution lines that are paid for by consumers at first hand. The informal electricity adds up to 40% of the total electricity demand (Ghanem, 2018).

Another governmental agency affiliated with the electricity sector exists, named the Lebanese Centre for Energy Conservation (LCEC). LCEC is a governmental organisation with financial and administration independence, this company has no decision-making powers within the electricity infrastructure. The agency acts as the technical arm for the Ministry of Energy and Water (MoEW) and the government when it comes to the fields of energy efficiency, renewable energy strategies, and green buildings.

3.1.1.2. The low Tariffs and its Impact

Starting with the tariff structure for electricity coming from EdL, the following table (Table. 2) summarises the various tariff structures given at different voltage levels, as well as for different consumers:

Category	Energy charge ($/kWh)
1. LV – households & lighting	$1 - 100$ kWh $\rightarrow 0.023$ $101 - 300$ kWh $\rightarrow 0.37$ $301 - 400$ kWh $\rightarrow 0.053$ $401 - 500$ kWh $\rightarrow 0.08$ > 500 kWh $\rightarrow 0.13$
2. LV – Private	
2.1 Industrial + Agriculture + Handicraft + Artesian wells + pumping stations	0.077
2.2 Special (religious, hospitals, hotels, cinemas, schools)	0.093
3. MV consumers	
3.1. MV >= 100 kVA	Night $\rightarrow 0.053$ Day $\rightarrow 0.075$ Peak $\rightarrow 0.21$
4. HV customers	0.077

5. Distribution Concessions (e.g. Zahle)	0.046
6. Palestinian Camps	0.087
Average energy charge	0.09

Table 4: Detailed tariff structure for EdL (2018). Source:

The low tariffs along with other losses is the high level of subsidies the Lebanese government is giving to the sector, in which the average charge/kWh was estimated at 0.09 ($/KWh). According to interviewee 4 and 7, the average marginal cost of electricity supply is around 0.17 ($/KWh), which is causing yearly losses to EdL and the government to compensate EdL with amounts that are shown in figure. 7.

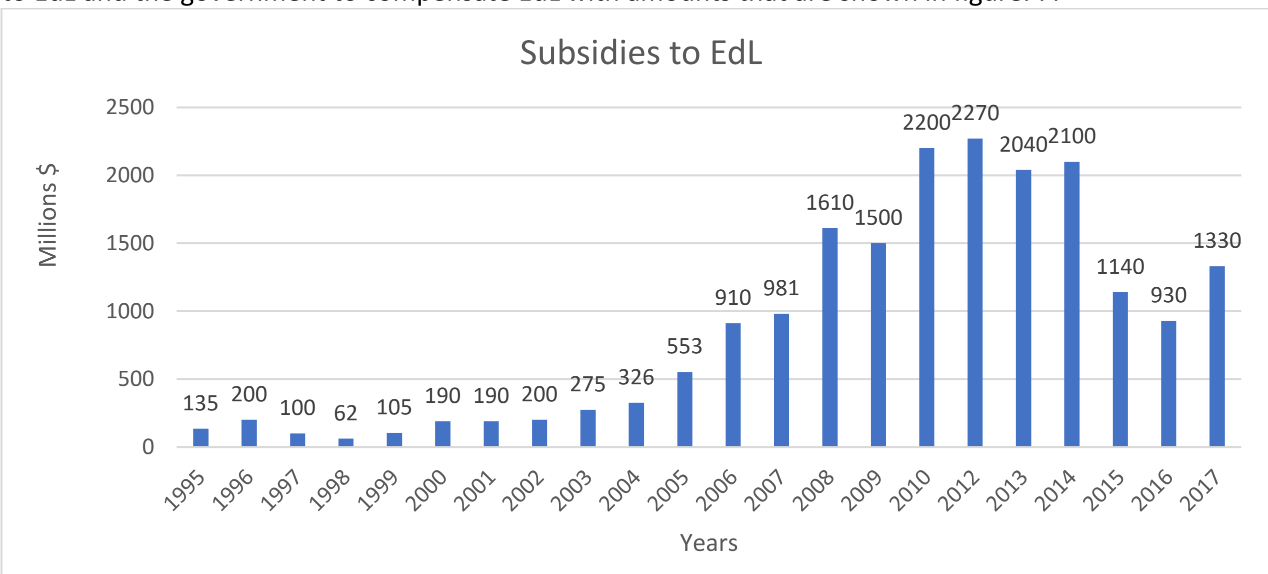

Figure 9: Subsidies to EdL from 1995 to 2017. Sources: Ibrahim et al. (2013, p. 263); Ministry of Finance (2013, 2015, and 2017)

As for the tariff structure of informal electricity, that comes from IEP, there is no official tariff structure to rely upon. Metering of electricity for this technology relied either on (i) restricted capacity subscription, e.g. 5, 10, 15 Amperes, given for a fixed monthly fee, or (ii) metered consumption with pay as per consumption amount (KWh). However, after July, 2018 the ministry of economics issued a ministerial decision to ban the fixed tariff structure obligating IEPs to stick with the second tariff structure, and mandating them to stick within the price range of 410-450 LBP/kWh, i.e. equivalent to 0.273-0.30 $/kWh (Dandash, 2018). However, the mandate was not issued from the MoEW (EdL), the council of ministers, or the parliament in the form of law; therefore, the IEPs still fall under the “illegitimate” zone (El-Ferezli, 2018).

3.1.1.3. Former Policies

After the proposition and approval of the law No. 462, i.e. the reform law, three official polices were formed, which dates to the years 2006, 2008, and 2010. A comparison table, in Appendix A, shows the detailed similarities/differences between the three policies. Large similarities could be seen between the 2006 and 2010 policies, where it is clear that the 2010 policy based its strategy on the one of 2006; however, the 2010 policy is more comprehensive and went into further details at the tactical level (Ibrahim et al., 2013).

Since the 2010 policy, i.e. proposed by the energy and water minister G. Bassil, overruled the 2006 and 2008 policies, this study opts to delve into this policy and does not consider the others. Some of the suggestions of this policy can be built upon when designing the new polycentric hybrid electricity sector.

First, the thesis lists the important aspects of the policy, and later on (section 2.4) a choice on the relevant aspects that can contribute to the final design of a polycentric sector will be made. The following are the most distinguishing points indicated throughout the policy:

- Amending the law No. 462
- Corporatisation of EdL
- Adopt an energy conservation law, and institutionalising LCEC
- Incentivise public private partnership (PPP) at both the generation and distribution levels of the value chain:
    - For generation:
        - Current generation plus an investment of 700-900 MW to be owned and operated by EdL (CCGT technology).
        - Mid-term (1500 MW) and long-term (1000 MW) capacity provision through Independent Power Producers (IPPs).
    - For distribution: private sector to be introduced in the form of service providers and not owners of the grid. Appointment is done through a bidding process, and the number of distribution operators will be determined based on technical and socio-political context.
- Transmission: this value was kept within the jurisdiction of EdL, and investments needed for expansion and improvements would be financed through the government and international loans.
- Construction of an LNG marine terminal and a gas pipeline along the coast to provide generation plants and other industries with a stable supply of fuel.
- Setting an objective for renewable energy sources to constitute 12% of electric and thermal supply by the year 2020.
- Tariffs: increasing the tariffs gradually in connection with reliability improvements and abolishing subsidies, except for low income consumers and productive sectors.

A 10-year reform plan based on the 2010 policy was approved by the Lebanese government, i.e. council of ministers, on 28 March 2017 (Machnouk et al., 2017). However, the same could be said about the 2006 policy and the approval of the 2010 policy, where none of the policies were implemented. But, the 2010 policy is more promising than the others, in which in 2012 activities related to operation and maintenance of the distribution network were outsourced to private companies (Machnouk et al., 2017). Even with the implementation of this step, the 2010 policy still faces a lot of obstacles and barriers to be implemented, mostly linked to political and sectarian conflicts.

3.1.2. The Lebanese Electricity System

In this subsection, the thesis will introduce the physical layer of the Lebanese electricity sector. The subsection is sub-divided into three parts, where the first presents the generation and load portfolio. The second part describes the Lebanese transmission network. The third and final part explains the Lebanese distribution network and its current division.

3.1.2.1. Generation vs. Load

Formal electric generation in Lebanon can be divided intro two categories, (i) thermal power plants, (ii) renewable energy sources. First are the thermal power plants which are owned and operated by EdL, excpet KPS-1 which is leased by an independent power producer. The power plants depends on either heavy or low fuel oil technologies. Heavy fuel oil (HFO) power plants constitute around 1100MW, while light fuel oil (LFO) plants sum up to around 1000 MW. The LFO plants were originally constructed to operate on natural gas, i.e. combined cycle gas turbines and open cycle gas turbines (Ibrahim et al., 2013).

Second are the renewable energy sources, which are divided into currently operatring resources, and upcoming resources. Current renewable energy comes from hydroelectric power plants distributed over the Litani, Ibrahim, and Bared rivers. Their installed capacity sums up to 274 MW, but their actutal generation capacity is 190 MW (Bassil, 2010); in 2009 hydropower covered 4.5% of the yearly produced electricity in Lebanon (Bassil, 2010). Whereas upcoming renewable energy sources (RES) comes from:

a. Approved power purchasing agreement between EdL and private sector to provide 200 MW of wind power. The project is under construction, and will be operational in 2020 (Interviewee 10).
b. A possibility of 180 MW of solar power farms, located throuhout 12 geographical locations in Lebanon. The bids are currently under technical evaluaiton by the LCEC (Interviewee 10).

Both projects will be connected to the transmission grid, making them fall under centralised energy resources.

Existing Power Plant	Capacity	Availability	Fixed cost	Fuel	SFOC	LCOE	Ownership	Years active
	MW	%	USC/kWh		g/kWh	USC/kWh		
Beddawi-1	424.0	82.0%	1.10	LFO	194.0	13.75	EDL	1994
Zahrani-1	448.0	82.0%	1.00	LFO	182.0	12.87	EDL	1994
Zouk-O	331.0	60.0%	1.56	HFO	291.0	13.61	EDL	35 years
Jieh-O	143.0	59.8%	1.52	HFO	361.0	16.47	EDL	retire in 2019
Tyre	44.0	60.2%	0.61	LFO	306.0	20.57	EDL	1997
Baalbek	46.0	60.1%	0.61	LFO	295.0	19.85	EDL	1997
BWSC - Zouk	194.0	91.5%	1.20	HFO	200.0	9.48	EDL	2017
BWSC - Jieh	78.0	91.5%	1.20	HFO	200.0	9.48	EDL	2017
Hraycheh	23.0	20.0%	0.60	HFO	300.0	13.02	Kadisha/EDL	1970s
KPS-1	370.0	90.0%	5.80	HFO	207.0	14.37	Lease	2013 - 2018
All thermal Plants	2,101.0					13.37		
Hydro 1	204	n.a.					Litani river (ONL)	~1965
Hydro 2	70.0	90.0%	2.67			2.67	Concessions/EDL	~1924
Syria	100.0	70.0%	15.70			15.70	Import	Not continuous
All Plants	2,475.0	78.1%				13.08		

Table 5:Installed capacity in Lebanon. Source: Ghajar (2018); and Bassil (2010).

Even though the total installed capacity of power plants in 2018 sums up to approximately 2475 MW, the actual generation capacity did not surpass 1650 MW in 2010 (Ibrahim et al., 2013) and was approximated at 1800 MW in 2017 (Machnouk et al., 2017) and 2018 (Ghajar, 2018). The suppressed demand, i.e. difference between supply and demand, is compensated through independent energy providers (IEPs) which produces electricity through diesel technology, i.e. LFO (Ghanem, 2018). The maximum suppressed capcity in the month of January 2018 was 1285 MW (Appendix A). However, there is a vaiation in peak between summer and winter, and according to interviewees 4&7 peak demand is close to 3500 MW (summer). Therefoer, suppressed capacity goes up to 1500-1700, in which tourism sky rockets and there is a huge influx of Lebanese expats during the summer season (interviewee 4; Houri and Korfali, 2005). According to Ghanem (2018), consumption that comes from IEPs sums up to around 40% of the yearly consumption, with variations in rationing the supplied electricity from EdL to regions. Table. 3 in the appendix shows these variations, that start from a minimum of 3 hours up to 12 hours per day.

When it comes to the distribution of load in the Lebanese market, the residential and commercial (business) sectors mount up to 45%, the industrial sector consumes 23%, administrative buildings (public sector) consumes 12%, distribution concessions consumes 5%, and 15% goes as technical losses (Said, 2005).

3.1.2.2. Transmission Grid

Lebanon's transmission network is operated by EdL, and consists of four kinds of high voltage power lines, i.e. 66, 150, 220, and 400 kV as presented in the figure below. The 400-kV line only serves as one of the three interconnecting lines between Lebanon and Syria; however, this line is not operational due to the lack of infrastructure at the Syrian side as well as the missing substation at the Lebanese side (Bassil, 2010; Ibrahim et al., 2013). EdL owns 58 main substations that converts high voltage to medium voltage. The Transmission Directorate, i.e. part of EdL, is responsible for maintaining, operating, monitoring, and constructing all transmission lines. The organisational management within the Transmission Directorate can be found in the Appendix (Ibrahim et al., 2013). Technical losses at the transmission network adds up to 3.5%, which is higher than the international standard of 2% (Booz&Co, 2012).

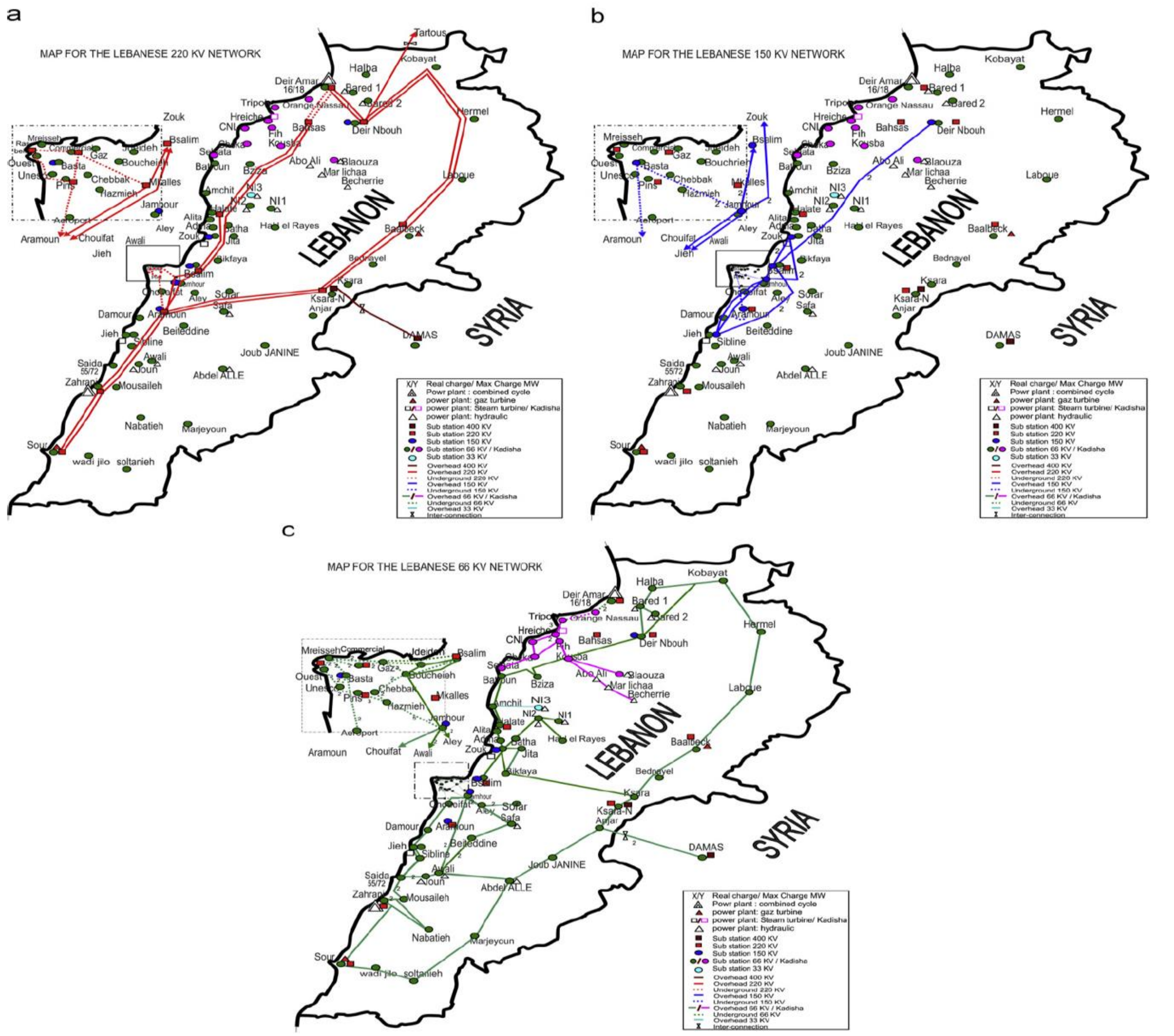

Figure 10: Schematic overview of Lebanon's transmission network (a) 220 kV, (b) 150 kV, (c) 66 kV. Source: Ibrahim et al. (2013)

3.1.2.3. Distribution Grid

As for the distribution network in Lebanon, it consists of both medium and low voltage (LV) lines. Medium voltage (MV) lines mainly operate at 11, 15, and 30 kV, while low voltage lines operate at 38/220 V (Ibrahim et al., 2013). Prior to 2012, EdL had two Distribution Directorates, i.e. "Regions Directorate" and "Beirut and Mount Lebanon Directorate", responsible for managing the network, each within its own geographical jurisdiction. Managing the network included maintenance and construction, operation, metering and collection, and customer service. However, in 2012 and following the 2010 energy policy, the government handed over operation and management of the distribution network to Distribution Service Providers (DSPs), i.e. private sector. These DSPs are required to handle the following operations (Electricite du Liban, 2010):

1. Project mobilisation: for construction of new assets in the distribution network.
2. Network survey: to assess the current, i.e. at the time of handing over, condition of the network.
3. Plans and programs: developing the plans and programs to execute the activities to be performed by the DSP.
4. Develop the investment plan to improve the assets of the distribution network
5. Asset management: planning and designing the distribution network throughout the contract period.
6. Construction of distribution facilities: related to network extension and re-enforcement. Examples include, new connection to customers, installation of substations (MV and LV), cable laying…etc.
7. Distribution network operation and maintenance: this include operation services, repair services, maintenance services, and management and coordination services.
8. Advanced metering infrastructure: this include supply and installation of meters and accessories for customers, M-voltage feeders, and MV/LV transformers.
9. Meter Reading.
10. Bill collection.
11. Customer services.
12. Reporting: providing adequate reports for the owner (EdL) throughout the contract period.

The distribution network was subdivided into three service areas (figure. 11), and the following criteria were taken into consideration (Electricite du Liban, 2010):

1. Percentage of number of customers
2. Percentage LV subscribed amperes
3. Percentage MV Subscribed Capacity (kV A)
4. Percentage of Total MV IL V Transformers
5. Percentage of Transformer Capacity (kVA)
6. Percentage Number of Buildings
7. Percentage Area (Hectares)
8. Percentage kWh Consumption
9. Percentage MV/LV Revenues

Lot Number	Zone Combination
1	2, 3, 4, 5, 6
2	1, 7, 8, 9
3	10, 11, 12, 13, 14, 15

Figure 11: Map of the Distribution Network Service Areas. Adapted from: Electricite du Liban, (2010).

Following the bidding process, three private companies, i.e. BUS, NEUC, and KVA, won the bids for the contract period of two years. Following both party's approval, i.e. EdL and the DSP, the contracts have been extended and are still running.

One of the main drivers and objectives for the Lebanese government to initiate the DSP program was the technical and non-technical losses that the electricity sector suffers from (interviewee 7). According to a report by Booz&Co (2012), the non-technical losses that comes from theft and uncollected bills was around 19%, such losses are only present at the distribution level. The technical losses at the distribution level were approximated at 15%, i.e. higher than the international standard of 6% (Booz&Co, 2012). However according to interviewee 7, technical losses have drastically decreased to around 8% because of the given concessions (DSPs). However, no electrification problems face the Lebanese sector, with electrification rate nearly at 100% (Ruble and Nader, 2011; Ibrahim et al., 2013).

3.2. The Context of Lebanon

This section presents a brief description of the socio-political, and economic context of Lebanon. The section is divided into two subsections, the first discusses the socio-political context, and the second describes the economic context of the country. The aim of this section is to brief the reader about the Lebanese aspects, i.e. historical and current, that influence the electricity sector. Introducing socio-political context is important for the reader to understand why the concept of a polycentric hybrid electricity sector would fit the Lebanese situation. Whereas, presenting the economic situation of the country gives an idea of why reforming the sector would be economically advantageous for Lebanon. The two-subsections does not necessarily

3.2.1. The Socio-Political Context

Lebanon is a Mediterranean country in Western Asia, what is also known as the Middle East. Lebanon's geographical location and rich history that spans more than 5000 years, e.g. the city of Byblos witnessed settlements dating back to 4000-8000 B.C. (Byblos, 1999), has shaped its cultural identity with diverse religious and ethnic groups. The country spans over an area of 10,452 km^2, and has a population estimated at 6.1 million (World Bank, 2019). However, a major part of the current population is of Syrian refugees that are estimated at around 1.5 million refugees (Kadi, 2017). Contemporary Lebanon was found in the 1920s by the League of Nations, and became independent from France in 1943. Lebanon is a parliamentary democratic republic that includes confessionalism, which distributes political and ruling power amongst its 18 recognised religious sects. An example is the president (head of state) who is a Christian Maronite, prime minister is a Sunni-Muslim, the speaker of the Parliament is Shi'a-Muslim, and the deputy prime minister/deputy parliament speaker is Eastern Orthodox (Christian). The existence of this political system is designed to prevent sectarian conflict between the various sects (Khodr and Hasbani, 2013); however, analysts link the eruption of the Lebanese civil war (1975-1990) to the lack of unity within the political system, the confessionalism system, and the struggle of power between the various factions.

Many of the important decisions, whether it has to do with forming the council of ministers, electing the president (head of state), or even deciding on infrastructure investment plans takes a long and spiral pathway before arriving to the final decision. The major reason for such upheaval and the slow decision-making process is the emphasis on consensus decision-making amongst the political parties that form the government. Even though this is not constitutionalised, major decision-making positions within the government is divided equally amongst Christians (e.g. Maronite, Orthodox) and Muslims (e.g. Shi'a, Druze), and this has become the norm ever since present-day Lebanon was found (Mühlbacher, 2009). The misrepresentation of a major sect, e.g. Maronite, Orthodox, Sunni, or Shi'a, in decision-making is seen as means to alienate that sect, and thus instigating bad sectarian sentiments amongst each other. A representation of the complicated Lebanese political system was manifested when it took the parliament a staggering 29 months to elect the current president (Nakhoul and Perry, 2016). Another example is the current struggle amongst political parties to construct a natural gas pipeline along the Lebanese coast, which was first mentioned in the 2010 electricity plan by G. Bassil. In its initial phase, i.e. 2013, a plan was instigated to construct one LNG marine terminal to supply the proposed pipeline with natural gas, nonetheless due to political struggles an agreement could not be reached on the location of the terminal (El-Ferezli, 2018). A current proposal between the political parties is to construct three terminals instead of one, which is not technically necessary or even economically feasible (El-Ferezli, 2018); nonetheless, no final decision has been reached yet.

Another important aspect that effects the social and political life in Lebanon is the continuous struggle and conflict between Lebanon and Israel. The conflict dates back to 1968, with several significant and major events taking place in 1978, 1982, 2000, and 2006. Briefly speaking, Israel's invasion of Lebanon started in 1978, furthering its occupation in 1982 to Beirut, and retreating in 2000. This struggle has left Lebanon suffering economically, and socially. Another side of the constant conflict in that region is the existence of the Palestinian camps that host refugees dating back to 1948 and 1967, with an approximate population of 500,000 refugees (Mühlbacher, 2009).

3.2.2. The Economic Context

The Lebanese economy is a weak economy that is heavily based on services, especially real estate, retail, and financial services (World Bank, 2018). The economy's export is oriented towards its neighbouring region, which includes Syria, Jordan, and the Arabian Gulf region. Being in a conflict region and heavily relying on services has exposed the economy to volatile growth and macroeconomic imbalances. The GDP of the country was estimated at $52 Billion in 2017, i.e. $8,500 per capita. However, the average GDP per capita cannot be solely as an indicator of the economic situation. Poverty percentage, unemployment rate, and debt/GDP ratio can further elaborate the situation in Lebanon. Poverty in Lebanon is defined as a person that consumes less than LBP 4,729,000 per year ($ 3100); it is estimated that 27% of the Lebanese population fall below the poverty line (Central Administration of Statistics and World Bank, 2015). In addition to that, the World Bank estimated that as a result of the Syrian crisis and the huge influx of refugees and additional 200,000 Lebanese citizens were pushed into poverty (World Bank, 2018). Unemployment also skyrocketed, with overall unemployment at 25% and youth unemployment going up to 37% (Kadi, 2017). The debt/GDP ratio has exceeded the 150% level in 2017 (153.4%) due to low growth and high debt financing (World Bank, 2018). The government's debt is expected to grow as well with the current economic plan and financing coming from the international community through the Cedar (CEDRE) conference, which pledged close to $11 Billion in the aim to support investment programs and boost Lebanon's economy (Irish and Pennetier, 2018). According to the French president E. Macron the CEDRE conference holds an "unprecedented responsibility" for the Lebanese government to carry out reform plans to stabilise and modernise the economy to put it back on the right path of growth (Irish and Pennetier, 2018). This presented opportunity was met by mixed feelings within the Lebanese community. Some Lebanese viewed the conference and the international backing as a positive sign which presents a new beginning and hope for the future, while the other parts of the community viewed the conference negatively. The reason for this scepticism was the previous similar conferences (Paris I, II, III) that failed to modernise the Lebanese economy and failed to achieve its objectives (Diba, 2018). Nevertheless, the CEDRE conference does hold an opportunity for Lebanon to modernise its economy and to bring stability to its people; but that means that drastic changes should be made at several levels. This include but not limited to battling corruption, and transforming the economy to a production-based instead of a service-based economy.

When it comes to the effects of the current state of the electricity sector on the economic situation in Lebanon, this study distinguishes between the effects at the macro level and the ones at micro level. At the macro level, and in accordance with a survey conducted in 2013 by the World Bank, private enterprises listed the current electricity situation as the second major obstacle for investing in the Lebanese market, succeeding the political instability in the country (Appendix A). As for the effects at the micro level, the study chose to check the energy expenditure of Lebanese households in comparison to the annual expenditure. According to a study conducted by Central Administration of Statistics (CAS) in Lebanon, the average Lebanese energy expenditure is around 9.4% of their yearly income. However, no detailed data exists for the poverty-stricken Lebanese families; nonetheless, the data acknowledges that 41.6% of the expenditure for poverty-stricken households goes to the category of rent, energy (electricity & heat), and water supply (which constitutes less than 1% of expenditure) vs. 28.3% for an average Lebanese household. This high percentage of expenditure for low income families can be attributed to rent and the high energy expenditure, which can be estimated through calculations (not necessarily accurate) at around 14% of their yearly expenditure. To put matters into perspective, many studies investigate the definition of energy poverty, in which a typical definition of an energy poor household is one which has to spend more than 10% or 15% of their annual or monthly earnings on energy (DTI, 2001; Winkler et al., 2011; Sovacool, 2012). Consequently, this categorises 27% of the Lebanese households (poverty-stricken) into the "energy poor" category, as for the average household (9.4%) the margin is not so far for them to be included into the "poor energy" category. This immense pressure of energy on the total expenditure of the Lebanese household can be attributed to the two bills that a Lebanese household must pay for electricity, i.e. to EdL and to IEPs.

3.3. Summing Up

This section is responsible to sum up the set of peculiarities that distinguish the Lebanese case. The section is divided into two subsections; the first, handles the set of contextual peculiarities (economic and political) that must be taken into account. The second subsection, handles the aspects directly related to the electricity sector, which include aspects that can be based upon when designing the new sector.

3.3.1. Context Peculiarities

The two above sections identify a set of obstacles and special characteristics that might hamper the development and implementation of an energy policy. The following lists the contextual aspects that must be kept in mind while designing the sector:

- Sectarianism: the political context of the country, where confessionalism leads to the division of power between the various sects. This obstacle is considered to be the most complicated aspect that is slowing down decision-making (Khodr and Hasbani, 2013).
- Politicised decision-making: the LNG terminal is a prime example
- The high-level of debt/GDP ratio, and the high percentage of poverty
- Absence of policy continuity: where the 2006, 2008, and 2010 policies have stalled for long time. However, this is starting to change, and some hope resides with points connected to the 2010 policy.
- Continuous conflict with Israel and terrorism crossing from the Syrian borders (after the conflict started in 2011).

The question would be, would the concept of polycentricity be able to circumvent the above obstacles or at least part of those obstacles. The thesis argues that using polycentricity in the electricity sector to combine centralised and decentralised generation is a solution to avoid the conflicts inflicted by sectarianism and politicised decision-making. The thesis believes that such a design would actually please the different political parties in Lebanon. This is further solidified through the intention to divide the country into different distribution zones based. Furthermore, decentralised generation could be one way to solve the vulnerability of centralised generation in wars and terrorism (Bouffard and Kirschen, 2008).

The total amount of investment needed for the sector was estimated to be around $5-6 Billion (Bassil, 2010; Ruble, 2011). However, the benefits of restructuring the sector is expected to exceed the costs. Benefits goes both ways, the government would be able to cut down on subsidies, and households would be able to spend less on energy since they would be eliminating the IEP's bill. In turn, this would help in decreasing the number of Lebanese households that fall under the definition of "energy poverty".

3.3.2. The Aspects of the Electricity Sector

Two lists related to the electricity sector can be taken from section 3.1. The first relates to the general aspects of the sector, while the other relates to the aspects of the 2010 policy that can still assist in developing a new polycentric design for the sector.

- The status-quo of the IEPs
- High electrification rate, i.e. almost 100%. This is good news for a developing country, and thus would not pose problems for design.
- High theft percentage, i.e. estimated at 20%

As for the recommendations given by the 2010 policy paper, the following points could be used to assist in designing the polycentric electricity sector:

- The current situation at the distribution network, i.e. DSPs, and the already divided service areas. This is used as the geographical jurisdiction for the centres at the "decentral level" in the polycentric structure.
- Incentivise public private partnership (PPP) at both the generation and distribution levels. Example, IPP at the centralised generation level, and private management at the distribution level.
- Transmission: this value was kept within the jurisdiction of EdL, and investments needed for expansion and improvements would be financed through the government and international loans.
- Tariffs: increasing the tariffs gradually in connection with reliability improvements and abolishing subsidies, except for low income consumers and productive sectors.

Finally, designing a polycentric hybrid electricity sector for Lebanon should take into account the above points and peculiarities. These would serve as inputs for both the strategic design, i.e. the structure or shape of the design, and the tactics, i.e. the design option taken for each design variable (section 2.5).

4. A Polycentric Design for Lebanon

This chapter aims to design the polycentric hybrid electricity market of Lebanon. The chapter fuses the information obtained from chapter two, i.e. theoretical framework, chapter 3, i.e. the Lebanese electricity organisation, and information gathered from interviews conducted with experts. The chapter consists of six major sections, and follows the steps given at the end of chapter two.

The first section uses the information gathered from interviewees that belong to category one (table. 1), to select the actors involved in the polycentric structure (figure. 8), which corresponds to the second step of the "Polycentric Market Design Framework" (PMDF). The second section assigns the geographical jurisdiction of each centre (DSO), corresponding to the third step of the PMDF. The third section addresses the issues of modes of organisation that organises the relation between the levels (actors) involved in the new design, where attributes of polycentricity, information from interviewees, and the Lebanese context intertwine to decide on the best mode of organisation to choose; this section answers the fourth step of the PMDF. The fourth section argues and decides on which market design variables must be addressed, and decides on the option that best serve the Lebanese case; therefore, this section answers steps five and six in the PMDF. The fifth section addresses the topic of technical functions, a decision based on earlier decisions, the interviewees input, and the timescale required to execute the technical function results in allocating the function to the respective actors in the sector. The final section takes a final look at the design of Lebanese polycentric hybrid electricity sector, where the final structure is presented.

4.1. Levels in the Polycentric Lebanese Design

This section delves into the second of designing the polycentric hybrid electricity sector of Lebanon as given by the Polycentric Market Design Framework (PMDF) in section 2.6. The first step in the PMDF framework was already established in the second chapter which ultimately lead to creating figure. 8, that represents a general polycentric structure for an electricity sector. Therefore, this section starts from figure. 8 (step 1) and investigates which levels and actors are relevant for the Lebanese case (step 2). The section is divided into four subsections, which first discusses the necessity to unbundle distribution from transmission, and explains the role of the DSO in the sector. The next subsection analyses the option of unbundling centralised generation from the TSO. The third subsection explains the need for incorporating decentralised generation in the energy mix. The fourth and final subsection discusses whether to incorporate a retailer/aggregator in the Lebanese structure or not. The main objective of this section is to discover the actors to be involved and determine the degree of market opening at both Central and Decentral levels in the polycentric structure. The decisions taken in this section will have an effect on which of the design market variables play a role in designing the details of the Lebanese electricity sector.

4.1.1. Unbundling Distribution from Transmission

Chapter two argued that for a polycentric structure to exist in the electricity sector, vertical unbundling between the distribution and transmission is theoretically necessary. However, this should be possible within the context of the case; as described in the third chapter, Lebanon's distribution grid has been outsourced in 2014 to three distribution service providers. Thus, for Lebanon unbundling distribution from transmission should not be a barrier that hinders the implementation of a polycentric structure. Interviewees 1&2 (P. Bhagwat & S. Bhagwat) and 8 (T. Jamasb) stated that unbundling the businesses of distribution and transmission would clear out the inefficiencies that they suffer from. In this case the system is better suited to pinpoint where the problems are located, i.e. pinpointing the location and aspects of the yearly losses (figure. 9), and thus improvements are executed faster.

However, currently in Lebanon DSOs (labelled DSPs) have limited power and autonomy to realise the benefits of the proposed system. Moving towards high penetrations of decentralised generation (subsection 4.1.3.) requires distribution system operators to move away from their current tendency to make only limited use of control and decision-making (Bell and Gill, 2018). The authors discuss three relational models between the TSO and the DSO, in which they base their propositions were based on a paper conducted by on DeMartini and Kristov (2015). The model that best fits our theory and the need to incorporate high numbers of DGs is a “Market DSO”, which maximises the DSO’s role, and hands it operational and coordination power, thus minimising complexity for the TSO. In such proposition, the TSO would only see the aggregated power coming from distributed generation at the transmission-distribution interface. The “Market DSO” option looks the best fitting for the polycentric hybrid electricity model, in which it gives the DSO autonomy to coordinate and aggregate the distributed energy resources, which is also compatible with the notion of polycentricity. This model was also considered by Bell and Gill (2018) to be the simplest, especially for the interaction between the DSO and TSO.

According to Poudineh and Jamasb (2014), transforming the traditional DNO (distribution network operator) to a DSO (distribution system operator), i.e. “Market DSO”, would allow it to be linked to the following activities:

a. Non-dispatchable resources (RES)
b. Dispatchable resources (e.g. gas turbines, combined heat-power, diesel generators)
c. Smart infrastructure
d. Commercial aggregation, needed for non-dispatchable resources (RES)
e. Ancillary services: frequency response, reactive power and black start, primary and secondary reserve through generation and demand, warming and hot standby, fast start load reduction.
f. Technical aggregation: done to aggregate and optimise the combination of non-dispatchable sources, dispatchable sources, and flexible demand.
g. Flexible demands: storage, demand side management, and electric vehicles

The figure below shows the transformation of a DNO to a DSO, along with the newly linked activities to the DSO. This DSO model is a preliminary model for Lebanon, where the possibility of its implementation will be discussed in the next chapter.

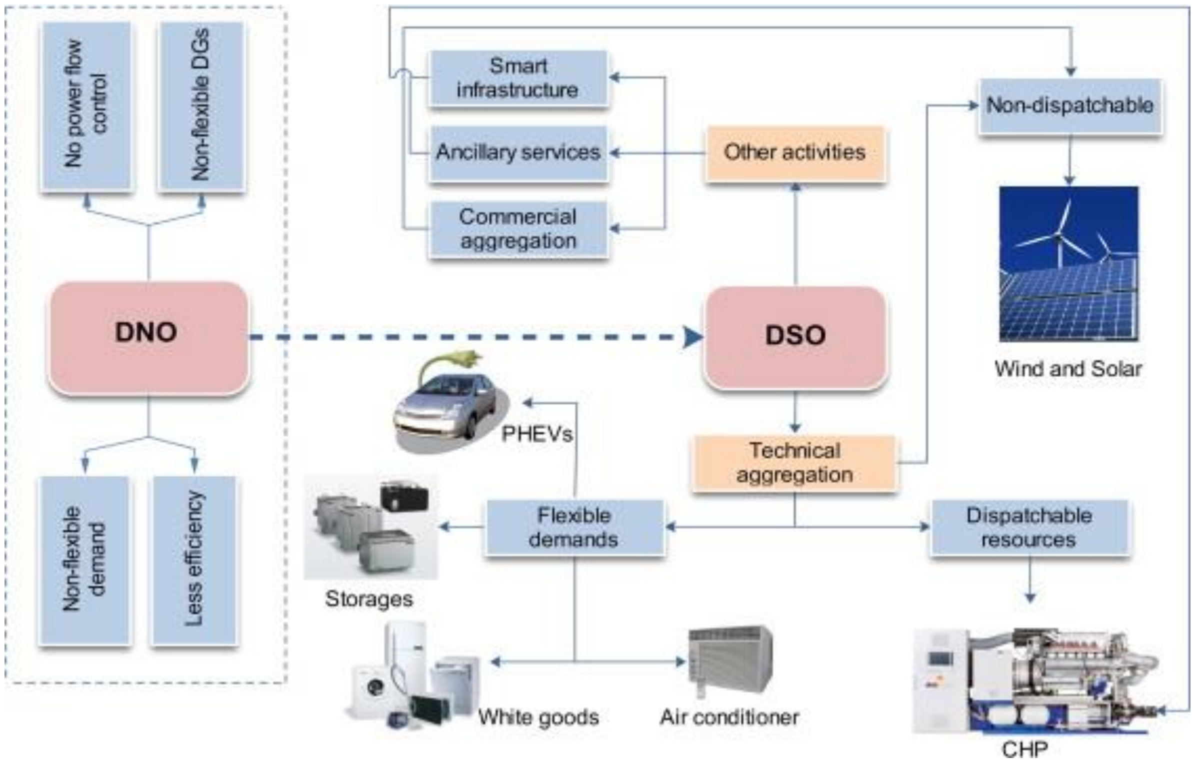

Figure 12: The Model of a Distribution System Operator. Source: Poudineh and Jamasb (2014, p. 224)

4.1.2. The Structure of the Central Level

This topic holds three options, either (i) to keep centralised generation bundled with the TSO and thus EdL, or (ii) introducing independent power producers (IPP) and transforming the central level of the structure into a "single buyer model", or (iii) completely unbundling generation from transmission and introducing competition at this level.

Most of the current centralised generation (CG) in Lebanon are owned by EdL, with the exception of one power-plant which is leased, and the upcoming centralised renewable energy sources which are under the IPP model. Switching into whole-sale competition and unbundling generation from transmission holds a lot of problems for a case like the Lebanese case. All experts that were asked about this topic, i.e. interviewee 3, 4, and 11, answered negatively when asked about the possibility of whole-sale competition in Lebanon. According to Dr. de Vries, from a theoretical point of view and not looking at the transaction costs unbundling generation from transmission is recommended. However, in a small country like Lebanon, with a peak demand of 3500 MW, there might not be enough room for actual competition. On the other hand, an integrated utility provides the following benefits for the central authority (EdL):

- Simpler organisation and planning compared to other models, which helps in safeguarding technical functions, and
- The ability to keep electricity tariffs regulated, which is the current situation. In the 2010 energy policy, the government's intention was to gradually rescind subsides for electricity except for low income households (section 3.3.2). Thus, the intention of the government is to alter the tariffs, but keeping them regulated.

According to Prof. Ghajar and Mr. Mubarak, interviewee 4 & 11, the option of IPP for centralised generation is gaining momentum in Lebanon. This is emphasised by the recent signing of PPAs with three private companies to produce energy by wind technology (200 MW). In addition, one of the main bottlenecks for the development of the electricity sector, is the government's deteriorating fiscal power, which have immensely worsened in the past years (interviewee 11). Therefore, a combination of the existing centralised generation that are owned EdL (government) and future IPPs is seen as the solution for the Central Level. However, investment in generation capacity at the central level is subjected to technical constraints of the transmission grid.

4.1.3. Decentralised Generation

Three primary reasons necessitate the introduction of decentralised generation (DG) in the new design for the Lebanese electricity sector, two of which are practical and one theoretical. As discussed in the second chapter when proposing the general structure of a polycentric electricity sector, DGs provide each of the centres at the "Decentral level" the kind of autonomy needed for these centres to function and exercise their opinions in decision-making. As for the contextual reason, i.e. practical:

a. According to interviewee 7, i.e. Ali Ismail, the major bottlenecks that face the physical layer of the sector is at the transmission level. Where transmission lines do not hold enough capacity (66 kV, and 150 kV) for an increase in the centralised generation capacity; in addition to that, capacity of the transformers (high to medium voltage) is low and not enough to withstand increased capacity. Another barrier facing the expansion of the central level, i.e. CG and transmission, is the need to acquire lands from the private sector, which would cost a lot of investments and social barriers.
b. The time to implement the design is an important factor for Lebanon (interviewee 7 and 11). This is due to the annual incurred losses of EdL and the fiscal problem of the government (interviewee 11). According to Ali Ismail, implementing the idea of decentralised generation at the Decentral level is quicker than introducing further centralised generation and developing the transmission grid.

Therefore, opting for decentralised generation would circumvent the technical barriers found on the central level, and hastens the needed change in the Lebanese electricity sector. Two options could be considered for realising decentralised generation in Lebanon, either (i) through the already existing IEPs (small diesel generators), or (ii) through new investments.

According to interviewee 4 and 6 (Ghajar and Ibrahim), connecting the existing "illegal" diesel generators to the distribution grid has many technical and economic difficulties. The main problem comes from the need for large finance for the small diesel generators to connect to the grid. This large sum of money comes from the need to synchronise the output (power) of the diesel generators to that of the distribution grid, i.e. speed and frequency. Another problem for diesel generators comes from fluctuating demand which means that the diesel generators would have to turn on/off too many times in a day, causing diesel generators to overheat. In turn, this would lead to high maintenance cost and high maintenance periods that might rise up to 50% of the time (interviewee 4). This fact was emphasised through an interview with an IEP (independent energy provider-interview 9), where the owner mentioned that he has three generators, one of which acted as a backup/reserve generator. This shows that the existing diesel generators in Lebanon suffer from high unreliability issues, and thus are deemed as an infeasible option for decentralised generation. The other option is new investments of medium sized decentralised dispatchable generation, i.e. 5-50 MW generation (Krager and Hennings, 2009), and to incentivise solar power generation at the consumer level (interviewee 3, 4, 6, and 10).

4.1.4. Retailing and Aggregating

In the first subsection a decision was taken against whole-sale competition in Lebanon. Given that retail-competition is a next step in market opening that comes after whole-sale competition (figure. 4), it would make no sense to have retail competition. According to interviewees 3 and 8 (de Vries and Jamasb) unbundling distribution from retail would only add transaction cost, and therefore raising the electricity bill for the consumer. Another issue that comes with unbundling retailing from distribution is the need to come up with a mechanism to insure generation investments. It is harder to finance investments in a retail-competition market model (interviewee 3), where capacity mechanisms would become necessary (de Vries, 2007).

The other function that the local government could assume in figure. 8 is an aggregator of locally generated power. The need for an aggregator in Lebanon depends on two arguments:

a. The decision whether to go with the IEPs as the source of decentralised generation. According to interviewee 1 & 2, an aggregator is needed for small diesel generators (e.g. 350 kW generators), which would make it easier for DSOs to call upon larger power capacities when needed. An advantage of this is lowering the technical complexity for the DSO, but it increases transaction costs.
b. The technical and institutional viability of this option. According to interviewee 12, appointing the municipalities (LGs) as the aggregators needs technical knowledge and infrastructure to make the idea achievable. Aggregation should happen at connection points between the DSO and the jurisdiction of municipalities, thus there should be a possibility of physical separation.

Both of the two arguments are not viable; as explained above, electricity power coming from IEPs is not technically and economically viable. On the other hand, in Lebanon the distribution grid has no separation points that separates the grid at the entrance level of a municipality level. Microgrids that gives the possibility of islanding each municipality does not exist. This makes the possibility of having the municipality performing the role of an aggregator technically not possible. Therefore, separate aggregators would not play a role in the market design, and as Jamasb (interviewee 8) explained the DSO is better suited to do the job of the aggregators in a more technical and economic efficient manner.

A conclusion of all the above subsection is that the polycentric hybrid electricity sector in Lebanon would constitute an integrated central level (generation and transmission), three DSOs, decentralised generation, and consumers/prosumers.

4.2. Assigning Jurisdictions

The section identifies the jurisdiction of each of the Central level and the several Decentral levels in the Lebanese polycentric electricity structure. The section is responsible to give an answer to step three in the Polycentric Market Design Framework (PMDF).

On one hand, no division over the jurisdiction will happen at the central level; whether the central level is made up of only EdL and centralised generation or it also incorporated the electricity regulator (decision in section 4.4), the central level will serve the entire country with its respective services. At the Decentral level, the study will adapt the present jurisdiction, i.e. indicated in section 3.1.2.3. This division separates the distribution network into three separate partitions, and is already in place. The reason for sticking with this jurisdiction is the ability of this division to provide equal economic opportunities for the operators of the networks, where percentages of consumers, transformer capacities, revenues…etc. (section 3.1.2.3) are already taken into consideration. In addition, this division was approved by the Lebanese government, which means that the way to divide the country wouldn't hinder the implementation of the final design. Figure 13, gives another representation (simpler to fig. 11) of the proposed division.

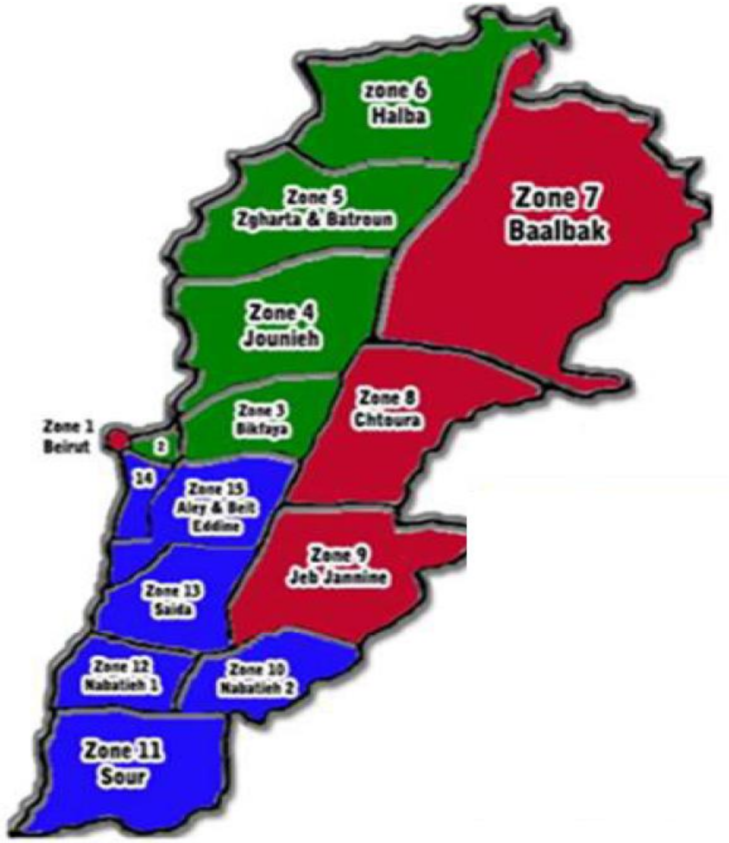

Figure 13: Map of the three Jurisdictions for Distribution System Operator at Decentral Level. Source: Booz&Co (2012)

4.3. Connecting the Levels

This section aims to execute the fourth step of the PMDF (section 2.6.), i.e. selecting the mode of organisation that governs the relation between the various layers in the polycentric structure. The section is divided into two subsections, where the first subsection describes the relation between the TSO and the DSO. The second subsection explains the relation between the DSO and decentralised generation. The chosen mechanisms to organise the relations between the actors should be in-line with either the definition of the "lead-organisation" or the "participant-governed" modes of organisation (section 2.4).

4.3.1. The Relation between TSO and DSO

The relation between TSO and a DSO has two important aspects to be solve. The first aspect has to do with allocating the responsibility of balancing the system, and the need of coordination between TSO and DSO to achieve proper balancing. The second aspect is the economic relation with respect to power trading, where the transfer of power from centralised generation (TSO) could be easily achieved through contracts; but power flowing in the other direction could be complicated. This aspect will be investigated below, and whether trading between DSOs is achievable in this design for Lebanon.

4.3.1.1. Balancing

With the introduction of large amounts of decentralised generation, which will amount to an approximate 40% of total generation capacity, i.e. the current generation deficit in Lebanon, balancing the distribution network becomes an important aspect that needs to be answered. According to interviewee 7, balancing would have to be separated between DSO and TSO, where the TSO would be the one responsible to balance the transmission network and the DSO should be given responsibility to balance the distribution network.

The principle to divide balancing responsibility between DSO and TSO was labelled "Devolution Principle" by Kim, Pollitt, Jin, Kim, and Yoon (2017). The principle selects the DSOs as the actors who primarily have responsibilities for covering the cost of system balancing, since they represent the participants of the energy markets in their own jurisdiction. Under this principle, each DSO with high RES tries to reduce and manage the uncertainty within its jurisdiction through various measures such as active scheduling and control of generation/demand, energy storage, encouraging efficient long-term investment, advanced forecasting, and not disrupting balance at the transmission level. However, the challenge in implementing this principle is the lack of incentives for DSO to cut down on balancing costs that are incurred by the TSO, which are reimbursed by DSOs. According to Kim et al. (2017), the current scheme of allocating balancing cost is based on the contracted amount of energy, which is not compatible with the cost incurred for balancing, i.e. caused by variability and uncertainty in load and not the contracted energy amount. Therefore, the authors suggest a new cost allocation scheme (CAS), which is labelled as the cost-causality principle. The DSO would be responsible to pay the TSO for the balancing costs caused by that specific DSO, and thus incentivising the DSOs to manage and reduce imbalances at the connection (interface) level with the TSO. In turn, the DSO would transfer the cost of balancing to its respective costumers under its jurisdiction. However, if the full amount of balancing cost is transferred to the final customers another problem would surface. According to Kim et. al (2017), passing the full amount to consumers would render the DSOs indifferent to balancing costs. A solution was provided by the authors, in which an incentive regulation scheme would have to be created that stipulates the DSO to pass only part of the balancing cost to the consumers. The passed costs would have to be less than a 100% and more than 0%, and the DSO can decrease balancing cost through strategic action and technological innovation to manage uncertainty and variability (Kim et al., 2017). According to the authors, this incentive scheme could be designed through a comparison with the incentive regulation scheme for the TSO's balancing service given by Ofgem (2017). However, delving into details of this scheme is beyond the time and scope given to this thesis.

If the devolution principle is adopted, the DSO with high RES penetration would be risking high payments for balancing the system. This would disincentivise DSOs towards RES, thus working against the possibility of Lebanon achieving the targeted percentage of RES. To solve this issue, Kim et. al (2017) propose a risk hedging instrument which is named balancing payment insurance (BPI). This hedging instrument allows the DSO to choose whether to be completely exposed to the uncertainty of balancing payments which is based on the cost-causality principle; or, the DSO could hedge the uncertainty through agreeing on an ex-ante balancing payment arrangement with the TSO. However, constructing a BPI is beyond the time and scope of this thesis.

Properly designing the cost allocation scheme, the incentive scheme for transferring the balancing cost, and the BPI would come a long way in ensuring the compatibility of rules and economic incentives, thus abiding with the indicator P3 of the LSP framework. This proposed mode organisation between the TSO and DSO to conduct balancing is closest to the "Participant-governed" mode of organisation described in section 2.4.

4.3.1.2. Power Trading

We can notice from looking at the direction of power flow from the TSO to DSO in figure. 8 that there is a possibility of having electricity trade between DSOs. At the physical level, power would have to flow through the transmission lines to pass from one DSO jurisdiction to another. However, the question remains whether to involve the TSO in this economic transaction or not. Discussing this matter with the interviewee it was found out that trading between DSOs in Lebanon would not be possible, for the following reasons:

- Trading between the DSOs would not be technically feasible, this is due to the low capacity of the transformers at the interface level between transmission and distribution, and the low capacity of the transmission linen (interviewee 7).
- In Lebanon there is energy deficit in the system, which makes bringing stability to each DSO as the number one priority. Trading between DSOs with the current power deficit would not make sense. However, if trade is permitted to happen, one region's price would go up and the other would go down, and that is not very popular (interviewee 8).

Nonetheless, if trading would happen somewhere in the future, i.e. after surpassing the deficit problem, it is recommended to be done via the TSO (interviewee 3,4,7, and 8). Therefore, trading rights at the transmission level would only be given to the TSO, i.e. EdL in Lebanon (integrated entity). According to de Vries (interviewee 3), a regulation would need to be setup which makes the TSO pay the marginal price of the last summoned distributed generation in DSO 1, add a regulated fee, and then sell it to DSO 2. However, for the time being trading is not feasible in Lebanon and not recommended.

4.3.2. The Relation between the DSO and Distributed Generation

This subsection aims to introduce a model that delivers network services, i.e. decentralised generation, demand response, and storage services. The possibility of incorporating demand response and storage facilities in this model is to design for other possibilities that might be of interest to Lebanon, even if they do not currently exist. Demand response was mentioned in the latest energy policy (2010) and with this proposed design, it might be of further relevance to Lebanon. However, the advantage of this model is that it can incorporate all of the mentioned services, and cancelling any of one of the services does not hinder the implementation of the model. The model is based on a contract deferral scheme (CDS), and is introduced by Poudineh and Jamasb (2014).

Under this approach, the DSO enters into contractual agreements with decentralised generators, demand response providers (e.g. industry), and storage facilities. This would render the DSO as the power purchasing authority within its own jurisdiction. The mechanism is realised through a competitive forward auctioning process which reveals the value of the product (capacity) and maximise the revenue, on the condition that a sufficient number of bidders partake in the auction (Poudineh and Jamasb, 2014). The market participants who won the bids will be obligated to have their capacity available when they are called upon, and in return the DSO will pay them a capacity payment.

The Contract Deferral Scheme (CDS) auction is implemented in three phases:

- "Evaluation Phase": the DSO has to determine the constrained zones that experience distribution bottlenecks, the optimal locations for investment, and the resources needed for auctioning, e.g. the type of decentralised generation which usually are dispatchable units, electricity intensive consumers that can offer demand response, or storage facilities. The descending clock auction was deemed by the authors as the best fitting auctioning model, i.e. due to the characteristic of the proposed decentralised market (single-buyer model). The descending clock auction is executed in multiple rounds, and the DSO begins the first round with a "starting price" that is fairly high. The service providers bid for the quantity they are willing to offer based on the provided price. Next the DSO sum up the committed quantities and calculates the excess capacity. The second round starts if excess capacity exists, and this time the DSO lowers the offered price. Thus, the quantity offered by the market is lowered. This procedure is done several times until the excess capacity is nullified.

- “Planning Phase”: following the acceptance of offers, the DSO needs to determine the lead time given for developers to complete the project and starting fulfilling their obligations. Example, demand response can be implemented in a shorter-time span than constructing decentralised generation.
- “Implementation Phase”: the DSO enters into contracts with successful bidders, where the service providers will be obligated to deliver the agreed-on capacity when summoned. The service provider will be compensated based on the cleared price.

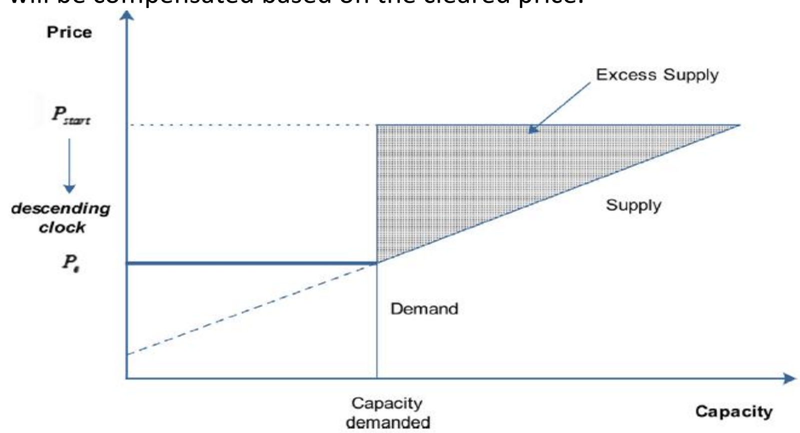

Figure 14: Descending Clock Auction. Source: Poudineh and Jamasb (2014, p.228)

Other important aspects must be addressed, which include:

- The length of the Contract Deferral Scheme: according to Poudineh and Jamasb (2014), it is preferable to engage in long-term contracts with the service providers, where longer-term contracts are provided to new capacity when compared to existing capacities. A good example is 2-year contracts for existing capacity and 5-year contracts for new capacities. For Lebanon the contracts will only be for new capacities, since there are no existing capacities.
- The location of generation: location is an important factor, where siting of DGs close to congested lines or close to demand centres is advantageous for DSOs. A lack of mechanism to incentivise DG developers to invest in the optimal location could negatively affect the system. Therefore, a solution could be developed through the access regulation for DGs, which includes the real cost of connection and rewards the DG when installation is in line with the optimal operation of the grid (Jamasb et. al, 2005).
- Renewable energy sources are usually separated from this model (CDS) because of their intermittent nature, and they could be integrated in the system through feed-in tariffs or other mechanisms (Poudineh and Jamasb, 2014). For Lebanon, the current incentives are deemed a good starting point (interviewee 10).

The above explained auctioning mechanism to organise the relation between the DSO and decentralised generation was tipped off by Prof. Jamasb (interviewee 8). This mechanism is also in line with the other recommendations given by the consulted interviewees. Interviewees 1&2, 4, and 7, agreed on the concept that the DSO should have the ability to enter into power purchasing agreements with decentralised dispatchable generation, the mechanism was not discussed with the interviewees, but handing the sole responsibility of entering into power purchasing agreements to the DSO was validated by them. In another interview conducted with Dr. de Vries (interviewee 3), the interviewee discouraged the idea of fixed rate payments, i.e. per kW, which would pose high risk for generators; the interviewee advised to select a mechanism that provides fixed payments per month and a variable payment based on the marginal cost of generation. The above proposed mechanism is therefore in line with what interviewee 3 suggested.

The above explained mechanism that govern the relation between the DSO and decentralised generation or other service providers clearly belongs to the "lead-organisation" mode of organisation, where the DSO plays the role of the single powerful buyer, coordinates between the various "weaker entities", and provides certain services to align the goals of all involved parties to the end goal of the network.

4.4. Market Design Variables

This section aims to solve the rest of the unanswered market design variables taken from Littlechild (2003). Some of these variables were answered above with decisions on the actors needed to implement the polycentric structure in Lebanon, and the decisions regarding the modes of organisation that govern the relation between these actors. In addition, some of the market design variables are either deemed unnecessary for the design, e.g. capacity mechanisms, or were not answered now because of their less importance compared to others.

We start with the first market design variable, i.e. the degree of market opening. At the central level and in line with what was discussed above, a vertically integration should be kept between the transmission operator and centralised generation. The technical constraints of the transmission network hinder the development of new generation capacity at that level (interviewee 7). However, given that some of the power plants are old and are due for decommissioning (interviewee 11), new centralised generation would be needed. The current fiscal situation of the Lebanese government entails that EdL will face problems in investing in new capacity, leading for the need of the private sector to invest. The recommended model would be for independent power producers (IPP) to replace old power plants (interviewee 11). Thus, EdL would own centralised generation and would be getting a portion of the needed power from IPPs. At the decentral level, as explained in section 4.1.3. the DSO would be the power purchasing authority within its own jurisdiction, making the market their a single-buyer model.

The next variable which was solved above is the network unbundling, it was argued that distribution and transmission should be unbundled for the construction of a polycentric electricity sector. However, the form of unbundling and the ownership of the network was not solved. Based on the conducted interviews, ownership unbundling was not recommended for Lebanon (interviewees 1&2, 4, 7, 8, and 11). However, two options of unbundling and ownership were discussed with the interviewees:

a. The first was keeping the ownership of DSOs to EdL with legal (management) unbundling, and handling over operation and management of the DSOs to the private sector through concessions. This is the current case in Lebanon, i.e. DSPs (distribution service providers), but these DSPs have minimal power as discussed in chapter 3 (3.1.2.2).
b. Legal unbundling of DSOs from EdL, and creating new state-owned DSOs to manage and operate the three distribution networks.

The thesis interprets legal unbundling as the situation where EdL and the DSO belong to the same owner (state-ownership), but EdL would have no control on the DSOs' activities, such as investment decisions or pricing (Cremer et al., 2006). Therefore, for this model to work separate legal entities should be created by the state where EdL would keep its management over the central level. However, this model would require strong institutions to be able to manage state-owned companies at arm's length (interviewee 8). On one hand, ownership unbundling (privatisation) should be out of the question, and it is seen as the last step when reforming the sector (interviewee 8). The argument is that one should not pass on the difficult decisions, e.g. pricing, to private owners in a politically sensitive country like Lebanon, especially that energy is politically sensitive and a necessity for people. On the other hand, Lebanon's institutions might not be strong enough to exercise arm's-length management of the state-owned entities at the central and decentral levels, and the current fiscal problems could hinder much needed investment at the distribution network for implementing the DSO model (figure. 12). Therefore, the first option could be seen as a more realistic option for Lebanon, at least for the time being. Concessions could be given to private companies for at least 5 years, i.e. in line with the Contract Deferral Scheme mechanism (section 4.2.2), where investments by private companies would ensure the proper implementation of the design. However, this solution needs further studies, and decisions would have to be made on (i) a way for the owner (state) to oversee the work of the private company (e.g. supervisory committee, shareholder board), and (ii) what decision are to be allocated to the private company and what should be kept as part of the owner's decisions (e.g. pricing).

Next important market design variable to be solved is the "network regulation for tariffs and access condition". At the central level, there is no issue to be solved because of the integration between generation and transmission. However, at the decentral level where there is unbundling between network and generation, access regulation and network tariff must be established. According to Poudineh and Jamasb (2014), devising an efficient access charge that not only includes the cost of connection but also benefits a DG when installation is in line with optimal location on the network. Therefore, this thesis recommends to follow the recommendation set by Jamasb et al. (2006) where the authors devise a "Long-term Framework for Electricity Distribution Access Charges", in which the following two principle are important:

a. Connection charge: to follow the shallow connection charge, i.e. generators pays for connection equipment and the system operator (DSO) pays for reinforcement needed to the grid. The connection charge must be contractually fixed for a certain period of time, so that it minimises risks for new generation. Such a mechanism would remove financial constraints on DGs and ease their entry (Jamasb et al., 2006).
b. Distribution network use of system (DNuS): a charging mechanism with locational signals that is based on forward-looking "long run incremental cost" (LRIC) should be utilised (Jamasb et al., 2006). A numerical model to calculate the LRIC should reflect the DSO's cost/benefits due to new connection at that location. The model should include the benefits which some from changing the time of upgrading the network (linked to the net-present value principle), benefits that come from loss reduction due to delaying network upgrade, and marginal cost of network expansion (Jamasb et al., 2006). The authors advice that the selected model should be made public and freely accessible for transparency purposes. This requires publishing future demand and generation patterns, which might be deemed politically sensitive in a country like Lebanon (security reasons). Therefore, a solution would be for the regulator to monitor and receive access to the data to validate the tariff structure (Jamasb et al., 2006).

A more extensive explanation of the model for determining access charges is beyond the scope of this thesis. However, an extensive description could be found in the paper of Jamasb et al. (2006).

Another relevant and important market design variable for the Lebanese polycentric structure is the regulator's position. As explained in the second chapter, it is desirable in a polycentric electricity structure for the regulator to be located at the central (national) level. This design variable was addressed to interviewees 1&2, 3, and 8, in which an agreement between the interviewees was on the fact that the regulator should be a totally independent entity at the national level. The following arguments made it easier to validate this selection:

a. Lebanon is a small country
b. The combination of autonomous regional DSOs with autonomous regional regulators could lead to "regulatory capture", i.e. dominance of DSO's interest over decision-making of the regulator. This might ultimately lead to regional tyranny.

c. Having multiple regulators to create flexibility and specificity for each region, e.g. different access regulations for DGs, might be politically/socially sensitive. Different access regulations would mean different tariffs and different rules, which would be considered arbitrary by citizens.

Therefore, one national regulator that is well staffed and independent is better than multiple. One regulator would have more knowledge, more capacity, would be able to compare performances of the various DSOs, and instigate yardstick competition between them (e.g. for access regulation). In addition, one national regulator is more capable of countering the market power of the biggest player, i.e. EdL (Central level).

For the "balancing mechanism" variable, subsection 4.2.1.1 recommended the balancing mechanism to be used for this design, i.e. "devolution principle".

For the arrangements with neighbouring networks and interconnector congestion management. Lebanon only has electricity interconnection with Syria, which is currently under the jurisdiction of EdL. With EdL keeping control over the transmission network and centralised generation, responsibility of interconnection would still exist with EdL, and it is up to EdL to check the necessity to go into trade with Syria for power.

Both the "Integrated vs. decentralised market" and "congestion management" variables are linked together as explained in the second chapter. For this thesis, due to time constraints detailed investigation on these two aspects was not conducted. However, given the recommended model of contract deferral scheme (CDS) and the above-explained access regulation, managing the congestion in the distribution network would be simple, authoritative, and would not need an economic tool to be achieved.

As for the "capacity mechanism" variable, according to de Vries (2007) if retail competition is not included in the sector, then a capacity mechanism is not needed. This is the case for Lebanon, therefore this variable is irrelevant for this design.

The "wholesale and end-user price regulation" variable is relevant for the Lebanese sector. This was mentioned in the latest Lebanese energy policy (Bassil, 2010), were regulated prices could be developed for low-income households. However, delving deeper into this aspect is beyond the scope of this thesis, and it's considered a political decision.

The variable "Competition policies and horizontal unbundling" is irrelevant for this sector design. No whole-sale and retail competition is realised in this design, where the market model at both levels is either a vertically integrated model with a possibility to divert into a single buyer model (central level), and a single-buyer model at the decentral level. therefore, no competition and horizontal unbundling policies are needed.

4.5. Allocating Technical Functions

The below table reveals the technical functions of the designed polycentric electricity sector of Lebanon. The table appoints the relevant actors responsible to safeguard the technical functions, along with the respective institutional arrangement. The appointed actors and the institutional arrangements take into account the decisions taken above, e.g. balancing, the timescale needed to execute the technical function, and the need to establish coherence between the appointed responsibility and the economic benefits for the appointed actors. It is important that technical functions with low timescales, i.e. real-time, are executed by one entity without the need for coordination with another entity (authoritative arrangement), whereas long timescales could be realised with coordination or through a designed mechanism, e.g. CDS auctions for DG investment.

Technical Function	Timescale	Institutional Scope (allocated actor)	Institutional Arrangements
Generation (Central Level): - Operation - Investment - Maintenance scheduling	- Real time - Lead time in several year, and life cycle in decades - 1 year to 3 years	EdL	Authoritative (monopoly)
Generation (Decentral Level): - Operation - Investment - Maintenance scheduling	- Real time - Lead time in several year, and life cycle in decades - 1 year to 3 years	- DSO - Firms - Firms	- Authoritative - CDS auctions - Collaborative between DSO and Firms
System Operation: - Scheduling generation - Balancing - Black start capability - Maintaining operating reserves	- Hours before real time - Real time - Real time (availability), months/years (Investment) - Days, months	- EdL for CGs. DSO for DGs - EdL & DSO - EdL for CG & DSO for DG - EdL	- DSO as leader - Devolution principle - EdL for transmission. Contracts between DSO & DG at distribution - EdL: Contractual arrangements between EdL and DSOs
Transmission network management: - Voltage control - Congestion management - Network investment	- Real time - Day-ahead to multi-year solution - Years in lead time, and decades in life cycle	All EdL	Authoritative for operation, voltage control. Congestion management: controlled by EdL Network investment by TSO but subject to approval by independent regulator.
Distribution network management: - Operation - Voltage control - Network investment - Congestion management	- Real time - Real time - Years in lead time, and decades in life cycle - Day-ahead to multiyear solution.	All DSO	Authoritative for operation, voltage control. Network investment by DSO but subject to approval by independent regulator. Congestion management: controlled by DSO
Interoperability: Norms and standards	Years	EdL & DSOs	Coordination between TSO and DSO, with directive planning by regulator

Table 6: Technical Functions of the Lebanese Polycentric Electricity Sector. Based on Table. 2

4.6. The Final Design

The figure below shows how would the polycentric hybrid electricity sector for Lebanon looks. Two stakeholders are located at the central level in Lebanese design, which are EdL and the electricity regulator. EdL is responsible for transmission duties as well as centralised generation. As explained above, centralised generation can either come from the existing generation capacity that is owned by EdL, or from IPPs that will serve the purpose of replacing existing plants when decommissioned. At the decentral level, three DSOs representing three different regions in Lebanon and each one is regarded as the main player in that respective region. The jurisdiction of each DSO is based on figure. 13, which ensures socio-political approval, technical applicability, and optimum economic benefit. Legal unbundling is preferred between distribution and transmission for Lebanon, with the need to hand operation and management to private companies through concessions for further developing the network. The DSOs in figure. 14 are labelled with the current private companies that manage and operate each jurisdiction, however this is a mere representation and does not have to hold. Electricity only flows one way from the central level towards the decentral level, where there is not current technical possibility of having a two-way flow of electricity. At each DSO level medium-sized decentralised generation are connected to the distribution network, and this is done through shallow connection charges and locational based incentive mechanism for the DNuS. The DGs are selected based on the Contract Deferral Scheme (CDS) auctioning mechanism. Each DSO acts as the retailer in its respective region, and no possibility of retail competition would exist in Lebanon. Therefore, consumers are directly linked to the DSO for sale, but they have the possibility to turn into prosumers by producing electricity through solar power and sending it back to the grid (two-way flow of power). Balancing at the distribution side is handed over to the DSOs, and the balancing mechanism to handle the relation between the DSO and TSO is done through the devolution principle.

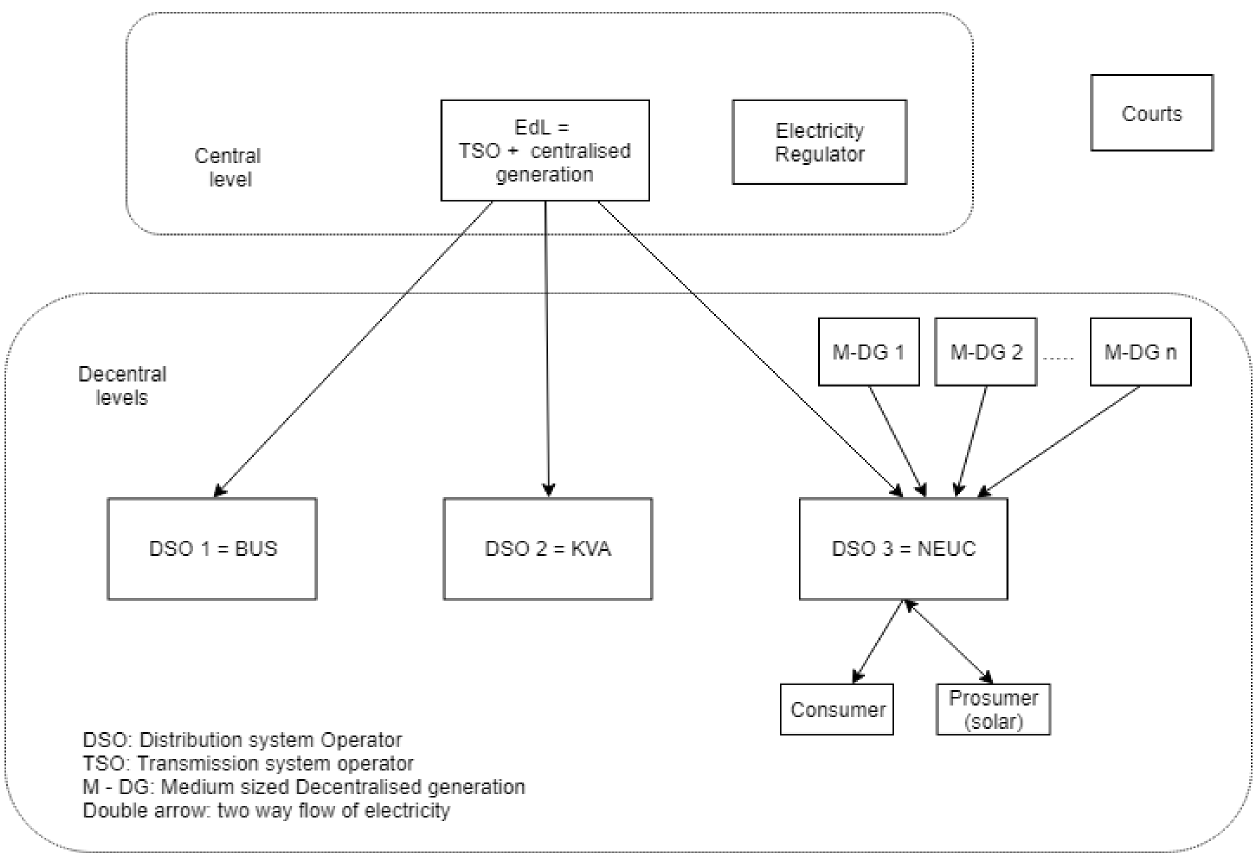

Figure 15: The polycentric structure for the hybrid electricity sector in Lebanon

5. Acceptability of the Design

This chapter discusses the possibilities and barriers for of implementing the sector design from chapter four in Lebanon. Several aspects of the design were discussed with Lebanese experts to come up with possible recommendations when it comes to implementing the design. The main aspects discussed were related to the general structure of the design (figure. 14), the possible acceptability of the design by the political regime and the public, the generation technology for decentralised generation, the general notion of polycentricity in the Lebanese context, and the possible challenges that come from implementing the reform design. The chapter is divided into three sections, with the first section discussing all aspects relating to implementing the electricity sector design, i.e. acceptability by political regime and public, and generation technology. The second section discusses whether polycentricity can be implemented in Lebanon. The third section presents the foreseen barriers and possible challenges that might come out of implementing the design.

5.1. Is it Implementable?

This section aims to discuss the acceptability and advantages of introducing the polycentric design in Lebanon. The section is divided into two subsections; the first subsection discusses the acceptability of the general polycentric structure for the case of Lebanon and argues that existing technical and institutional conditions in the electricity sector are suitable to move into the recommended design. The second subsection discusses the suitable generating technologies that could play a role in decentralised generation.

5.1.1. Accepting the General Structure of the Design

The term “acceptable” is of significance to this thesis, in which it is attributed to being acceptable by both the political regime and the public’s eye. For the political regime, the design should be able to bypass the previous bottlenecks that lead to other policies not being implemented, i.e. confessionalism and sectarianism. As for the public’s opinion, the design should end the unreliability of the electricity sector whilst providing consumers with lower end prices compared to the current situation.

To start with, the general structure of the design, i.e. figure 14, was introduced to several of the Lebanese interviewees. Interviewees 4, 6, 7, and 10 expressed their approval and saw the added value of the design; the interviewees saw the design as a way to circumvent either the political or the technical barriers facing the electricity sector. According to interviewee 4, introducing decentralised generation would mitigate the political contest between parties on the location of the large centralised generation plants. Interviewee 7 stated that the strategy this thesis took to design the sector is very much logical with the Lebanese political context, and is in-line with the current situation of dividing the distribution network into three zones operated by Distribution Service Providers (DSP). The design also mitigates the technical barriers that are present at the transmission network (capacity of lines and capacity of substations). Interviewee 11 expressed a positive viewpoint regarding unbundling distribution from transmission, and saw that the current trend for the electricity sector is going in that direction. The interviewee along with interviewees 4 and 7 believed that the situation of the DSPs is here to stay and might develop further. However, interviewee 11 opposed the other interviewees viewpoints on the need for decentralised generation to be introduced to the electricity sector, and advocated for IPPs at the centralised level as a better economic solution. But what was not taken into consideration in the conversation with the interviewee is the high investment costs needed for developing the transmission sector, i.e. expressed by interviewee 7. Even with expressing scepticism regarding the economic viability of the proposed design, interviewee 11 did acknowledge two important benefits for decentralised generation, (i) the ability to introduce renewable energy sources at the consumer level, and (ii) mitigating the security threats that are facing the country.

An important aspect that would make the proposed design accepted by some political parties and part of the Lebanese society is its ability to mitigate security concerns (interviewee 4). These concerns come from some of the Lebanese parties that are termed in Lebanon as the resistance who took up arms against the Israeli occupation and aggressions (last aggression dates to 2006). Some of the current non-technical losses are due to the parties' concern to hand data of electricity usage to EdL in certain geographical locations, e.g. Beirut suburbs. Introducing decentralised generation and handing over operating and management powers to the DSO could simplify the matter. The concerned DSO would be able to identify the node at the distribution network where losses are happening, and can come up with an agreement with the concerned political party to accommodate for the losses through additional decentralised generation. This is not possible for a centralised regime that only has centralised generation as the source of power. Thus, mitigating these concerns while decreasing the non-technical losses could be achieved through the proposed design.

The final point mentioned by the interviewees regarding the acceptability of the proposed design, is its ability to be implemented in a relatively fast time when compared to centralised solutions. The current fiscal situation of the Lebanese government along with the high losses incurred by the government from the electricity sector has made time an important factor in decision-making. Therefore, following the design leads the government to save time and money.

In conclusion, the proposed design is able to mitigate time constraints, the confessionalism political regime, security concerns, and the technical obstacles of the Lebanese context. The economic constraints of the government could be also be mitigated through relying on the private sector to invest in decentralised generation, and distribution network through concessions. As for the Lebanese public, it remains to be investigated whether the proposed design is the optimum economic option when compared to centralised solutions. However, implementing the design would bring consumers the ability to invest in solar panels and make use of the net metering incentive, which would go a long way in mitigating the possible higher electricity tariffs when compared to centralised solutions (e.g. IPP at transmission). It is also of the opinion of the author that in Lebanon a trade-off would have to exist between the political acceptability and the optimum economic solution. However, this doesn't eliminate the fact that the proposed design is expected to decrease the total expenditure on electricity by the average Lebanese household, especially with the current high electricity prices that come from paying the independent energy providers (diesel generators).

5.1.2. Technologies of Decentralised Generation

As previously expressed in section 4.1.3, using the existing diesel generators from IEPs to produce power for the distribution network is technically and economically infeasible. This is mainly attributed to the high existing numbers of IEPs, i.e. >3000 IEP (interviewee 9), the inability to synchronise the generators with the network at a low economic cost, the high unreliability of the generators, and need for regular maintenance (interviewee 4, 6 and 9). Therefore, other means of generation are needed for DGs.

Diversification of technologies is encouraged; at one hand, medium sized (5-50MW) dispatchable generators that rely on fossil fuels (diesel or gas) would play the major role in decentralised generation. On the other hand, solar power at the consumer level would contribute in decentralised generation. This viewpoint was validated by interviewees 4, 6, 7, and 10, where it was recognised that dispatchable technologies must take centre stage, and the percentage of solar power from the energy mix would vary between areas. According to interviewee 10, implementing the proposed design and ensuring the reliable supply of electricity, along with the current incentives for solar power (section 3.1.1) would make solar power highly attractive for consumers. This would easily scale up solar capacity at the consumer level to at least 10% of the total generation capacity (interviewee 10). The variations of the percentage of solar power would depend on:

a. Whether consumers are in rural or urban areas. This has to do with the way buildings and houses are constructed in Lebanon, i.e. roofs of urban buildings are occupied with water tanks and TV antennas (interviewee 4). However, this problem could be mitigated by providing stands for the solar panels to be placed above water tanks and antennas (interviewee 6). Nonetheless, this would negatively affect the percentage of solar panels in urban areas.
b. The percentage of industrial consumers in the jurisdiction of the DSO. According to interviewee 10, the most promising demand sector to profit from such solar power is the industrial sector, where energy consumption is high and thus the benefits of solar power (net metering) is highly regarded.

As for the type of technology for dispatchable units, it will depend on the availability of fuel. In Lebanon, diesel fuel is used in both centralised generation plants, and IEPs. Thus, it can be predicted that new dispatchable DGs would rely on the same fuel. However, there is a possibility of natural gas based DGs, but this will depend on the progress of the current exploration for natural gas in Lebanon's offshore and the construction of infrastructure to supply the fuel.

5.2. Polycentricity in Lebanon

This section discusses the possibility of having polycentricity within the state of Lebanon. According to Ostrom (1999), for polycentricity to exist and be successful in a market, i.e. electricity market, certain pre-conditions should be met (section 2.3.2). Those preconditions were discussed with a Lebanese lawyer, i.e. M.L. Sami Hammoud (interviewee 5), where questions were asked about polycentricity in the constitutional rule, the judiciary system, and the selection of political leadership and coalitions.

As Ostrom (1999) explains for polycentricity to exist in the constitutional rule certain conditions must be met. The following table lists the six conditions for polycentricity in constitutional rule and presents the status of each in Lebanon.

Condition	status
Right of governance is assigned amongst diverse decision structures and authorities.	Exist
Constitutional changes and the process are not done the same way legislation process is done. The terms of a constitution can't be altered by a government acting upon its own authority.	Exist
Decision making capabilities are scattered amongst diverse decision-making structures, and each structure can exercise their rights in an independent manner from the others. However, there are limits and veto capabilities for structures to impose on other structures in specific cases.	Exist
Recourse to concurrent authorities with overlapping jurisdictions to reinforce the constitutional rule.	Exist
Limitations exist on governmental authorities, and constitutional rights are given to individual persons. Individuals have the right to claim for judicial remedies against the government/government officials who threaten to harm their constitutional rights.	Exist

The enforceable system of the constitutional rule will depend on the willingness of the citizens to pay the price for civil disobedience. Those citizens are also willing to challenge the constitutional rules and face punishment if their cause is not affirmed.	Exist

Table 7: Polycentricity in the Lebanese constitutional rule

Based on the answers given by interviewee 5 (table. 7), it is safe to assume that polycentricity does exist in the Lebanese constitutional rule.

Having polycentricity in the judiciary system means that the judiciary system has autonomy to rule, and is independent from the political system. Ostrom (1999) states that "if legal judgments turn only upon the discretion of superiors who are capable of directing persons as legal subordinates, then persons will have no security in their legal rights." Therefore, actors in a market who don't have confidence in the enforcement of property laws and contractual obligations will be exposed and will have little incentive to participate in the market and take economic risks. According to Interviewee 5, this is a complicated subject and can be answered in a couple of ways. The first answer comes from the Lebanese constitutions, where it asks for independence between the judiciary system and the political system, i.e. the parliament or the council of the ministers. However, in practice this is not always the case, where some infringements of the constitution are visible. An example is the process of appointing the highest Lebanese judiciary council, which comes through a split decision between the council of ministers and other judiciary chambers. This council is responsible for the judges' promotions and appointment to courthouses. However, this infringement is not visible to the everyday court proceedings (interviewee 5), nonetheless such an appointment methodology opens the door for political interventions in the judiciary system.

As for the third pre-condition, i.e. polycentricity in the selection of political leadership and in the organisation of political coalitions; Ostrom (1999) says that if there is a possibility of single political coalition to dominate the political seen within the government, this would lead to undermining the polycentric governance, legal/judiciary system, and the constitutional rule. If this is avoided, i.e. single domination, then polycentricity is safeguarded, which is the case in Lebanon. The confessionalism political system along with the need for consensus decision-making within the government opposes the formation of a single political coalition that can dominate others.

In conclusion, polycentricity in both the constitutional rule and in selecting political leadership and coalitions apply to the Lebanese case. Even with the doubt about the applicability of polycentricity in the Lebanese judiciary system, the thesis does not view major obstacles which can emerge from the above preconditions to apply polycentricity to the Lebanese electricity sector. This is also backed by the previous discussion about the possible contradiction of assuming that these preconditions must exist prior to applying it to a market (section 2.3.2).

5.3. Barriers and Challenges for Implementation

This section discusses the barriers and the possible challenges for implementing the proposed polycentric hybrid design for the Lebanese electricity sector. The following barriers could hinder the progress of the sector:

- Assigning an independent electricity regulator: the regulator would hold a lot of regulatory power, and would influence the outcome of the electricity market. Thus, political intervention might hinder the development of the regulator. According to interviewee 10, assigning the regulator was the major bottleneck for not implementing the electricity law No.462 which asked for liberalisation and privatisation of the sector. However, given the current circumstances and the perceived changes in the sector, assigning the regulator should not be a major barrier this time around (interviewee 7).

- <u>The technical and non-technical losses in the sector</u>: this is an actual barrier for any sector reform as conceived by all the interviewed Lebanese experts. However, both types of losses have been decreasing ever since the introduction of DSPs in the year 2012; in addition, implementing the polycentric hybrid design would also help in decreasing the losses.
- <u>The current tariff structure of EdL</u>: according to the latest energy policy (2010), the tariffs must be altered to be in-line with the market value of electricity produced. However, if the tariff structure is altered and subsidies are rescinded, consumers who are paying will be burdened with the increase, while consumers who are not paying will reap the benefits of increasing reliability at no cost. This a social barrier, since paying consumers will rightfully argue that they are paying for their consumption and for non-paying consumers. Therefore, solving the non-technical losses should be given priority to altering the tariff structure. This barrier is not only linked to the proposed design, but any reform strategy for the sector should take this into consideration.
- <u>The economic efficacy of the proposed design</u>: as mentioned above, it remains to be seen whether the proposed design is more economically feasible than a centralised one. However, given the other benefits of the design, it is probably a more realistic solution for Lebanon.
- <u>Transmission cost</u>: this has to do with the cost of expansion and reinforcement of the transmission lines. A mechanism needs to be devised to divide the transmission costs amongst the three different DSOs. The challenge comes from the means of this division; the author sees three possible options, (i) costs to be socialised and equally divided between the DSOs, or (ii) costs to be linked to the usage of power by each DSO, or (iii) other means like the cost-allocation scheme suggested above for balancing. This matter will eventually affect the end user price within each region, which takes us to the next challenge.
- <u>Different end-price for consumers</u>: according to interviewee 11, the proposed structure could lead to different end prices for consumers in different regions. This has to do with the degree of reliability and the investment decisions taken at level of each DSO jurisdiction. A difference in end prices and the performance of the DSOs could be means for the regulator to conduct comparisons which might ultimately lead to more efficiency in all the regions. However, the question remains, to what extent the political system and society can tolerate the difference in end prices between regions, and would that instigate public uprising against the possible price difference?

6. Discussion and Reflection

This chapter is divided into six sections to discuss the design in relation to the theory (polycentricity), and to reflect on the findings. The first section checks if the design for Lebanon is compatible with the polycentric indicators found in the "Logical Structure of Polycentricity" framework, and the ones indicated by Sovacool (2011). The second section discusses the polycentric aspect of spontaneity in the electricity market design, and whether it exists or not. The third section discusses the methodology of the Polycentric Market Design Framework (PMDF) and its contribution to market design. The fourth section explains the rationality of the steps in the PMDF, where it relates the PMDF steps to the level of analysis (figure. 5). The fifth section discusses the methodology used to conduct the thesis, and gives future recommendations for further research topics. The sixth and final section reflects on the polycentric design in relation to the Lebanese society and sectarianism.

6.1. Polycentric Indicators in the Electricity Sector

In order to assess the compatibility of the given polycentric electricity design to the indicators given by the Logical Structure of Polycentricity (LSP) framework, we need to check the compatibility of the design to both the fixed indicators in the LSP along with the need to have conflict resolution mechanism, and to the rest of the indicators in the LSP framework, i.e. A, B, C, D, E, F, and G. A conclusion on whether to generalised the indicators to other cases will be made at the end of the section.

The following can be said about the compatibility of the design with the fixed indicators and the presence of a conflict resolution mechanism:

1. Multiplicity of decision centres (attribute in LSP): the proposed design (figure. 14) has three decision-making layers, which are EdL, DSO, and prosumer.
    a. Active exercise of diverse opinions (P1): the proposed design does allow different levels in the electricity sector to exercise their diverse opinion. For example, the design hands the DSO active power to either direct the region towards more decentralised generation or relying on centralised generation from the higher level; consumers are allowed to be actively involved in generating electricity power (prosumers).
    b. Autonomous decision-making (P2): the design distributes decision making power among the player involved in the sector. Examples are: (i) consumers have the right to invest in solar power and are actually rewarded for that; (ii) the DSOs have some degree of autonomy from the central level when deciding on the investment capacity for DG in their market; (iii) DGs have the right to choose the investment technology for power generation, i.e. under certain constraints (environmental).
2. Incentive compatibility, alignment between rules and incentives (P3): to the best of the author's knowledge this aspect was preserved in the design. The selected balancing mechanism to organise the balancing relation between EdL and DSO (devolution principle) tries to align the responsibility of causing balancing cost at the transmission line with the payment. In addition, the selected access regulation mechanism for DGs balances the responsibility for DGs to connect at the optimum location at the distribution network with the charges incurred by the DG to pay for using the system.
3. Presence of conflict-resolution mechanism: in the proposed design, there exists two conflict resolution mechanisms. The first being the electricity regulator, which is responsible to balance the market power given to EdL, to protect consumers/prosumers from local tyranny through specific regulations, and to solve any conflicts that might arise between DGs and DSOs or between DSO and TSO. The other conflict resolution mechanism is courts, which is a normal conflict

resolution mechanism in most countries, and can be considered as the second line of conflict resolution if the regulator fails to do the job.

Therefore, the proposed design is compatible with the fixed indicators and the need for conflict resolution mechanism. Now turning to the rest of the indicators from the LSP framework (figure. 7), i.e. indicators A, B, C, D, E, F, and G, the following elements from those indicators describe the proposed design:

- Indicators A (Aims): the design has both shared and individual goals (A1 & A2). For example, individual goals reside in the DGs goal, i.e. to maximise profits; as for common goals, is the balancing and the reliability of the electricity network (transmission and distribution) which is shared between EdL and DSOs.
- Indicator B (Jurisdiction): the design selected B1, i.e. territorial jurisdiction. This is logical for the case of an electricity sector, given the need to dissect the regions for the DSOs to have responsibility over.
- Indicator C (Rule Design): C2 is preferred over C1. Choosing C2 might enhance the market power of certain player, e.g. DSO or EdL. Therefore, major decisions for designing the sector, e.g. unbundling rules, balancing mechanism between TSO and DSO, are converted to the regulator. However, this does not exclude the communication lines that must exist between the sector players and the regulator, e.g. EdL or DSO, who can offer feedback on the outcome of the sector design.
- Indicator D (Collective Choice): the design mainly follows the individual decisions choice (D2). For example, decentralised generation investment (by DG providers), switching from consumer to prosumer, capacity needed for decentralised generation (by DSO) …etc.
- Indicator E (Entry): the design only allows merit-based entry (E2) for DG at the distribution network, i.e. based on the lowest bid by the DG bidders. However, for consumers, free entry (E1) is guaranteed for solar power generation (prosumer).
- Indicator F (Exit): it is not in the best interest of the DGs to exit the network (loss of investment), this makes it a constrained exit (F2). For prosumers, there are no specific laws that constrain their disconnection from the network, however it is also not of their interest to disconnect their solar panels from the network.
- Indicator G (Information): for the proposed design, some information is designed to be public (G1), e.g. the Contract Deferral Scheme (CDS) auctioning mechanism, which provides transparency and trust to the public. Other information, e.g. the ones used to calculate the "long run incremental cost" (LRITC) for the distribution network use of system (DNuS) are meant and recommended to be public (G1). However, other considerations in the Lebanese context must be taken (security), which might lead it to become private (G2). This switch from G1 to G2 is one of the risks that could lead the polycentric structure to become a monocentric design (Aligica and Tarko, 2012).

According to Aligica and Tarko (2012), certain choices in the above (un-fixed) indicators render the design susceptible to failure, i.e. the design could fall towards either a monocentric system or chaos. Those choices are A1, B1, C2, D3, E2, F2, and G2. Comparing the choices done for Lebanon with the given risky choices we notice that the design chose to use B1, and C2, while partly choosing A1, E2, F2, with the possibility of G2 for some aspects of the design. Thus, the proposed Lebanese design does not completely adhere to those constraints/indicators set by the LSP framework.

The outcomes of the above analysis are:

a. The fixed indicators of the LSP (P1, P2, P3), the need for a conflict resolution mechanism in the sector, and the indicator B1 could be generalised for other cases when designing a polycentric electricity sector.
b. The polycentric indicators for energy infrastructures which are presented by Sovacool (2011), i.e. explained in section 2.3.4.1, can also be utilised as constraints for designing a polycentric hybrid electricity market. The indicators given by Sovacool captures all the fixed indicators from the LSP (P1 P2, and P3), in addition to the need for a conflict resolution mechanism, and encouraging sharing of information between stakeholders, i.e. making information public (G1).
c. Choosing G2 for Lebanon with respect to the information involved in the distribution network use of system (DNuS) mechanism (LRITC) is undesirable.
d. It remains to be seen if the indicator options A1, C2, E2, and F2 pose a threat to the design of a polycentric electricity sector. Therefore, this study is not able to answer the question related to the suitability of those unfixed indicators to the design of a polycentric electricity sector.

6.2. Spontaneity in Designing the Electricity Sector

This section examines the compatibility of designing an electricity sector with the element of spontaneity which is found in polycentricity. Ostrom (1999), explained that in a polycentric structure spontaneity meant that the modes of organisation should be self-organising or self-generating, so that actors will be self-incentivised to establish appropriate relationships between each other. However, this is not the case for the design of the electricity sector; the intention of designing the electricity sector is to find the appropriate design options and relationships between the various actors to achieve the objectives of the design. In this case the objective was to design an "acceptable" structure for the Lebanese electricity sector, which is able to circumvent the political and social barriers of Lebanon. Therefore, a structured approach needed to be used to come up with the design, which lead to designing and selecting the modes of organisation between the actors involved.

Three conclusions come out of this:

a. For the Lebanese case: Subjecting the modes of organisation to the rule of spontaneity is not an option for the electricity sector, otherwise the author sees the outcome of the sector turning into chaos. This is specially the case for relations between the actors involved in the Lebanese situation.
b. The aspect of spontaneity needs further investigation when it come to the relation between the prosumers and aggregators/local governments in an environment different than the Lebanese one. Spontaneity can be an important aspect when explaining the relation between prosumers and local governments, where it can play a role in creating local energy communities. These local communities would be connected to the DSOs through local governments, i.e. aggregators.
c. Spontaneity can only serve the relation between prosumers and local governments. Other relations within the sector must be subjected to a structured manner that are designed and defined prior to implementation.

6.3. Assessing the Polycentric Market Design Framework

This subsection discusses the Polycentric Market Design Framework (PMDF), specifically reflecting on its methodology and its contribution in designing an electricity market. Creating the PMDF necessitated two important phases; the first was done by devising the general structure of a polycentric electricity sector. The first phase is shown through the first step in the PMDF, which took most of chapter two to achieve. The second phase is the rest of the steps, which actually dictates how to design a polycentric electricity sector for a given case.

The first phase can be described as the phase that looms in the "back-stage", and is not case-specific. This phase was achieved through referring to the most relevant polycentric indicators in the LSP framework (P1, P2, P3, and conflict resolution mechanism), the description of markets within a polycentric structure, a general polycentric structure (figure. 6), and constraining the modes of organisation that govern the relation between the different actors in the sector into two modes. Thus, the first phase ended at the end of section 2.4, and by creating figure. 8. This phase resulted in several aspects, which include:

a. Unbundling of transmission from distribution. However, the nature of unbundling (ownership, legal, or accounting) is not determined.
b. The creation of a multiple levels of decision making in the sector, i.e. central and decentral levels.
c. Existence of centralised and decentralised generation
d. Desirability of having prosumers in the structure
e. Existence if a regulator: its position is not finalised, even though a recommendation is given for it to operate at the central level.
f. The Question of whether to have local (decentral level) retail competition or not.
g. The Question of whether to have local aggregators or not.
h. Modes of organisation being constrained between "lead organisation" and participant-governed" modes.
i. Having local markets at the decentral level.

We can see that this phase has opened the door for new hybrid market models, which do not abide with the singularity depicted by the four market models introduced by Hunt and Shuttleworth (1996), i.e. figure 4. In general, an electricity market can be categorised as belonging to one of the four models presented by Hunt and Shuttleworth. However, the PMDF could end-up with a hybrid model, that integrates two of the four models. For example, the Lebanese context ended-up in having vertical integration (with the possibility of IPPs) at the centralised level, while having a market model at the decentral level that resembles a single-buyer model with private decentralised generation. Another outcome of the PMDF could be having the vertical integration at the central level, while having retail-competition at the decentral level.

The second phase of the PMDF starts from step two of the framework till the last step, i.e. step 7. These steps are responsible to design the polycentric hybrid electricity market in a given context, e.g. Lebanon. The logic of the first step in this phase, i.e. step two in the PMDF, is that you need to investigate and select which of the actors presented in the general structure (figure. 8) fits the context you have. This step results in determining the degree of market opening for your case. After selecting the jurisdiction of the DSOs within the decentral layer (step 3), the PMDF moves to the fourth important step which is figuring out how to govern the relations between the various actors in the sector. When designing the Lebanese sector, it turned out that this step would answer the following:

a. The balancing mechanism, i.e. separation of balancing duties between DSO and TSO.
b. The relation between the DSO and the decentralised generators which is the market design at the decentral level, i.e. the quasi-market (section 2.3.5).
c. The mechanism of trade amongst different jurisdictions, i.e. possibility of trade between the DSOs. This was not relevant for Lebanon.

Another question the fourth step would have to answer for other case studies is "capacity mechanisms". This was not a relevant question for the Lebanese design, because of the non-existing retail competition. However, in other cases this aspect has to be resolved in the fourth step due to its nature in figuring out the organisational relation between some actors in the sector. Capacity mechanisms are put in place to incentivise investors to provide the adequate level of investment in generating capacity (de Vries et. al, 2010). This means that this variable governs the relation between generation investors and another actor within the polycentric structure. For example, if the "reliability contracts" mechanism is chosen, it would mean that organisational contracts are held between the investors and the system operator (de Vries et al., 2010). If reliability contracts are aimed at decentralised generators, it means that the system operator would be the DSO in the polycentric sector. Another example is the "capacity subscription" mechanism, which dictates a mode of organisation between the investors and the consumers, i.e. retailers (de Vries et. al, 2010). This line of reasoning would also apply to the "congestion management" market design variable, where it answers relational aspects between specific actor. Therefore, we can conclude that both "capacity mechanism" and "congestion management" must be solved within the fourth step.

The fifth and sixth step in the Polycentric Market Design Framework (PMDF) select the relevant market design variables and their respective options. However, it can be noticed from the above steps that five out of the initial 13 market design variables are already answered. This means that eight are left unsolved, and steps 5 and six should tackle them. The seventh and final step decides on a pathway to implement the design, i.e. which aspect comes first when implementing in real-life.

Several conclusions could be made from looking at the explanations above, and comparing the methodology of the PMDF with the approach of Littlechild (2003), i.e. adopted by Correljé and de Vries (2008), in designing an electricity market:

a. The first phase of the PMDF (step 1) is not context-specific, it is the starting point and a reference point to design the case-specific sector. While all the variables and market design exercise in Correljé and de Vries are context-specific.
b. Second conclusion is that the PMDF starts the case-specific design phase (phase 2) with the most comprehensive market model, i.e. retail-competition, and moves backwards to investigate which actors for that case are relevant and which are not. Whereas, Correljé and de Vries approach describes how an electricity market moves forward and opens up from being a vertically integrated sector all the way to end-up with the retail-competition model (figure. 4).
c. Third conclusion is that the PMDF decides that transmission and distribution must be unbundled in the first phase of the PMDF (step 1), i.e. even before designing for a specific case. While in Correljé and de Vries approach this aspect is decided per context.
d. The fourth conclusion is that the PMDF is a smoother and more-structured way to design an electricity market, where there is a starting point to reflect upon. The simplicity of the PMDF method also comes from its ability to explain how each step serves the purpose of coming up with the final structure of the sector. For example, the explanation given by the step of modes of organisation is important in the respect that it answers the questions of relationships between the various actors. This does not mean that Correljé and de Vries's approach does not answer all the important questions when it comes to design the sector, which also include the relationship between the actors. But, the PMDF makes it clearer and shows how the market design variable are related to the general structure of the sector (figure. 8). Therefore, it can be said that the PMDF has more explanatory power over Littlechild's (2003) approach (adopted by Correljé and de Vries (2008, p. 76)).
e. The Fifth conclusion is that the PMDF does not create a new market model out of the blue, but instead opens up the possibility of integrating two different market models within the same country, i.e. one at the central and another at the decentral level.
f. The sixth conclusion is that Correljé and de Vries approach is a broader and a more comprehensive approach than the PMDF. The PMDF is mainly directed at a polycentric hybrid electricity sector, where the first phase of the PMDF methodology constraints the rest of the case-specific decisions that follows.

Positioning the PMDF within the conceptual framework that explains the different factors that influence the development of the electricity markets (figure. 16) gives a better understanding of the contribution of the PMDF. Figure. 16 is devised by Correljé and de Vries (2008), and within this framework the PMDF can be positioned in the market design box (red coloured). This explains that the PMDF is a methodology to design an electricity market, and it does not capture the entire picture which shows the contributions for developing the sector. Nonetheless, it's still a very important component in the whole picture.

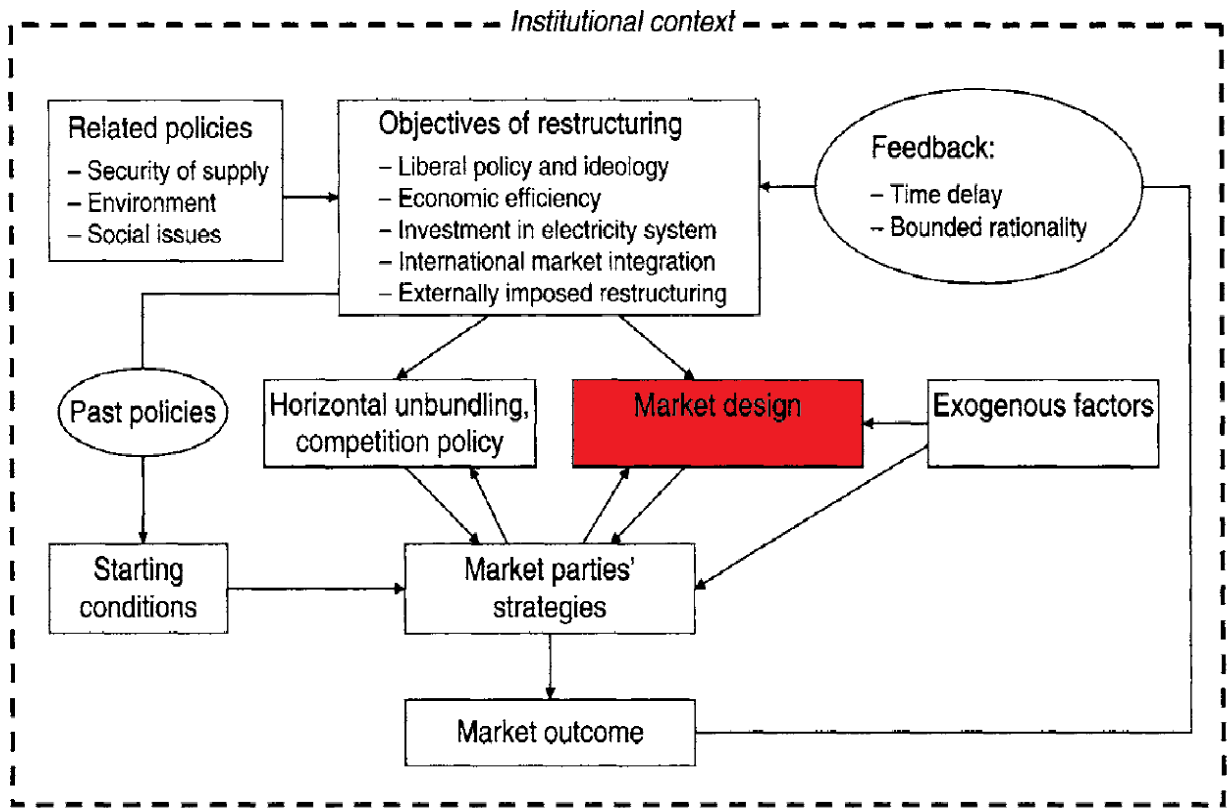

Figure 16: Conceptual Framework showing different factors that influences the development of electricity markets. Source: Correljé and de Vries (2008, p.75).

6.4. The Rationality of the Polycentric Market Design Framework

This subsection discusses the rationality of the presented steps in the Polycentric Market Design Framework (PMDF), and the link between the three blocks that constitutes the PMDF, i.e. the polycentric theory, the concept of modes of organisation, and the electricity market design variables. The aim of this section is to check whether the PMDF followed the line of analysis presented in the four-layer model of Williamson (figure. 5). At the beginning of the study it was stated that Williamson's model is utilised as a way to link the three main blocks that constitute the PMDF. The study started with the logic that each block is separate from the other blocks, and that decisions or selections are finalised within a block and then the design would move on to a different block. Categorising the three blocks in Williamson's framework was done to get a logical sense on how to create the sequential steps in the PMDF, i.e. which block should come prior to the other blocks while designing the PMDF. Thus, one way or another Williamson's model aimed to shape the design of the PMDF.

When it comes to the first major block, i.e. polycentricity, this block was situated in level 2a in Williamson's framework. It was stated that the indicators and attributes of polycentricity would mainly serve as constraints to the decisions made in the succeeding levels of Williamson's model, i.e. the other two blocks. The aspects of utilising the indicators and attributes of the polycentricity as constraints proved most fruitful to design the sector. However, it can be noted now that only limiting the indicators and attributes to level 2a is not entirely accurate. For example, indicators P1 and P2 from the "Logical Structure of Polycentricity" (LSP) could perhaps be situated in level 2a, because they constrain the highest level of electricity market design, i.e. unbundling and degree of market opening. While other indicators in the LSP framework could actually be utilised to constrain decisions made on market design variables that belong to lower end levels of Williamson's framework, i.e. variables belonging to layer 3 and not layer 2b. An example is the indicator G (information), where the need to have information public is a desired design trait for the design, and this would concern the market variable "Network regulation for tariffs and access conditions" (layer 3). This indicator, and whether to have information public or private would also concern other design aspects in different levels of the Williamson's framework, i.e. level 4 where resource allocation and employment issues are done. Therefore, while I do still believe that the structure and main indicators of polycentricity (fixed indicators), e.g. multiplicity of decision centres and presence of conflict-resolution mechanism, does reside in layer 2a of Williamson's framework, not all indicators of polycentricity can be categorised in layer 2a of the framework. Two conclusions come from the above; first conclusion is that polycentricity is a theory or way of thinking that affects all aspects of the electricity market design, from layer 2b to layer 4. Second conclusion is that positioning polycentricity and its fixed indicators at the start of the analysis to start with designing the PMDF was done correctly in chapter 2.

Next is the market design variables block (thirteen), in which the variables were positioned in two layers, i.e. layer 2b and layer 3. The variables that belong to layer 2b are "network unbundling", "capacity mechanism", and "degree of market opening". This positioning was taken from the adopted model of Williamson, i.e. done by de Vries (2017). The PMDF methodology does not come in conflict with categorisation of two of the above variables, i.e. "network unbundling" and "degree of market opening". The "network unbundling" variable is solved in the first step of the PMDF, where it can be noticed that the PMDF moves from layer 2a (aspects related to polycentricity in general) to aspects related to polycentric electricity sector and its general structure (layer 2b). The "degree of market opening" is solved in the second step of the PMDF, which means that the second step could be categorised in layer 2b as well. Thus, for the second step there is not conflict between the PMDF and Williamson's model. The third variable "capacity mechanism" is solved in the fourth step of the PMDF, categorising it in the modes of organisation block (as well as market variable block). However, the "modes of organisation" block was categorised in layer 3 in Williamson's model (figure. 5). Therefore, there might be an error in exclusively categorising the "modes of organisation" block in layer 3.

The rest of the market variables that also belong to the modes of organisation block, i.e. balancing mechanism and congestion management (figure. 17), are categorised in layer 3. It can be therefore noted that step 4 in the PMDF is a transitional step that covers both layers 2b and 3 in Williamson's model. Step five and six in the PMDF, which design the rest of the market design variables, belong to the third layer in Williamson's model. Therefore, no conflict exists in those steps between the PMDF and Williamsons' model.

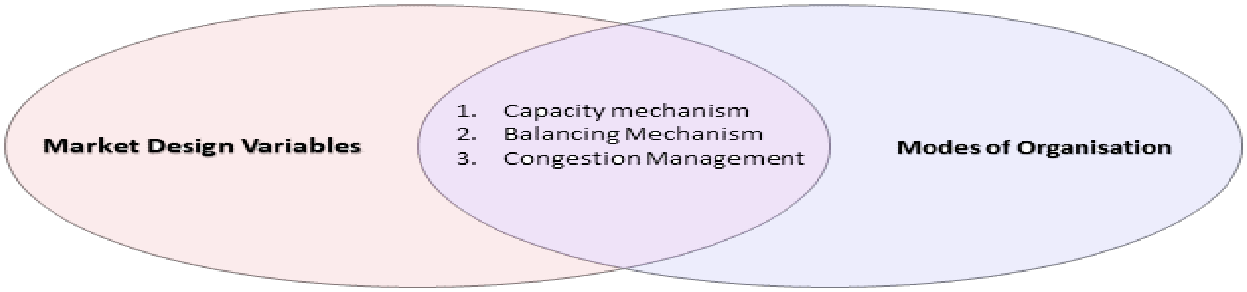

Figure 17: Common aspects between the Market Design Variables and the Modes of Organisation blocks

This section concludes the following important outcomes:

a. The influence of the polycentricity block spread from layer 2a to layer 4.
b. The “modes of organisation” block belongs to both layers 2b and 3.
c. The “market design variable” block belongs to layer 2b and 3.
d. Williamson’s model initiated the way of thinking to try and link the various aspects in the three important blocks. However, relying solely on Williamson’s model and the exercise of categorising each block to an exclusive one layer in the model turned out to be wrong. All of the three blocks proved to belong to various layers in the model.
e. Williamson’s model is not able to give a stepwise methodology to design a polycentric hybrid electricity sector. It is more of an indication to understand how some aspects influence each other. The process of understanding and coming up with a stepwise framework from the Williamson’s model proved to be extremely difficult.
f. There are common aspects between the “market design variable” block and the “modes of organisation” block (figure. 17).
g. The initial though of separating each of the three blocks is understandable and can be deemed necessary at the beginning. This separation allowed the study to understand the blocks separately, understand the interaction between their asoects, and finally understanding the common aspects between the blocks. Therefore, at this stage of the study it is not necessary to keep them separated.
h. Investigating and deciding on all aspects within one block and moving on to another is found to be incorrect in the Polycentric Market Design Framework (PMDF).

6.5. Scientific Reflection and the Way Forward

This section reflects on the methodology used in conducting the research for this thesis. It also reflects on the novelty achieved by the PMDF and gives recommendations on the way to move forward for future research.

Starting with the methodology used to conduct the research for this study; the author relied on two important aspects, (i) literature studies, and (ii) interviews. Both research methodologies proved to be most fruitful in coming up with the final findings of this thesis. The Literature proved to be the most important aspect to create the Polycentric Market Design Framework (PMDF). Whereas the interviews were instrumental in designing the Lebanese polycentric electricity sector, and validating the design.

Information on designing came from interviews of category one, while validation came from interviews from category 2 (Table. 1). Experts were not asked to validate the Polycentric Market Design Framework, and the logic used to create it. This was not done, because the PMDF's final design was done at the latter stages of the thesis. However, it can be noted that the experts' opinions regarding the Lebanese design helped in shaping up the steps of the PMDF in an indirect way. Another shortfall of the methodology is the inability of the author to conduct an interview with one of the Distribution Service Providers (DSPs) found in Lebanon (check section 3.1.2.3). An interesting investigation of this research could have been to check if the existing DSPs are able to switch their business model from the current situation to the one proposed by this thesis, i.e. a Market Distribution System Operator (figure. 12).

The study was able to achieve new outcomes and overcome many hurdles. The thesis took a novel approach in designing an electricity sector, where it might be considered one of the pioneers in designing a polycentric electricity sector. To the best of the author's knowledge no prior attempts have been made to design a polycentric hybrid electricity sector. This attempt resulted in creating the Polycentric Market Design Framework (PMDF), along with a general polycentric structure for the electricity sector (figure. 8). The PMDF proved to be most fruitful in guiding the designer to achieve the polycentric design for Lebanon, and the logic behind its methodology is a novel approach to design an electricity market.

As discussed above (section 6.3), the PMDF does not contradict with Littlechild's and Correljé and de Vries's approaches. It just sheds light on the market design for a polycentric structure from a different angle using some of the same tools, i.e. market variables, indicated by Littlechild. However, the PMDF approach was only used for a polycentric electricity structure, and it remains to be seen whether the same methodology can be utilised for other electricity structures.

Given the findings of this thesis, we can indicate the following recommendations in moving to the next stage of research. These recommendations are mostly directed to research not related to the Lebanese situation:

a. Investigating which of the options in the unfixed polycentric (LSP) indicators could pose a threat to the design of a polycentric hybrid electricity sector. The ones indicated by Aligica and Tarko (2012) were A1, B1, C2, D3, E2, F2, and G2, i.e. for a general polycentric structure. However, it was proven (section 6.1) that B1 and C2 are more logical and enhance the electricity polycentric structure rather than risking the failure of design. Therefore, it remains to be seen whether the rest, i.e. A1, D3, E2, F2, and G2, pose a risk to the design if they are chosen.
b. Linking the unfixed LSP indicators and the detailed steps in the PMDF could be a next topic to investigate. The current PMDF gives clear indication on the way the fixed LSP indicators along with the need to have a conflict resolution mechanism effect the final structure and design of the polycentric electricity sector. However, the same is not done when it comes to the unfixed LSP indicators. Those indicators would most probably affect decision that happen in steps four, five, and six, i.e. modes of organisation and market design variables. Therefore, a detailed analysis to check which unfixed indicator constrain which market variable or relation between actors could be a good way forward for the PMDF.
c. The PMDF's steps five and six could be further divided into more steps. After step four in the PMDF eight market design variable remain to be investigated, which are in steps five and six. The logic would be to investigate which of the remaining variables should be selected prior to the other.
d. The technical functions of the electricity sector were indicated early on, i.e. chapter two. They were treated as constraints, i.e. the need to safeguard them by making sure that the actors responsible to execute those actions are incentivised to do so. This exercise was established at the end of chapter four for the case of Lebanon, where responsibilities were assigned. Assigning

the responsibilities was done as a result of the market design exercise throughout chapter 4. However, the PMDF does not clearly show this aspect, which is natural since it's a market design framework. Nonetheless, to further develop the PMDF research could focus on integrating the need to safeguard the technical functions in the PMDF steps. This could probably be realised by taking inspiration from Scholten and Künneke's "Comprehensive Design" Framework (2016), check Appendix A.

e. Investigating whether the PMDF methodology could be utilised for other electricity market design models, i.e. other than polycentric.

6.6. The Design and Sectarianism

As explained in the introduction and chapter 3, Lebanon's political system is a sectarian confessionalism system. This system is seen by many as the reason behind the continuous political and social turmoil that engulfs the country, as well as the major reason behind the instigation of the civil war which lasted for 15 years (1975-1990). The proposed polycentric design relies on a dividing the distribution network (already in place) into three regions (centres) and giving each centre some degree of autonomy for decision-making and exercise of governing power, which is distinct from the others and from the central level. While such design has a high possibility of ending the political disagreement over the electricity sector, in turn it might bring more social separation. There might be a good reason to fear that such a sectoral design is actually reinforcing the sectarian conflicts between the factions instead of bringing them unity. The other side of the coin is that the design might be reinforcing social capital, which is done through incentivising RES at the consumer level, or the possibility that the DGs (medium-sized) are provided through community investments (e.g. municipality).

As argued above, development in the electricity sector has not been happening mainly due to the political interventions and the fight over power or control over resources in the country. Not taking the possibility that this design might be fuelling the sectarian conflicts in the country, it is easy to say that this design can actually be a very promising solution for Lebanon. However, handing over power to the DSOs, i.e. division of DSOs, I am acknowledging that current socio-political structure of Lebanon is here to stay. Therefore, instead of providing unity through the "network effect" I might be dividing the country further. To achieve an answer for the question of "Does the proposed polycentric electricity design fuels the already existing sectarian political system in Lebanon?" very difficult question it is advisable that a study concerning this topic must be done.

7. Conclusion and Recommendations

This chapter concludes and give recommendation for futuristic research related to the polycentric design of the Lebanese electricity sector. The chapter is divided into two sections, the first section elaborates the conclusions. The second section provides recommendations for further research linked to the Lebanese situation.

7.1. Conclusion

This section is divided into two subsections to differentiate between the conclusions from coming up with the Polycentric Market Design Framework, and the conclusions related to the Lebanese design. The first subsection relates to the PMDF and the theoretical framework used, while the second related to the Lebanese context.

7.1.1. Theoretical Framework

An important outcome of this thesis is its ability to create a novel approach to design a polycentric hybrid electricity sector. The approach termed, the "Polycentric Market Design Framework" (PMDF) is believed to be generalisable and has the ability to serve other cases to design a polycentric electricity structure. In addition, the conceptual polycentric model created for the PMDF (figure. 8) can also be generalisable to serve as a starting point for the design exercise of specific-cases, i.e. second phase of the PMDF. This approach has proven to be a very efficient and explanatory methodology in designing a polycentric electricity structure.

This thesis was able to achieve several important outcomes, most notably is the comparison between the comprehensive and general indicators of the polycentricity, i.e. found in the LSP framework, and the indicators given by Sovacool (2011) which describe a polycentric energy infrastructure. The study believes that Sovacvool's narrower indicators, that do not come into conflict with the LSP's indicators, are better served to be utilised as constraints to design a polycentric hybrid electricity sector.

7.1.2. Lebanon

This study started with the objective to design a polycentric hybrid electricity sector for the Lebanese case. The intention of the design was to help Lebanon overcome its barrier (political and social) and to achieve a reliable electricity sector, and for that the following main research question needed to be answered:

"What polycentric governance structure(s) would constitute an acceptable arrangement for a hybrid electricity sector for the case of Lebanon?"

The question asked for two things, (i) designing a polycentric hybrid electricity structure, and (ii) having that structure accepted in the Lebanese context. We can conclude that this thesis was able to achieve its objective of designing an acceptable polycentric hybrid electricity structure for Lebanon. The proposed structure (figure. 15), was able to build on the current electricity market of Lebanon to get to the final design. The design kept EdL as the major player at the central level of the design, i.e. transmission and centralised generation; while separating distribution and creating a level of autonomy for distribution system operators (DSP) to run the decentral level of the structure. A division of the distribution network was achieved based on the current situation, i.e. only three regions, which would cushion the potential negative effects of dividing the country into small sectarian-related regions, while having this division accepted by the involved political parties of Lebanon. The ownership model of the DSOs would remain as the current model depicts, i.e. concessions to private entities, with the eventuality of retrieving the operation and management rights to legally unbundled state-owned distribution firms. This option is prioritised for Lebanon, because there is a need for continuity and fast implementation which are two important deciding factors. The decentral level would also include decentralised generators (DG) that would have to be selected based on the auctioning mechanism named “Contract Deferral Scheme”; and the DGs would be incentivised to connect to the distribution grid at the optimum location. Prosumers would also play an important role in this structure, in which the current incentive mechanism to produce solar power at the household level would go a long way in encouraging consumer switch to prosumers.

Therefore, the proposed design (figure. 15) is able to circumvent the political and social barriers imposed on reforming the electricity sector of Lebanon. Whether the barriers come from the sectarian-political system of the country, or the social need to lower the total electricity bill (EdL’s plus IEP’s bills); the design would be accepted by both mentioned actors. The proposed design, i.e. division and market power given to DSOs, would go a long way in persuading the political parties to accept the design. It also ensures that consumers are able to produce cheap solar power to mitigate part of the electricity bill. In addition, the design was able to mitigate the technical bottlenecks which are found at the transmission level, giving this design the potential of being much cheaper for the Lebanese government when compared to the latest Lebanese energy policy of Bassil (2010). Now, whether to call the design a polycentric one might be up to different interpretations. If “spontaneity” and all the unfixed indicators in the LSP framework are essential for the realisation of a polycentric structure, then the proposed electricity sector design could not be fully described as a polycentric one. However, if interpreting polycentricity comes from the indicators (variables) that are indicated by Sovacool (2011), then the proposed design did adhere to those indicators and thus it can be categorised as a polycentric electricity sector. Therefore, the author thinks that the proposed design is a polycentric one.

On a final note, the author thinks that branding the final design as polycentric or not is not as important as finding the right structure for the Lebanese electricity sector, which was achieved through this thesis.

7.2. Recommendations

The following recommendations also serve the purpose of progressing with this study to achieve and implement the final aim of an acceptable and reliable polycentric electricity sector in Lebanon:

- Investigating ways to implement the seventh step of the Polycentric Market Design Framework, which calls for finding out how to implement the design. Investigation should look at which of the design aspects should come first, e.g. should the regulator be appointed at the beginning to oversee the plan of action.
- Investigating the investment level needed by the Lebanese government to apply the proposed design, and compare it with the one proposed in the latest energy policy (Bassil, 2010).
- Investigating whether the existing Lebanese DSPs are able to change their business model into a market DSO (figure. 12).
- The optimum balancing cost distribution between DSO and consumers (0-100%). This is part of distributing the economic-risk of balancing the distribution between the DSO and the consumers. Therefore, it is important to make a decision on that for the Lebanese case.
- Exploring the hedging mechanism which is supposed to protect the DSO from the uncertainty created in the Devolution principle for balancing costs. The hedging mechanism should remove any deterrent for the development of renewable energy sources.
- Investigate whether there is a possibility for local governments, i.e. municipalities, in Lebanon to play a role in the proposed electricity sector. This does not mean having them as retailers or aggregators, because that was proven to be incompatible for Lebanon. But a proposition is to have municipal boards to monitor the activities of the DSOs, which would bring more involvement to the communities in the electricity sector. Such monitoring could be utilised in order to make sure that the interest of prosumers and consumers are safeguarded, and would serve as a second

mechanism to safeguard consumers interests. This second mechanism would be advised to interact and coordinate with the first monitoring entity, i.e. the regulator.

- Investigating the possible effects of the proposed design on the Lebanese society and the possibilities that such a design is reinforcing sectarian conflicts instead of reinforcing social capital. If the former is found to be true, the author believes that such a design should not be implemented in Lebanon, and an alternative electricity market design should be investigated.

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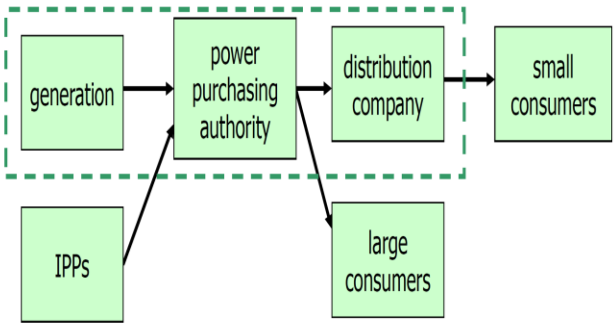
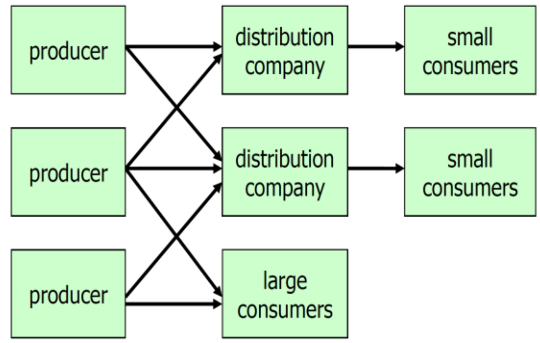
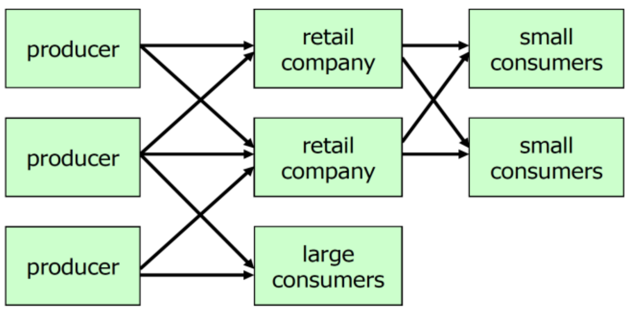
Appendix A







Single Buyer Model, Wholesale Competition, and Retail Competition (respectively). Source: de Vries (2017, p. 33)

Recommendations	Plan of Minister Mohammad Fneish	Plan of Minister Alain Tabourian	Plan of Minister Jebran Bassil
Generation			
Use NG/LNG for operating Deir-Ammar/Zahrani plants	☒		☒
Rehabilitate or upgrade existing plants		☒	☒
Build new public CCGT plants	☒	☒	☒
Build new IPP-CCGT plants	☒		☒
Build new coal power plants		☒	
Convert/build most power plants on natural gas	☒		☒
Install generators for the short term		☒	☒
Diversify energy sources		☒	☒
Build new capacities in the field of renewable energy	☒		☒
Allow private generation	☒		☒
Build new public or private hydro power plants			☒
Build new IPP-wind power plants (private sector)			☒
Build new "waste to energy" power plants			☒
Conduct pre-feasibility studies on Photovoltaic (PV) farms			☒
Build a gas pipeline along the coast			☒
Build LNG marine station(s)	☒		☒
Transmission			
Complete the 220 kV network	☒		☒
Complete the 400 kV Ksara station	☒		☒
Establish the Electricity National Control left	☒		☒
Build regional substations			☒
Distribution			
Implement Automatic Meter Reading (AMR) schemes or remote control meters	☒		☒
Encourage the private sector to invest in and develop the distribution networks	☒		☒
Administration and finance			
Increase the human resource capacity	☒		☒
Activate the financial and administrative computerization	☒		
Accounting and financial auditing	☒		
Energy auditing			☒
Appoint a new board of directors	☒		
Corporatization of EDL	☒		☒
Increase the tariff			☒
Implement Time Of Use (TOU) tariffs			☒
Legislation			
Amend the Law 462	☒		☒
Adopt an energy conservation law			☒
Resolve the problems with the current concessions			☒
Ratify the Kyoto protocol	☒		
Adopt a Law that encourages all forms of public private partnership at the level of generation			☒
Energy efficiency			
Encourage the adoption of solar thermal energy (SWH)	☒		☒
Encourage the use of compact fluorescent Lamp			☒
Encourage the use of energy saving public lighting			☒

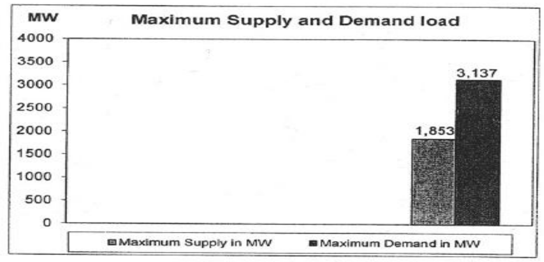
Table. 1: Summary of electricity reform plans. Source: Ibrahim et al. (2013, p. 271)

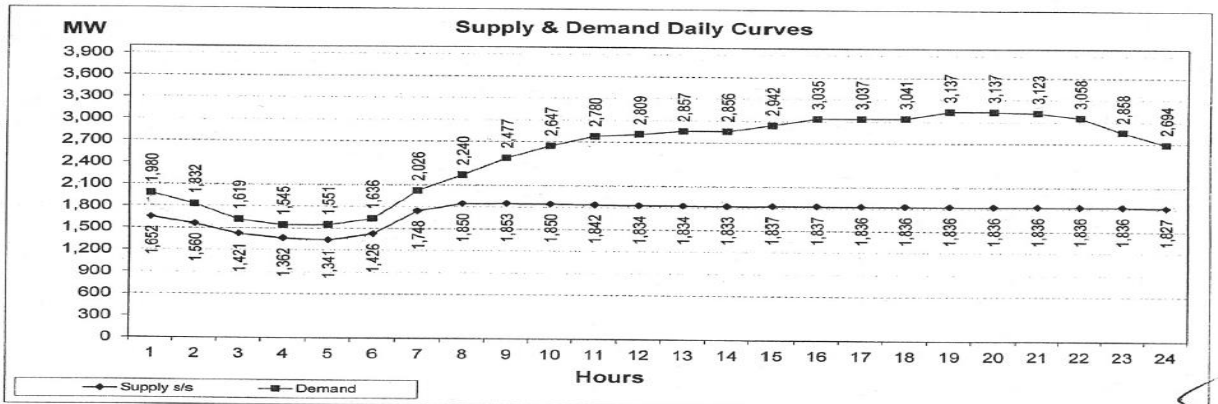
كهربــــاء لبنــــان
مؤسسة عــامة
مـديرية النقل-مصلحة حركة الطاقة

جدول رقم -2-
مقارنة يومية بين الطاقة المستمدة والطاقة المطلوبة

Tue, Jan 23, 2018			
Temp./c : 17	Humidity : 63%		
	Supply s/s	Demand	Suppressed
1	1,652	1,980	328
2	1,560	1,832	272
3	1,421	1,619	198
4	1,362	1,545	183
5	1,341	1,551	210
6	1,426	1,636	210
7	1,748	2,026	278
8	1,850	2,240	390
9	1,853	2,477	624
10	1,850	2,647	797
11	1,842	2,780	938
12	1,834	2,809	975
13	1,834	2,857	1,023
14	1,833	2,856	1,023
15	1,837	2,942	1,105
16	1,837	3,035	1,198
17	1,836	3,037	1,201
18	1,836	3,041	1,205
19	1,836	3,137	1,301
20	1,836	3,137	1,301
21	1,836	3,123	1,287
22	1,836	3,058	1,222
23	1,836	2,858	1,022
24	1,827	2,694	867
Total(MWh)	41,757	60,915	19,158
Average(MW)	1,740	2,538	798
Maximum(MW)	1,853	3,137	1,301
Minimum(MW)	1,341	1,545	183

Load Shedding:	
Daily Load Shedding:	7.55 hours or 452.88 min.
of average demand equivelant	114.79 days per year



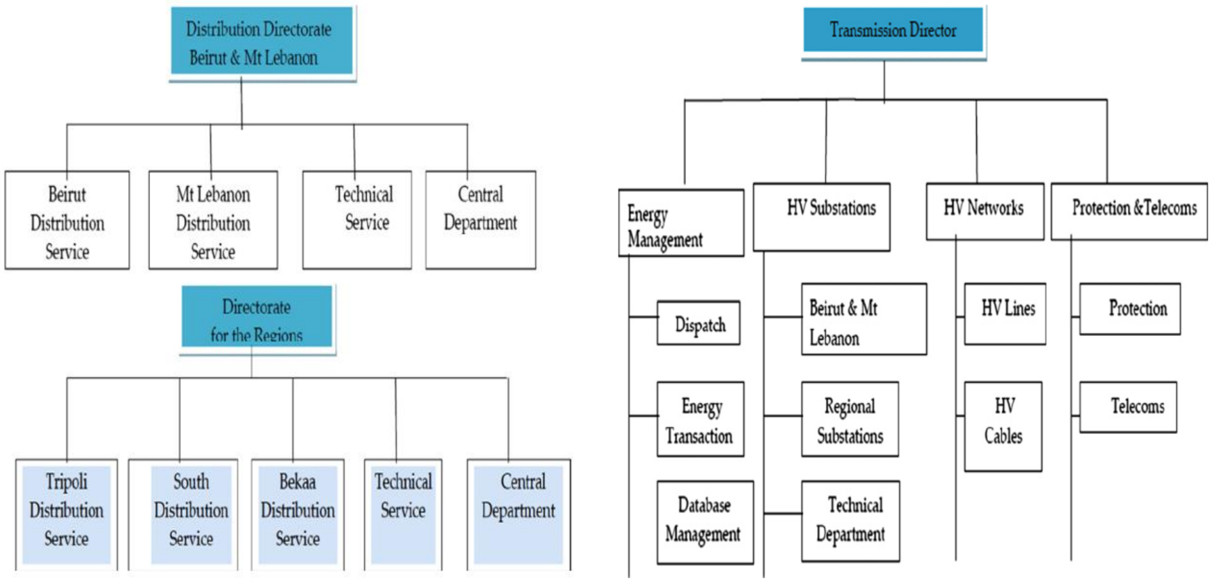


NOTE : SUPPLY S/S = SUPPLY AT SUBSTATION

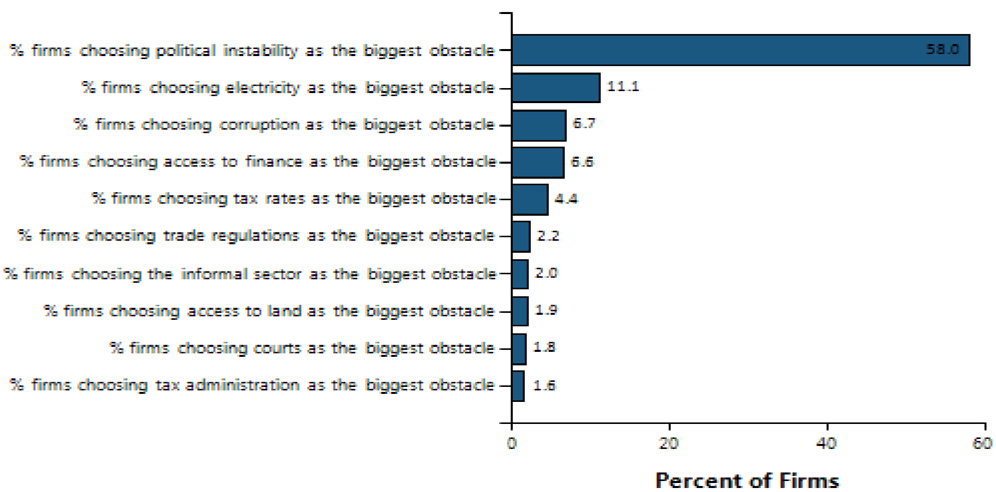
Supply vs. Demand on 23, January 2018. Source: Ghajar.

Research participant	Location	Family size	Area type	House type	Power cut/day (approx.)
1	Greater Beirut	4	Suburban dense	Flat	6–8 h
2	Greater Beirut	3	Peri-urban	House	8–12 h
3	Greater Beirut	5	Peri-urban	House	8–12 h
4	Greater Beirut	3	Suburban dense	Flat	6–8 h
5	Greater Beirut	4	Suburban dense	Flat	6–8 h
6	Central Beirut	2	Urban dense	Flat	3–6 h
7	Satellite town	3	Semi-rural	House	8–12 h
8	Greater Beirut	3	Suburban medium	Flat	8–12 h
9	Greater Beirut	4	Suburban dense	Flat	6–8 h
10	Central Beirut	5	Urban dense	Flat	3–6 h

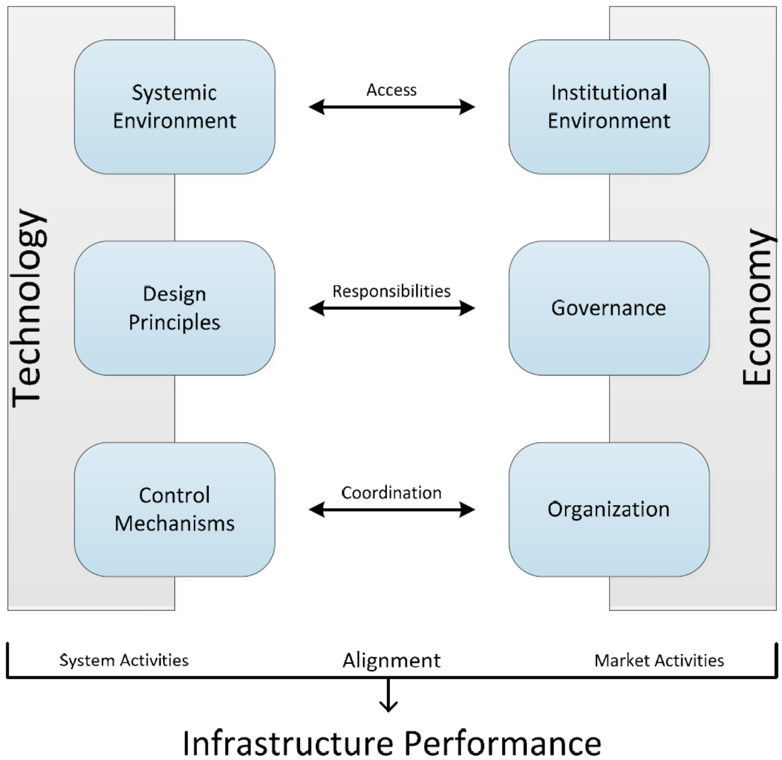
Table. 3: Average power cut in the region of greater Beirut. Source: Abi Ghanem (2018, p. 39).



Organisation of Distribution and Transmission Directorate in Edl. Source: Ibrahim et al. (2013, pp. 266 and 269)



Ranking of the Top Business Environment Obstacle for Firms in Lebanon. Source: World Bank (2019).



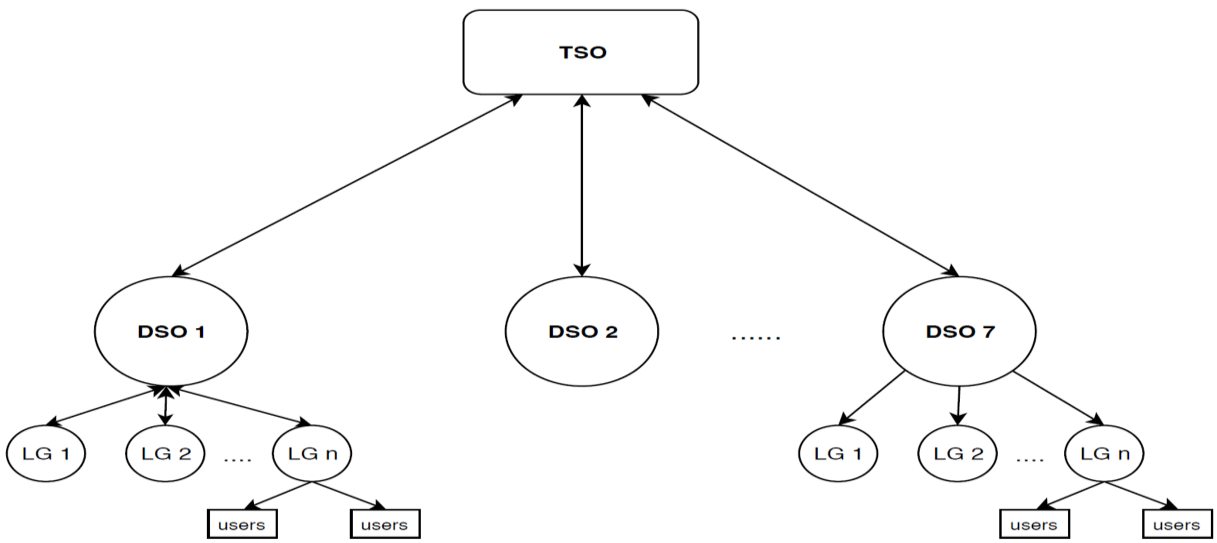
The Comprehensive Design Framework. Alignment of the technical and economic (institution) design of energy infrastructure. Source: Scholten & Künneke (2016, p.14), adapted from Künneke (2013).

Appendix B: Strategy for Interviews (category 1)

My thesis circles around the problem of the electricity sector in Lebanon, a developing country located in the Middle East. Consumers in Lebanon only get 60% of their electricity demand from the legal electricity entity (state owned vertically integrated monopoly); the rest (40%) comes from “illegal” decentralised diesel generators (private ownership), which distribute electricity through their own grid.

I am trying to design a polycentric electricity sector, to be able to combine both centralised and decentralised generation. The reason for choosing a polycentric structure is the sectarian (18 sects) political system in Lebanon, which is the main reason behind having the above situation last for over 25 years (post-civil war).

The objective of the interview is to discuss the below configuration of the sector along with market design variables.



The above configuration assumes that the TSO and centralised generation (not shown) are kept integrated, an option between accounting and legal unbundling could be considered. The DSO’s role is maximised, where it is handed operational and coordination power. Decentralised generation will be connected to the distribution grid, and local governments (LG) are treated as retailers. The two main issues with the above configuration are:

1. The mode of organisation between the TSO and the DSO on one hand and the DSOs amongst each other on the other hand.
2. The decentralised generation market, where there are two options (i) either an integrated market at the DSO level, or (ii) a decentralised market at the local government’s level.

After discussing the two main issues, I also want to discuss a couple of variables concerning the market design.

a. Accounting or legal unbundling of the TSO from centralised generation
b. Ownership unbundling of the DSO from the local governments (retailers).

Appendix C: Interview Summaries

Lebanese Interviews:

Raymond Ghajar (interviewee 4):
Since 2017 three DSPs, distribution service providers, were allocated to provide service over the distribution grid. These services consist of operation, maintenance, construction of new lines, metering and collection, and reducing non-technical losses. The operation was handed down from EdL to these companies, with a possibility of contract renewals. The jurisdiction of each DSP is almost equally divided, with one taking the North, one the South, and one the valley (inner country).
Problems:
The three system providers are NeuC, BUS, and KVA. BUS is the highest performer with no financial problems, the IFC (International Finance Corporation) has recently invested in this company. Whereas NEUC is the lowest performer, and the KVA doing just fine. These are determined through as set of KPIs, and they are being monitored by EdL. NEUC is not doing good due to the security reasons and high non-technical losses. The business model for those companies, is that they provide these services and they get compensated by metering and billing the customers where they take a certain percentage and transfer the rest of the amount to EdL per kw billed. Electronic metering was introduced to the Lebanese households, which is an accomplishment.
NEUC was faced with the most difficulties, were electricity bills are not metered in large chunks which is linked to security reasons. The other reason for the problems were the what is so called as "daily workers", that went into strikes against the new DSP in the south, this could easily be linked to a political agenda. When the NEUC was divided into two, and thus making sure that one political party which instigated the problems were happy, thus ensuring a conflict resolution with these employees.
For the connection between the DSOs and the TSO, Ghajar approved the same as Jamasb and de Vries pointed out. This entails that the DSO has to go through the TSO to do trading with other DSOs.
No unbundling between centralised generation and the TSO.
The idea of introducing the IEPs into the distribution grid is practically and economically impossible. The main problem comes from the need for large finance for the small diesel generators to connect to the grid. This large sum of money is due to the need to synchronise its output with that of the distribution grid, i.e. frequency and voltage. The problem is that due to fluctuating demand the diesel generator would have to turn on/off too many times in a day. This would lead to high maintenance cost and high maintenance periods needed that could go up to 50% of the time. This would actually lead to reliability issues. Diesel generators would over heat, and high maintenance times.
A better solution according to Ghajar is to provide decentralised electricity through two ways:

- a. PPA with medium sized electricity plants, i.e. 7-8 MWs.
- b. Solar panels. Though this solution has two main obstacles:
    - a. An optimisation problem needs to be made to figure the optimum percentage that the grid can introduce into the grid.
    - b. No proper regulations exist to incentives the consumer to turn into a prosumer. There is only one mechanism which is called net metering, which actually calculates the fed solar power to the grid. at the end of each month, the consumer would have to pay the difference between consumption and feed-in power, if the amount is to the consumer's side then EdL would not remunerate the consumer. This method while not economically feasible if compared to EdL's prices, some consumers still find it feasible since they are able to substitute the diesel generators with their owned produced solar power. The major investment is linked to batteries, because consumers are trying to substitute IEPs

with solar panels. But some households have experienced that solar panels are not sufficient to cover all the power needed form IEPs.

c. A solution for Ghajar is to shift the subsidies given by the government to its own company, i.e. EdL, to consumers to start producing electricity power. As well as introducing PPAs at the decentralised level. Because solar panels might not be enough, this problem is mainly found in large cities and crowded neighbourhoods. This is because of the buildings found in those locations that have on their roof tops either water containers that provide water to the households, as well as TV dishes and antennas that are still used in some parts of Lebanon. Solar can play an important role in rural areas through.

DSO are state owned and the management level would be privatised, where it can provide operation and maintenance, but not generation capabilities. Generation would come from PPAs and solar panels.
A board would have to be made from the shareholders of the DSOs, which is the state, to control the operation level.
Constructing the gas pipeline has major problems. Technically only one LNG terminal and one degasification plant are needed for Lebanon. However, due to the trespassing of private construction on the public coast line two degasification units and LNG terminals are needed. The private trespassing on the coastline starts from Byblos, passes through Beirut, and ends in Jiyeh, which sums up an approximate of 65 km. So, even with the above solution, no pipeline wold be constructed along this 65 km. This creates a problem for the largest power plant in Lebanon, which is located in that geographical region and it feeds the highest populated area in Lebanon. therefore, this large power plant would not be able to use or take advantage of the constructed pipeline, which prevents it from shifting from diesel technology to natural gas technology. You cannot demolish this plant as well, since the largest transmission line is located there.

Sami Hammoud (interviewee 5):
A structured interview was done with the lawyer to ask about the six sub-topics concerned with polycentricity in the constitutional rule, and the topic of polycentricity in the judiciary rule.
As Ostrom explains for polycentricity to exist in the general structure of government institutions and thus constitutional rule, several conditions must exist (Ostrom, 1999). Those conditions were discussed with the interviewee, and the following answers were given:

Condition	status
Right of governance is assigned amongst diverse decision structures and authorities.	Exist
Constitutional changes and the process are not done the same way legislation process is done. The terms of a constitution can't be altered by a government acting upon its own authority.	Exist
Decision making capabilities are scattered amongst diverse decision-making structures, and each structure can exercise their rights in an independent manner from the others. However, there are limits and veto capabilities for structures to impose on other structures in specific cases.	Exist
Recourse to concurrent authorities with overlapping jurisdictions to reinforce the constitutional rule.	Exist
Limitations exist on governmental authorities, and constitutional rights are given to individual persons. Individuals have the right to claim for judicial remedies against the government/government officials who threaten to harm their constitutional rights.	Exist
The enforceable system of the constitutional rule will depend on the willingness of the citizens to pay the price for civil disobedience. Those citizens are also willing to challenge the constitutional rules and face punishment if their cause is not affirmed.	Exist

Polycentricity in the judiciary system means that the judiciary system is independent from the political system. Ostrom say, “if legal judgments turn only upon the discretion of superiors who are capable of directing persons as legal subordinates, then persons will have no security in their legal rights.” Therefore, actors in a market who don’t have confidence in the enforcement of property laws and contractual obligations will be exposed and will have little incentive to participate in the market and take economic risks. According to the Interviewee, this is a complicated subject and can be answered in a couple of ways. The first answer comes from the Lebanese constitutions, where it asks for independence between the judiciary system and the political system, i.e. the parliament or the council of the ministers. However, in practice this is not always the case, where some infringements of the constitution are visible. An example is the process of appointing the highest Lebanese judiciary council, which comes through a split decision between the council of ministers and other judiciary chambers. This council is responsible for the judges’ promotions and appointment to courthouses. Even though, this infringement is not visible to the everyday court proceedings (interviewee SAMI), but such an appointment methodology opens the door for political interventions in the judiciary system.
As for the third pre-condition, i.e. polycentricity in the selection of political leadership and in the organisation of political coalitions; Ostrom (1999) says that if there is a possibility of single political coalition to dominate the political seen within the government, this would lead to undermining the polycentric governance, legal/judiciary system, and the constitutional rule. If this is avoided, i.e. single domination, then polycentricity is safeguarded, which is the case in Lebanon. The confessionalism political system along with the need for consensus decision-making within the government opposes the formation of a single political coalition that can dominate others.

Dr. Oussama Ibrahim (interviewee 6):
Highly recommends the pathway this thesis is taking. The reform structure proposed by this thesis is able to surpass the political barriers, as well as circumventing the high technical losses that the transmission lines is causing, i.e. 15%. Therefore, this thesis is contributing in two major outcomes, avoiding political obstacles and increasing the efficiency of the sector.
The proposition of using the IEPs as a short-term solution to provide decentralised generation is not technically and economically feasible. The major problem with solution is the synchronisation problem between the small diesel generators and distribution grid. This would cost large investments from the IEPs which they are not willing to invest, as well as the problems of reliability and maintenance of the generators.
The highest potential for decentralised generation is solar power, where he didn’t see the existence of water tanks and antennas on the roofs of building, especially in populated cities, as barrier for implementing decentralised solar. This barrier could be easily surpassed by providing stands to the panels and placing them on a higher level than the water tanks and antennas.

Ali Ismail (interviewee 7):
The major bottlenecks that face the physical layer of the sector is at the transmission level. Transmission lines do not hold enough capacity for an increase in the centralised generation capacity; in addition to that, capacity of the transformers (high to medium voltage) is low and not enough to withstand increased capacity. Another bottleneck facing the expansion of the centralised system, i.e. generation and transmission, is the need to acquire lands from the private sector, which would cost a lot of investments and social barriers. An example is the inability to construct a 2 km of transmission line which would close the 220-kV loop and thus leading to an increase in stability and reduction in technical losses at the transmission level. This reason for not constructing the link is attributed to the weakness of the government institutions and political bigotry. On the other hand, opting for decentralised generation would circumvent the technical barriers imposed on the centralised system as well as the social barriers.

(add the example of the pipeline in the text). An important added benefit is the time taken to implement the suggested design is much quicker than opting to invest in the centralised system.

Technical and non-technical losses impose major barriers for the development of the sector. The current concessions given to three DSPs have been investing to battle both technical and non-technical losses at the distribution lines. Non-technical losses are only present at the distribution lines, which comes from theft, unbilled meters…etc. Cutting down non-technical losses is done through the AMI (advanced metering infrastructure) strategy, which transmits real time energy usage and enables two communications. Technical losses are present at both transmission and distribution grids; at the distribution level the losses are very high and approximated at 15% in 2014 but according to Ali losses decreased to around 8% due to DSPs, while at the transmission level losses are approximated at 3.5% (Booz).

Generation technology: Ali's viewpoint is that solar might play a role in supply but not a very big role that is at least at the beginning. Decentralised generation would have to come from PPAs that depend on fossil fuels, i.e. either gas or diesel. The challenge here would be the transportation of the fuel to rural areas, but that would have to be the responsibility of the private sector. solar energy can start playing an important role, after having a reliable supply of electricity in the grid.

Balancing: the balancing issues was discussed, and according to Ali it is relatively easy to separate balancing of the grid at the substation level. So, balancing of the transmission line would be the responsibility of the TSO, i.e. EdL, and balancing of the distribution grid would be the responsibility of the DSO. A mechanism would have to be created to incentivise both TSO and DSO to keep ensure the reliability of the grid.

Trading between the DSOs would not be technically feasible, this is due to the capacity of the transformers and the capacity of the transmission lines. Therefore, if trading would need to happen it is recommended that it passes through the TSO.

The strategy and the structure I am proposing is very much logical for the Lebanese case. what emphasises this is the current situation of the DSPs, which already divided the country into three regions. PPAs and traditional fuel would be a better solution than solar at least for the time being, this has to do with the peak load in Lebanon being between 7-10 p.m. which opposite to the availability of solar power, demand side management would have to play an important role if the peak needs to change.

As for the ownership, it is preferable to keep the ownership of distribution with EdL and to go with concessions for management and operation with private companies, which is what is happening at the present moment.

Raymond Khazzka (interviewee 9):

It is preferable for IEPs to connect their generators to the national grid, in which they would sell directly to the DSO/EdL. They would rather come to an agreement with "EdL" on a price per KWh produced that would cover their investment rather than the fixed (capital) + marginal cost. However, the quality of their produced electricity cannot travel more than 300 meters before suffering problems with its cycle (frequency). The need to synchronise the generator, i.e. frequency and speed, with the grid pose a problem to the IEP. The IEP would have to be responsible invest in new infrastructure to protect the generators; for example, a large change in the frequency of the grid would cause the generator to fall out of synchronisation and create short circuit that would damage the generator. In addition, the present diesel generators are not able to continue producing power on a 24-hour basis or daily basis, with so much maintenance needed.

Raymond has 3 diesel generators, two with a capacity of 350 KW each and the third of 300 KW. Two out of three operate when EdL's electricity is cut, and the third is used as a backup/reserve generator.

Other than the technical barrier, three main barriers obstruct the realisation of this solution. First is the method to transport the fuel to the generators; second, placing the diesel generators close to their respective consumers. The third barrier is the environmental impact of keeping diesel generators.

Dr. Sorina Mortada (interviewee 10):
Recent updates on the renewable energy topic in Lebanon have been happening, where in 2018 power purchasing agreements (PPA) were signed with three private companies to construct and sell wind power to EdL. The 20-year contracts, i.e. PPA, agreed on providing a capacity of 200 MW in wind power. The permits and licenses were issued, and operation is expected to start in 2020. On the other hand, solar is starting to pick up, with bids already handed to the ministry of energy for 12 geographical locations of 10-15 MW each. The total capacity of the auctioned solar power is 180 MW, and at the moment the bids are under technical evaluation. These solar panels will be connected to the transmission lines. Payment is also done under PPAs, with EdL providing payments for 20 years per KWh produced; it is expected that the bids will around 0.07 $/KWh. Environmental assessments are done for both solar and wind bids. Only licensing and permits are given by the ministry when the bid is won, whereas connection (shallow connection) to the grid, investment, land, operation and decommission are done through the private company. The Lebanese target for renewable energy is 12% of total demand in 2020, and 30% for 2030. A combination of centralised and decentralised RES is needed to reach that target.
According to Sorina, the most promising sector where decentralised solar energy can thrive is the industrial sector. Even with the current minimal incentives, it is fairly easy for solar energy to go up to 10% of total demand, i.e. only from solar at the distribution level. This is mostly attributed to the need of low-cost energy by the industrial sector, and the known benefits of solar within the industrial sector.
The incentives offered for consumers for investing in decentralised solar panels are the following:

e. Subsidised loans, i.e. 0.75%
f. Tax exemptions on solar panels and inverters (only made in EU), but not on batteries.
g. Grants, e.g. UNDP and EU. No numbers could be found.
h. Net-metering regulation. At the end of each month, EdL checks the balance, and if there is a surcharge for the consumer, this amount of extra KWs is subtracted from next months balance. Otherwise the consumer has to pay EdL for the extra used energy. This is done throughout the year, and at the end of the year if the consumer owes EdL, then the consumer pays; otherwise, the meter is nullified and EdL doesn't pay the consumer.

According to Sorina, the above incentives are enough to make decentralised solar power economically efficient and a real option for consumers if electricity supply becomes continuous and reliable.
My market structure is a real possibility and can be implemented according to Sorina, this emphasises the opinion given by Prof. Ghajar. The major source of energy at the distributed grid needs to be continuous energy, i.e. thermal generation, either gas or LFO, which is easily done through PPAs. However, the structure needs to be reformed and power must be given to the new DSOs to conduct such activities. The major barrier for my structure to be implemented is establishing the regulator, and according to Sorina this was the major barrier for implementing the law no. 462 which calls for reforming the sector.
The law numbered 228 is currently giving the authority to the ministry council based on the recommendation of the ministry of energy and water to allocate production capacities through PPAs. However, this law has been renewed twice for short periods of time. Law 228 gives licensing rights to an inter-ministerial committee, i.e. from the ministries of energy and power, finance, environment, and EdL, to auction for PPAs. This law is prolonged every two years, thus creating regulatory risks for investors.

Sameh Mubarak (interviewee 11):
According to Sameh the major problem now for Lebanon is fiscal, the government is not able to invest large amounts of money in the electricity sector, while suffering from huge losses in the form of subsidies to EdL. Time is an important aspect to take into consideration, the quicker the solution for

Lebanon the better, and the current government is seriously aiming to solve the issue. According to Sameh, centralised generation will suffer further deterioration in the coming years because the power plants are very old and they are set to be decommissioned in the upcoming years.

Sector Structure: Sameh believes that the current Distribution service providers (DSP) will remain at the centre stage in the Lebanese electricity sector. He sees that the current division of three distribution companies will remain in the future. The world bank is pushing for the single buyer model for centralised generation, where EdL will be the single buyer, while keeping the concessions at the distribution grid level for DSPs. At the same time EdL needs to be corporatized. He believes that the 462 law does not match the context of Lebanon and should be changed, because Lebanon is too small to have competition at the centralised generation level.

The technical and non-technical problems pose an important challenge for reforming the electricity sector and increasing generation capacity. Increasing the generation capacity has the following challenges:

a. Will lead to more losses for EdL with the current tariff structure, subsidies, and losses.
b. If the tariff structure is altered and subsidies are rescinded, consumers who are paying will be burdened with the increase of tariffs. If EdL wants to start making a profit, paying consumers will be paying for consumers who are not paying. This a social barrier, since paying consumers will rightfully argue that they are paying for their consumption and for non-paying consumers.

Therefore, solving the technical and non-technical losses should be a priority before increasing the tariffs.

<u>My structure/proposal</u>: Sameh sees only part of my structure as implementable. Management unbundling between transmission and distribution is already in place, as concession have been given to DSPs to manage and operate the distribution grid. However, he recommends that the ownership remains with EdL while giving long-term concessions for private companies to operate and manage the distribution grid. According to Sameh, ownership unbundling between DSO and TSO, while having the DSOs as state owned corporates and separated from EdL (TSO) would not solve the problem. He sees no guarantee that those corporate DSOs would work efficiently.

Several challenges will threaten the implementation of my structure:

a. The structure might lead to different tariffs between the different regions. This mostly attributed to level of reliability achieved in each region, the area served in each region which will affect the needed investment for the DSO…etc.
b. Who will pay for the balancing duties, is it going to be socialised for the entire country? For example, if one region has a lot of solar power, then more balancing is needed for that region as well as more backup capacity.
c. Transmission cost, would that be socialised, i.e. are all regions responsible to pay the same for different transmission services? This has to do with investment in the transmission lines, e.g. expansion
d. Fuel transport for decentralised generators, i.e. diesel or natural gas.
e. Not enough resilience in the distribution grid, specially for introducing decentralised renewables. However, this can be solved through investment in the distribution grid.

Generation: Sameh sees decentralised generation as economically inefficient for Lebanon, i.e. when comparing traditional generation technologies and not renewables. However, from a security perspective, that has to do with the regular conflicts between Lebanon and Israel, decentralised generation has an advantage over centralised generation. As for generation technologies, renewable energy can play an important role in the rural areas, e.g. Bekaa region, and thermal technologies would still constitute the bulk of production. If electricity becomes reliable, decentralised solar production will scale up.

Another important barrier for reforming the sector, i.e. for any new structure, is assigning the independent regulator. Achieving the regulator would curtail the power of the ministry of energy & water, which is seen as a political barrier.

As a summary, Sameh sees that the current trend is going towards DSO and TSO management unbundling, with distribution operation given to private companies through concessions. While generation is going to be centralised generation. However, through incremental changes my structure is achievable and it is possible that the sector might end up (long-term) in the form I am proposing.

Non-Lebanese Interviews:

Swetha Bhagwat & Pradyumna Bhagwat (interviewee 1&2):
Aggregators could play the role of intermediaries to operate and aggregate the diesel generators and connect them to the DSO. You are putting another layer, but you are also reducing the complexity for the DSO. If you don't add the aggregator layer, then each diesel generator would have to sign a contract with the DSO which is way too complicated.

- There will be resistance from the current vertically integrated utility to split the DSO business. The steps to achieve what I am aiming for is: accounting unbundling then you break into one single DSO (legal unbundling) then you break the DSO into 3 or 7 DSOs.
- Swetha: an example is the capital region of India, New Delhi, where they split the state-owned DSO into 6/7 zones and there was a combination of private & public partnership.
- According to Pradyumna, state-owned corporates is a preferable choice over PPP for a small and unstable country like Lebanon. The instability in Lebanon causes investors to drift away, which makes the government in Lebanon responsible to take the lead and invest.
- For Lebanon you have two choices:
  a. You either have one big vertically integrated company that you try to make as efficient as possible,
  b. Or, you divide it into several state-owned companies that collectively are more efficient than the current state.
- How to remunerate the diesel generators: power purchasing agreement would have to be done.
- Is DSO splitting the best way to go forward for Lebanon? Why is not IPP a better solution?
- Splitting distribution into 7 DSOs might create more problems for the country given the way Lebanon is setup. They don't find the argument that says: because Lebanon is a sectarian country and a lot of the systems in the country is divided according to this sectarian system, the solution for the electricity sector is to divide the distribution grid into several DSOs.
- Liberalising at the generation level would take power and decision-making away from the government and political parties.
- A first step in vertical unbundling is to split the TSO from DSO, which results in having different management for the two companies (TSO and DSO). This might lead to higher efficiency in Lebanon, and Pradyumna sees the TSO achieving efficiency and making profit prior to the DSO.
- Regulator: the better position for the regulator is at the national level, since Lebanon is a very small country. The regulator should be totally independent from the government and politics.
- Unbundling the two businesses, i.e. TSO and DSO, is a good idea since the current company (EdL) is a loss-making company. When you split them, you put the loss-making part together and the profit-making together, and you would be able to pinpoint your exact problems and tackle them. However, dividing the DSO into 7 regions is not a good idea, because it would create more inefficiencies. It is better to do one DSO vs. my proposal.
- Having more pieces from the beginning does not make sense, a better approach is to have one DSO at the beginning and check its performance. If the DSO is not performing properly then you can take the next step of splitting the DSO into smaller DSOs. Splitting the DSO is easier done then regrouping the split DSOs.

- In developing countries, you reform in a phase wise manner. You cannot have an abrupt and radicle change. When reforming the sector, it is relatively easy to create the new institutions, but very hard to coordinate amongst these newly created institutions. Coordination is very had to accomplish between newly created institutions.
- An aggregator would make sense for small diesel generators, because the DSO would be able to call upon for example 1 MW from the aggregator who would have to make sure that the number of diesel generators operating at this time sum up to 1MW.
- At the beginning a DSO should stay publicly owned, and later on you can think about privatising or concessions to make it more efficient. You can have management unbundling for DSO, where private companies would operate the distribution sector, while keeping ownership with the state.
- A board from the private company would have to answer to the shareholders, i.e. the state.

Laurens de Vries (interviewee 3):
Theoretically, and not looking at the transaction costs, it is better to unbundle the TSO from centralized generation. However, given that Lebanon is small, there might not be enough scale for actual competition. Given that there are subsidies and regulated tariffs, it is much easier and more recommended that the monopoly remains.
Integrated utility is easier to plan, and it might be faced with regulated tariffs, which is easier to do through the government. There's another cons, please check.
3500 MW is lower than the economic scale for unbundling TSO from centralized generation.
The type of business between DSO and TSO is different, which makes it easier to unbundle TSO from DSO. The TSO has relatively few assets compared to the DSO, but these assets are more expensive compared to the DSO's. not so many
Unbundling DSO from retailers is not a good idea, because this would only put extra transaction costs, thus leading to higher prices. My first proposition was to have retailing given to municipalities, thus leading to no competition since each municipality would sell within its own jurisdiction. Thus, competition is not possible at the retail which makes unbundling not recommended.
Disadvantage of unbundling would be: it is harder to finance investments. Optimization question would be: which option would lead to lower prices:

- Municipalities unbundles from the DSO and buy electricity from EdL (centralized), and decentralized generation. Or
- No unbundling of retailing from DSOs: where DSO would buy from EdL and from decentralized generation.

There is always a trade-off between transparency and simplicity, economic efficiency. So, if I actually make the DSOs as regional monopolist, would I be able to make them reasonably efficient (economically)? Maybe regulations or incentives would have to be given to make them efficient and for them not to abuse the market.
The Dutch model for DSOs: ownership is given to local governments, i.e. municipalities. There is a legal corporate structure for the DSOs, where the shares within the DSO cannot be bought by private entities, only municipalities can trade there shares amongst each other. It is mix between province and cities, and not all communities within the jurisdiction have shares in the DSO.
No going back if the DSOs ownership is handed to the local governments. The better option is keeping the DSOs state owned as corporates, and create local oversight committees. Local control in a different way, the state would own the shares, and the sate by law can give local governments certain influence. This gives the government a certain flexibility to change the law if it doesn't work. The city can have a certain flexibility to have influence on the rates, a possibility would be the city can have more reliability, given that the rates are higher.
My questions would have to answer:

- Give some input, some measure of control over the tradeoff between reliability and prices. More reliability means more investment
- How well do you maintain the grid?
- How much do you invest?
- How do you remunerate local generation?

Integrated market helps in congestion management, where congestion management is integrated in the market clearing. Nodal pricing is integrated market. It's complicated but it works. The generator would. You need a minute to minute pricing to signal the generators to ramp up or down.

Long-term contracts would be: paying the IEPs a fixed monthly price to make sure they are there, and then pay the variable cost of generation. If one IEP is more expensive, then I will ask you to produce less than your less expensive rival. Because per moment, generation has to move up and down as per demand. Fixed rates per kw, i.e. regardless of how much you produce, then you as a generator have be problem because you would have too much cost to start your generator, and that means there's a higher risk on generators. So, a fixed payment per month and a variable payment per kw is more efficient for both sides. For the system operator side, this would entail that the DSO would know what is the marginal cost for the generator to produce one kw, and thus the system operator can select the cheapest generator at any moment in time. So, long-term contracts does not have to be a fixed price per month.

Trading between DSOs:

- It is inevitable that trade has to go through the TSO, because you have to use its grid since the TSO is not unbundled. Would the TSO pay fair prices from one DSO and sell it to another DSO at another fair price? An oversight or some sort of regulation from the regulator is needed. You can make the TSO buy it at that given price from the DSO, since there is marginal price of the last IEP that was summoned to produce. Thus, the TSO can put an extra fee and sell it to the other DSO.
- It is important for the TSO to have trading rights. If the other option which is created through contracts between the two DSOs is taken, then the situation becomes messy since the TSO is not unbundled from centralized generation. The major reason behind having the TSO having control over trade is balancing.

Regulator issue:

- Flexibility and having different access regulations for decentralized generation might create problems between different zones. That might be considered arbitrary by the people since the rules would be different per district.
- One regulator that is well staffed and independent is better than multiple. One regulator would have more knowledge, more capacity, yardstick competition where the regulator can compare between the performances of the various DSOs. For staff capability, it is easier to have one big regulator than small ones. You need one big and capable regulator that can actually counter the market power of the biggest player, i.e. EdL (TSO and centralized generation).

How to reimburse the diesel generators:

- Pay the IEPs the marginal cost of generation
- Can't make contract with all the IEPs because that will drive you crazy as a DSO. IEP have already invested.
- Price caps is not an option

Solar panels: "if you can sell back to the grid and you get the marginal cost of generation maybe then a lot of people are going to start buying solar panels, because at that price, if you get 25-35 ct/kwh it would be a no brainer for a country like Lebanon." "maybe you would have to go through a hump". The main question is, can people handle the increase in prices when the DSO starts to buy large volumes of diesel generator's power.

The major people to be impacted are the ones that are too poor to buy electricity from diesel generators, but with my design it would lead to a major increase in prices which would be imposed on poor households as well.

Prof. Tooraj Jamasb (interviewee 8):
Some level of autonomy could be given to DSOs, accounting autonomy could work. Ownership unbundling could create tensions between the various factions of society, conflict might arise on who would own the DSOs.
If DNOs are put on the market, they become a source of power for organisations that buy them. This is not recommended for the Lebanese case.
My structure and proposal of handing over control, i.e. division of DSOs, means that I am acknowledging the current socio-political structure of Lebanon, i.e. sectarian divide. This is a one-way decision, that can hardly be reversed. Jamasb doesn't see clear advantages of dividing, strengthening the state-owned utility, i.e. EdL, could turn into a unifying actor. So, despite of the people division they would have something in common, and you don't cut out the remaining links between the state and its people. Electricity network should be used as a unifying factor amongst the communities, so communities would have something in common. One of the important factors of a network is the network effect, which is a positive externality; therefore, why would you want to divide the sector and thus deleting the positive externality of a network.
Privatisation is seen by the interviewee as the last step or resort when restructuring the sector. Don't pass on the difficult decisions that will have to be made centrally to private owners, especially that energy is politically sensitive, and it is a necessity for people. There are hard decisions, i.e. political decisions, for example pricing. Don't leave such decisions in the hands of the private sector; these are hard decisions that the government must take. The state has the duty to maximise its assets, even if it is intending to sell those assets. In a context like Lebanon, privatisation (ownership) is unlikely to ever be reversed, so it is not advisable to privates the assets.
It is clear from other cases that some distribution companies are better managed then others.
If you unbundle TSO from DSO and corporatize them, then the inefficiencies become easily visible. You are better able to pinpoint where the problems are located, and thus improvements come more naturally. A simple division could be a good start. This is legal unbundling and not ownership unbundling. This solution would be close to Norway's model, but Norway has very strong institutions and a long tradition of managing state-owned companies at arm's length. Lebanon is not there yet, but you still need to make the problems and inefficiencies visible so you can tackle them.
The first legal step would be to corporatize both TSO and DSO, no matter what you intend to do next with the sector.
Trading between DSOs: in Lebanon there is energy deficit in the system, which makes trading not implementable. The number one priority is to bring stability to each DSO, trading is not a priority and currently not achievable. Trading with the current power deficit does not make sense. If trade is permitted to happen, one region's price would go up and the other would go down, and that is not very popular.
<u>Mechanism to connect DGs to DSO</u>:
The DSO is better suited to do the job of the aggregators in a better and cheaper way. A business model for the DSO is proposed by the article sent. A form of auctioning system is suggested by the article, which combines distributed generation with demand response and renewables, and integrates everything together. The case that the article discusses is that DSOs can run internal markets, and act as TSOs at the distribution grid which combines DG, heat, demand response, and RES.
In the Lebanese political context, separation of retail from distribution is not recommended. In the structure that I am discussing a competitive market would not exist, so unbundling distribution from retailing would only add cost to the consumers with no added benefits.

Regulator: the combination of autonomous regional DSOs and autonomous regional regulators might be a recipe for trouble, and could lead to “regulatory capture”. Two other options could be:

a. One national regulator that supervises and regulates the entire country.
b. One national regulator, with multiple offices, i.e. one in each region.

I have to take into account with my proposed structure, whether I am reinforcing/introducing aspects of social capital or I am actually reinforcing the sectarian conflicts and positions within the country.

Dr. Neil Yorke-Smith (interviewee 12):
The diesel generators in Lebanon are a by-product of the current system, and pose many environmental issues.
The interesting thing about my structure is making consumers also producers. This would put Lebanon at the forefront of development in the electricity sector when compared to the rest of the world; this would come as a result of the predicted high percentage of prosumers in the market.
Trade between DSOs, and the link with TSO: either option would work, i.e. trading between DSOs without involving the TSO in the transaction or involving the TSO in the transaction as the intermediary. Trading via the TSO creates a higher degree of centralization, while trading amongst DSOs is more of a market style governance which requires more regulation and is more complicated. In the case of having trading directly amongst the DSOs, an important question would be: who bears responsibility for the social/physical well being of the system? A disadvantage of this option is that for some reason, two DSOs might engage in trading amongst each other while refusing to trade with the third DSO. Sectarian ties and political bigotry might play a hand in refusing to engaging in trading with the third DSO. A central authority does not force the DSOs to trade, but it will intervene and prevent unjust transactions. On the other hand, too much power will be given to the TSO, and the question would remain who controls the TSO?
Link between DSO and decentralized generation: the question is how much work would the DSO has to do and the level of coordination, especially if local governments are involved? For example, if there are a lot of prosumers, would the DSO be able to coordinate and balance the grid? The current trend is to do balancing at the neighbourhood level, or the substation level. A technical coordinator would be responsible to coordinate the supply below the substation level, and above the substation can be hypothesized to have unlimited supply (hypothetical). The question remains, at what level does the municipality operate? If the jurisdiction of a local government extends to all consumers that are fed through one substation, then the local government can act as an aggregator
For the regulator question: it is advisable that everyone, i.e. all regions, have the same regulation. The overhead would have to be socialized to consumers, but having one regulator means less overhead.
Generation: an option would be that a set of neighbouring households or a neighbourhood might agree on investing in alternative generation solutions, e.g. solar, at the decentralized level and sell to the grid. T Due to the flexibility of the scheme that I am proposing, compared to a centralized scheme, it has the potential to introduce high numbers of decentralized generation, especially renewable energy.

Appendix D: Scientific Paper

The Lebanese Electricity Sector: A Polycentric Viewpoint

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Polycentricity, electricity sector, market design, Lebanon, decentralised generation.

ABSTRACT

This paper presents a new theoretical approach to design a polycentric electricity sector. The study focuses on Lebanon and its electricity sector, and tries to reform the sector using a proposed polycentric structure.

The study utilises the polycentric indicators and general structure, along with organisational modes, and electricity market design variables to come up with a standardised stepwise model, i.e. "Polycentric Market Design Framework", to design a polycentric hybrid electricity sector. This is followed by applying it to the Lebanese case.

Two important outcomes are gained from this study, (i) that the polycentric indicators developed for the energy infrastructure are better suited to develop a polycentric design for the electricity sector when compared to the more comprehensive design used in the LSP framework; (ii) the Polycentric Market Design Framework could be generalisable for other cases when designing a polycentric electricity sector.

1. Introduction

The Lebanese electricity sector suffers from immense reliability problems that causes power outages to be a daily routine to the Lebanese consumer. Power rationing is used by the state-owned monopoly, i.e. Electricite du Liban (EdL), to distribute the limited amount of energy capacity to consumers, and power outages varies between 3 to 12 hours a day depending on the region of the country (Verdeil, 2016). Lebanese consumers rely on independent energy providers (IEPs), i.e. small diesel generators, to mitigate these daily outages (Ghanem, 2018). In the meantime, several energy reform policies have failed to be implemented and transform the sector into a well-functioning one, and this is mainly attributed to the political-sectarian system of the country (Ibrahim et al., 2013).

Numerous studies were conducted to address the current situation of the Lebanese electricity sector and the barriers that hinder its development (Ghanem, 2018; Verdeil, 2016; Ibrahim et. al, 2013; Khodr and Hasbani, 2013; Fardoun et. al, 2012; Ruble and Nader, 2011). However, no found studies analyses or prescribe a reform solution to the sector. Therefore, thesis attempts to reform the Lebanese electricity sector, and uses a novel approach in an attempt to surpass the political system in the country as well as taking into account the societal and economic need in Lebanon.

An interesting and unconventional description of the electricity infrastructure comes from Künneke and Finger (2009) and Goldthau (2014), where the authors identify the infrastructure as a common pool problem. In-line with this definition, Goldthau (2014) calls for a polycentric governance for the sector, in which it can provide solutions at multiple levels (centralised and decentralised), and therefore allowing for higher integration of decentralised generation options. An identification of polycentric energy infrastructres was carried out by Sovacool (2011), where the author explored several [polycentric cases and was able to argue that polycentricity is able to promote "equity, inclusivity, information (distribution of data), accountability, organisational multiplicity, and adaptability".

Given the above reasons, the thesis believes that polycentric governance can be a solution to a hybrid (centralised and decentralised generation) electricity sector in Lebanon. The article proceeds in section 2 by describing the theoretical framework used to design a polycentric hybrid electricity sector. Section 3, presents the Lebanese case, where it explains the situation of the electricity sector and the socio-political and economic context of the country. Section 4, designs the polycentric hybrid sector for Lebanon where it follows the design steps assigned in section 2. The fifth section, discusses the prospects for implementing the new-found design. The sixth and final section, reflects on the findings and concludes with a set of recommendations.

2. Research Framework

According to literature (Goldthau, 2014; Scholten, 2013; Loorbach et al., 2010; and Smith et al., 2005), the electricity infrastructure fits the definition of a socio-technical system. This definition emphasizes two things for this study, (i) that the electricity infrastructure is actually embedded in its surrounding, i.e. its society, (ii) when addressing the complex issue of the electricity sector, e.g. designing of a new structure for the Lebanese electricity sector, both technical and institutional/market aspects of the sector must be considered. however, given the way polycentricity is defined the thesis chooses to focus on the market design side of the electricity sector. Nonetheless, the technical side will not be totally neglected, therefore at the end of the market design exercise the study will allocate the responsibilities of safeguarding the technical functions of the electricity system to the appropriate actors, along with the institutional arrangement to execute the function.

For the rest of this section, the objective is to explain the theoretical framework for designing the polycentric sector. The chapter has four sections, with the first section introducing the concept of polycentricity and relates it to the electricity sector. The second section explains the modes of organisation which are utilised to explains the relations between the different layer within a polycentric structure. The third section, explains the different market design variables and their respective options which are utilised as the tactics to operationalise the strategy of the structure, i.e. taken form polycentricity. The final subsection, describes the "theoretical sequential mode", which a stepwise mechanism to design a polycentric hybrid electricity sector.

2.1. Polycentricity

2.1.1. Concept and Indicators of Polycentricity

The foremost concept that this thesis is building on is polycentricity, which was first envisaged by Michael Polanyi and later introduced to governance studies by Vincent and Elinor Ostrom (Aligica and Tarko, 2012). V. Ostrom, Tiebout, and Warren (1961, p. 831), characterise polycentric structure by multiple levels and/or centres of governing authorities rather than a centralised one.

An important aspect of this concept is that larger units, e.g. centralised regulator, may intervene to resolve problems associated with "local tyrants, non-contributors, or inappropriate discrimination", and can even incentivise new innovations (Ostrom, 2010). The figure below (fig. 1) shows a general structure of polycentricity for governing decentralised resources.

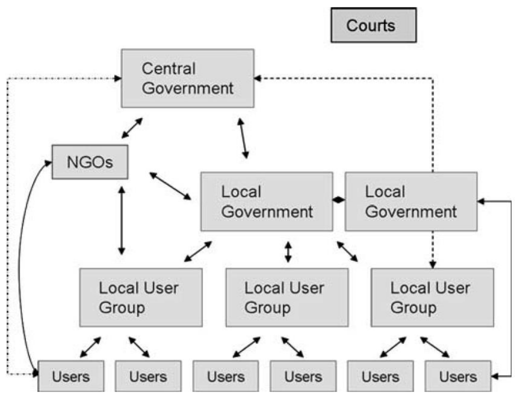

Figure 1: The conceptual model of decentralized resource governance from a polycentric perspective. Source: Andersson and Ostrom (2008, p. 78).

Aligica and Tarko (2012) developed a robust analytical structure called "Logical Structure of Polycentricity" framework, which is utilised for the study of complex phenomena, e.g. socio-technical systems. This study treats the indicators found in this framework as constraints that govern the strategy for designing the sector, the main indicators are:

- a. *Active exercise of diverse opinions* (P1)
- b. *Autonomous decision making* (P2)
- c. *Incentive compatibility, alignment between rules and incentives* (P3)

The rest are visible in the LSP framework (figure. 2).

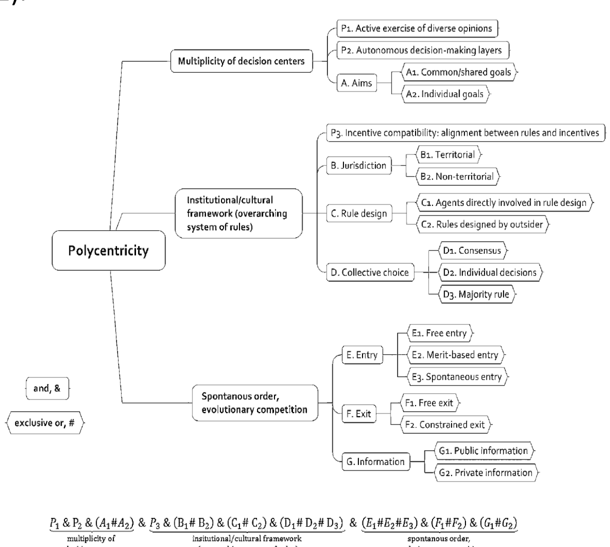

Figure 2: Logical Structure of Polycentricity. Source: Aligica and Tarko (2012, p. 257).

2.1.2. Polycentricity in the electricity sector

Polycentricity in the energy infrastructure was studied by Sovacool (2011), where he was able to identify a set of variables (indicators) that gave an inclination towards a more effective polycentric energy governance, those variables are:

- a. Equity
- b. Inclusivity
- c. Information monitoring
- d. Accountability
- e. Organisational multiplicity
- f. Adaptability

No contradiction is found between the set of indicators; however, the LSP framework give a more comprehensive view for the designer. Therefore, the LSP indicators are applied at the beginning as the constraints for designing the polycentric sector. A later conclusion will be made regarding the suitability of which of the two sets of variables.

Forming the structure of the polycentric electricity sector was a result of combining the structure given by Andersson and Ostrom (figure. 1), the above identified polycentric indicators, and the actors found in an electricity sector that follows the retail-competition market model. The reason behind choosing the electricity actors based on the retail-competition model is the inclusivity and the widest possible number of actors in this model.

Figure. 3 shows the resulting structure, where the central government in figure. 6 is represented here by the centralised generation, TSO, and electricity regulator. Assigning the electricity regulator's position can change depending on the final design; this is the case if the designer chooses to opt for a regulator at the regional/local level instead of a national regulator. However, given the nature of the regulator's job in a liberalised electricity sector, one can deduce that along with the courts the electricity regulator plays the role of resolving/preventing possible conflicts that might arise between the different actors in the sector.

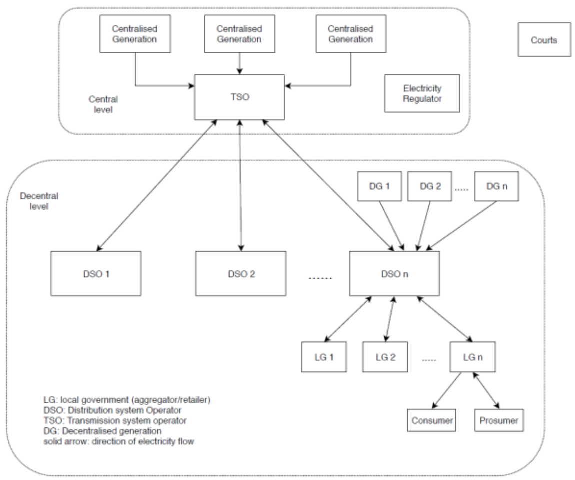

Figure 3: Polycentric structure of a hybrid electricity sector

2.2. Modes of Organisation

Modes of organisation is an integral factor in this thesis, where they are seen as the tool to govern the relation between the different actors in the polycentric structure of an electricity sector. Organisational structures vary from centralised forms to completely decentral operations (Scholten, 2013). In order to capture the various modes/structures of governance, this thesis opted to investigate the works of Ménard and Shirley (2008), Provan and Kenis (2008), and Scholten (2013); four modes of governance could be distinguished from the above studies:

a. Vertical integration
b. Lead Organisation
c. Participant-governed (common operation)
d. Incidental Coordination

Both "Lead organisation" and "Participant" modes come closest to the concept of hybrid arrangements as defined by Ménard (2008). The concept of hybrid arrangements is defined as a set of autonomous organisations/entities that participate in a set of arranged agreements to do business together to achieve a certain end goal.
The definition of hybrid arrangements, and the three fixed indicators of polycentricity (P1, P2, &P3) match together; in which it is clear to see that both the chosen governance modes call for the exercise of autonomous decision-making organisations. Hybrid arrangements, i.e. lead and participant modes, call for active exercise of opinion through their modes of collaboration and interaction that happens amongst the network members.

Therefore, this study accepts that both modes of organisation or a combination of both can represent relations between layers/actors in a polycentric structure.

2.3. Market Design Variables

The objective of this section is to present the market design variables along with the respective design options that are utilised as the tactical options to achieve the final design of the polycentric hybrid electricity sector (figure. 8). The following design thirteen variables, are taken from the study of Littlechild (2003), whereas the design options per step are taken from studies by de Vries (2007), Correljé and de Vries (2008), Bauknecht and Brunekreeft (2008), de Vries et al. (2010), and Bell and Gill (2018).
Determining the degree of market opening, which discusses the degree of competition and openness of the market. Options are:

a. Corporatisation of the state-owned monopoly.
b. Single buyer model
c. Wholesale market model
d. Retail market model

Second variable is the "pace of market opening", i.e. either a follower or a leader.
Third variable is network unbundling, i.e. distribution and transmission networks. According to de Vries et al. (2010), network unbundling influences the incentives and independence of network managers to provide equal environments for network users. Options for unbundling are accounting, legal, or ownership unbundling (de Vries, 2007).
Fourth variable is "integrated vs. decentralised market". Two options exist for this step, either integrated or decentralised markets. An integrated market signifies that congestion management is integrated in the market clearing.
The fifth variable is deciding upon the "balancing mechanism" strategy. However, if the market is

integrated (step 4), then a balancing mechanism is not needed (de Vries et al., 2010).

The sixth variable is "Congestion management method". The design options for this step are:

a. Nodal pricing (integrated market)
b. Counter trading
c. Re-dispatching
d. Explicit auctions
e. Market splitting

Seventh variable is congestion management at the interconnection, i.e. with neighbouring countries.

Eighth step is the ownership issue. Four options for ownership can be found in the literature, private, public, public private partnership (PPT), or commons ownership. When it comes to ownership four important decisions would have to be taken:

a. Ownership of DSO.
b. Ownership of TSO.
c. Ownership of centralised generation.
d. Ownership of decentralised electricity production.

Ninth variable is "Network regulation of network tariffs and access conditions". This is linked to the incentives given to either TSO and DSOs. An inappropriate distribution of risk between actors will act as hinderance to achieving the objective of low-cost electricity system (Bell and Gill, 2018), as well as culminating to a chaotic polycentric sector (Aligica and Tarko, 2012). The main concern in this study is the incentives and network regulation for the DSO.

Tenth variable is "Wholesale and end-user price regulations". This is aimed at protecting consumers from volatile and high prices; however, there exists a trade-off between the interest of consumers and investment incentives for generators to cover demand.

Eleventh variable is "capacity mechanism" issue. However, if retail competition does not exist, then this step is not required (de Vries, 2007). When retail-competition exists, one of the following options could be used:

h. Capacity payments
i. Strategic reserve
j. Operating reserves pricing
k. Capacity requirements
l. Reliability contracts
m. Bilateral reliability contracts; or
n. Capacity subscriptions

Twelfth variable is the "position of regulator". According to de Vries et al. (2010), the regulator's position could be at the local, provincial, national or supranational level. For a polycentric structure, the position would either be at the national (Central) or Decentral level. However, it was recommended above for a polycentric structure to have the regulator at the central level.

The thirteenth and final variable is "competition policy and horizontal unbundling". This variable serves the purpose to decide on the kind of competition law utilised to regulate the sector. Two options reside for this step, either a sector regulation law that targets the sector alone, or to make the competition in the sector follow the general competition law of the country.

2.4. The Polycentric Market Design Framework

This section presents the necessary steps for designing a polycentric hybrid electricity sector. Those below steps form the structure for this thesis to design the Lebanese polycentric electricity sector, and were determined from the above discussed sections:

1. Start with the general structure of a polycentric electricity sector (figure. 3), polycentric indicators, and the actors found in the retail-competition model of an electricity sector.
2. Investigate and decide on the relevant actors with respect to the case in hand, e.g. Lebanon in this study. This step ultimately decides the shape of the sector, and answers the first market design variable, i.e. the "degree of market opening".
3. Select the geographical jurisdiction of each of the centres, i.e. the DSO's and its accompanying actors (DGs and LGs). This matches the indicator B1 in the LSP framework.

4. Investigate and decide on the mode of organisation that will govern the relation between the different levels in the polycentric structure. The choice is limited to either the “lead organisation model” or the “participant-governed”.
5. Make a choice on which of the remaining market design variables are relevant to your case.
6. Select the market option per market variable. Each selection is constrained by the context of your case, and the previous choices made in the above steps.
7. Create a conceptual framework that describes the pathway towards achieving the new electricity sector design.

3. Case Study and Methodology

This section investigates the peculiarities of Lebanese electricity sector along with that of the country’s context (socio-political and economic). The section starts by introducing the methodology used to investigate the Lebanese case, and to get answers when designing the polycentric sector (section 4).

The strategy in selecting the interviewees for this thesis was based on the knowledge and perceived added value of the interviewees towards the findings of this thesis. The author decided to interview experts that are mainly knowledgeable in the fields of electricity market design, and the Lebanese electricity sector. Information from experts who have knowledge in market design was used to design the proposed polycentric electricity sector, while experts in the Lebanese sector were interviewed to validate the design, check its feasibility, and acquire some information on the Lebanese electricity sector. The list of interviewees is shown below, where category one reflects interviewees utilized for designing the sector, and interviewees belonging to category 2 were utilized to for validating the design and providing other important information.

Interviewee number	Expert Name	Category	Institution	Position	Relevant Expertise
1	Bhagwat, Pradyumna Dr. M.Sc.	1	Florence School of Regulation	Research Fellow	Energy policy and regulation
2	Bhagwat, Swetha M.Sc.	1	Florence School of Regulation	Research Associate	Technology, policy & regulation, finance and business development in the renewable energy sector.
3	De Vries, Laurens Dr. ir.	1	Delft University of Technology	Associate Professor	Electricity market design
4	Ghajar, Raymond Prof. dr.	1 & 2	Lebanese American University. Ministry of Energy & Water	Dean, School of Engineering. Senior Energy Advisor at MoEW	Electricity utility restructuring (Lebanese situation)
5	Hammoud, Sami M.L.	2	Private office	Lawyer	Lebanese constitution and judiciary system
6	Ibrahim, Oussam Dr. M.Sc.	2	Lebanese University	Lecturer	Research in the Lebanese electricity sector
7	Ismail, Ali M.Sc.	1 & 2	Electricite du Liban (EdL)	Head of Dispatch Centre	Technical knowledge of the Lebanese sector
8	Jamasb, Tooraj Prof. dr.	1	Durham University – United Kingdom	Chair in Energy Economics, and Co-Director at the Durham Energy Institute	Energy sector reform and market liberalisation (developing countries)
9	Khazzaka, Raymond	2	Private sector	Independent Energy Provider	The sector of Diesel Generators in Lebanon
10	Mortada, Sorina Dr. M.Sc.	2	Lebanese Centre for Energy Conservation. Lebanese University	- Technical Consultant. - Associate Professor	Renewable energy in Lebanon
11	Mubarak, Sameh	1 & 2	World Bank	Senior Energy Specialist. Energy Extractives Global Practice, MENA region.	Electricity sector reform in Lebanon
12	Yorke-Smith, Neil Dr.	1	Delft University of Technology	Associate Professor	Socio-Technical Algorithmics and knowledge in the Lebanese case

Table 8: List of interviewed experts

3.1. Lebanon’s Electricity Sector

Two important headlines from the current situation of the sector could affect the design of the polycentric electricity sector. The first relates to the general aspects of the sector, while the other relates to the aspects of the non-implemented 2010 energy policy that can still assist in developing a new polycentric design for the sector. Aspects of the first headlines relate to:

- Lebanon’s electricity sector is owned by a vertically integrated state monopoly called Electricite du Liban (EdL).
- On average, 60% of the consumer’s electricity comes from EdL, while the rest comes from other sources, and mainly from IEPs (Ghanem, 2018). IEPs rely on small diesel generators, that are decentralised, and each IEP has his/her own private network.
- Distribution services are outsourced (concessions) to three private companies, i.e. management

unbundling from the rest of the electricity value chain.
- High technical losses at the transmission and distribution networks. Transmission network capacities are low (grid and substations).
- High electrification rate, i.e. almost 100%. This is good news for a developing country, and thus would not pose problems for design.
- High theft percentage, i.e. estimated at 20%, at the distribution network.

As for the recommendations given by the 2010 policy paper, the following points could be used to assist in designing the polycentric electricity sector:

- The current situation at the distribution network, i.e. DSPs, and the already divided service areas. This is used as the geographical jurisdiction for the centres at the "decentral level" in the polycentric structure.
- Incentivise public private partnership (PPP) at both the generation and distribution levels. Example, IPP at the centralised generation level, and private management at the distribution level.
- Transmission: this value was kept within the jurisdiction of EdL, and investments needed for expansion and improvements would be financed through the government and international loans.
- Tariffs: increasing the tariffs gradually in connection with reliability improvements and abolishing subsidies, except for low income consumers and productive sectors.

3.2. Lebanon's Socio-political and Economic Context

The following lists the contextual aspects that must be kept in mind while designing the sector:

- Sectarianism: the political context of the country, where confessionalism leads to the division of power between the various sects. This obstacle is considered to be the most complicated aspect that is slowing down decision-making (Khodr and Hasbani, 2013).
- Politicised decision-making: the LNG terminal is a prime example
- The high-level of debt/GDP ratio, and the high percentage of poverty
- Absence of policy continuity: where the 2006, 2008, and 2010 policies have stalled for long time. However, this is starting to change, and some hope resides with points connected to the 2010 policy.
- Continuous conflict with Israel and terrorism crossing from the Syrian borders (after the conflict started in 2011).

The question would be, would the concept of polycentricity be able to circumvent the above obstacles or at least part of those obstacles. The thesis argues that using polycentricity in the electricity sector to combine centralised and decentralised generation is a solution to avoid the conflicts inflicted by sectarianism and politicised decision-making. The thesis believes that such a design would actually please the different political parties in Lebanon. This is further solidified through the intention to divide the country into different distribution zones based.

4. A Polycentric Design for Lebanon

Figure. 4 below shows how would the polycentric hybrid electricity sector for Lebanon looks. Two stakeholders are located at the central level in Lebanese design, which are EdL and the electricity regulator. EdL is responsible for transmission duties as well as centralised generation. Centralised generation can either come from the existing generation capacity that is owned by EdL, or from IPPs that will serve the purpose of replacing existing plants when decommissioned. At the decentral level, three DSOs representing three different regions in Lebanon and each one is regarded as the main player in that respective region. The jurisdiction of each DSO is based on the current division, which ensures socio-political approval, technical applicability, and optimum economic benefit (number of consumers, area covered…. etc.), and besides this jurisdiction is already in place which ensures the acceptability by the decision-makers in the government. Legal unbundling is preferred between distribution and transmission for Lebanon, with the need to hand operation and management to private companies through concessions for further developing the network. The DSOs in figure. 4 are labelled with the current private companies that manage and operate each jurisdiction, however this is a mere representation and does not have to hold. Electricity only flows one way from the central level towards the decentral level, where there is not current technical possibility of having a two-way flow of electricity. At each DSO level medium-sized decentralised generation are connected to the distribution network, and this is done through shallow connection charges and locational based incentive mechanism for the DNuS. The DGs are selected based on the CDS auctioning mechanism. Each DSO acts as the retailer in its respective region, and no possibility of retail competition would exist in Lebanon. Therefore, consumers are directly linked to the DSO for sale, but they have the possibility to turn into prosumers by producing electricity through solar power and sending it back to the grid (two-way flow of power). Balancing at the distribution side is handed over to the DSOs, and the balancing mechanism to handle the relation between the DSO and TSO is done through the devolution principle.

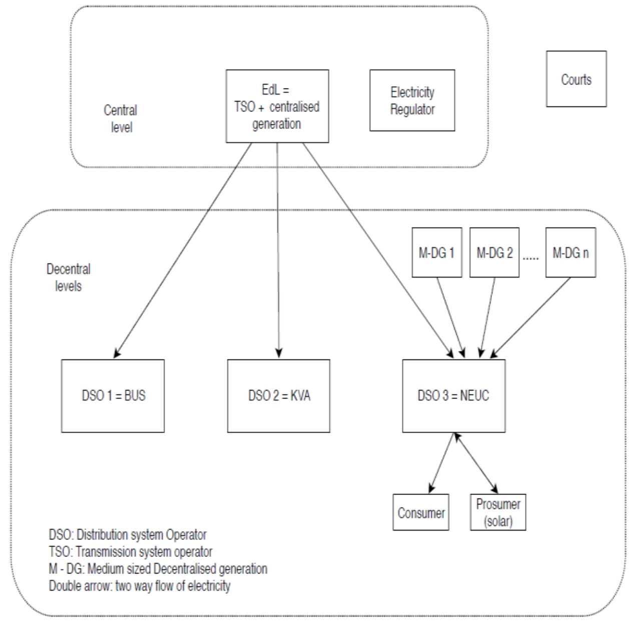

Figure 4: The polycentric structure for the hybrid electricity sector in Lebanon

5. Acceptability of the Design

This section discusses the acceptability of the general polycentric structure for the case of Lebanon and argues that existing technical and institutional conditions in the electricity sector are suitable to move into the recommended design.

The term "acceptable" is of significance to this study, in which it is attributed to being acceptable by both the political regime and the public's eye. For the political regime, the design should be able to bypass the previous bottlenecks that lead to other policies not being implemented, i.e. confessionalism and sectarianism. As for the public's opinion, the design should end the unreliability of the electricity sector whilst providing consumers with lower end prices compared to the current situation.

To start with, the general structure of the design, i.e. figure 14, was introduced to several of the Lebanese interviewees. Interviewees 4, 6, 7, and 10 expressed their approval and saw the added value of the design; the interviewees saw the design as a way to circumvent either the political or the technical barriers facing the electricity sector. According to interviewee 4, introducing decentralised generation would mitigate the political contest between parties on the location of the large centralised generation plants. Interviewee 7 stated that the strategy this thesis took to design the sector is very much logical with the Lebanese political context, and is in-line with the current situation of dividing the distribution network into three zones operated by Distribution Service Providers (DSP). The design also mitigates the technical barriers that are present at the transmission network (capacity of lines and capacity of substations). Interviewee 11 expressed a positive viewpoint regarding unbundling distribution from transmission, and saw that the current trend for the electricity sector is going in that direction. The interviewee along with interviewees 4 and 7 believed that the situation of the DSPs is here to stay and might develop further.

Two other important aspects that the design is able to mitigate are security concerns and quick implementation time (interviewee 4 and 7). For the first concern, introducing decentralised generation and handing over operating and management powers to the DSO could simplify the matter, thus identifying geographical locations where non-technical losses are happening and coming up with a solution for that area that is able to alleviate security concerns. As for the issue of fast implementation, this advantage comes from the current fiscal situation of the Lebanese government and the high losses incurred by the government from the electricity sector.

6. Conclusion

This study started with the objective to design a polycentric hybrid electricity sector for the Lebanese case. The intention of the design was to help Lebanon overcome its barrier (political and social) and to achieve a reliable electricity sector, and to a large extent the thesis and the presented design were able to achieve the objectives. Whether to call the design a polycentric one might be up to different interpretations; if the second category LSP indicators are essential concepts and indicators for the realisation of a polycentric structure, then the proposed electricity sector design could not be fully described as a polycentric one. However, if interpreting polycentricity comes from the indicators (variables) that are described by Sovacool (2011), then the proposed design did adhere to those indicators and thus it can be categorised as a polycentric electricity sector.

This study was able to achieve several other important outcomes, most notably is the comparison between the comprehensive and general indicators of the polycentricity, i.e. found in the LSP framework, and the indicators given by Sovacool (2011) which describe a polycentric energy infrastructure. The study believes that Sovacvool's narrower indicators, that do not contradict the LSP's indicators, are better served to be utilised as constraints to design a polycentric hybrid electricity sector.

Another important outcome of this thesis is its ability to create a novel approach to design a polycentric hybrid electricity sector. The approach termed, the "Polycentric Market Design Framework" is believed to be generalisable and has the possibility of serving serve other cases to design a polycentric electricity structure.

The following recommendations also serve the purpose of progressing with this study to achieve the final aim of an acceptable and reliable polycentric electricity sector in Lebanon:

- Investigating ways to implement the seventh step of the Polycentric Market Design Framework.
- Exploring the compatibility of the DSO model presented in figure. 12 to the Lebanese context. This could have been established by investigating the distribution service providers (DSPs) in Lebanon, e.g. interviews.
- Investigating the possible effects of the proposed design on the Lebanese society and the possibilities that such a design is reinforcing sectarian conflicts

instead of reinforcing social capital. If the former is found to be true, it is my belief that such a design should not be implemented in Lebanon, and an alternative electricity market design should be investigated.

- Investigating the congestions management method for the proposed Lebanese design.
- The optimum balancing cost distribution between DSO and consumers.
- Exploring the hedging mechanism which is supposed to protect the DSO from the uncertainty created in the Devolution principle for balancing costs. The hedging mechanism should remove any deterrent for the development of renewable energy sources.

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