Firm's upgrading in the Solar Photovoltaic Energy Value Chain

An exploratory study in Costa Rica

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By
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Executive Summary

Costa Rica’s electric grid is dominated by renewable sources, mostly by hydropower 74% and with geothermal 12.4% and wind 10.6%. Hence, in dry season when the water levels drop significantly, there are difficulties to supply the national electricity demand (CENCE, 2016). Despite this and the added fact that the country’s has enormous solar energy potential, solar PV technology has not been diffused to act as an energy complement during dry season it merely represents 0.01% of the energy grid as outlined by Valverde, Lara, Lobo, & Rojas (2015). However, recent global and local developments have spurred the country’s demand for solar PV projects. Globally, there has been a dramatic decrease in solar PV panel’s prices causing significant cost reductions for solar PV installations (Feldman & Barbose, 2015). In Costa Rica a recent executive decree resulted in enabling and regulating the distributed energy generation model on renewable systems however only for self-sustaining purposes including that of solar PV.

These advances have begun to stimulate the emergence of Small and Medium Enterprises (SMEs) solar PV developers in parallel to Incumbent energy distribution companies. However, most of these companies are merely focused on dealing with operational, contextual issues and growing their knowledge capabilities. Thus, the development of research and local studies to support companies growth and increase the technology diffusion are scare, and thereby local firms still require support to develop better local and global strategies

For this reason, in order to support the local companies’ growth and solar PV technology diffusion in Costa Rica, the objective of this study is to: ***“Develop a conceptual model and provide recommendations for the upgrading of Solar PV firms based on the value chain context and knowledge functions analysis.”***

This case study is focused on solar PV energy firms in Costa Rica and uses two data collection methods. Individual interviews were applied to 22 relevant stakeholders from different value chain activities of solar PV industry, ranging from Institutional stakeholders to equipment suppliers, going through energy distribution and SMEs developers companies. This information is further strengthened through secondary data obtained from research aimed to describe the solar PV energy domain and associated literature.

The research process consists of different steps developed through this thesis. First, a literature review is performed to combine in a theoretical framework the concepts of Technological Innovation Systems from Carlsson & Stankiewicz (1991) and Global Value Chain from Humphrey & Schmitz (2002). After that, the case study is performed to analyze the conditions for the combined concepts of *value chain context and knowledge functions*. Moreover, the next step is based on the findings from the case study to identify the barriers, facilitators, and opportunities for the upgrading of Costa Rican firms. Finally, the last step builds up from the case study’ findings to establish a final conceptual model illustrating how the GVC and TIS are combined towards the identification of firms’ upgrading possibilities.

Therefore, the major outcomes from this study are the identification of barriers, facilitators and possibilities for firms’ upgrading in the value chain represented below in “table a” and “table b“, hence, the development of a conceptual model and finally the recommendations to solar PV companies and policymakers in Costa Rica.

Table a. Barriers and facilitators identified in section 6.1.

Barriers	Facilitators
The negative impact by incumbent companies.	The government policies to promote solar PV energy.
Electric generation regulation	The executive order that enables the Distributed Generation Model (DGM).
Limited commercial viability of solar PV systems	The financing opportunities for the solar PV projects.
SMEs are limited in resources to invest.	The high demand from the market.
Small market with weak global participation.	The regional infrastructure for energy trading.
Poor Industry documentation.	Enough basic solar PV knowledge.
Limited knowledge sharing and collaboration.	
Insufficient advance knowledge.	

Table b. Firms' upgrading possibilities by model identified in section 6.2.

Upgrading model type	Possibilities
Process	Continue the development of DGM for solar PV.
	Increase the regional energy trading.
	Expand outside the domestic market.
Product	Diversify into utility-scale solar PV projects.
	Implement technology complements for solar PV.
Functional	Inter-segment upgrading.
	Diversify the company energy services into new activities.
Inter-segment	Move into other renewables energy developments.

The final conceptual model consists of three sections, the value chain context, the TIS knowledge functions and GVC upgrading. The main benefit from the conceptual model is that it illustrate a systemic approach based on structural and functional aspects to identify firms' barriers, facilitators, and upgrading possibilities of technology-based firms in developing countries.

Furthermore, the final chapter of this study defines four key recommendations for firms and policymakers in Costa Rica. These four recommendations are:

1. The creation of a Solar PV research & development center (R&D) to help Costa Rican firms increasing the Knowledge documentation and Knowledge diffusion performance locally and globally.
2. Current energy legislation must be updated to facilitate the solar PV development of distributed generation and utility-scale projects alike.
3. The global engagement of solar PV firms must increase.
4. To facilitate and increase the participation of incumbent electricity distribution companies in related solar PV projects.

To conclude, this study provides a valuable guide for the Costa Rican firms and its government to better define and prioritize development paths towards firms upgrading and increased solar PV energy diffusion. Moreover, the study represents the first of its kind for combining TIS and GVC literature in such a way as to importantly help study firms in developing country and emerging Technological Innovation environment.

Preface

This thesis is fully dedicated to my beloved parents, Miguel and Ana.

Furthermore, I also want to recognize the support of many of my friends, in particular to Nick, who helped me out to translate my wordiness and to Pamela, who shared with me the master's experience from beginning to end.

Finally, I want to thank all my interviewees and especially my supervisors Claudia and Linda.

J. Carvajal

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Content

Nomenclature

ARESEP:	Public Services Regulatory Authority
BOO:	Build, Own and Operate. ICE buys energy to private plants.
BOT:	Build Operate Transfer, energy concessionary operation model
CICR	Costa Rican Chamber of Industries
CNFL:	National Power and Light Company
CO2:	Carbon dioxide
DG:	Distributed Generation
DGM:	Distributed Generation Model
DGSC:	Distributed Generation for Self-Consumption
EGS:	Electricity Generation Segment
EPC:	Engineering Procurement and Construction
FIS:	Functions of Innovation System
GAO:	Government Audit Office, in Spanish Contraloría General de la Republica
GCV:	Global Value Chain
GPN	Global Production Network
ICE:	Costa Rican Electricity Institute (Instituto Costarricense de Electricidad)
IoT:	Internet of Things, latest sensors technology trend
IPP:	Independent power producers
IS	Innovation Systems
MER:	Regional Electrical Market (Mercado Eléctrico Regional).
MICITT	Ministry of Science, Technology and Telecommunications
MINAET:	Environment and Energy Ministry (Ministerio de Ambiente y Energía).
MLP:	Multi-Level Perspective
MW:	Megawatts
mW:	microwatts
PPA:	Power Purchase Agreement
PV:	Photovoltaic
SEN:	National Electrical System (Sistema Eléctrico Nacional).
SME:	Small and Medium Enterprise
R&D	Research and Development
ROI:	Return of Investment
TIS:	Technological Innovation System

1. Introduction

This chapter introduces the main aspects from this research such as the background, objective and approach. At first, it introduces the project background, the problem definition and the research objective. After that, the chapter defines the research questions and why this study is relevant for the academia and the industry. Finally, the research roadmap and document outlined are described to increase the process of analysis done during the study.

1. 1. Background

Since the 1950's, Costa Rica's electricity energy development have been based largely on renewable energies. A major accomplishment was obtained in 2016; the data shows that during that year 98.21% of national electricity consumption was produced from renewable sources (CENCE, 2016). The state-owned companies have developed a renewable energy grid mainly based on hydropower which accounts for 74.4% from the total generation (CENCE, 2016). Hydropower plants provide ample and stable energy supply, given the abundance of rain during wet season from May until October.

However, the energy supply from this source poses a production problem during dry season. From November until April rain levels drop considerably to the point that water reservoirs are insufficient to meet electricity demand in terms of daily peaks and yearly consumption increase. I.e., during April 2016 the national energy supply fell short by 13% to where it was necessary to import energy from the regional market and furthermore burning fossil fuels (GrupoICE, 2017b). This represents an important negative impact on the renewable energy efforts made by the government.

As a result of the electricity limitations observed during dry seasons, the government has slowly tried to diversify the energy grid. During the 1990's, changes in the utility-scale generation legislation were made to partially include private energy developers to increase the share of alternative energy sources such as wind and biomass (GovCRC, 1995). Also, in 2010 the state-owned company ICE started a pilot plan for a distributed generation energy model (DGM) that lasted four years until the installation capacity target of 10MW was reached (GrupoICE, 2015). In 2015 this DGM development resulted in the enacting of the executive decree 9220 from the Costa Rican Ministry of Energy (MINAET). This decree allows the development of alternative renewable energy projects (such as solar PV) under the model of distributed generation for self-consumption purposes (MINAE, 2015b).

Solar PV is considered an energy source that must be promoted in Costa Rica based on the country's current energy conditions and its potential to bring socio-economic benefits. According to studies from Ackermann (2017) and (Valverde et al., 2015), solar PV energy represents an optimal complement to hydroelectric energy. This energy source could help to mitigate the production risk during summer and secure a more balanced power generation grid. This conclusion is based on the country's large generation potential since it is located in the tropical belt with high solar irradiation values up to 2000 kWh/m²/year as mentioned by Weigl (2014). Furthermore, in the recent decades, the worldwide manufacturing capabilities of PV suppliers have expanded into assembly lines causing an unexpectedly quick decline in manufacturing costs and therefore a reduction of solar PV panel's cost, this caused an increase in the accessibility of Solar PV goods and services into emerging economies (Wesoff, 2017).

Lastly, recent fast emerging battery storage technologies are very promising for the future solar PV integration; the projected prices drop could allow their diffusion to provide grid stabilization and prosumers energy backup (Clover, 2017).

Moreover, Solar PV industry has proven to be a driver of social and economic development within emerging countries. I.e., the mini and microgrids implementation in Africa helped to reduce social gaps (IRENA, 2016) and the rise of solar PV in Bangalore helped to reduce the energy costs and boost energy security (Martin & Ryor, 2016). This solar PV emergence has diversified the electricity supply and minimized the dependence on diminishing hydroelectric energy. Additionally, these benefits from solar PV have been noticed in the Latin American region as well, where solar PV markets have been booming in the recent years. Thus, many local and transnational firms are trying to get part of the regional market share (Munsell, 2016).

Despite the previous developments described, the diffusion of PV energy in Costa Rica is lagging compared to other countries in the region as Colombia, Honduras, Panama, and Chile (Critchley, 2015). The national data shows that solar energy is used to produce less than 0.01% of the total electricity consumption (GrupoICE, 2017a). From the Distributed Generation Model(DGM), the total national capacity installed for PV systems has not been formally documented, but according to ICE and MINAET, the estimated number is circa 12MW (GrupoICE, 2015; MINAET, 2017). In addition, by June 2017, the only active solar PV project, as an utility-scale project, was a small 1 megawatt(MW) energy plant called "*Miravalles"* donated and developed by the Japanese government (Ackermann, 2017).

Therefore, In Costa Rica, the solar PV technology diffusion has not been significantly promoted in comparison to the other alternative renewable energies such as wind, biomass and geothermal, regardless of the government's willingness manifested in the energy plans (MINAET, 2015). In 2016, the energy grid showed percentages of 12.4% of geothermal energy, 10.6% of wind energy and 2% of biomass energy (CENCE, 2016). The growth of the solar PV industry in Costa Rica has been somewhat uncertain in recent years as described by the feasibility studies from Ackermann (2017) & Valverde et al. (2015).

However, as it is suggested by studies by Echeverria & Monge (2017) & Valverde et al. (2015) the recent executive decree enacted in 2015 for DGM has permitted to increase the demand for solar PV systems in Costa Rica. The executive decree reactivated the solar PV industry in Costa Rica after the freezing period created when the pilot plan was ended. It is driving the development of imports, installation, sales and more activities within the industry value chain. The market is emerging quickly to the benefit of many solar PV developers and clients.

Incumbent companies consider that all necessary conditions are available for firms and technology to develop, while other stakeholders as industry associations and SMEs feel strongly that regulatory aspects are the main reason for the poor diffusion of technology in Costa Rica. However, there are no studies that specifically focus on the understanding of these assumptions. It would be relevant for the solar PV energy industry in Costa Rica to invest in a better understanding of the potential barriers and facilitators for the development of solar PV companies.

The lack of systemic processes for creation, interaction, and dissemination of knowledge could be hindering the firms' development. I.e., the development of firms can be hindered when there is poor technical and financial documentation on the characteristics of the Costa Rican solar PV industry or mechanisms to share information are informal. Also, if there is a lack of interaction between relevant stakeholders such as SMEs, local knowledge institutions, and national energy decision makers, the development of firms can be hindered. Therefore, under these circumstances, it is challenging to create data-driven strategies for the development of solar PV companies.

Therefore, this emerging local environment poses a research opportunity that will be explored in this study. It is considered necessary to increase the understanding of the current value chain activities performed in CR, as well as the knowledge and context conditions to perform such activities. Then, using the insight from this group of conditions, it allows determining the firms' barriers and facilitators for potential growth within the electricity generation segment of the value chain.

1. 2. Problem Definition

The practical problem at stake can be studied from a scientific perspective within the theories and concepts related to technology transitions, emergence and diffusion of technological innovations, industry characterization, and economic upgrading possibilities, Technological Innovation Systems (TIS), and knowledge management. A suitable scientific approach is applied to determine the potential possibilities of firms to increase the value added of their activities when they are involved in emerging technological industry.

Within the literature, there are several relevant theories to analyze technology innovations and technological transitions. As it is the case of the theory of Technological Innovation Systems (TIS) and its Functions mentions that functions are a significant determinant of technological change and are relevant to guarantee sound performance from the Innovation System (Hekkert, Suurs, Negro, Kuhlmann, & Smits, 2007). Also, the framework of Multi-Level Perspective (MLP), it suggests the phenomenon of how technological innovations are incorporated into society (technological transitions) mainly occur by the interactions between processes and actors at three different sociotechnical levels: Landscape, regimes, and niche (Geels, 2011).

Additionally, the combination of TIS and MLP frameworks to analyze emerging technologies has proven to be relevant to their diffusion, by managing potential niche markets while incorporating a broader socio-technical analysis (Geels, 2011). The combined theories described above are mainly used to introduce new technologies successfully into niche markets using a broad perspective (MLP) and have a systems approach (TIS) as mentioned by Geels (2011) & Kamp (2008). However, this project is not interested in the niche markets or the application of MLP. Instead, it will focus on a firm-level, taking a globalized and industrial upgrading approach to determine the companies' barriers and facilitators to growth.

An approach that can help overcome this shortcoming is the combination of TIS concepts with the global value chain perspective. The value chain literature organizes the firm's process flows into activities that bring value to the entire product and service cycle. This view enables a sequential and segmented understanding of how global and local industries are organized. Also, the Global Value Chain (GVC) perspective helps to understand how local and geographically dispersed actors are connected along a value chain (Gereffi & Fernandez-Stark, 2016). Lastly, the GVC perspective also studies how companies and countries can move from low value-added activities to higher value-added which is described as upgrading by (Humphrey & Schmitz, 2002).

This type of research is limited, the combination of TIS and GVC analysis was initially used and suggested for future research by Pietrobelli & Rabellotti (2011). They mentioned that exploiting this line of research could be helpful to firms because companies that manage to engage properly in GVCs are able to penetrate new markets for their products and moreover enhance their learning and innovation knowledge. In the study from Pietrobelli & Rabellotti (2011) the authors suggest that mixing concepts of innovation with Knowledge development (learning mechanisms) is essential to the competitiveness of firms and the country's growth.

Therefore, this study aims to shed light on this combined perspective to explore the companies' upgrading possibilities. While Pietrobelli & Rabellotti (2011) focused on governance and learning mechanisms respectively from GVC and TIS combination, this study focuses on the local institutional context and upgrading of GVC analysis and it focuses in system's structure and functions performance of TIS analysis. Pietrobelli & Rabellotti (2011) mentioned the GVC literature is limited analyzing the institutional context, and therefore the combination of GVC with TIS analysis is aimed to strengthen this limitation highlighted by the authors as TIS analysis provides a better understanding of the institutional structure.

1. 3. Research Objective

In response to the problem definition from section 1.2, this study explores the approach of combining Technological Innovation Systems from Hekkert & Negro (2009) and Global Value Chain from Humphrey & Schmitz (2002) literature. This approach is expected to increase the understanding of the effects of Knowledge conditions and the value chain institutional context towards the identification of firms' upgrading possibilities.

Moreover, aiming to shed light on this combined perspective, a conceptual model is expected to be built combining Technological Innovation Systems(TIS) and Global Value Chains(GVC)concepts. This model is expected to illustrate a systemic approach to determine solar PV firms' barriers, facilitators, and upgrading possibilities.

For this reason, the research objective of this thesis is to:

"Develop a conceptual model and provide recommendations for the upgrading of Solar PV firms based on the value chain context and knowledge functions analysis."

1. 4. Research Questions

In order to reach the research objective abovementioned and motivated to mitigate the problem identified for Costa Rica solar PV energy. Thus, the main research question and a succeeding set of sub-research questions have been formulated following the logical sequence described below.

Main research question: *"How do the knowledge development, knowledge diffusion, and context conditions affect Costa Rican firms' upgrading in the solar PV energy value chain?"*

In the interest of answering this main research question, five sub research questions has been proposed, and those are:

SRQ1. What are the main elements to analyze firms' upgrading in the solar PV energy sector based on knowledge and emerging institutional context conditions?

This sub research question is meant to explain the main theoretical concepts and the respective indicators that define this study. Thus, it provides the theoretical basis covering the relevant concepts from Technological Innovation Systems theory, the Global Value Chains industrial perspective and the lastly the solar PV technology domain. Additionally, answering this research question will result in the first step to accomplish the research objective from section 1.3 to develop a conceptual model.

SRQ2. What are the value chain context conditions for Costa Rican solar PV energy firms?

This research question is directed to describe in chapter four, the global value chain segmentation and also the institutional context in which the solar PV firms are embedded. It is intended to analyze the structure of the study case' value chain and institutional context based on indicators defined during the literature review in section 2.4. This descriptive analysis will provide insights of the potential barriers, facilitators, and possibilities related to those conditions.

SRQ3. What are the knowledge functions conditions within the value chain segment of Costa Rican solar PV firms?

This research question intends to analyze and describe in chapter five the performance of solar PV firms' in terms of knowledge development and diffusion functions. This case study analysis is based on the theoretical concepts and indicators defined in section 2.4 of the literature review. This descriptive analysis increases the understanding regarding firms' knowledge conditions to determine the potential barriers, facilitators, and possibilities.

SRQ4. What are the value chain upgrading barriers, facilitators, and possibilities for solar PV firms in Costa Rica?

This research question digs into the existing knowledge and contextual conditions to identify the current barriers, facilitators, and possibilities of solar PV firms for upgrading in the value chain. These findings documented in chapter six will be valuable to elaborate practical recommendations for firms and policymaker in the last chapter of this study.

SRQ5. How do the concepts of institutional context integrate with the firms' knowledge development and diffusion to identify firms' upgrading possibilities?

The resolution of this question will provide the final step in defining the conceptual model to illustrate how the value chain context, knowledge functions and GVC upgrading elements are integrated. The final conceptual model considers the elements of theoretical basis provided in the literature review and is improved with the findings from the thesis analysis.

1. 5. Research Relevance

This exploratory study is intended to deliver relevant scientific and practical contributions. The scientific relevance of this thesis focuses on the development of a conceptual model that combines the Technological Innovation Systems theory proposed by Carlsson & Stankiewicz (1991) and Global Value Chains perspective proposed by Humphrey & Schmitz (2002). This model illustrates a systemic approach to determine firms' barriers, facilitators, and upgrading possibilities. As stated by Pietrobelli & Rabellotti (2011) this combination could be helpful for firms to penetrate new markets for their products, enhance their learning mechanisms and innovation knowledge to increase their competitiveness. The intended practical relevance of this thesis has outcomes at different levels of the solar PV industry in Costa Rica. At a broader level, it provides a deeper insight of current knowledge and context conditions for the domestic Industry. Besides that, the study will provide the domestic industry with a list of potential upgrading possibilities, along with their recognized barriers and facilitators.

1. 6. Research Roadmap

The research is divided into five sections to address the main research question. These five sections are literature review, methodology, research analysis, research findings, and conclusions. Figure 1.1 illustrates the research roadmap for those five sections and how they are distributed to answer each sub-research questions (SRQ).

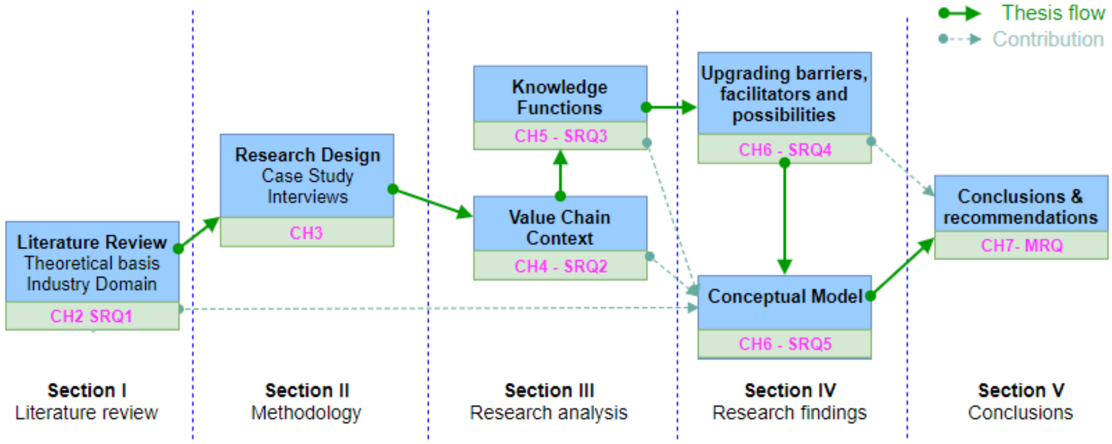

Figure 1.1 Research roadmap

The **first section** covers the literature review and desk research methods used to define the main theoretical concepts and the Industry domain to research. The section addresses the SRQ1, describing the theoretical concepts from literature of Global Value Chains and Technological Innovations Systems. Then, the solar PV energy industry domain is explained to provide the technological background in which this study is placed. At last, all concepts are combined to define a conceptual framework that serves as the thesis structure.

Section two describes the research design for this study. The section explains the exploratory case study about Costa Rican firms within the electricity generation segment for the solar PV energy value chain. Furthermore, this section provides details about the individual interviews and how these are executed. The main concepts determined in section one, are used as codes during the selective coding analysis.

Section three divides the research analysis in two parts. The first part provides a descriptive analysis of the value chain context conditions in Costa Rica. The second part is the analysis of knowledge development and knowledge diffusion conditions of Costa Rican firms. This section follows the structure defined in the conceptual framework from section two. The information obtained from section two is used in section four to derive the final conceptual model and to define firm upgrading possibilities also in section four. Consequently, this section is aimed to answer SRQ2 and SRQ3.

Section four builds up from sections one and three to provide barriers, facilitators, and possibilities for the upgrading of firms within the value chain. Then, this section develops an enriched conceptual model using the conceptual framework basis and information from the case study and at last provides the research findings discussion for the thesis. Therefore, this section expects to answer SRQ4 and SRQ5 from this study.

Section five provides final recommendations for firms, by which the research objective is accomplished. Following the roadmap, in figure 1.1 the main RQ can be answered. Therefore, by using the conceptual model of section four, it is possible to explain how the conditions analyzed in section three, affect the upgrading of firms in the solar PV energy value chain.

Document Outline

This document contains seven chapters divided as follows:

- Chapter 1: Introduction
- Chapter 2: Literature review
- Chapter 3: Research design
- Chapter 4: Value Chain Context
- Chapter 5: Knowledge Functions State
- Chapter 6: Results and Discussion
- Chapter 7: Conclusions and Recommendations

Chapter two introduces the relevant concepts from Global Value Chains, Functions Technological Innovation Systems and solar PV energy domain as part of the definition of theoretical framework for the structure of this study. Chapter three explains to the reader how the researcher is going to achieve the main objective. It provides the research approach, the case study details, the case study participants, the data collection methods and the data analysis made to the individual interviews. Chapter four provides a descriptive analysis of the value chain context and the value chain segments observed in Costa Rica. Chapter five concerns about the knowledge functions state of firms within the electricity generation segment. Chapter six builds up from previous chapters 4 and 5 to extract the upgrading barriers, facilitators and possibilities for Costa Rican firms. Besides this defines the improved conceptual model and elaborate a findings discussion. At last, Chapter seven contains answers to the research questions, the thesis contributions, the practical recommendations to firms, a reflection on the thesis limitations and final research suggestions.

2. Literature Review

The research objective of this study aims to develop a conceptual model based on a combined perspective of Technological Innovation Systems (TIS) from Carlsson & Stankiewicz (1991) and Global Value Chains (GVC) from Humphrey & Schmitz (2002). Therefore, this literature review will clarify why such combination is relevant for the solar PV energy industry; it will describe the concepts involved in the model, and explain how the concepts could be combined proposing indicators for the analysis.

The desk research used "Google Scholar" as the primary search engine to get secondary data for the literature review. This scholar search engine offers significant flexibility and further a significant availability of journals and articles, although other search engines were used as well such as Scopus, Science Direct, and Web of Science. The keywords used were "*Innovation Systems," "*value chains," "solar PV," "firms upgrading* barriers" "knowledge management" and "Costa Rica energy." Additionally, from Edsand (2017) and Pietrobelli & Rabellotti (2011) scientific articles the snowballing technique was used since those are some of the more recent articles addressing a similar research problem and desired approach. Besides the web research, the interview participants provided approximately twenty documents related to solar PV local context, such as relevant legislation, local feasibility studies, distributors' solar PV contracts, university specialization programs and presentations delivered in solar fairs.

The literature review chapter consists of four main sections to address SRQ1; the first motivates to combine these concepts and description of the relevant theoretical concepts found in the GVC and TIS literature. The second section describes relevant concepts from the solar PV energy domain which as the technological field for this study. The third section, integrate the relevant concept into a theoretical framework and finally, indicators are proposed to guide the analysis and make it possible to operationalize.

2.1 Theoretical Basis: GVC & TIS

The studies from Chaminade & Vang (2008) and Pietrobelli & Rabellotti (2011) became the points of departure to define the combined analytical approach and concepts for this thesis. The study from (Chaminade & Vang, 2008) used the GVC and knowledge analysis combined. Chaminade performed a knowledge and emerging Innovation System analysis for IT technological firms in Bangalore from a value chain perspective. Their conclusions suggested that improving knowledge capabilities from local companies help them to improve the emergent Innovation Systems and upgrade firms positions along the value chain alike.

Similarly, the research from Pietrobelli & Rabellotti (2011) attempted to understand the interaction of global value chains with innovations systems by analyzing how the governance structure of the value chain impacts the learning mechanism from innovation systems. Their study suggests that mixing innovation with knowledge research is essential to firms' competitiveness and growth. Moreover, it stated that companies in developing countries that manage to engage in GVC establish and enter new markets for their products that could enhance their learning and innovation knowledge.

Given their findings, this study follows the author's suggestion to do more research on how to merge Global Value Chains and Innovations systems literature. It further aims to shed light on this combined perspective to explore the companies' upgrading possibilities. While (Pietrobelli & Rabellotti, 2011) combination of GVC and TIS focused on governance and learning mechanisms and (Chaminade & Vang, 2008) on value chain segmentation and

Knowledge building; instead, this study focuses on the local institutional context and upgrading of GVC, and the system's structure and functions performance of TIS.

The theoretical basis description is separated into two main pillars, the Global Value Chain (GVC) and Technological Innovation Systems (TIS). The concepts description starts from the most general towards the most specific. On the one hand the industry Global Value Chains including the value chain dimensions of segmentation, stakeholder positioning and local institutional context and finally the firms upgrading types. On the other hand, as related to the Innovation Systems, the focus is placed on the specific Technological Innovation Systems (TIS) thus within TIS the concept of system's functions and system's structure are reviewed. Finally, the TIS functions, with specific detail being placed on knowledge development and diffusion.

2.1.1 Industry Global Value Chains

The value chains analysis is relevant for this study since it provides the desired industry perspective for this thesis. This view has been used to characterize and promote upgrading opportunities for several industries such as the apparel, horticultural, automotive, agriculture and others in studies from (Bernhardt & Milberg, 2011; Gereffi & Fernandez-Stark, 2016; Schmitz, 2007).

The social and economic benefits from upgrading within Global Value Chains have been researched by several authors. Studies from (Lee, Gereffi, & Barrientos, 2011) and (Morrison, Pietrobelli, & Rabellotti, 2008) claim that a global understanding of the industry value chain's dynamics is essential to companies in developing countries. Additionally, (Gereffi & Fernandez-Stark, 2016) mentioned that companies and countries upgrading in the value chain could have significant and positive implications to productivity, employment, global knowledge, and trade.

The GVC literature is divided into several dimensions to characterize and formulate the upgrading opportunities. The dimensions used in the literature are value chain segmentation, stakeholder positions, local context, governance and geographic location (Gereffi & Fernandez-Stark, 2016). Moreover, another concept from the global value chain literature is the characterization of firm's upgrading into different types or modes (functional, process, product and inter sectorial)(Humphrey & Schmitz, 2002). Those dimensions and upgrading models are explained in this section.

Another research stream, Global Production Network (GPN), performs studies related to firms and industry characterization as are the cases of (Barrientos, Gereffi, & Rossi, 2011; Henderson, Dicken, Hess, Coe, & Henry, 2002; Milberg & Winkler, 2011). This perspective presents many similarities to GVC studies since they also characterize the production activities and perform upgrading analysis for industrial conditions. However, as it is indicated by (Sturgeon, 2001), where they differ as to how they highlight the nature and extent of inter-firm relationship which is not directly related to the type of analysis or objectives of this research. As similarly outlined, this study previously follows the characterization of a vertical sequence of events as that used in the GVC literature. Therefore, the GPN approach is used only indirectly since it provides useful insights on how the authors analyze the upgrading opportunities.

Global Value Chain dimensions

The two dimensions of **segmentation and stakeholder positioning**, provide together the perspective of organizing the firms' process flows into activities (segments) that bring added value to the entire product and service cycle, thus is quite relevant to this thesis. This method enables a sequential and segmented (input-output) understanding of how global and local industries are organized. Then, the stakeholders are mapped, and their role is explained by Gereffi & Fernandez-Stark (2016). This characterization strategy has been used in many industry studies as previously mentioned and thus appropriately aligns with the study objectives given it is focused on the development of firms in a particular segment.

Another dimension outlined in the GVC literature by several actors as (Bamber, Abdulsamad, & Gereffi, 2014; Gereffi & Fernandez-Stark, 2016; Pietrobelli & Rabellotti, 2011) is the **institutional context** within value chains. This dimension is related to policy and regulations, finance, education, training, research and other support industry associations' organization. Bamber (2014) did a Global Value Chain analysis for the Burundi energy sector taking into consideration the different value chain segments. However, even when it considered the influence of the finance, policies, and regulations, etc. the analysis shows no specific detail on what are the connections or effects on the upgrading opportunities; but instead, the focus is placed on the other dimensions. The case of (Gereffi & Fernandez-Stark, 2016) the study looks into several industry cases in which the Global Value Chain analysis is applied. It also further describes this dimension and considers that the local context analysis could increase the understanding of how the industry is embedded locally to determine if this could be hindering or promoting the industry growth and development. However, it was not possible to find in the GVC literature research in which the institutional context influenced the upgrading opportunities.

Besides these examples related to local context, (Pietrobelli & Rabellotti, 2011) are the first authors to analyze partially the aspects of Innovation Systems such as technology policies and organization combined with governance dimension types from GVC. In this approach, they discuss the interaction of both terms observed in the local system for education and training. Therefore, as the authors suggest, the study provides a good foundation to continue merging these concepts in different approaches.

The last dimensions to discuss from the Global Value Chain literature are the dimensions of **governance and geographic location** and their impact to firms upgrading opportunities which have been broadly studied by several researchers (Gereffi, Humphrey, & Sturgeon, 2005; Humphrey & Schmitz, 2002). They explain how the governance types of global value chains could affect upgrading in different cases. However, the effect of the value chain governance and geographic location are not relevant for this thesis. As it is explained in section 2.3, historically the electricity industry is governed by utility companies that usually are granted a natural monopoly at several vertical value chain segment, this was the case analyzed in Burundi by (Bamber et al., 2014). Therefore, the understanding of the governance of the value chain is not necessary.

The last relevant concept covered in the Global Value Chain literature is related to the **firms' economic upgrading**. According to (Gereffi et al., 2005), the business and countries can achieve economic upgrading in the GVC by adding value to the process, given production initiatives or moving into higher segment activities. This concept is seeing as the main outcome of developing a GVC analysis since it helps to define four different types of upgrading. Those upgrading types used in GPN are intended to characterize the potential opportunities for firms engaged in the Global Value Chain.

In the literature, a variety of upgrading types have emerged since (Humphrey & Schmitz, 2002) described **economic upgrading** for the industrial context. This also was done by (Brach & Kappel, 2009) and later the study was expanded to social aspects by the authors (Barrientos, Gereffi, & Rossi, 2010; Bernhardt & Milberg, 2011; Lee & Gereffi, 2015). This study endeavors to understand them within the knowledge and contextual studies for sectorial groups as per similar initiative started by (Chaminade & Vang, 2008; Giuliani, Pietrobelli, & Rabellotti, 2005; Pietrobelli & Rabellotti, 2011).

For this thesis, the types or models described initially by (Humphrey & Schmitz, 2002) used as a reference and these are as follows:

1. **Functional upgrading:** is defined by the movement into higher value-added activities, therefore requires acquiring new functions to increase the skill content.
2. **Product upgrading:** given by changing/improving the existing product line to more sophisticated ones.
3. **Process upgrading:** modifying the efficiency or technology of the production systems to transform the inputs or outputs.
4. **Inter sectorial (intra-chain) upgrading:** when firms leverage the knowledge and skills from another GVC to enter into a different GVC.

These types of upgrading characterizations are relevant for this study since it is possible to determine the upgrading possibilities using these particular definitions when the analysis of the conditions is done.

The Figure 2.1 summarizes and highlights in red boxes, the concepts from the GVC literature that is used in the final theoretical framework, the other concepts is excluded from this study. In section 2.4 the integration of these selected concepts into their general framework is explained.

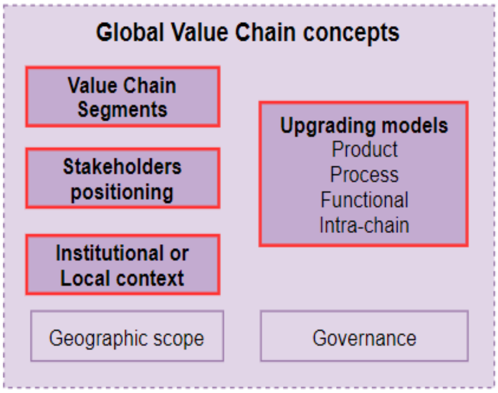

Figure 2.1. Relevant GVC concepts for thesis study. (Gereffi & Fernandez-Stark, 2016)

Figure 2.1 summarizes the relevant concepts considered for this study from the literature related to Global Value Chains. The geographic scope and governance are concepts not considered due to the characteristic of energy value chains, usually governed locally by state companies as it is the case of Costa Rica. Instead, the segmentation and positioning are relevant to define the potential upgrading direction to consider in the value chain. Also, the institutional context is relevant since it provides structure to the analysis in a similar manner that Innovations System structure.

2.1.2 Innovation Systems

As outlined above, these theoretical sections start by describing the most general concept, in this case, the Innovation System (IS). Then the description details narrows it down to the more specific concepts. Hence, the following concept described is that of the Technological Innovation Systems (TIS) which is but one of the analytical variations within IS. For TIS, the two relevant aspects of systems functions and systems structure are explained. Additionally, it explains how the TIS analysis is adapted for cases of developing countries in which the technological systems are usually immature, and therefore the analysis has to be modified from that of developed countries studies. At last, the specific systems functions for knowledge development and diffusion are also explained to finally describe all the concepts that are integrated into the theoretical framework.

For that of Innovation Systems, the literature has several definitions. However, all of them have the same purpose and are derived from the same definition which was given by (Freeman, 1987) that says:

"…systems of innovation are networks of institutions, public or private whose activities and interactions initiate, import modify and diffuse new technologies."

Therefore as one can expect, IS literature is relevant to increase the understanding when companies or stakeholder are introducing technologies and innovations to a specific country or region.

There are different types of Innovation Systems that can be segregated given the perspective level they take and also the purpose of the analysis. Several types are directed to the higher or broader level, as is the case of national innovation systems (Chaminade, Intarakumnerd, & Sapprasert, 2012; Freeman, 1987) for Thailand and Japan respectively. The regional and sectorial Innovation Systems from Munich, Cambridge and Massachusetts were analyzed for the biotechnology industry by (Cooke, 2002). Also, by (Fritsch, 2002) in several European cities and the study from (Ooms, Werker, Caniëls, & Bosch, 2015) comparing successful and non-successful regional innovation cases. Additionally, a more specific Innovation System is the case of Technological Innovation Systems developed by Carlsson & Stankiewicz (1991). TIS is used widely afterward by researchers as (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert & Negro, 2009; Markard & Truffer, 2008) to develop specific analytical applications.

As appropriately explained by Hekkert & Negro (2009), to understand the technological change, it is necessary to increase the insight into how the innovation system is built-up around the new technology. If we consider the higher level perspectives such as regional or national, the number of stakeholders and relevant institutions are difficult to map. However, the focus on a particular technology done by the TIS analysis reduces the study complexity (Bergek et al., 2008; Hekkert & Negro, 2009) which has caused it to be widely used for analysis.

Technological Innovation System (TIS)

Since this Innovation Systems perspective focuses on a specific technology it's useful to use it for the diffusion of solar PV energy technology per this case study.

According to Carlsson & Stankiewicz (1991, p. 94), the TIS is defined as:

"A network of networks of agents interacting in a specific technology area under a particular institutional infrastructure to generate, diffuse, and utilize technology."

Within the TIS literature it states that Innovation Systems success could be determined in large part by how the innovation system builds up and in particular as to how it functions (Bergek et al., 2008; Hekkert et al., 2007). For this reason, the literature about Innovation Systems has two critical concepts that have been analyzed in several studies; these are IS structure and their functions.

Innovation System Structure

The IS structure consists of the actors, networks and institutional components that constitute the technological system. How well the IS functions depends on how the different stakeholder interacts with each other at different levels (Bergek et al., 2008; Hekkert & Negro, 2009). The relevant elements of the structure are supply and demand, policy and institutions, research, education and support organizations as detailed in figure 2.2 below.

Innovation System Functions

The other relevant aspect from Innovation Systems is how the system functions. An initial system of functions was developed by (Johnson & Jacobsson, 2001) and later on, different studies have applied the systems function approach which resulted in a given list of functions. The definitions for these seven main functions from the TIS literature is provided by (Hekkert & Negro, 2009), these functions are entrepreneurial activities, knowledge development, knowledge diffusion through networks, guidance of the search, market formation, resource mobilization and creation of legitimacy.

The functions analysis of this study is limited to knowledge functions of development and diffusion described below since they are recognized at the core of the TIS relative to performance and evolution (Bergek et al., 2008). However, the analysis could be expanded to the other functions listed above.

Figure 2.2 below, shows the list of Innovation Systems functions as well as the relevant components from the Innovation system structure. The functions highlighted in red boxes are the focus of this study, since they are mentioned as the core of the Technological Innovations System Function (Bergek et al., 2008) and based on preliminary interview they represent a problem for development. The concepts related to the IS structure definition are used directly for the institutional context section during the theoretical integration except for the supply and demand concepts which are used indirectly as part of value chain segments definitions.

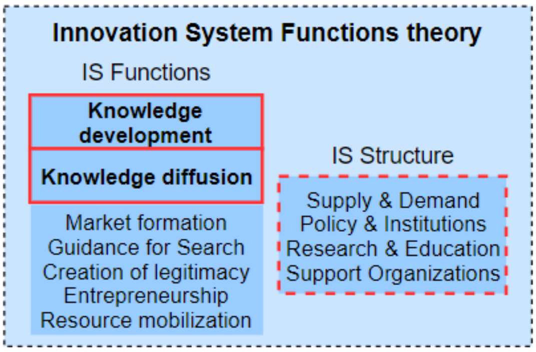

Figure 2.2. Functions of TIS concepts for this thesis study. Adapted from (Hekkert & Negro, 2009)

A TIS framework extension to is provided by Edsand (2017) to include modifications in the case of developing countries studies using TIS analysis. Those extensions were considered from the Multi-level Perspective (MLP) framework developed by Geels (2002) which is used to analyze technological transitions and it is usually combined with Innovations Systems analysis to provide a broader emphasis than regular TIS. The changes proposed by Edsand (2017) include modification to three of the seven functions and also adds six landscape factors. The modifications to the seven TIS functions affect the knowledge development function. The aspect of creation of adaptive capacity from the developing country is included in the functional analysis. This aspect is considered relevant to determine if the country is capable of incorporating a new technology into their current Innovation System.

Knowledge Development

Under this function three concepts are relevant, the knowledge creation, the adaptive capacity and the learning mechanism used to create the knowledge. The value chain segments require learning different and specific competencies to their activities. However, the mechanisms to learn are generalized within the TIS literature (Hekkert & Negro, 2009).

Adaptive Capacity

This function is described by (Edsand, 2017) as the Human, organizational and institutional capacity of a country to receive new technology. It could be operationalized only to the degree of the qualified technicians and engineers or higher education programs such as specialization, master or doctoral degrees this within the particular technology application of TIS.

Knowledge Creation

This concept is related to the knowledge aspects of quality, amount, and type. It is necessary to understand if the amount and quality of knowledge are sufficient for the appropriate development of the firm and its technology.

It is quite relevant to have an understanding of the basic types of knowledge established during the analysis and to understand if the knowledge developed fits the needs of the firm and the Innovation System. There are two main types of knowledge development, explicit and tacit. The explicit type of knowledge is one that is formalized, codified and that could be transmitted in system languages, and the tacit type of knowledge refers to intuitive, abstract that are communicated only through the active involvement of the teacher or professional (Dhanaraj, Lyles, Steensma, & Tihanyi, 2004).

Learning Mechanism

The learning mechanisms are used to acquire knowledge and build on the necessary competencies for the development of particular technologies. Learning by searching and learning by doing mechanisms helps to create the requisite of knowledge from the innovation system as mentioned by (Hekkert & Negro, 2009). Learning by doing is anchored in the concept that knowledge is achieved through practice, minor innovations, and improvement (Reese, 2011). Learning by searching can foster the actor's ability to acquire knowledge. It is an inquiry-based method from constructivist theory to promote learning by the discovery that takes place in problem-solving situations using facts and relationships from the learner's past experiences (C. Yin et al., 2013).

Knowledge Diffusion

The creation of stakeholder's networks or user-producer networks and the recognition of activity could be seen as a precondition for the knowledge diffusion mechanism (Hekkert & Negro, 2009). The particular role of knowledge diffusion could be difficult to verify in the empirical data, but the use of interviews with actors within the innovation system it is possible to obtain real insight into this functions relevance (Hekkert & Negro, 2009).

Network Activity

The network activity studies the relationships between actors on the Innovation Systems. These are usually complex, and they play a role on how the problems are solved, how the organizations are run, and the level and type of interaction with relevant stakeholders. It is important to determine if there is enough exchange between relevant participants such as users, industry and science (Hekkert, Negro, Heimeriks, & Harmsen, 2011).

Learning Mechanisms

To enforce the knowledge diffusion there are two learning mechanisms recognized in the literature, learning by interacting and learning by using which are dependent of the existence of networks.

Learning by interacting: this mechanism is related to the interaction of actors within the technology system. These interactions will fall into four dimensions that provide different views of the learning process such as transactions (interpersonal, academic, collaborative), outcomes, social presence and experience (Donnelly, 2010). Learning by using: This type of learning describes how stakeholders could increase their productivity by using the new technology; over time they learn how to use it better (Mcwilliams & Zilbermanfr, 1996). Then, this type of learning is usually used in user – producer networks. Finally, the typical indicators used to operationalize the performance of knowledge functions are platforms, workshops, and conferences.

2.2 Solar PV Energy Industry

In this section, the technology domain of solar PV industry is described including the relevant concepts for this study. The benefits of the solar PV energy, as well as the components of the system, electricity energy models associated with solar PV development and consequences of integrating solar PV systems into the energy grid, also discussed here.

Solar PV technology is known to be the most abundant and clean of all renewable resources (Parida, Iniyan, & Goic, 2011). It is one of the excellent ways to harness solar power and is, therefore, part of the future renewable energy technologies.

Photovoltaic devices are stable, simple in design, they require little maintenance, and they have standalone constructions, which makes them very useful in different applications. The solar PV energy systems could provide outputs to power up electronic devices (microwatts) to megawatts able to power up an entire village (megawatts). Solar PV devices are mostly used as a power source, for communications, water pumping, satellites, remote buildings and scalable power plants (Parida et al., 2011).

The solar PV energy systems consist of components like PV cells(panels), mechanical mountings, electrical connections, batteries and electrical power modulators/modifiers such as inverters (Parida et al., 2011). The Photovoltaic conversion done using the solar panels, allows sunlight to turn into direct current (DC) electricity. These solar panels are mounted either on rooftops or on the ground using mechanical mountings. The DC electricity is fed into the inverter to transform it into alternate current (AC) electricity that could be stored or immediately distributed and consumed.

For solar PV there are two different systems setups to generate power considering the electrical distribution grid: connected (on-grid) or disconnected (off-grid). The on-grid solar PV systems are connected to a large independent electrical grid; the off-grid solar PV systems are standalone, meaning that they are not connected to any external electrical grid (Eltawil & Zhao, 2010). Also, within the on-grid connected system, there are two possible energy source models in which solar power is generated, either centralized or distributed.

The traditional centralized electricity generation model has a large-scale electric power source system structure providing a “unidirectional” power flow and is located close to the where the resource is most available. This model starts at large generation centers at high voltage; then the energy moves from electric transmission networks that connect to distribution centers. These centers convert the high tension to medium tension, and the electricity uses a distribution grid to reach the end consumers (Valverde et al., 2015).

The distributed generation model is an alternative system to traditional centralized which allows other generation sources to connect directly to the distribution grid at medium tension/scale for commercial or self-consumption purposes. In contrast to the centralized model, this model interacts with the electrical grid under a “bi-directional” power flow manner. The systems interact with the electrical grid feeding energy to the grid if there is a surplus or extracting energy from it, this is what causes the bi-directional power flow. Also, the DG energy systems are connected to the distribution grid closer to the consumption place. Finally, the model minimizes several social and technical challenges that the centralized model presents and is a relatively fast way to increase the renewable systems integration such as that of wind, biomass and solar PV (Valverde et al., 2015).

However, distributed PV resources integration into the electrical power grid entails difficulties for energy dispatch and management. Solar PV power availability is intermittent, and this creates uncertainties for the production of electricity since it could lead to problems with supplying energy continuously and uninterrupted (Woods.stanford.edu, 2010).

Nevertheless, the distributed generation model has changed the energy value chain turning the regular electricity consumers into energy prosumers. "*Prosumers are end-use consumers of electricity who also produce their electricity at the point of consumption to meet their own electricity needs, to export electricity to "the grid" (the electricity system), or some combination of both. Simply, prosumers are electricity consumers interacting with the grid by generating some amount of electricity*" (Martin & Ryor, 3:2016)

The figure below represents a schematic diagram of a PV system that is connected to the electrical distribution grid. For this example, it has only one rooftop prosumer, but it could be expanded to attend a group of consumers called a microgrid (Toledo, Oliveira Filho, & Diniz, 2010).

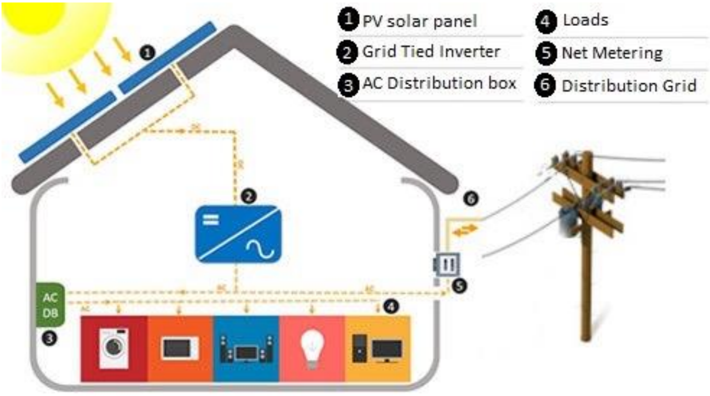

Figure 2.3. On-Grid PV system connected or self-consumption. Source: (Toledo et al., 2010)

In the past decade, renewable energies have benefited from the implementation of the Distributed Generation Model. Around the world, many countries have started wind and solar PV projects among other renewable technologies with the intention to reduce the CO2 environmental impact from fossil fuels energies. In many countries, governments are starting to promote either the developments of solar PV utility project or solar PV distributed energy projects for self-consumption usually referred to as Rooftop PV.

Solar PV Energy Segmentation

In this section, is defined the integrated activity framework for the solar PV energy value chain. This segmentation helps to describe the interconnected activities of this industry. This Global Value Chain segmentation is used to map the local actors and the activities that they perform within the solar PV energy value chain. Recognizing the relevant activities of the value chain is used to determine the associated case study actors to interview. Moreover, the segment that presents more local firms becomes the case study focuses on understanding the knowledge conditions and upgrading possibilities.

The existing literature for solar PV segmentation does not have an integrated framework that covers the activities from materials extraction to product disposal. Available analyses made for the solar PV energy industry are focused on specific sections of the value chain process.

Within the literature, an electrical energy GVC analysis made for the country of Burundi by Bamber et al. (2014) mapped the final section of the value chain process. It covers many value chain activities starting from the electricity generation up to that of the customer. However, it does not consider activities related to the disposal or reuse of the components. In other segmentation done by Gereffi, Dubay, Robinson, & Romero (2008) and Greenrhinoenergy.com (2013) they focus mainly on the process of elaboration of solar PV components, they map the initial sections of the value chain of material extractions up to the electricity generation segment as end users.

The two available analyses are overlapping in the electricity generation segment, and these are oriented to the centralized energy generation model. For that reason, those frameworks are merged in this section to define a complete activity segmentation framework for centralized solar PV energy (utility-scale). Additionally, the final framework includes two horizontal segments also included by Bamber et al. (2014) analysis that could moderate the development of the value chain segments.

The following segmentation framework contains seven value chain segments recognized within the literature and several activities associated with the institutional context in the horizontal axis, with two main moderator activities. The figure shows the final input-output framework defined for the centralized model of solar PV energy industry.

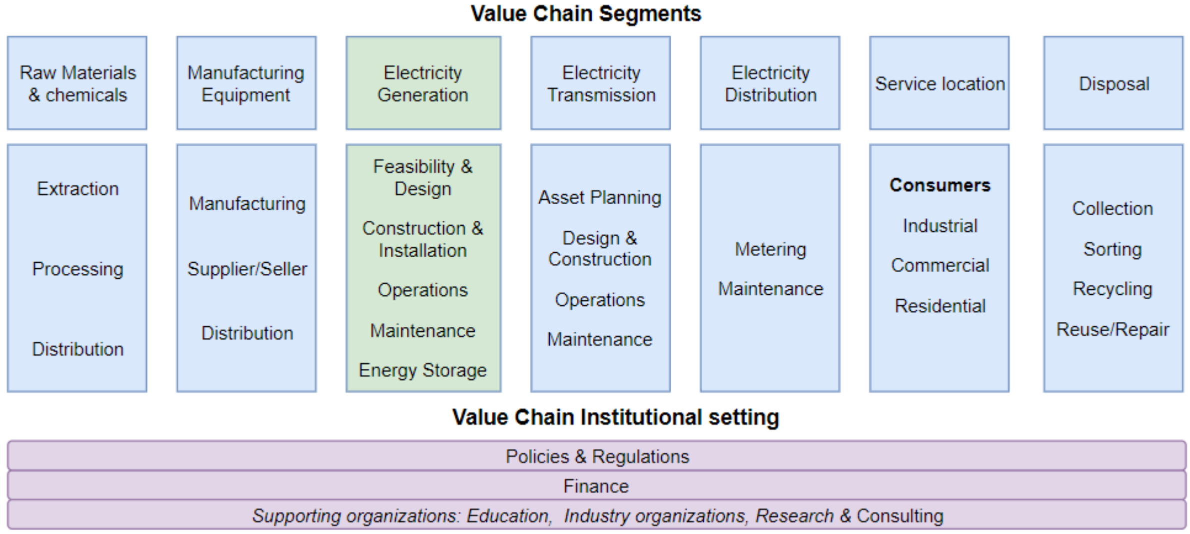

Figure 2.4. Centralized solar PV energy activity segmentation framework deducted from literature.

Vertical Value Chain Segments

This section proceeds to clarify the industry process and activities associated with each segment. The first value chain segment from the framework is the **raw materials and chemicals segment,** and, thereby, is the initial point of value creation for the industry. The activities in this segment are related to extraction, processing, and distribution of the raw materials used in equipment manufacturing such as solar PV panels, inverters, and mechanical mountings.

The following process segment within the solar PV energy value chain is the **equipment manufacturing;** this segment covers activities for manufacturing components required by the solar PV systems, that also supply and distribution that equipment. Depending on the type of connection of this segment to the local industry it could lower or increase the prices of the project and eventually the energy produced.

In the value chain, the next significant segment is **electricity generation;** this segment is intended to develop grid-connected solar PV installations utility-scale projects using the equipment provided by the suppliers. These on-grid projects could be built either for distributed generation or large-scale centralized generation. Also, this segment covers the activities of *feasibility study & design, construction & installation, operation & maintenance and energy storage* (Bamber et al., 2014).

Therefore, after the solar PV energy projects are built, they are then connected either to the transmission or distribution lines depending on if they are centralized or distributed energy model projects. If the project requires the value chain activities of **transmission,** the companies from this segment manage activities such as assets planning, design, engineering, construction, operations and maintenance of transmission lines (Bamber et al., 2014).

If the project requires the **distribution** grid, this electrical grid serves to distribute energy to the service locations. The distribution grid provides the services of voltage and frequency regulation to the solar PV systems connected to the grid. Also, the firms in this segment are responsible for maintenance and measuring the consumption (metering) of electricity by individual consumers (Bamber et al., 2014).

Further, in the value chain segmentation, it follows **the service location and customer demand segment.** This segment is related to where the electrical energy is consumed either by powering devices or by turning it into another type of energy. Typical energy consumers are households, industrial complex or business. Trained electricians manage installation and maintenance of electrical systems at the service locations (Bamber et al., 2014).

The last segment of the value chain is **disposal;** this segment has increased its relative importance in the latest value chain analysis due to the high relevance to transform the waste back into inputs to make them reusable. In different industries, this environmentally sensitive segment is highly regulated (Sturgeon, 2013).

Horizontal Value Chain Segments

As part of the value chain segmentation framework, other stakeholders influence the vertical segments of the solar PV energy industry. These stakeholders' activities are represented horizontally in figure 2.4 and are associated to finance, policies and regulations explained below.

The **financial** activities could be developed either by the public (government) or private stakeholders such as banks or investors. The value chain segments require investments and incentives for infrastructure, equipment and projects development. Hence, activities and actors from this segment provide a direct impact on the development of the solar PV energy industry.

The second horizontal segment that is relevant to the development of the solar PV energy value chain is the **policies and regulations.** This segment provides the required institutional context of norms, standards, policies, and incentives that directly affect the value chain segments. I.e., the national government could enact a policy to increase the production of solar PV energy by 2020, and this could entail regulatory changes to the incentive for the different sectors. Additionally, given regulations could act as barriers to development if results they are created to limit the development of the technology or firms.

Therefore, these two segments do not affect the final energy service or product as such, but instead, they could affect the potential development either creating direct or indirect barriers or facilitators.

Support Institutions and Organizations

Supporting institutions and organizations are not part of the value chain; however, they interact and affect specific value segments in different aspects. For this reason, they should be considered as part of this study since they become part of the local context for the companies within the solar PV industry.

The activities for **research & education** are usually covered by institutions developing public or private research or educational training programs related to the solar PV industry. These are usually research centers, universities, technical academies or training institutions. Regarding solar industry companies, these support organizations are directly responsible for developing the knowledge capabilities from actors among the segments.

Another supporting actor is the **industry organizations**. Usually, they are organizations to help support firms and technology development since their actors are involved in developing the industry. These institutions usually connect and enforce interaction among relevant actors or help form alliances to boost the technology diffusion.

The Distributed Generation for Self-Consumption Value Chain

Within the solar PV industry, the distributed generation model came to modify both the industry and the energy value chain. This will be therefore more noticeable in the solar PV value chain, as stated before; figure 2.3 that represent the case of a centralized project. For the case of usage of self-consumption model, the figure has to be adapted because there are several distinctions outlined below.

The first is that the development of electricity generation activities is not going to be developed in the electricity generation segment. For this case, the activities of *feasibility study & design, construction & installation, operation & maintenance and energy storage* are developed on the client's related location. The second is that solar clients under DGM are not only consumers anymore as they have become prosumers as outlined in the previous section. A prosumer is a customer who is a consumer and producers as well. Thus, the transmission segment lacks relevance since projects do not require the transmission lines, DGM projects are connected only to the distribution grid.

2.3 Theoretical Framework Combination

In sections 2.2 and 2.3 the relevant concepts were described, those concepts are combined into a theoretical framework. This section explains how the concepts of Technological Innovations Systems (Bergek et al., 2008; Carlsson & Stankiewicz, 1991; Hekkert et al., 2007) and the concepts of Global Value Chain (Gereffi & Fernandez-Stark, 2016; Humphrey & Schmitz, 2002) may be appropriately integrated into a theoretical framework.

It uses the existing framework for Technological Innovations Systems(TIS) analysis, and it is further strengthened by the global industrial perspective from GVC that places more emphasis on the wider context than TIS. As a result, the framework allows analyzing Solar PV firms upgrading in a Global Value Chain setting. Moreover, it would be possible to determine upgrading recommendations for the firms embedded in an emerging technological environment.

Figure 2.4 shows the theoretical framework that has three main sections, which are the value chain context (structure analysis), the knowledge functions (functions performance analysis) and the GVC upgrading (firms upgrading analysis). Each section is directly related to addressing a sub-research question. The value chain context addresses SRQ2, the knowledge functions is directed to SRQ3, and GVC upgrading block to answer the SRQ4. Furthermore, the definition of this theoretical framework represents the first step towards answering the SRQ4 question which is that of the final and improved conceptual model.

Regarding the components of the three framework sections, first, the **value chain context** has two elements, the structural components of value chain segmentation and the value chain institutional setting. Second, the **knowledge functions** section focuses on one specific value chain segment (Electricity Generation) and the analysis of the two knowledge functions of the Innovation System. Third, the **GVC upgrading** block considers the previous analysis for the contextual and knowledge conditions to determine the firm's upgrading possibilities.

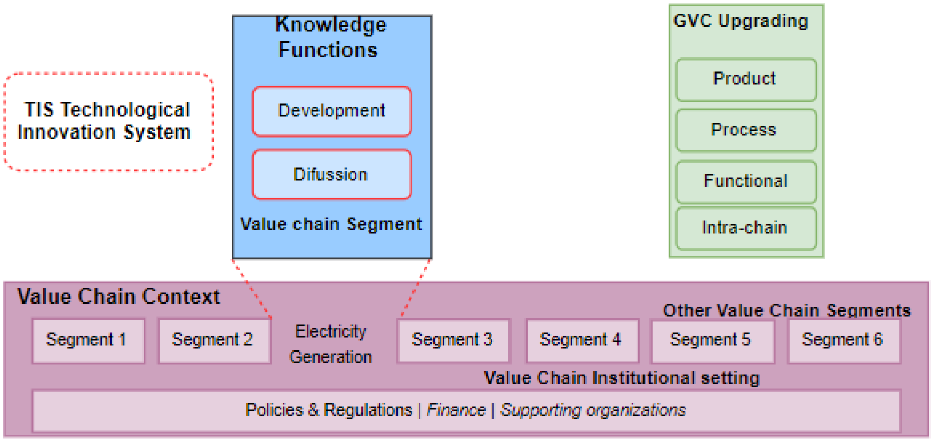

Figure 2.5 Conceptual framework used as building blocks for this case analysis

The segment of electricity generation was chosen to be the focus of this study since it is the segment where the majority of solar PV firms are concentrated and developing activities in Costa Rica. In this segment, it is possible to identify both the emergent private SMEs and the incumbent companies (state-owned and public). Whereby, these companies have direct and indirect connections with most of the other segments of the value chain and the institutional context. Therefore, we consider that favoring the development of companies within this segment results in the fact that a more significant socio-economic impact is reached given the number of people and the number of related economic activities that are involved.

Value Chain Context

The value chain context section from figure 2.5 has referenced the whole solar PV GVC segmentation framework so defined in the literature review. Additionally, it is subdivided into two sub-sections first the value chain institutional setting and second the value chain segments all to identify and describe the TIS structural elements within this GVC segmentation.

The value chain context (structural analysis) section goes beyond the typical TIS structure approach mentioned by Bergek et al. (2008), it expands the structural perspective incorporating the elements of value chain activity segmentation and stakeholders positioning described by Gereffi & Fernandez-Stark (2016). Thus, the structural analysis allows locating the TIS structural elements within the Global Value Chain segmentation framework and thus defines the stakeholder's roles and engagement in the global value chain.

Knowledge Functions

The knowledge functions section from figure 2.5 represents a function's performance analysis applied to the firms within the value chain segment focus (study applies to electricity generation). Given research constraints, the functions analysis was narrowed down to two functions of the total seven analyzed within the TIS functions approach.

The functions performance analysis related to Knowledge development and Knowledge diffusion as is defined in the TIS research from Hekkert & Negro (2009). These functions were selected because Hekkert & Negro (2009) emphasizes the two functions as the most relevant for emerging Technological Innovation Systems. However, the function's performance analysis could further be expanded to cover other functions from TIS theory.

GVC upgrading

The GVC upgrading section is related to a firms'-level analysis, and it is based on the models of industrial upgrading characterization from Humphrey & Schmitz (2002) which are described in section 2.1.1. This section analysis builds up from the results of the other two sections those that establish how the firms' upgrading possibilities are influenced by the structural and functions performance conditions.

These previous two sections increase the understanding of the contextual and Knowledge conditions and thus this section allows determining the potential barriers or facilitators for the firm's upgrading. Moreover, based on these barriers and facilitators it is possible to identify the firm's upgrading possibilities and eventually provide strategies or recommendations similar to the TIS analysis applied from Edsand (2017).

Barrier & facilitators concept definition

The knowledge and contextual conditions are expected to affect the companies upgrading possibilities. For this study, it is considered that if the conditions observed affects the upgrading options positively they are called *facilitators*. Otherwise, if such conditions affect the upgrading possibilities, negatively they are called *Barriers*. Thus, these facilitators and barriers are used to develop the firm's strategies for further development.

2.4 Theoretical Framework Operationalization

This section guides the analysis done in chapters 4, 5 and 6 which is based on the theoretical framework. For each block in figure 2.5, this section provides specific dimensions, a second layer of analysis including detailed concepts and associated indicators are also explained for each block. The definition of these Indicators was based on the literature of Gereffi & Fernandez-Stark (2016) for GVC and from Bergek et al. (2008), Edsand (2017), Hekkert & Negro (2009) for the TIS analysis.

Value Chain Context

The analysis scheme from the value chain context is shown in figure 2.6. This scheme is used for the chapter four definitions since it provides the conceptual descriptions. The concepts for dimensions are two, institutional setting and value chain segmentation.

For the **institutional setting** the second level of analysis is focused on the one hand on the policies and regulations and the contrary finance and support organizations that form the institutional context described by the IS theory in section 2.2.2. For the policies and regulation, indicators to consider during analysis are the types of taxes applied to the technology or companies, the subsidies given by the government, and also the regulations that impact the technology of the firms for their developments. For other aspects related to finance and support organizations, it is relevant to determine the financial resources provided by the banks, or government to the companies developing the solar PV technology. Also, relative to the support organization aspect, it is important to consider the role and relevance of the industry associations and the institutions in charge of developing the training programs.

For the second dimension, the **value chain segmentation**, two aspects are relevant to consider from the second layer of analysis. The stakeholder positioning and the value chain activities. For those the main indicators are the descriptions of the main actors by segment as well as determining the relevant firm's activities.

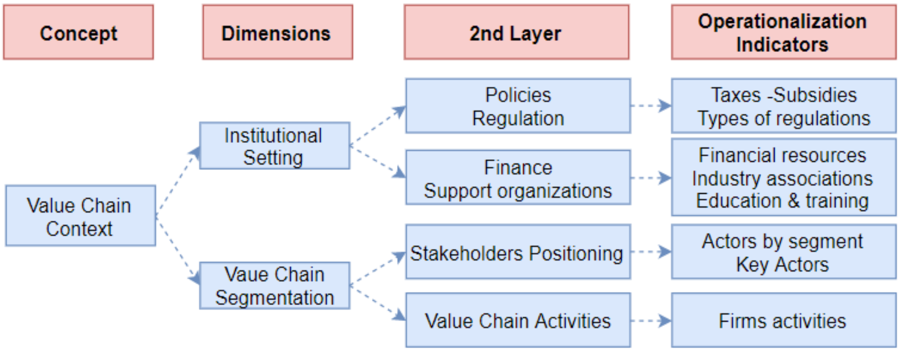

Figure 2.6. Value chain context layers of analysis and indicators

Knowledge Functions

The analysis scheme for knowledge functions section is shown in figure 2.7. The dimension of knowledge development has three aspects to analyze, knowledge creation, adaptive capacity and learning mechanism such as learning by doing and searching. The typical indicators that are used to analyze the performance of knowledge development functions are the development of specialized training programs, R&D projects, patents, desktop assessment, feasibility studies, and reports.

The dimension of knowledge diffusion has two aspects to analyze, network and sharing activities and also the learning mechanisms such as learning by interacting and using. The indicators analyzed are the existence of networks, sharing platforms, workshops, and conferences.

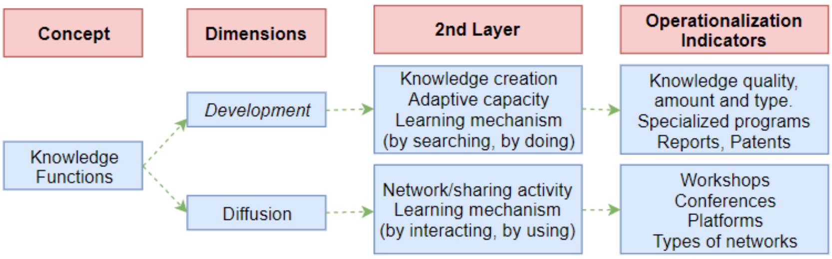

Figure 2.7. Knowledge functions layers of analysis and indicators

GVC Upgrading

The analysis structure for GVC upgrading section is shown in figure 2.8. It is possible to determine the barriers and facilitators identifying from the knowledge and context conditions the negative or positive aspects.

The relevant operationalization indicators for the upgrading types of functional, process, product and intra-chain are the execution of outsourcing activities, the changes in activities to increase the efficiency of processes or productivity, the changes on products within the company portfolio and the possibilities of change to industry goods or processes using the acquired knowledge. The segmentation and operationalization from figure 2.8 was deducted from the studies of Gereffi & Fernandez-Stark (2016) and how they analyzed the cases from their studies.

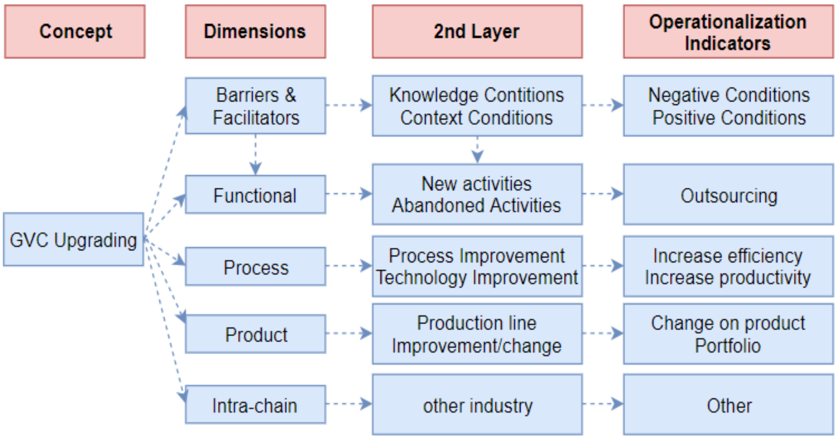

Figure 2.8. GVC Upgrading layers of analysis and indicators

Figure 2.8 provides a second layer of analysis and indicators to operationalize the upgrading models from the literature. These are useful during the case study to identify the possibilities for upgrading.

2.5 Summary

The relevant concepts for this thesis from TIS Carlsson & Stankiewicz (1991) and GVC Humphrey & Schmitz (2002) literature were described in this chapter. Moreover, a conceptual framework was proposed in this section represented in figure 2.5 to help answering SRQ1. This framework provides a structural approach including specific indicators for analysis to determine the firm's upgrading opportunities by analyzing the value chain structure of institutional context and the firm's functional knowledge conditions.

Using this approach to the case study is expected to deliver an understanding of the value chain coverage of the Technological Innovations System. Also, it would be possible to determine if the firms engaged in the Global Value Chain have strong global ties or their connections are limited to the domestic industry. The further analysis of these sections in the next chapter allows the researcher to determine barriers and facilitators given the factors and conditions shown in each chapter.

The framework building blocks are used in chapters four and five to guide the analysis applying the indicators explained in section 2.4.2. Furthermore, in chapter six, the finding of the conceptual relationship is explained. Thus given a further possible definition of strategies or recommendation help improve the firm's knowledge and value chain conditions.

3. Research Design

The previous chapter described the relevant concepts and defined the theoretical basis including indicator to be used in this study. Subsequently, this chapter aims to explain how the research objective from section 1.4 is going to be achieved. The chapter provides the research approach, the case study details of background, participants and data collection methods. Then in gives the details of the data analysis methods used. At the end of the chapter, the reader will have a broad perspective of how the research questions are answered to achieve the research objective.

This research has a qualitative explorative with theory building approach using selective coding interview analysis to understand and clarify an industry phenomenon for new technologies. The phenomenon to explore is the upgrading possibilities of GVC within an emergent industry, taking the solar PV energy business of Costa Rican firms as a case study. It is a qualitative exploratory since there is little information about Costa Rican context for firms in solar PV industry and entails a complex background that needs more in-depth understanding.

As part of the qualitative process, the research design was modified while the information was being gathered during the interviews. Also, the research questions had to be modified several times based on the experience from the fieldwork, and multiple interviews with different segments were made to understand the context of the phenomenon better. There are a lot of different actors with different scale of capabilities in a small market with aspects that were very open to interpretation.

The theory building approach used is based on two main kinds of literature to increase the rigor and provide systemic procedures towards the analysis of this phenomenon. These theoretical concepts are Global Value Chains and Functions of Innovation Systems. GVC cover the different upgrading models that companies used within the certain industry. Functions of Innovation System addresses the mechanism that a company involved in emerging technology could use to achieve this change/improvement. Each theory focuses in the following way: for GVC, mainly focuses on functional & process upgrading and for TIS focuses on knowledge development and knowledge diffusion.

The theory building research strategy is used to explore a new conceptual model of analysis for global value chains directed to emerging industries and combining two perspectives. This analysis is useful to understand the upgrading possibilities of specific segments of the value chain of a new technology/industry. As it is stated by (Eisenhardt & Graebner, 2007) about theory building, this research strategy is one of the best to go from rich qualitative evidence to mainstream deductive research. Also, this model aims to provide a balance of theoretical and practical outcomes as it was described in the research objective.

3.1. Research Approach

During section 1.6 of the introduction chapter, a general thesis roadmap description was given. In this section, the specific detail of how the thesis was developed is explained on a step by step basis. Figure 3.1 provides an advanced representation of figure 1.1 including more details of each section of the thesis.

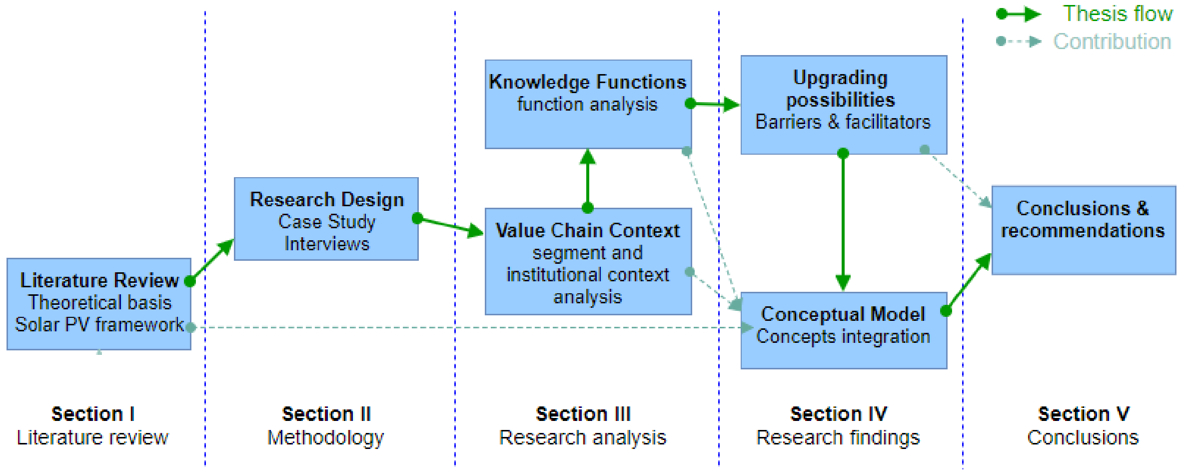

Figure 3.1. Detailed research approach

As it is explained in the research objective of section 1.4, this thesis has two primary outcomes. One outcome is to develop a conceptual model to illustrate how the components of two theories affect the firms' upgrading possibilities. The other outcome is to provide recommendations for the upgrading of solar PV firms in the value chain. By the use of the research approach in figure 3.1, these two outcomes can be accomplished. Besides that, from figure 1.4 the solid green arrows represent the thesis sequence (flow) and the dotted arrows represent contributions to forthcoming sections (when are not next in the sequence).

The **first section** covers the literature review and provides the theoretical base for the study. It defines the main concepts of this thesis, combining the GVC and TIS literature in a theoretical framework, which is used in the research analysis in section three and as base for the conceptual model development in section IV. The literature review defines the Global Value Chain framework. Consequently, the GVC segmentation framework is used for analysis of solar PV energy.

The conceptual framework consists out of three main blocks: the value chain context, the knowledge functions, and the GVC upgrading possibilities. This framework provides the structure for the case study and the theoretical basis for the development of the final conceptual model in section four.

Section two about research methodology describes the approach taken in this study, and it addresses the research objective and research questions. In this section, it is explained which approach is used to create a conceptual model and which approach is used to create recommendations for companies to upgrade in the value chain. The methodology describes the relevant aspects which build the structure of the research and the case study, such as selection of participant, the data collection methods used, and the data analysis following the principles mentioned by R. Yin (2014).

The case study participants (the interviewees) are stakeholders at different segments of the value chain and also from organizations of the institutional context of solar PV TIS in Costa Rica. The individual interviews were the primary source of data collection and the information collected was complemented with secondary data from desk research. All the data was grouped using selective coding methods and codes derived from the literature review (see section 3.4). This final set of data is analyzed in section three of this study.

Section three the case study analyzes the two base components of the conceptual framework given in section 2.4. The information obtained from this section also contributes to section four to derive the final conceptual model and to define firm upgrading possibilities.

The analysis performed uses the indicators also defined in section 2.4 to operationalize the data and shed light on the firms' current conditions. The first component analyzed is the overall value chain context which includes the structural aspects of TIS as described by Bergek et al. (2008). The second component analyzed is the performance of knowledge development and knowledge diffusion functions derived from Hekkert et al. (2007) for firms that are embedded in the electricity generation segment of the solar PV energy value chain.

The value chain context analysis is used to identify the TIS structural components and the value chain segments. For this reason, the analysis is divided into two sections called value chain institutional setting and value chain segments. This analysis uses the interview data and indicators from figure 2.6 to extract two elements of relevance. The first element involves the stakeholders and their roles along the whole value chain and other institutional organizations from TIS described in section 2.4.2. The second element is about the conditions that might be affecting the firms' performance such as norms, laws, regulations, culture, and routines. As it is noted by Bergek et al. (2008), it is relevant that institutions, activities, and actors align to new technology since this facilitates the technology diffusion.

Knowledge development and knowledge diffusion analyses are intended to understand the current performance of firms in the electricity generation segment. The operationalization of their performance was made using the indicators described in section 2.42. For knowledge development, the indicators used are the quality, type (tacit or explicit) and amount of knowledge, the existence of adaptive capacity in specialized programs, the creation of patents and reports, and the learning mechanism used. For the knowledge diffusion, the indicators used to understand the networks activity and the capability to share knowledge are the existence of workshops, conferences and other platforms, and the use of learning mechanisms for knowledge sharing. This type of analysis contributes to section four to shape the conceptual model and define firms' upgrading barriers, facilitators, and possibilities.

Section four is divided into two main parts, which together provide the main outcomes from this thesis. The first part describes barriers and facilitators that affect the firms' upgrading possibilities. The second part illustrates in a conceptual model how the concepts of value chain context, knowledge functions, and firm's upgrading possibilities are related.

The first part elaborates on the main barriers and facilitators derived from related analysis of knowledge functions and institutional context of TIS and GVC. To justify the selections of those conditions two aspects are considered: the relevance was given by the stakeholders interviewed and the literature associated with these concepts. To derive the upgrading possibilities also two aspects were considered: the explicit possibilities given by interviewees during individual interviews and the findings from the research analysis which are categorized into the four upgrading models mentioned by Humphrey & Schmitz (2002).

Regarding the second part, section 2.4 provides an initial theoretical framework to begin developing the enriched conceptual model. The framework is reshaped into a final conceptual model with the addition of the insights from the value chain context and knowledge functions analysis. Moreover, there section ends with a discussion of the overall findings for each relevant section, explaining their combined effect toward upgrading opportunities and the conceptual model definition in overall.

Section five provides the conclusions that can be derived from this research. Also, the thesis contributions and practical recommendations to Costa Rican firms are made based on the barriers and facilitators, associated with the upgrading possibilities. At last, it does a reflection on the limitations and provides suggestions for future research.

3.2. Case Study Conditions

The units of analysis for this single case study are the firms involved in the solar PV energy value chain in Costa Rica. The analysis is focused on firms responsible for developing the electricity generation projects either for centralized or distributed generation connected to the electricity grid. Firms in other sectors or segments of the value chain are also considered during the interview process to cross-check the validity of the information. However, the scope stays about the electricity generation sector.

The case study is relevant because there is a market with great potential, multiple actors, and stakeholders interested in developing the electric market (solar PV), lack of managerial documentation and need for a framework that provides structure to derive upgrading possibilities and strategies.

The validity and rigor of this case study are considered as part of the analysis. The internal validity of the analysis increases due to the cross-checking of information provided by interviewing stakeholders from other segments (transmission and distribution) and supporting organizations (government, universities, and banks). The rigor of this case study is improved by the use of the case study protocol to document the interviews and observations made during the interviews.

Case study background

The electricity sector in Costa Rica is governed by a monopoly from a national company. This means that all energy generation projects(large or small scale) for commercialization purposes are developed only by this national institution or by private companies assigned under a concession model. However, distributed generation energy projects for self-consumption purposes are allowed to be developed by private firms if they align with certain regulations.

There is an increased demand for solar PV energy projects for self-consumption purposes stimulated by the decrease of solar PV panel prices and the possibility of developing private projects in CR. The solar PV sector has grown in the past years aligned to this energy distributed generation model. An SME group conformed by around hundred firms has emerged to satisfy the increasing demand for low-scale solar PV projects (less than 500 Kilowatts).

Finally, even when Costa Rica's usage of renewables energies for electricity purposes was of 98.21% by 2016, the electricity generation share from solar PV was only 0.01% (CENCE, 2016). Therefore, the firms from this case study are positioned within a context of developing the country with low resources that has an emergent Innovation System of solar Photovoltaic energy technology that has not been able to diffuse.

3.3. Case Study Participants

The segmentation framework and the literature associated with section 2.3 increases the solar PV industry understanding, to help to identify the actors from different value chain segments and support organizations in Costa Rica. Based on the activities for each segment is possible to associate the organizations performing those in the case study.

Also, the Costa Rican Association for Solar Energy (ACESOLAR) was contacted to obtain information about relevant actors from those sectors and their contact information. The initial stakeholders were divided into three main groups, relevant actors from different institutions/organizations related to the energy industry in Costa Rica, electricity distribution and transmission actors and finally solar PV developers, all characterized within the segmentation framework.

Figure 3.2 describes the different segments in which the selected are located. It helps to visualize their positioning in the value chain, the institutional setting and within the electricity generation segment represented as the green box.

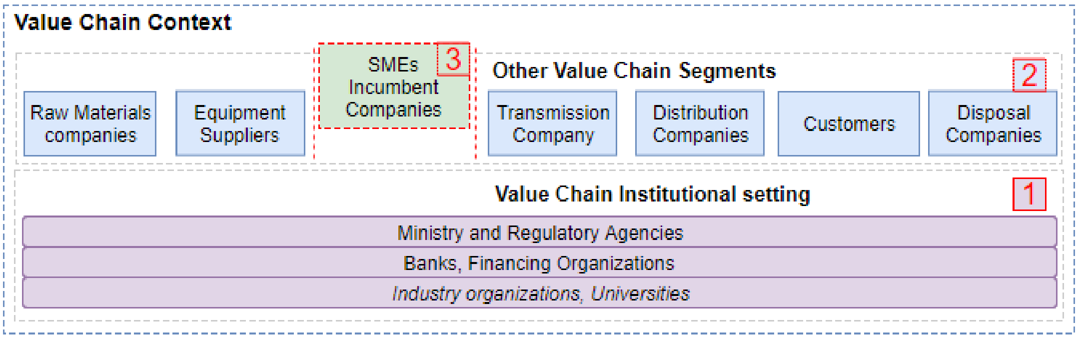

Figure 3.2. Case Study participants detail for Individual Interviews

The first group of stakeholders is very diverse and scattered horizontally along the value chain activities and support organizations from the sector to provide a broader context and different opinions about the firms' context and upgrading possibilities. The following list of relevant stakeholders was contacted and interviewed during this study. At least one actor per segment was interviewed, but in some cases, more than one actor was interviewed due to their availability and willingness to participate in the study. The full list of actors could be seen in the appendix 1 section 1. Also, referencing the actors from the interviews in chapter four and five uses a reference code indicated in that table and this format. I.e (actors 1,2).

- Banks
- Regulators
- Government Departments
- Universities
- Industry Association

The second groups of stakeholders were companies located in the different segments of the value chain; the total number of actors in this category is eight and four off those were selected for interviews according to their availability.

- Equipment Suppliers
- Electricity Transmission company
- Electricity Distribution companies
- Customers

The third group of stakeholders were the incumbent companies and Small and Medium Enterprises (SME) dedicated to developing energy projects in the region and Costa Rica. The incumbent companies have been developing energy projects for decades and are allowed to initiate solar PV projects if they want to as part of their energy distribution activities. It was noticed that most of the SMEs companies present many similarities. Most of them are developing similar solar PV projects sizes(less than 200Kilowatts), all of them are SMEs with less than fifty employees and all of them present a very similar target market for their projects (solar PV and thermal PV).

The selection of candidates for the third group of this study was based first, on the availability for collaboration. Also for SMEs selection, two criteria were relevant characteristics to provide more variability in the information. Those criteria were the size of the company and the maturity or years of establishment. The two criteria are the company size and establishment on the market. The company size divides the groups into incumbents (large companies) and emerging SMEs. Furthermore, the maturity is defined by the years in the energy market, and it is noticed among the SMEs the breaking point is five years.

Figure 3.2 shows the variability observed according to the criteria used from the third group of firms present in this study. It is observed that based on this criteria it was possible to obtain firms in three different quadrants to increase the variability of the data. There is a quadrant that did not have stakeholders since all the large energy companies have been in the market for many years.

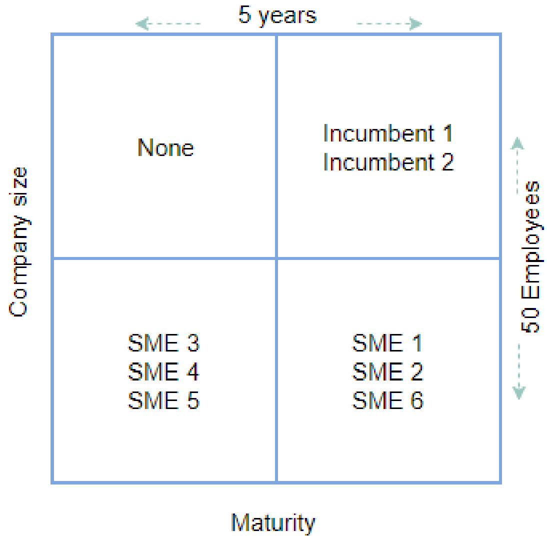

Figure 3.3: Companies selected based on criteria's of size and maturity.

Table A1 from appendix 1, gives the detail for the companies selected. The interview process started by contacting three companies, and as networking process those stakeholder allowed to contact new actors that were eventually contacted until all the relevant actors in the segmentation frameworks were covered.

3.4. Data Collection Methods

This qualitative research gathers the data for analysis from a mix of two main data collection methods: desk research and individual interviews. Secondary data gathering is used as part of the desk research to develop the literature review related to relevant concepts, to generate the semi-structured interviews used during the case study research and to describe the case study context in which the phenomenon is developed.

3.4.1 Individual Interviews

The main primary data resources are **individual interviews** applied to several representatives from firms at different segments of the value chain and not the only segment of the value chain where the majority of firms are located. Many organization and support institutions were considered as part of the interviews as it was detailed above.

The individual interviews data collection method allowed obtaining in-depth and first-hand information around the knowledge topic to understand how the companies are managing it. This information would not have been possible to obtain using only a desk research due to the lack of documentation available on the web. Furthermore, due to the willingness to collaborate of most of the interviewees, the personal interview method opened a communication channel that was beneficial when specific aspects had to be clarified remotely after the interview.

3.4.2 Data Documentation

The **case study protocol** was the process used to document the interviews of this research; this process increases the rigor of the documentation process and facilitates the analysis of the semi-structured interviews. The interviews were made in Spanish, and then this data was trans-scripted also in Spanish.

The semi-structured interview has three main sections; the first section is about the Global Value Chain aspects from the firm such as activities performed, relevant actors and context. The second is to understand the knowledge development and knowledge diffusion context such as methods for learning, documentation practices, interactive learning and alliances. The third was to understand the upgrading possibilities from the company and barriers that companies are experiencing. The cases study protocol and the semi-structured interviews are part of Appendix 3 and 4 respectively.

3.4.3 Data Collection Process

The interviews process was developed in three rounds, the rounds occurred sequentially. The first initial round was made remotely via telephone, taking written notes to gather basic information about relevant actors and to define the value chain segments. The second round was done in Costa Rica, in person and every interview was recorded digitally. The third round was made again remotely via telephone to clarify specific details that were not properly clarified during the previous rounds.

The following table provides the detail of the stakeholders interviewed during the process according to the rounds explained before. The full detail of stakeholders interviewed is in Appendix 1 table 1 representing a total of 22 companies

Table 3.1. Interview rounds from the exploratory research of Costa Rican firms.

Round	Stakeholders types	Stakeholder (qty)	Method	Number of Interviews
First	3	Private financing (1) CR Solar Association (1) Project developer (1)	Telephone Interview	3
Second	9	Equipment Suppliers (2) Banks (2) Project Developers (4) Universities (2) Regulators (1) Industry Association (1) Customers (2) Electricity Transmission (1) Electricity Distribution	Personal Interview	20
Third	2	Project developer (3) Electricity Distribution(1)	Telephone Interviews;	4

This methodology chapter explained how this exploratory research would be performed. The research method uses a combination of desk research and SME case studies. The information from the SME is obtained using personal semi-structured interviews, and the data analysis is done using selective coding grounded in TIS and GVC theory.

3.5. Data Analysis

Data analysis used the desk research to access secondary information from web pages of national institutions in the field of energy generation. Also, many of the actors interviewed provided documents that were in their possession but were not open to the public. All this information was categorized according to the relevance to the study, and it was used to corroborate the information provided in the interviews. The documents included information about energy contracts, solar PV training programs from universities, legislation and feasibility studies.

3.5.2 Individual interviews

As part of the grounded theory from Corbin & Strauss (2015), the data analysis process that is based on coding research, typically has four stages of building theory which are exploration, specification, reduction, and integration. Selective coding was based on the grounded theory saving time and had to perform only the last two steps reduction and integration.

- **Reduction (Selective coding):** on this stage, the codes to be analyzed are obtained from the grounded theory. These codes (concepts) helps to select from each interview only the data related to those keywords and discard the data that is not associated with those codes. The data from all the interviews is clustered together for the next step.

- **Integration:** Using these clusters we can build a story that connects the concepts. It is possible to define connections to provide explanations, understanding, and interpretation of the unknown phenomena that is being investigated.

These stages allow the researcher to build theory and could be performed manually or using software to facilitate the process. For this study, we used software to perform the selective coding to facilitate the documentation process since handling data from 22 interviews could be challenging if it is done manually.

The transcriptions were coded in English and the coding process was done using NVivo software for research that helps to organize, and analyzing data to find insights from qualitative data. The codes used from theory are detailed in the following section.

Main Codes and Sub-codes Application

The relevant codes used were extracted from the literature review from chapter three of GVC and TIS literature. The main clusters of codes are socio-economic context, institutional context, segmentation, knowledge development, knowledge diffusion, stakeholder positioning, process upgrade, product and functional upgrade.

The codes within those clusters are also concepts or indicators from the TIS and GVC literature. Also, during the coding process, two other categories were selected to group the data within each code. These categories were positive and negative comments about each concept. For example, if the interview data expressed a positive comment about policy regulation this information is grouped into the positive code or if the comment was negative the data is grouped into the negative category. This helped to differentiate the results to define potential barriers and possibilities.

These specific codes used on NVivo software, are listed in figure 3.4, provides the detail of main codes and codes used. The last column is representing a set of indicators that allows operationalizing the data to define potential dynamics.

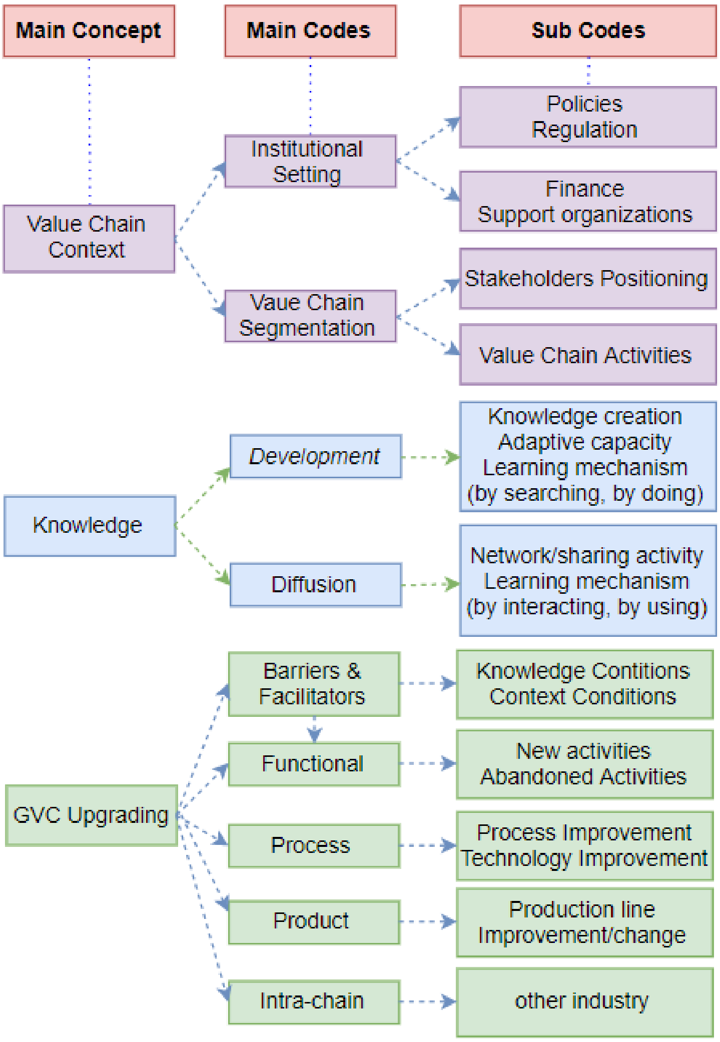

Figure 3.4. Selective coding scheme applied during the analysis process.

Finally, based on this selective coding analysis process and using several stakeholders it was possible to derive conclusions; it helped to performed triangulation between data sources (different stakeholders) to increase the validity of the conclusions. This coding process followed to increase the rigor of the research, and the data gains valuable meaning as it was specified in the literature Corbin & Strauss (2015).

3.5.2 Barriers, facilitators and possibilities analysis

The selective coding based on established indicators allows extracting and determining the conditions for each section (value chain context and knowledge functions) acting as barriers or facilitators. Moreover, the subsequent analysis pairs each concept from the value chain context section with each concept of the knowledge functions section to determine the combined effect of these conditions. This helps to determine if the conditions have a combined effect, either as a barrier or facilitator in the study case.

Furthermore, regarding the upgrading possibilities analysis and identification, this is done considering the explicit possibilities given by actors during the individual interviews and deduction from the research findings from the process described in the previous paragraph. The actors during the interview process are asked to provide possibilities to improve in the solar PV value chain, either in their segment or other segments. This information is used in combination with the previous insights to determine the firms upgrading possibilities based on the types from Humphrey & Schmitz (2002).

This systematic analytical and empirical process allows obtaining the barriers, facilitators and the associated upgrading possibilities for the case study. This process is also relevant to discuss the insights from the study case.

3.6. Summary

This chapter defined the research approach which defined the five fundamental steps for the elaboration of this study: Literature review, methodology, research analysis, research findings and conclusions, and recommendations. This approach provides the proper guidance to address the sub research question and lastly the main research question.

The chapter also provides the relevant aspects to develop the research strategy, namely a case study in Costa Rica. The chapter described the case study background, how the participants were selected using triangulation between value chain segments. Also, it described the company size and maturity criteria to select the participants within the electricity generation segment. Besides that, the chapter described the individual interviews data collection method and the data analysis strategy using selective coding applied during this research.

This research design section is fundamental to develop a proper research documented in the coming chapter. The next chapter develops the value chain context components of the theoretical framework, including value chain institutional settings and value chain segmentation.

4. Analysis of Value Chain Context

Based on the results of the interviews and desk research data, this chapter provides a deeper understanding of the contextual conditions for Costa Rican firms within the electricity generation sector. The contextual and structural analysis from this chapter shed lights on the current barriers and facilitators faced by firms working in the solar PV industry. These insights will be eventually be used to identify upgrading possibilities in section 6.2 and also to complete the development of the final conceptual model in section 6.3.

As it is shown in figure 4.1 below, the chapter is divided into two different sections; the first section describes the institutional setting, including policies, regulations, finance and supporting organizations of the solar PV industry in Costa Rica, as discussed in section 2.4. The second section describes the value chain segments, aiming to recognize the global and domestic segments according to the stakeholder's interviews. Finally, within the second section an specific description of the electricity generation segment. The dimensions and operationalization indicators from figure 2.6 are used for this analysis.

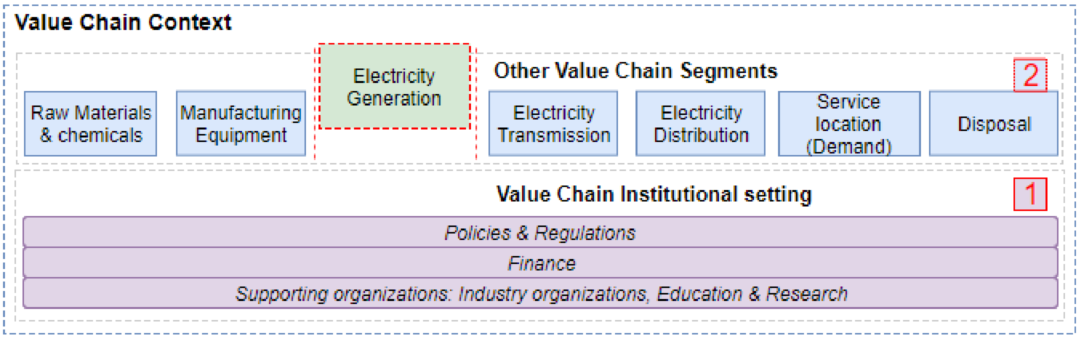

Figure 4.1. Value Chain Context and respective sections segments

Moreover, the first sub research question regarding the value chain segmentation and institutional context conditions for solar PV firms in Costa Rica is addressed in this chapter. The chapter makes references to the individual interviews, the list of actors interviewed are described in the table A1 of Appendix 1. The references are distinguished by the interview code number from the last column of the table, I.e. (actors 1,14).

4.1. Value Chain Institutional Setting

Figure 4.1 shows the elements of the value chain institutional setting dimension. Those elements are described in this section, the policies, regulations, finance, and supporting organizations as industry organization and education for the solar PV industry in Costa Rica.

4.1.1 Policies

There are three relevant policies associated with companies from the solar PV industry. Thos are the tax exemption incentive from the government to import solar PV equipment (GovCRC, 1994), the pilot plan for distributed energy generation implemented from 2010 to 2015 (GrupoICE, 2015), and the National Energy Plan elaborated by the government in 2015 (MINAET, 2015). Those policies are described in this section in the same order as they were put into practice in the country.

Taxes exemption of solar PV equipment imports; this policy is backed up by legislation "7447," and it is explicitly mentioned for its positive effect by SMEs interviewed (actors 1,2,3,4,5). However, the two international equipment suppliers interviewed (actors 6, 7) compared Costa Rica's solar PV diffusion with other countries in the region (i.e., Honduras and Panama); they considered that more incentives should be implemented to match their faster diffusion. I.e., incentives related to building utility-scale projects.

Pilot Plan for the Distributed Generation energy model (DGM) for self-consumption; this pilot plan was executed by ICE from October 2010 to February 2015, as mentioned by most of the interviews and data from the web (GrupoICE, 2015). The main goals of this plan were: increase knowledge within all the actor, test the potential effects of variable energy sources connected to the distribution grids, and to determine how the energy market could grow to adopt this new technology (GrupoICE, 2015). The pilot plan allowed a total power generation of 1.2 Megawatts from projects of different renewable energy sources such as micro-hydro, solar PV, and biomass. For solar PV technology, a total of 366 projects were installed, with an exponential growth every year reaching approximately 7MW of installed capacity. Furthermore, this plan motivated the emergence of many solar PV developer SMEs as represented in the report (GrupoICE, 2015).

A **National Energy Plan;** it was developed and documented in 2015 by the government which included sixty different actors in the process (MINAET, 2015). The National Energy Plan defined steps to reduce Costa Rica's carbon footprint to become C02 neutral in the future. SMEs interviewed from the institutional context (actor 16,17) gave more relevance to this plan.

As it was mentioned by three interviewees (actors 2,3,17), the reduced amount of incentives is compensated the government willingness to diffuse the technology and the high electricity rates to most likely cause an incremental and slow technology diffusion. Nevertheless, in the end, this could be beneficial for smooth transition and integration into the market.

4.1.2 Regulations

In Costa Rica, the existing legislation for electricity generation in Costa Rica is very complex and was designed to protect the state-run monopoly for power generation. Such protectionist legislation prohibited solar PV grid interconnections, highly limiting solar power installations and therefore electricity production (GrupoICE, 2017b). However, in 2015, enacted executive decree "39220" approved grid interconnection and net metering for renewable energy sources. This decree reduced its protectionist element that favors state-owned companies (ICE and CNFL) and energy distributors companies, authorized through ICE (MINAE, 2015b).

Below it is explained the general legislation framework and its approach towards utility-scale project. After that, it is also described the recent executive decree enacting the norm that allows the development of distributed energy projects of renewable sources for self-consumption purposes (referred as "DG Norm")and finally the two major actors related to regulations are mentioned.

Legislation for Electricity Generation

In Costa Rica, the energy distribution is defined as a public service, running since 1949 by a state-owned monopoly called Costa Rican Electricity Institute (ICE). This institution was entitled by legislation (Law 449), and it has to guarantee the energy supply and security for the increasing demand in Costa Rica.

The regulatory energy field in Costa Rica is complex, as there are at least six main laws directly related the energy generation service. ICE, its subsidiary the National Power and

Light Company (*CNFL by its Spanish acronym*), energy cooperatives and public service municipalities are allowed to develop energy projects under laws 449, 2 and 8345 respectively. Legislation 7200 regulates electricity generation from private producers. Finally, the Distributed Generation Model for self-consumption is regulated by the norm enabled by executive decree 39220 (MINAE, 2015a).

There is a consensus among different stakeholders of the government, incumbent companies, SMEs and industry associations (Interviewees actors 3,6,14,16,19) arguing that current legislation is not properly updated to new emergent energy technologies like solar PV , and that the lack of flexibility in the regulatory framework creates a roadblock to the development and growth of such technologies.

As it was mentioned by the President of the Energy Producers Association: "*the maximum size limit of 20MW for Utility-scale projects limits the benefits from economies of scale for private developers… Also, the 15% limit for BOT projects based on maximum national installed capacity affects private company's development since there is a long list of potential projects and it is very difficult to be accepted"(Actor 14).*

Distributed Generation Norm (DG Norm)

The "DG Norm" was granted by executive decree 39220 from MINAE on October 8th, 2015. This executive decree allows the development of distributed generation projects from renewable energy sources such as solar PV, mini hydro and wind for self-consumption purposes. However, this norm has several negative aspects, which are described below based on the comments given by the different interviewed stakeholders.

The employee from the Ministry of Energy (actor 16) and an SME manager (actor 1) considers that the current norm must be turned into legislation as soon as possible since the current executive decree is vulnerable to changes in an upcoming government.

All SMEs and even an incumbent company manifested to have problems with the procedures such as inspections and forms required by the DG Norm. The SMEs employees consider that these processes increase the time and cost of each project, reducing their feasibility.

The DG Norm has a limit for the number of projects that could be installed in a specific distribution electricity circuit, set to 15% of the distribution circuit capacity, and distribution companies check this percentage before granting permits for construction (MINAE, 2015b). A researcher from UCR University considers that:

> *"the 15% limit in the Norm was established without a technical Grid study. Hence, this limit should be eliminated and replaced by a Software simulation analysis (which is available in CR) to determine, in real time, if solar PV would not risk the grid capacity" (actor 9).*

The new billing methodology is based on the concept of net-metering, a mechanism that credits solar energy system owners for the electricity they add to the grid (SEIA, 2017). The Costa Rican method only allows the clients to access 49% of the total energy produced (MINAE, 2015b) and besides that, also charges for accessing the energy in the future. On one hand, the actors from incumbent companies recognized that the new billing methodology does not compensate the cost of tension and frequency regulation neither the power nor energy back up from the electrical grid to the distribution companies. On the other hand, the emerging SMEs and ARESEP argued that billing methodologies are limiting the commercial viability of new prosumers, since based on consumption profiles their profits are limited. Therefore, as it was also indicated by universities, equipment suppliers, and MINAET that the current billing mechanism does achieve a favorable balance compensating electricity distribution companies costs neither the commercial viability (return of investment ROI) of new clients.

In Costa Rica, there are two major and relevant governmental institutions involved in the elaboration of regulation and policies for the solar PV energy industry, the Ministry of Environment, Energy, and Telecommunications (MINAET) and the Public Services Regulatory Authority (ARESEP). MINAET has an internal department called Sectorial Energy Directorate (DSE) that handles the energy sector directly. ARESEP is an autonomous institution in charge of regulating the public services in Costa Rica, and specifically defining the electricity tariffs from all energy distributors. The stakeholder's table A1 from appendix 2 summarizes the relevant actors from the institutional context that are involved in regulation activities for Costa Rica.

4.1.3 Financing

A relevant aspect mentioned in the literature (Hekkert et al., 2011) was the financial support for companies, customers, and research and development. In Costa Rica this support is available. The banks interviewed (actors 11,12) and a financing company (actor 13) mentioned they are offering loans with competitive conditions for “green” solar PV projects using the solar panels as warranty and financed by international development funds. However, for SMEs (actors 1,13,10) the conditions from banks are not so attractive since the interest rates are not very low, and the procedures are slow. Additionally, the university professors (actors 8,9) mentioned that financial resources for university research in solar PV are available. However, they lack time allowance, personnel availability, and flexibility in their R&D processes.

Another aspect mentioned during the interviews by SMEs, banks, and clients (actors 3,10,21) was the commercial viability or return on investment (ROI) from solar PV projects. This aspect was mentioned as one of the main drivers for clients to install a solar PV system. If the project’s ROI is not significantly positive in the short term, the potential client is not willing to acquire a solar PV system, as mentioned by banks and SMEs (actors 5,9,12). Therefore, if possible, the conditions that limit the commercial viability of solar PV projects should be improved to help upgrading firms. Therefore, if it is possible to improve the conditions that limit the commercial viability solar PV project, it could be possible to help firms upgrading.

Several stakeholders such as SME developer (actor 3) consider that the current DG legislation is limiting the profitability of the DG solar PV projects and the 49% maximum limit from the net-metering billing mechanism reduces the profitability of many customers whos consumption profiles do not match the daylight. I.e., the residential clients who are outside the house during the day and come back to use electricity during the night. This situation leads to a lack of willingness to invest by the client, due to the low profitability even having bank loans available.

According to a university researcher interviewed and author of a financial feasibility study Valverde et al. (2015), he mentioned during the interview:

> “*under the current DG legislation and based on their consumption profile, the residential clients are not going to find it very profitable to install a solar PV system. Instead, the Industrial and commercial clients could be benefited. For these consumers, their productive activity occurs during the day and matches the daylight used to generate power. Hence, if the installed solar PV system cause them to move from a consumption above 10KWh(high-cost rate) to a consumption below 3KWh(low-cost rate), the final electricity cost is very low for them.*” (actor 9)

The relevant banks and organizations providing financial support directly or indirectly to SMEs and governmental solar PV energy projects are summarized in the stakeholder's table A1 from appendix 2. It is possible to recognize local banks, private companies and international development funds and entities that provide the financial support in Costa Rica.

4.1.4 Industry Organizations

As it was mentioned by (actors 1, 2, 4, 9, 14), there are three major private industry associations engaged actively in promoting the development of solar PV energy and firms at a different level. One organization is located at the macro level of the industry sector; it is called Costa Rican Chamber of Industries (CICR, *by its Spanish acronym*). The second organization, Costa Rican Association of Energy Producers (*ACOPE by its Spanish acronym)* was formed to strengthen the energy producers sector, and the last one, Costa Rican Association for Solar Energy (*ACESOLAR by its Spanish acronym*) was created specifically to promote the development of solar energy industry. The stakeholders table A1 from appendix 2 provides further detail for roles and responsibilities.

4.1.5 Education, Research, and Development

The generalized opinion amongst interviewees is that Costa Rican knowledge institutions such as universities or education centers have qualified people to deliver the specialization programs. Additionally, according to University Instructors, it is considered that existing training programs for engineers are delivered on quality and frequency basis that satisfies the current market demand for DG solar PV experts. However, SMEs and suppliers mentioned that current programs should improve the local context approach to regulatory and financial circumstances.

Costa Rica Institute of Technology (*ITCR by its Spanish acronym*) and EARTH University are providing solar PV training programs for engineers. As part of their program, EARTH University collaborates with the International Renewables Academy (RENAC) to deliver hands-on training to locals engineers. These two universities provide basic Renewables and solar PV courses ranging from durations of 20 to 60hours, and they invite Industry experts as or guest lecturers. Additionally, university professors mentioned that University of Costa Rica (*UCR by its Spanish acronym*) and ITCR had started solar PV projects for Research and Development (R&D) in their laboratories. As a result, feasibility studies and specific solar PV research have been developed by UCR and ITCR. However, in the industry, there were no signs of R&D projects being developed or the existence of an R&D center.

Two more relevant aspects mentioned by interviewees were the lack of graduate programs (Master and Dr.Ing) covering solar PV Technologies and the lack of training programs directed to technicians. Regarding graduate programs, the university professors argued that current solar PV market is not large enough yet (based on Industry feedback) to create a specific master for solar PV but there are plans for the future. To mitigate the deficiency of highly qualified engineers, universities provide scholarships to members of their staff to study abroad, I.e., TU Delft. Also, the government has excellence scholarships to reward students willing to study graduate programs in the energy field. In regards to training for technicians, there are no public programs about mechanical installations, electrical installations, operation and maintenance of solar PV systems. The lack of training opportunities limits the availability of technicians and starts to become a problem for further upgrading opportunities of companies. The stakeholder's table A1 from appendix 2 provides further detail for roles and responsibilities.

4.2. Value Chain Segments

During the literature review, seven value chain segments were recognized that apply to the solar PV energy industry. The analysis for those seven segments is included in these subsections. This step of the study allows us to understand how the actors are connected and if the level of engagement from the main actors is global or local.

4.2.1 Stakeholder Positioning

After a thoughtful scrutiny, the number of actors positioned within the different sections of the value chain framework has been listed in Figure 4.2, from there, it was noticed that some of the segments from the value chain segmentation determined in section 2.4 are not present in Costa Rica. Consequently, the value chain segments have been sorted based on their presence in the country, as such those with no presence (or only existing through suppliers) are addressed as global value chain segments (highlighted in red) because they are mainly represented by international actors. On the other hand, the segments which have been detected to be present in the local ecosystem are addressed as domestic value chain segments (highlighted in green).

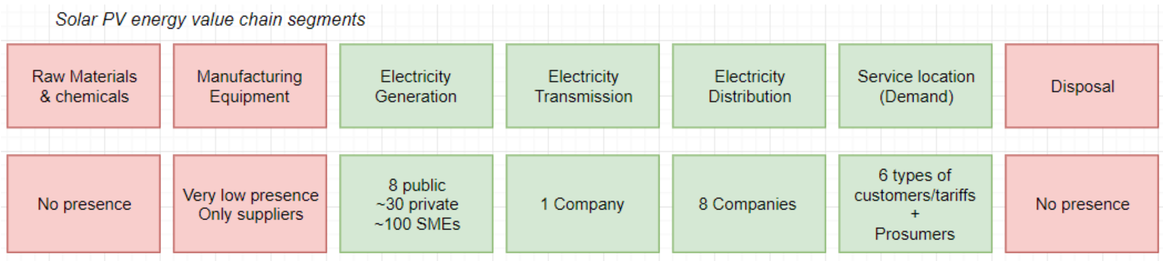

Figure 4.2. Actors present in the value chain for Costa Rica solar PV energy (source: interviews).

The value chain segments are described in detail in the next two sections. First, the global value chain segments (disposal, manufacturing equipment, and raw materials extraction) that, and then the domestic segments (service demand electricity generation, distribution, and transmission).

4.2.2 Global Value Chain Segments

Raw materials and Chemicals Value Chain Segment

There was no evidence that Costa Rican firms are involved actively in this segment. No stakeholders were recognized to extract or produce raw material or chemicals for the main components of the solar PV systems. However, it was mentioned by (actors 2,10) there is one firm (Extralum**)** that performs imports of aluminum raw material and then commercialize aluminum products like solar PV racks.

Even when this is characterized as a low-value component of the solar PV system, it represents a positive sign for the manufacturing industry. For practical reasons of this study, since the activity is an import and not export, it was assumed that CR is not involved in this segment and that Extralum is part of the equipment manufacturing section.

Equipment Manufacturing and Supply Value Chain Segment

The value chain segment to manufacture value-added equipment like solar panels or inverters which are commercialized in Costa Rica is absent. None of the interviewees mentioned using value-added products from Costa Rican companies. However, two interviewees (3, 8) mentioned the SME called Heart Transverter that manufactures inverters for solar PV systems in Costa Rica, with a small production line and commercialization only to the USA. Nevertheless, their sales numbers are unknown, and they do not have any connection to the local industry.

Also, there are two cases of manufacturing companies for low value-added products such as cable and aluminum racks as it was mentioned by (actors 3, 5, 10). Besides Extralum producing racks, a company called Conducen, a subsidiary of an American company Phelps Dodge, is producing and distributing cable used in electrical installations for solar PV systems.

The activities related to this segment are limited to sales and marketing of equipment from manufacturers outside Costa Rica as it was recognized by SMEs and equipment suppliers interviewed. Moreover, not all the equipment suppliers have representatives in the country. Some of the suppliers are based in other countries such as Mexico, Colombia, Panama or the USA as it was mentioned by SMEs and equipment suppliers interviewed.

For practical reasons of this study, we will state that in Costa Rica there are no equipment manufactures of solar PV equipment, there are only International Equipment suppliers and local brand ambassadors managing wholesale quantities. The stakeholders' table A2 in Appendix 2 summarizes the equipment suppliers actors recognized during the interviews.

Disposal Value Chain Segment

The disposal segment acknowledged in section 2.3 is absent in Costa Rica. There are no companies developing recycling or refurbishing activities, as the damaged equipment is returned to their suppliers as it was mention by (actors 3, 6, 8). One energy developer mentioned (actor 3) that solar panels come with a warranty for disposal and therefore in the future (15 years) those solar panels could be sent to the manufacturer for disposal.

4.2.3 Domestic Value Chain Segments

In relation to the active value chain segments, it was possible to determine that most of the electricity generation activities are performed mostly in Costa Rica. Only a couple of project developers are growing in the region since most of the firms do not have the financial capabilities to sustain operations abroad. Hence, the solar PV industry is not exporting goods or services, and mostly, the relationships are for import of products.

About the manufacturing equipment segment, it presents the major global engagement, which is done with equipment suppliers. Therefore, this relationship is not entirely beneficial for the local firms since they are acting merely as customers and not as providers.

Regarding transmission, distribution and customers segments, the activities are done merely in Costa Rica. Moreover, the connectivity to the regional electrical market (MER *by its Spanish acronym*) is not positive for Costa Rica since there are more energy imports than exports along the year (CENCE, 2016). Apparently, the government is still not focused on taking advantage of this regional connectivity.

The global engagement of Costa Rica's solar PV energy value chain is weak and not positive even when it has favorable conditions for Infrastructure, education, financial support and defined regulations. The industry is starting to develop, and many changes occurred in the sector in the past 5 years. Then, the current value chain behaves as a national value chain.

The domestic solar PV energy value chain is represented in figure 4.3. The main relevant actors are depicted according to their locally performed activities. As it is shown in the image, the relevant groups of stakeholders within the electricity segment are divided into two categories, incumbent and emergent. These actors acquire their systems from the international equipment suppliers and develop the project for the customers that eventually generate the energy for their consumption.

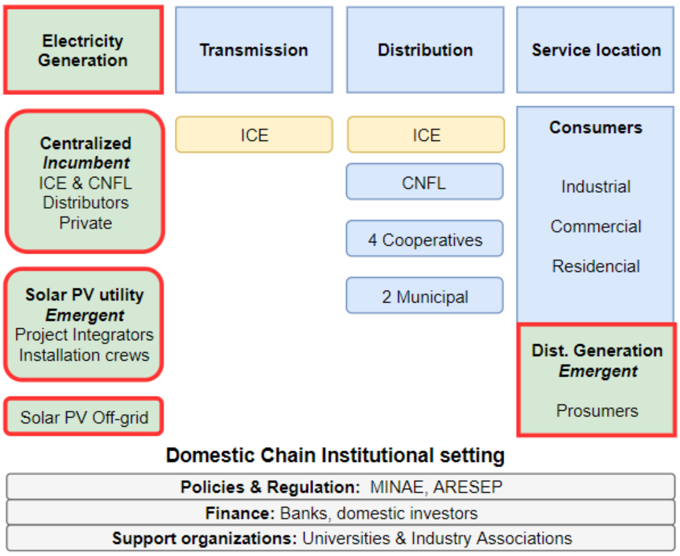

Figure 4.3. Domestic value chain observed for Costa Rica solar PV energy industry

Service Location Segment (Demand)

As it was noticed in section 2.3, there are two main types of solar PV energy systems, grid-connected, and off-grid. This study leaves aside the analysis of off-grid systems, and therefore, it recognizes two major types of solar PV energy systems demand in Costa Rica. Those two types are the demand for utility-scale solar PV projects and the Distributed Generation (DG) solar PV projects for self-consumption. As it is illustrated in figure 4.3, the demand for utility-scale projects is located in the electricity generation segment while the DG projects for self-consumption is located in the service location segment.

As it was mention in section 4.1.2, both segments have active regulations, Law 7200 for utility-scale projects and the norm enacted by Executive decree 39220 for DG for self-consumption. This section describes the value chain context conditions for these two types of demand, which vary significantly.

Utility Scale Projects (for Electricity Generation Segment)

The solar PV utility-scale project's demand in Costa Rica come from incumbent companies in charge of Distribution Generation activities or from private energy developers under Built Operate Transfer (BOT) or Build Operate Own(BOO) concession contracts.

Regarding the developments from distributed generation companies, Miravalles and Juanilama there are only two active utility-scale projects in Costa Rica. State-owned ICE manages "Miravalles" project with an installed capacity of 1MWp[1] of since 2012 when the government of Japan built it (CENCE, 2016). The "Juanilama" solar PV project is operational

[1] MWp is the peak production of the Solar project in standard conditions

since September 2017 and provides 5 MWp for the Coopeguanacaste western region. It was developed in collaboration with Panasonic Company. Additionally, Coopelesca and Coopealfaro will develop a 5 MW and 2MW solar PV project, respectively, by the year 2018 in the northern region of the country.

Regarding the private developers for utility-scale, Law 7200 restricts the concessions for them. The energy expansion plans up to the year 2030 from ICE are not significant for solar PV energy sector. The company has assigned only a small project of 5MW called Valle Escondido that is set to be finished in 2018. Instead, the ICE scheduled in their plans a total of 1000MW for geothermal, hydroelectric and thermal projects energies (GrupoICE, 2017b).

Based on previous utility-scale developments, It is noticed that demand is highly restricted to incumbent companies and those are not committed to developing this technology in the near future. Therefore, the short-term development of Costa Rican firms and solar PV energy diffusion lies under of Distributed Generation for self-consumption model.

Distributed Generation for Self-Consumption

Since the DG Norm was approved in October 2015 until to August 2016: a total of 390 applications for solar PV systems were filed (Echeverria & Monge, 2017). The applications are expected to increase but not at a higher pace due to the norms net-metering limitations impacting the solar PV projects profitability.

The increase in demand is expected to be led by the commercial, the small industry, and the large industry segments. According to financial estimations done by (Valverde et al., 2015) at least 30% of clients from those segments could have positive profitability values. The customers from rest of the segments do not present representative profitability values based on the consumption patterns and current tariff rates. Therefore, the increase in this demand is expected to impact significantly the sales of the Distribution Generation companies. Figure 4.1 shows that those segments represent around 60% of the Distribution Company's energy sales. To conclude, expected revenue lost from incumbent companies is one of the reasons why they are reluctant to integrate solar PV energy in Costa Rica.

In Costa Rica, there are six main customer's types of energy coming from the grid. Besides their specific rates charges, those clients have to pay a fee if they want to use the energy that was previously fed to the grid. This fee varies depending on the electricity distribution company.

The feasibility studies from Valverde (2015) show that residential customers are not likely to see profits from installing a solar PV system. This means the demand for solar PV DG is not going to be driven by households under current tariff conditions.

Table 4.1. Customer segments and Sales percentage in 2015 (GrupoICE, 2017b)

Customer categories	Sales (%)
Residential	39
Commercial	36
Small industry	13
Large industry	7
Public lighting	3
High power	2

Table 4.1 shows the customer categories defined by the ministry of energy (MINAET) for the distribution companies. The tariffs consider the fixed cost of providing energy service and are updated and maintained on a quarterly basis by ARESEP (17). Consumption profiles define the customer categories. For distribution energy companies the residential clients provide then a large number of sales, for this reason, the tariff methodologies were arranged to avoid benefiting these segments since it is mean significant losses.

Electricity Transmission Segment

Costa Rican National Electric System (*SEN by its Spanish acronym*) is formed by the generation, transmission and distribution systems. Since 1996 there are no isolated energy systems and all lines are fully interconnected into one system (GrupoICE, 2017b). The electrical transmission network system goes from the border with Nicaragua to the border with Panama and is connected to the Central America regional network (SIEPAC).

SIEPAC is formed by six countries in the region from Guatemala to Panama (GrupoICE, 2017b). SIEPAC Infrastructure facilitates the Regional Energy Market MER. For Costa Rica, ICE is the company allowed to trade energy in MER. Therefore, as it was explained during the interview to the planning engineer from ICE (actor 18), the company decides when, what type and how much energy to trade; either for import or export reason.

ICE owns, operates and maintains the transmission lines within Costa Rica and is the only actor allowed to perform activities within the transmission segment (Grupo ICE, 2017). For this purpose, ICE has large crews fully trained to support the whole country.

Electricity Distribution Segment

The energy distribution infrastructure in Costa Rica had a total distribution coverage index of 99.29% by 2015, and the distribution infrastructure is run by eight regional companies distributed geographically. The transmission and distribution lines in Costa Rica are able to fulfill almost 100% of the customers and are connected regionally. Besides that, a technical study done by UCR proved that transmission and distribution lines from CR are very robust and capable of handling the distributed generation solar PV projects that could be developed if they are properly geographically distributed (Valverde et al., 2015).

The country's electric energy distribution and also the commercialization activities of this public service are made solely by eight companies. These are stated-owned ICE and his subsidiary CNFL, two regional public services companies and four cooperatives of rural electrification (GrupoICE, 2017b).

Then, figure 4.4 provides a map detailing of the concessions areas for distribution activities and the companies handling clients within those areas. The ICE covers more area and his state-owned subsidiary the CNFL handles the area with highest customer's density. The distribution activities do not cover regions outside Costa Rica (GrupoICE, 2017b).

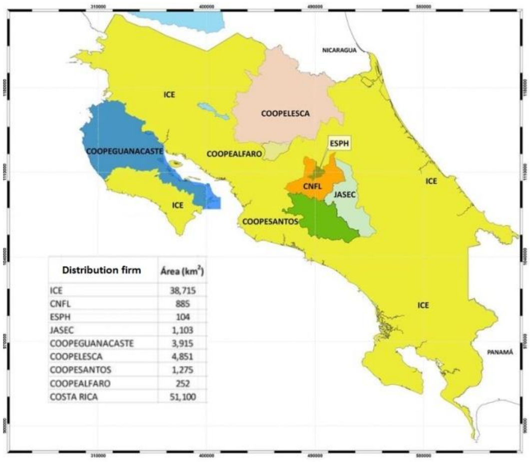

Figure 4.4. Concessions areas for energy distribution in Costa Rica, Image adapted (GrupoICE, 2017b)

According to Industry Associations, most of the distribution companies have been opposing to the implementation of the distributed generation model since they see it as a treat for their businesses. After the norm was passed in October 2015, they cannot deny access to projects if clients have all requirements. Interviewed SMEs mentioned that distribution companies try to delay projects inspections or are not cooperative with developers, delaying the implementation up to six months. However, as time passes the mindset from distribution companies is starting to change, and they are opened to start new Business models related to DG solar PV, as it was mentioned by an employee from the CNFL.

The electricity distributors table A3 in Appendix 2 provides detail from the eight incumbent companies, their area of commercialization and the sales percentage.

Electricity Generation Segment

In Costa Rica, this segment is intended to develop grid-connected solar PV installations of utility-scale and self-consumption projects using the equipment provided the suppliers. As it was described in section 2.3, this segment covers the activities of *feasibility study & design, construction & installation, operation & maintenance and energy storage* (Bamber et al., 2014).

The main actors from the electricity generation segment in Costa Rica are divided into two categories: the **incumbent companies** (centralized energy developers), and the **emerging SMEs** (distributed generation developers). The first group has been in the centralized energy industry developing and operating hydroelectric and wind projects for decades. However, they do not have experience developing solar PV projects. On the contrary, emerging SMEs mainly specializes in solar PV distributed generation projects locally and have been on the market for less than ten years.

Finally, incumbent companies usually develop and operate the energy projects that generate energy. Instead, developers from the second group design and install the solar PV project, but they are not going to operate to generate energy, the clients at the service location do it.

The incumbent renewable projects developers are divided into two sub-categories, one from the public sector and another from the private sector. The public sector companies are the same eight companies from the electricity distribution segment, and the private sector represents a larger group of approximately 30 companies. However, the public companies control the majority of projects and are the most prominent energy producers. Also, the companies from the public sector are larger in size and have been in the market for decades. I.e., ICE has around 15000 permanent employees (Lara, 2017).

The emerging group of distributed generation developers for self-consumption is formed by local, small and medium enterprises (SMEs). There are no precise public records of the actual number of emergent SMEs, but according to industry association and SMEs (actors 1, 2, 7, 10), there are about a hundred SMEs involved (90 are small sized, and 10 are medium sized, approximately). Emerging SME's actors outlined that some companies also perform activities outside of the electricity generation segment such as consultancy, equipment supply, training or even providing financing plans to clients and other small developers.

Finally, there are two types of SMEs: project integrators and installation crews. **The project integrators** serve as integrators of stakeholders as: suppliers, banks, manufacturers, installation crews, distribution companies and consultancy firms to deliver final turnkey project solutions. The **installation crews** could be part of the project integration payroll, or they work independently, being outsourced from project integrators to perform installation or maintenance activities.

Challenge for Solar PV Integration

According to the interview actors from ICE and MINAE, the fact that Costa Rica already has an electric grid based on renewables energies, producing very low carbon impact and presenting low energy supply variability makes unnecessary to integrate solar PV energy into the existing energy grid. However, SMEs argued that incumbent energy companies are reluctant to integrate the distributed generation model for self-consumption purpose for economic reasons. The new DGM represents a significant change in the industry, and it has challenged the current business models from the incumbent companies. Now the customers can install their own generation systems, and emerging SMEs are taking advantage of that increasing the installation and grid connection of small and medium scale Solar PV Projects. Therefore, this model is seen by incumbent companies as a significant threat to their revenue projections and debt repayment plans, let alone to the high price per kWh it is offered to their customers. Since incumbent companies' hydroelectric and thermal generation current installed base is extremely high capital and debt intensive

As a result, a future solar PV integration is more difficult since ICE controls the expansion plans for the energy grid and they are biased to hydroelectric energy. This is mentioned as a limiting aspect of firms and technology diffusion according to suppliers, industry associations, MINAE and ARESEP (actors 6, 14, 16, 17).

4.3. Summary

This chapter provided the analysis of the value chain context block found in the theoretical framework defined in section 2.4. The two main sections from this section: value chain institutional setting and the value chain segment were described using indicators which allowed his operationalization. This allowed to addressed the SRQ1 from section1.5 and provided insights to recognize barriers and facilitator that will be described in chapter six.

The value chain institutional described in section 4.1 provided several valuable insights such as, the solar PV Technological Innovations System in Costa Rica presents an emerging institutional structure with many institutional roles and regulations still establishing. Additionally, the combined effect of available policies is not causing an expedite technology diffusion; however, the result is positive for smooth transition and integration into the market. Besides that, the existing regulatory framework is considered outdated, centered in Hydroelectric and complex which makes it very difficult to develop utility-scale projects by limiting the participation of private developers. However, the recent approval of Decree 39220 gives room to develop solar PV projects self-consumption purposes. Moreover, the current DG legislation it is considered to be limiting the profitability of the DG solar PV projects, which outbalance the benefit of having financial support available. Additionally, the current basic training is available, provided mostly by universities, however, the lack of training opportunities for technicians and specialized (master programs) limits the availability of technicians and could become a problem for further upgrading opportunities of companies. Finally, the market presents high interest in developing DGM solar PV project and Industry organizations are pushing to diffuse solar PV technology by organizing events at national level.

The main insights from the value chain segments described in section 4.2 are: first, the Raw materials, manufacturing equipment, and disposal activities are not present in Costa Rica. Second, the country solar PV value chain behaves domestically with weak global connections. Third, the activities for energy generation, transmission, and distribution are ruled by MINAE and are highly dominated by the energy monopoly established for ICE and his subsidiary CNFL. Finally, two main stakeholders exists within the electricity generation segment. The incumbent companies act as a powerful group that has a strong effect on the diffusion of energy technologies. The emerging SMEs are a group of around 100 developing mainly DGM solar PV project which tries to gain space in the market.

5. Analysis of Knowledge Functions

In this chapter, the Knowledge development and Knowledge diffusion analysis(Hekkert & Negro, 2009) is focused on firms within the electricity generation segment and their connection with other stakeholders of the solar PV value chain such as universities and equipment suppliers. This analysis attempts to address SRQ2 proposed in section 1.4 by increasing the understanding of the knowledge functions conditions from TIS within the value chain. The findings made in this chapter are used to identify upgrading, barries, facilitators and posibilities in chapter 6, as well to enrich the final conceptual model development in section 6.3.

The framework for the analysis is defined in section 2.4 and is further shown in figure 5.1. Based on this framework, the chapter is divided into two main analysis sections: one for Knowledge Development and another for Knowledge Diffusion. The relevant aspects that were identified during interviews are under column "2nd layer". Those aspects were operationalized using indicators from the last column of the framework. Therefore, related to Knowledge Development, the aspects to explore are the adaptive capacity, the knowledge creation, and the learning mechanism; regarding Knowledge Diffusion, the aspects to explore are the network's activities, the knowledge sharing activities and also the learning mechanism. This framework is referenced and adapted from studies of Edsand (2017; & Hekkert et al. (2011).

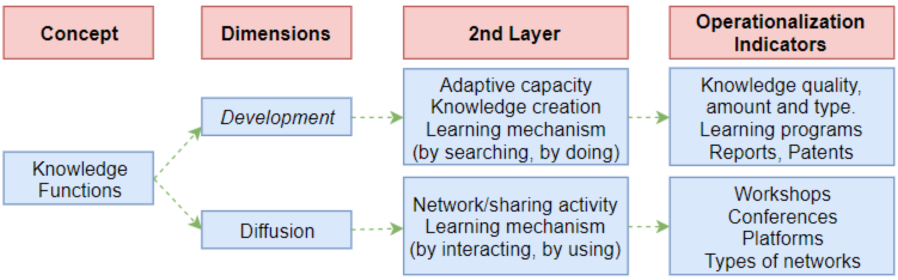

Figure 5.1. Framework to analyze the Knowledge Functions.

5.1. Analysis of Knowledge Development Function

The Knowledge Development analysis has three relevant aspects to explore as it is illustrated within the box in the "2nd layer" column of figure 5.1. The adaptive capacity is meant to determine if the value chain segment has the knowledge capabilities required to develop solar PV. The knowledge creation determines if the knowledge type, amount, and quality are enough for technology development to occur. The analysis of the learning mechanism: "by searching" and "by doing" is focused on understanding if they are present and effective within firms.

5.1.1. Adaptive Capacity

Adaptive capacity is described by (Edsand, 2017) as the ability of a country to integrate a new technology where it is possible to look into the human, organizational or institutional capacity. In Costa Rica in term of human capacity, there are qualified engineers with the required knowledge base to develop the initial diffusion of the solar PV technology as it was described in section 4.1.5. The knowledge base identified is related to activities such as:

feasibility & design, construction & installation, operations, maintenance, software, and equipment.

However, university professors and industry organizations outline that firms within the electricity generation segment already have several options to train new engineer to acquire the basic knowledge to be able to incorporate them into the market needs. However, it was noticed by SMEs actors that specific knowledge that could be required for further development is not available in Costa Rica. The country lacks specialized programs on topics such as the design of utility-scale solar PV, new DG business models, solar PV entrepreneurship, smart grids design and development, DG energy trading, contextualized financial aspects, net metering aspects, super capacitor type storage and delocalized grid battery storage.

Moreover, it was noticed that government institution's capacity to take actions for new innovative initiatives is slow as described by SMEs companies, incumbents companies, and research institutions. This slow response has been shown in the designation of public technical programs used to train technicians on how to perform solar PV Installations and maintenance. This has been recognized as a technical gap for the industry for several years already that has not yet been addressed.

Additionally, as it is described by incumbent companies the Costa Rica Institutional culture is reactive. I.e., the country is less than visionary or creative in that it does not plan ahead to prepare for the new technology until it is already happening. Therefore, the initiatives would have to come from the private sector since the government institutions are not investing in developing their internal or external capacities in terms of the new or leading edge stage of renewable technologies for solar PV.

5.1.2. Knowledge Creation

The knowledge creation element was explored considering three main aspects: the type of knowledge, the amount of formal knowledge generated and finally the quality of that knowledge. This allows determining if the current Knowledge Development practices are favorable or limiting the firms upgrading abilities.

Regarding the type of knowledge, the stakeholders were asked about their internal and external documentation processes, training and reports. It was observed by SMEs, that the majority of incumbent companies and equipment suppliers lack formal documentation of their solar PV activities. Most of the solar PV actors on the value chain base their activities on tacit knowledge, the exceptions are policy and regulatory institutions (MINAET, ARESEP & INTECO). Therefore, the conventional method to transfer knowledge is by informal conversations or during workshops or solar PV fairs.

Additionally, concerning to internal or external documentation, SMEs, and incumbent companies do not have an organizational culture for such a process. However, there are minor cases of companies applying documentation practices. I.e., a couple of SMEs do actually create templates for solar PV Project management and documentation of past project. ICE and CNFL, started a project to standardize their processes and thus ICE has relatively good documentation especially for their expansion plans (GrupoICE, 2017b).

During the stakeholder interviews and desk research into Costa Rican solar PV, several formal types of documentation were studied to determine the amount of documentation needed by local industry. It was determined that less than 15 were relevant documents and only four applications were identified related to solar PV energy in Costa Rica. Apparently, in the past five years, the electricity energy segment has been focused on defining the regulatory aspects of the Distributed Generation Model (DGM), which was finally enacted by executive decree in October 2015, a defining breakthrough year for growth in the documentation for this market segment.

Before 2015, only one relevant document relative to solar PV was encountered, that of a master degree thesis on performing a profitability analysis for solar PV systems in Costa Rica (Weigl, 2014). After 2015, three feasibility studies and nine scientific publications for solar PV projects have been documented by consultants and universities researchers. The feasibility studies from (Ackermann, 2017; Echeverria & Monge, 2017; Valverde et al., 2015) were funded by international development organizations to support the development of the Distributed Generation Model in Costa Rica.

Patent development and software applications saw null to weak development activities respectively. In fact, no patents have been filed in Costa Rica regarding solar PV to this date, and a mere total of four software applications were developed by SMEs, banks, and universities. These software applications were aimed at simplifying and expediting the profitability analysis for potential clients, using these applications the customer were better able to calculate a more precise ROI based on incorporating better criteria's for current and future investment projections circumstances.

The level of knowledge and documentation concerning solar PV energy is perceived differently amongst different actors. While researchers and industry associations consider there is sufficient knowledge base' documentation. SMEs and incumbent companies consider that more diverse types of feasibility studies must be done to reduce the uncertainties and increase the legitimacy for solar PV in Costa Rica. Moreover, studies on how to combine hydropower with solar PV at utility scale level are essential to penetrate this untapped market better.

5.1.3. Learning Mechanisms

The solar PV industry in Costa Rica consists mostly of individuals and emerging SMEs that were working in other industries and moved to solar PV as a new business opportunity. They used their previous knowledge base to integrate into the new solar PV sector. This is called in the GVC literature Inter-chain upgrading according to (Humphrey & Schmitz, 2002). The exceptions to such cases are the recent college graduates from local or international engineering programs that were hired at emerging firms in Costa Rica. Nevertheless, all those stakeholders used the learning mechanisms (by searching and learning by doing) to learn about renewables and solar PV to some extent driven by the related technology context differences.

The SMEs and incumbent companies used eLearning's, solar PV industry reports and webinar training available on the web as tools during their search process of learning. They were motivated to use this type of learning mechanism for two main reasons. The first is when their companies did not provide adequate internal training programs, and they look to expand and update their knowledge. Second, usually occurs after taking a formal specialization program, if they felt a specific topic was not properly covered. i.e., solar PV energy storage or financial aspects are not aligned to the local context.

The learning by doing mechanism was identified mainly in three different ways. The first is part of the formal training methodologies of Earth and ITCR University programs–where Students learn to design small solar PV Systems by doing. The second is part of the internal learning process within companies, in which the new employee learns from an experienced employee. The last case identified is that of those related to specific projects for incumbent distribution companies. Engineers learn about solar PV installations from the projects that get connected to their company grids, and therefore they are required to inspect. The drivers to use this mechanism are the lack of documentation from companies and equipment suppliers; and this void in the specific and contextualized knowledge. I.e., Costa Rica legislation, tariffs, and other factors differ from any given formal training. Therefore, these specific requirements modify the financial analysis given to potential clients.

5.2. Analysis of Knowledge Diffusion Function

The Knowledge Diffusion analysis is focused on three relevant aspects to explore as illustrated in figure 5.1. The aspect that is covered in this section is the network activity, the knowledge sharing, and the learning mechanism. The analysis of these three aspects provides a better understanding of how solar PV is being disseminated in Costa Rica.

5.2.1. Network Activity

Network activities are most beneficial to diffuse knowledge as described by (Hekkert et al., 2011). Costa Rica has three different industry associations that create networks of actors and promote the diffusion of solar PV knowledge. These industry associations are described in detail in Appendix 2 table 2.A.1. The first association outlined is directed towards DG Model companies (ACESOLAR), the other second association is focused on utility-scale companies (ACOPE) and the last, is that of the Costa Rican Chamber of Industries (CICR) is more in relation to broad energy topics. Therefore, in Costa Rica, apart from these virtual networks of companies, there are no other company clusters.

These industry associations organize events to diffuse knowledge about renewable technologies including solar PV energy. I.E., the CICR organized last year an energy congress providing speeches and conferences from regional experts (CICR, 2017). Also, since 2014, ACESOLAR organizes solar energy fairs in which SMEs can show their products to the public, and where small workshops and lectures are also provided (Acesolar, 2015). Moreover, equipment suppliers mentioned that they further organize events to showcase their products portfolios to solar PV companies. Therefore, these networks activities connect equipment suppliers, SMEs, incumbent companies, institutional organization actors and customers enforcing the Knowledge Diffusion in the value chain. To conclude, industry associations are good at promoting interactive learning activities. However, they have been quite limited to promoting the Knowledge Development within the industry, an area that needs to be improved in the future.

5.2.2. Knowledge Sharing

Despite the positive network activities described above, the knowledge sharing and collaboration are rather limited. SMEs, equipment suppliers, banks and incumbents companies expressed a fear of losing competitive advantage by sharing knowledge. This feeling is holding back many stakeholders to collaborate and diffuse solar PV energy knowledge. I.e., knowledge sharing and collaboration is restricted among banks, among equipment suppliers, within established SMEs and finally between incumbent companies and SMEs. Therefore, it is evident that competition limits the knowledge sharing and collaboration in Costa Rica.

However to the contrary, in the case of knowledge, it is in fact shared in cases that a hierarchical relationship exists. Thus the feeling of competitiveness is minimized. I.e., well-positioned and mature SMEs provide workshops to new SMEs acting as mentors or wholesalers. Equipment suppliers stated they provide free mentorship to their business customers. Finally, solar PV experts collaborate as guest lecturers at university training programs, etc.

The indicator related to knowledge sharing platforms shows that Costa Rica has at least two platforms available. ARESEP has a public web page providing energy statistics, relative legislation, regulations and electricity tariffs for the various Costa Rica industry players (Aresep.com, 2017). Also, the energy control department (CENCE) within ICE incumbent company has a platform showing daily and yearly energy statistic and reports (GrupoICE, 2017a).

Figure 5.2 describes the knowledge sharing between firms within the electricity generation segment and the rest of stakeholders within the value chain as described from the various interviews. I.e. there are no interactions between SMEs and incumbent companies with raw materials and disposal's stakeholders. Others stated: "several SMEs take the role of brand ambassadors and field support of equipment suppliers increasing the knowledge interaction". They further indicated that: "research collaboration between industry and universities is very low".

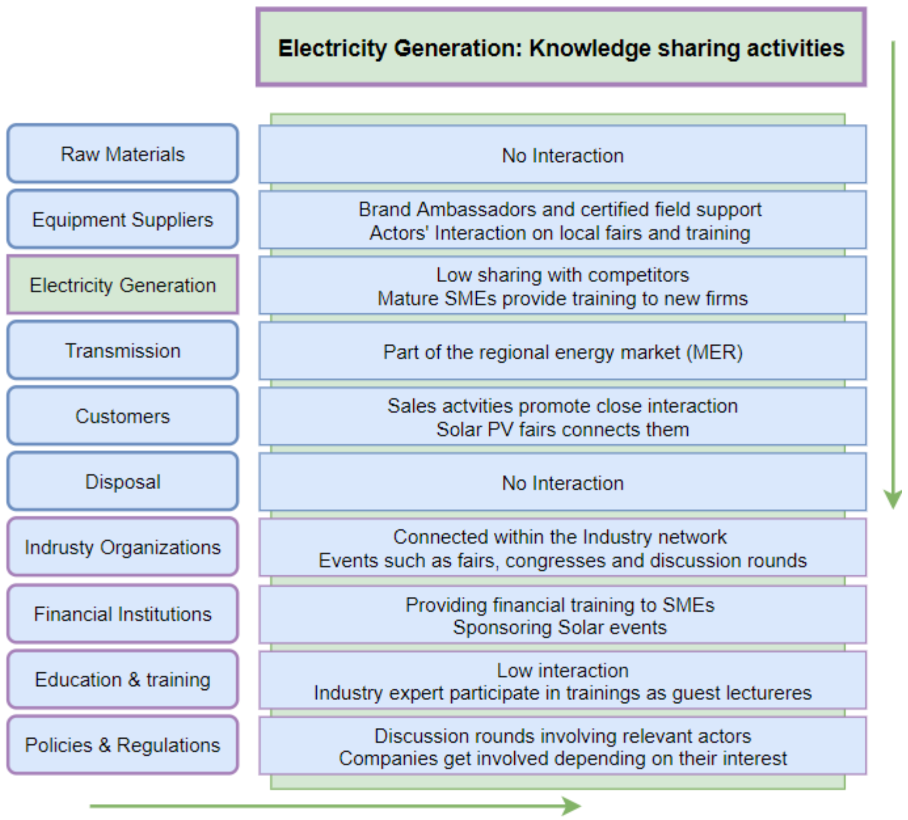

Figure 5.2. Stakeholders' interaction for Knowledge Diffusion. Source: interviews

5.2.3. Learning Mechanisms

The two main types of mechanisms for sharing knowledge described by (Hekkert et al., 2007) are learning by interaction and learning by using. This section describes how those mechanisms are manifested in Costa Rica within the electricity generation segment.

The learning by interacting mechanism is somewhat present in the segment. However, it is not sufficiently used enough to diffuse the technology thereby promote faster development. As outlined above, the interaction channels observed within the industry are weak, and stakeholders connect only at specific events or activities such as legislation generation, training event or as part of the elaboration of a feasibility study. Therefore, it is evident the actors are not used to interacting on a regular basis. Moreover, they stop interacting immediately after such events conclude and thus the flow of knowledge and thereby the learning process is interrupted

SMEs and incumbent companies use several interactive methods for learning such as attending industry specialized courses, workshops, and solar PV fairs, also by sharing with equipment suppliers and another expert their related experiences. University professors highlighted the relevance of Industry specific programs directed to improving SMEs expertise. They further mentioned that this, in fact, opened up project and research collaboration opportunities. Companies that attend the solar PV training program hence help professor connect with the industry which otherwise would see them be isolated given the resulting interaction channel between university and industry would, therefore, be nonexistent.

Learning by using mechanism is based on user-producers relationships as described by Hekkert et al. (2007). The interviewees shed light on two different cases for Costa Rica. The first is between solar PV clients with project developers, where the Knowledge Diffusion to customers has improved, and the results are visible. However, there are unfortunately still cases in which clients approach solar PV developers with unrealistic demands for their perceived solar PV systems. A SMEs Engineer quoted one clear *example "Once a customer approached us believing that a single solar PV panel would be able to supply energy for his entire business, and the real case was that he required 100 solar PV panels that would cover his entire building rooftop"* (actor 3).

The second case is between solar PV SMEs and the usage of equipment supplier's technology. SMEs have learned about the equipment and design software performance as they have developed more projects. SMEs mentioned that in some cases after learning from the technologies, they decided to change manufacturers to improve the quality deliverables of their projects. A good example of this case was a quote given by ICE, and CNFL Engineers regarding their DG Pilot Plan and Miravalles utility *plant in which they say: "for ICE and CNFL these projects represent a source of knowledge, similar to a living laboratory regarding solar PV performance in the grid"* (actors 18,19).

5.3. Knowledge Functions Summary

The individual interviews provided revealing information about the knowledge functions performance in Costa Rica. Table 5.1 provides a summary of the functions performance described in sections 5.1 and 5.2.

Table 5.1. Knowledge function's summary for firms within electricity generation segment

Function	Dimension	Summary of conditions from Interviews
Knowledge Development	Adaptive Capacity	Knowledge base regarding designing and installation of DG systems is sufficient to supply the market demand. However, firm's upgrading requires specialized knowledge on specific topics that are still deficient.
	Knowledge Creation	Knowledge is managed by a technical expert in a tacit way. Documentation is low, but feasibility studies were done, that have confirmed that solar PV provides a solid complementary alternative to hydroelectric energy, but further research is needed.
	Learning Mechanisms	Learning by searching is common for the majority of stakeholders to increase their knowledge and learning by doing; whereby we see companies using formal internal training for new engineers.
Knowledge Diffusion	Network Activity	There are several active networks in Costa Rica, promoted mostly by three industry associations. Those networks connect: equipment suppliers, SMEs, incumbent companies, and universities.

	Knowledge Sharing	Knowledge sharing and collaboration are limited for fear of losing competitive advantages. These channels of collaboration are broken and used mostly for related specific occasions.
	Learning Mechanisms	Learning by interacting is enforced through activities such as solar PV fairs and conventions. Learning by using is observed in cases of solar systems usage by clients and that of solar PV equipment & software developers.

The number of documents that have been generated for solar PV is minimal. In recent years, they include only a few feasibility studies, technical papers, and applications. Such documentation might be enough to perform the basic activities in the solar sector; however, it is quite clear that it is necessary to start documenting the processes and knowledge in order to promote further growth.

Industry associations are good at promoting interactive learning activities. However, they have been significantly limited to promoting the knowledge development (documentation) within the industry, an area that needs to be improved in the future.

In conclusion, the poor knowledge documentation and the limited knowledge sharing is seen to be hindering the firm's development. Due to the lack of government involvement and whereby the industry associations should begin to develop the knowledge documentation, promoting the opening and maintaining of knowledge sharing channels within the industry (emerging SMEs and incumbent companies) and universities.

Knowledge Differences for incumbent companies and emerging SMEs

In regards to knowledge conditions, the main companies within the electricity generation segment evidence that at present there are several differences worth mentioning. These differences are relevant and should be further considered in order to define the firms' upgrading possibilities.

Emerging SMEs have more in-depth solar PV Knowledge and practical experience than incumbent companies. The emerging SMEs have built a closer relationship with equipment suppliers benefiting from knowledge sharing regarding new advanced technologies. This relationship and ongoing solar PV project development give emerging SMEs an advantage with incumbent companies. However, this is not the case for utility-scale projects, where both groups have limited practical experience.

Moreover, SMEs usually have limited financial resources for training purposes and therefore, have to adapt to local offerings that might not fully meet their needs. Thus to the contrary, incumbent companies usually have more financial resources to attend high-quality training seminars or hire International agencies to deliver training programs in Costa Rica as was quite well expressed by incumbent companies.

Finally, most of SMEs are highly focused on improving their business operational model such as optimization of processes and gaining new customers using an empirical and more tacit approach. Hence, knowledge development and diffusion activities have less priority. On the other hand, incumbent companies are more focused on hydroelectric energy projects, and therefore their efforts are not focused on future planning or the integration of solar PV.

5.4. Summary

In this chapter, the knowledge development and knowledge diffusion conditions relative to two main groups of firms in the electricity generation segment were described. This Knowledge Development and Knowledge Diffusion information increased the understanding of the actual dynamics and relationship of concepts within the theoretical framework defined in chapter two. Additionally, the insights from this analysis are used to identify potential barriers and facilitators in chapter six.

The analysis shed light on the observed lack of knowledge documentation and limited knowledge diffusion conditions of firms within the value chain segment for electricity generation. Current conditions are enough to begin DG solar PV model. However, these conditions would have to be improved to upgrade within the value chain. The documentation practices must increase in the area of, feasibility studies and the overall solar PV industry knowledge base. The learning mechanisms have to be increased to speed up the overall knowledge adaptive capacity for emerging SMEs and incumbent companies. Furthermore, the collaboration networks have to be strengthened and thereby further sustain the knowledge sharing channels. Moreover, since government institutions are not investing in increasing the knowledge conditions, the industry associations need to consider taking the leading role (at least temporally) to ramp up said knowledge conditions.

And last but not least, the weak documentation in Costa Rica is, in essence, creating a barrier to market since many stakeholders are reluctant to invest due to the lack of fact-based research information. Nevertheless, there is no question the documentation has increased in the last two years creating a more positive outlook for the future, and all those aspects would be considered to extract the potential barriers and facilitators in the coming section.

6. Results and Discussion

As outlined in the research objective section 1.3, this thesis explores how the theory of Technological Innovations Systems by Carlsson & Stankiewicz (1991) and the Global Value Chain approach by Humphrey & Schmitz (2002) may be appropriately integrated and illustrated in a conceptual model to determine a firms' barriers, facilitators, and upgrading possibilities. Based on the insights and findings provided by chapters four and five, this chapter is intended to describe and discuss the study case results.

Sections 6.1 and 6.2 are meant to address sub research question four identifying the firms' barriers, facilitators, and upgrading possibilities. Moreover, section 6.2 attempts to answer sub research question five developing the improved conceptual model that integrate TIS and GVC relevant concepts starting from the theoretical framework defined in the literature review. Finally, section 6.4 offers a discussion of the findings from this study case, and overall in the following chapter, it will allow for the development of the final recommendations for the firms and the policymakers.

6.1 Barriers and Facilitators

Based on the value chain context and Knowledge function's analysis made in chapter four and chapter five it was possible to determine several conditions that are acting as barriers or facilitators for the upgrading of Costa Rican firms in the solar PV energy value chain. As described in section 3.5 for the data analysis process, these conditions were also analyzed to determine if there is a combined effect of the different concepts.

Consequently, this section elaborates on the main barriers and facilitators identified. A total of eight barriers and six facilitators are described in the following sections. The definition of these barriers and facilitators is part of the process to define the upgrading possibilities and finally propose recommendations for companies and policymakers.

6.1.1. Barriers Identification

The barriers described in this section are extracted from the two sections associated with the institutional context and knowledge functions analysis. As described further ahead, the majority of the barriers are associated with each concept of the value chain context and knowledge functions. From the value chain context, the regulation aspect provides the barrier linked to an outdated and biased legislation. Besides that, the financing aspect analysis allowed for identifying the SMEs limited resources as a barrier. Moreover, from the knowledge development functions, the associated barriers are the insufficient advance knowledge and the poor industry documentation. Finally, from the knowledge diffusion analysis, it additionally showed the limited knowledge sharing and collaboration condition as a barrier.

Nevertheless, considering a mixed analysis it was possible to determine barriers presenting an effect with a combined source, these are: the Incumbent companies' impact, the limited commercial viability, and the small market with relatively weak global engagement. All barriers, from an individual or combined source, are described below.

The first barrier to be described in this section is the ***electricity generation regulation***. Costa Rica's electricity generation regulation is further limiting solar PV energy integration into the energy grid and therefore firms upgrading possibilities as was shown in section 4.1. On the one hand, the legislation for utility-scale generation is over twenty years old as the last amendment was done in 1995 to allow under strict scrutiny by ICE the participation of private business (GovCRC, 1995). Also, the current energy legislation for utility-scale projects does not adequately integrate the development of new energy sources since it allows for ICE to control the energy development plans for the entire country and therefore this state-owned company is mainly focused on hydroelectric projects and to a minor extent into wind energy projects. On the other hand, for the Distributed Generation Energy Model (DGM), there is no actual legislation in place, only an Executive Decree (MINAE, 2015b). Moreover, existing DGM norm outlines limitations for solar PV technology diffusion in related aspects such as inadequate tariff methodologies, the limited profitability from the established net-metering model and given existing limits for solar PV projects developments, integration into the current distribution grid.

The second barrier comes from the negative impact of the energy incumbent companies. The incumbent companies play a decisive role in allowing or blocking emerging firm's growth and consequently the technology they are trying to diffuse as outlined by Edsand, 2017; Martin & Ryor (2016). In Costa Rica, the incumbent companies have been traditionally involved in the hydroelectric energy field, and they are relatively lacking legitimacy in solar PV technology all of which has cause reluctance to promote or take clear initiatives in favor of emerging solar PV. The fact that these incumbent companies are backed by current legislation, controlling and managing the energy sector becomes a barrier for different possibilities of firm's upgrading as is outlined in section 6.2. This barrier emerges as a combination of low knowledge diffusion that supports the relative lack of legitimacy and existing poor energy policies that provides political and legal power to these companies. For this study, this barrier is named the ***incumbent companies impact.***

The third barrier observed is directly associated with the financing aspect of value chain context. The analysis from chapter four highlighted the limited resources conditions in which many SMEs operate in Costa Rica. In the case study, it was noted that emergent SMEs have cash flow limitations and limited personnel to be able to expand and grow. For SMEs (actors 1, 2), the project's revenue and personnel are less than sufficient to support potential expansions plans. Moreover, many companies' executives are not willing to afford loans since current market uncertainties are not quite favorable and whereby other companies are not financially capable of meeting the bank's credit criteria. Resource mobilization is part of the Innovation Systems functions as described by (Hekkert et al., 2007) since it is relevant to support the emergence of the technology when the stakeholders have enough resources to invest. Based on this, the ***SMEs limited resources*** are seen as a barrier for firms upgrading possibilities.

The fourth barrier identified is the limited commercial viability for solar PV services and products, and this is the results of a combination of the financial and regulatory aspects of the value chain context. In the case of Costa Rica the solar PV equipment prices are relatively high, additionally, when batteries are included in the system design, the system does not return ROI economic benefits. Moreover, the recently approved DGM norm for self-consumption contains sections that decrease the commercial viability of solar PV projects for commercial and residential clients by limiting to 49% the net-metering model that provides economic returns to the prosumers as was shown in section 4.1. Other country governments are more willing to promote the diffusion of particular technologies creating policies and delivering incentives and subsidies for customers and companies to positively favor the commercial viability as shown in the case of solar PV irrigation systems in Turkey described by Senol (2012). However, Costa Rican policies are not achieving a considerable improvement in the commercial profitability of solar PV systems. Therefore, when the return on investments is not favorable to clients, the reception of the technology and the upgrading possibilities of the firms are thus limited as described by (Martin & Ryor, 2016). Based on this factor, the ***limited commercial viability*** of solar PV energy represents another barrier for the upgrading of Costa Rican firms because it reduces the related interest of potential clients.

The combination of aspects of knowledge and the stakeholders positioning in the solar PV energy value chain provides the fifth barrier for firms upgrading in Costa Rica. The achievement of a global value chain participation has been cited by authors like (Pietrobelli & Rabellotti, 2011) as an alternative to acquire new knowledge and open the firm's possibilities to enter new markets for their products and services. Therefore, such conditions will increase the firms upgrading opportunities. In the case of Costa Rican solar PV energy value chain, the study results show a domestic development with low global and regional connections as described in section 4.2. This weak participation is further adversely impacted by the poor knowledge development and diffusion conditions. Additionally, as stated by the equipment suppliers interviewed, the Costa Rican market is considered of relatively minor importance to their global operations, and thus reduces the attractiveness of investments. Based on the current adverse conditions, the ***small market with weak global participation*** is viewed as firms' barrier to upgrading in this study.

The author Edsand (2017) mentioned that countries lacking adaptive knowledge capacity could experience a delay in the integration and diffusion of new technologies. Under insufficient adaptive capacity conditions, the firm's upgrading possibilities are negatively affected which causes that technicians and engineers are not readily able to manage the new technology. In this case study, it was observed that the necessary knowledge to develop solar PV projects is in fact present, and therefore the market elements are in essence functioning. However, there is insufficient specialized and advance knowledge capacity both required to facilitate the firms upgrading and thereby additionally move ahead with technology diffusion. Costa Rica lacks specialized programs on specific knowledge topics such as: solar PV utility-scale development, DG business models, entrepreneurship management skills, smart grids design or development, DG energy trading, contextualized related financial capabilities, net metering implementation abilities, newer technology of combined high/fast energy on demand battery type storage, and household distributed battery storage. For this study, this barrier is called ***insufficient advanced knowledge***.

Relative to the previous barrier, all such new and advanced technology provides concrete positive results such as the example of Tesla-Australia lack of in-country Knowledge shown by the recently completed 100MW grid stabilization through a $50 Million project investment for distributed Tesla battery power packs. The company delivered a most successful implementation given the firms highest possible level of Knowledge confidence they were able to offer an installation guarantee of within "100 days or FREE". That goes to prove that such knowledge topics are now quite relevant to risk and that of achieving firms or country upgrading in the value chain successfully (Pressman, 2017).

Another barrier recognized is that related to knowledge development condition which is that of the ***poor industry documentation***. The lack of knowledge documentation represents a weakness within an Innovation System since it hinders the knowledge diffusion. In Costa Rica, the type of knowledge being shared is mostly tacit, and it was observed that firms had not developed a culture of documentation. Thus, the sparse documentation relative to technical and financial feasibility studies for the domestic solar PV industry is hindering overall firms' growth. As seen in section 5.2, knowledge is passed mostly verbally from person to person usually in informal training sessions or conversations with suppliers and clients. In general, this helps them maintain their competitive advantage but hinders the upgrading possibilities in the overall. However, the actual impact of this barrier has to be measured, since, within the emerging conditions of TIS, the current knowledge for documentation might not be limiting the upgrading possibilities as much as other barriers.

The last barrier recognized in this study is derived from the knowledge functions analysis and is related to the ***limited knowledge sharing and collaboration*** among Costa Rican firms and relevant stakeholders. As outlined in the research by (Hekkert et al., 2011), a well performing technological system must have active and open collaboration channels for knowledge diffusion among stakeholders. However, this study shows in section 5.2 that active collaboration or knowledge sharing is not happening when and if competitive advantage is at risk. Additionally, collaborations between private companies and universities or amongst companies are quite minimal. The fear of losing their competitive advantage by doing knowledge sharing with potential competitors causes firms to isolate themselves even further. The efforts from the industry associations to form industry networks and events that promote knowledge sharing are a good start. However, this study considers that currently, these steps are not enough for firms' upgrading in the value chain.

6.1.2. Facilitators Identification

The main facilitators for firms' upgrading were also derived from the institutional context and knowledge functions analysis made in chapter 4 and 5. A total of six facilitators were recognized in total, five of those arise from the direct analysis of each concept, and one is the result of a combination of two related aspects. Regarding the institutional context, there are four facilitators, and given the further knowledge functions analysis, two additional facilitators were derived.

The first facilitator is associated with government policies that are operating as facilitators for firms upgrading even when the government is not taking a leading role in the solar PV technology diffusion. The Ministry of Energy and Environment (MINAE) acts as a governance agent, controlling the technology diffusion and the many supporting government policies, such as lowering importing taxes for solar PV equipment, and that of finally developing a strategic National Energy Plan (MINAET, 2015). The Ministry of Science, Technology, and Telecommunications (MICITT) provides scholarships to students interested in related renewables' energy graduate and undergraduate study programs. These policies combined will create a more favorable environment towards a greater solar PV energy future even given the government does not, in fact, provide for strong investments incentives. Thus, this facilitator is referred herein as the ***government policies***.

The second and highly important facilitator is associated with the regulatory aspect of the value chain context analysis. As mentioned in section 4.1 in Costa Rica enacted an executive decree approved by the government in October 2015 which allows for the development of solar PV projects for self-consumption purposes. Although the decree left much room for improvements, it has at least opened up new solar PV opportunities. This study refers to this facilitator as ***DGM executive decree.***

The recent new financing opportunities offered by several Costa Rican banks and other private companies or institutions represent the third type of facilitator recognized for firm's growth in this study. In the recent years, banks have modified their credit portfolios offering more support to solar PV and renewable energy development projects in general. This financial aspect related to the Innovation Systems theory is usually covered by the analysis of the IS function of resource mobilization described by (Hekkert et al., 2007). Banks and customers interviewed mentioned that having the availability to have loans at more competitive conditions and rates provides an incentive to invest in a solar PV system. These new financial options make it possible for SMEs to acquire significantly more clients. This facilitator is referred to in this study as ***projects financing availability.***

Another facilitator observed from the context is related to the significantly favorable current customer's demand for solar PV systems. According to firms' interviewed, clients have three main motivations to acquire solar PV systems. The first is the possible significant cost reduction associated abnormally high Costa Rica electric energy prices. The second is that of the resulting important increase in a more positive eco-image factor for the company. The last but not least is that related to Costa Rica's leading edge global environmental image, therefore, the clients readily see the importance of reducing their carbon footprint. Based on such critical motivations the development of solar PV projects has seen high expectations from the market which are importantly reflected in the high current demand. For this important reason in this study, the ***positive market demand*** is considered as a facilitator.

In the value chain context analysis it was highlighted that Costa Rica is connected to a regional electrical grid which facilitates trading energy with several countries in the Central American region. The state-owned institution ICE has done a relatively good job enabling the connectivity within the regional electricity grid, and thereby an extremely important element for grid energy power security and overall regional stability all while being of great benefit given its positive uses for inter-regional energy trading. The existence of this infrastructure facilitates the opportunity to export energy to the region and increases the global participation in the value chain. For this study, the possibility for Costa Rica to be connected to a regional electrical grid enhances and further opens the possibilities for overall grid stabilities, security and emergency power for inter-regional energy supplies for firms but only if it is appropriately handled by the state-owned ICE. In this study, this facilitator is called ***regional electricity infrastructure***.

The knowledge functions analysis provided one very important facilitator, and it is related to the existence of a fundamental adaptive capacity for solar PV knowledge related to DGM technical aspects such as installation and design. The available training programs in Costa Rica are provided by local universities mainly to engineers, and those programs have been more than enough to begin the technology diffusion and in turn facilitate the emergence of new SMEs. This facilitator has been shown by (Edsand, 2017) as quite relevant for developing countries to allow for the integration of emerging technologies and therefore is referred to in this study as ***basic adaptive capacity***.

6.1.3. Barriers and Facilitator Summary

The analysis of institutional context components and the knowledge functions from the electricity generation segment allowed for extracting barriers and facilitators for a firm's upgrading. A total of eight barriers and six facilitators were defined based on the conditions observed in chapter five and six. The magnitude of the impact of these barriers and facilitators relative to the upgrading possibilities has not been measured as part of this study.

Section 6.2 describes the upgrading possibilities, and these barriers and facilitators and how they are linked to each possibility. Table 6.1 summarizes the barriers and facilitators described above. The barriers and facilitators in bold have a combined effect whilst the rest present an individual effect as outlined in sections 6.1.1 and 6.1.2.

Table 6.1 Barriers and facilitators to value chain context and knowledge functions analysis

Barriers	Facilitators
Incumbent companies' impact.	Government policies.
Electric generation regulation.	DGM executive decree.
SMEs limited resources.	Projects financing availability.
Limited commercial viability.	Positive market demand.
Small market with weak global engagement.	**Regional electricity infrastructure.**
Insufficient advanced knowledge.	Basic adaptive capacity.
Poor industry documentation.	
Limited knowledge sharing and collaboration.	

6.2 Upgrading Possibilities

This section elaborates on the upgrading possibilities identified for Costa Rican firms embedded in the electricity generation segment of the solar PV energy value chain. The method to identify these possibilities is based on a combination of the explicit possibilities given by actors during individual interviews and related assessments from the current barriers and facilitators described above in section 6.1.

The actors during the interview process were asked to provide possibilities to upgrade in the solar PV value chain, either in their segment or other related segments. Additionally, more possibilities were determined by assessing the firms' upgrading possibilities in case the current barriers end up being mitigated, and the facilitators being maximized.

Thus, a final list of possibilities was selected considering the direct interviewee's opinion and the possibilities identified from the value chain context and knowledge functions conditions. Hence, such possibilities were grouped based on the upgrading models cited by (Humphrey & Schmitz, 2002). Finally, using these upgrading models definitions, it is possible to identify further opportunities under such characteristics for Costa Rican companies.

Finally, this section describes eight possibilities, which are linked to one or more barriers and facilitators described in section 6.1. As a result, the upgrading possibilities, barriers, and facilitator shed light that leads to the final practical recommendations for firms in chapter seven.

Process upgrading type

The Process Upgrading type of possibilities are derived mostly by the existence of several facilitator factors such as the DGM decree to enable solar PV systems installation, the existing related regional electricity grid, the current high market demand for solar PV systems and also that of the sufficient adaptive knowledge capacity for DGM development. The possibilities herein described are meant to further improve the firms existing processes.

There are three upgrading possibilities for Costa Rican firms that fall into the process upgrading characteristics for the for solar PV energy value segment. One is meant to continue technology diffusion and the firms' growth using the DGM for solar PV facilitated by the new executive decree. The other two possibilities are additionally meant to improve the global engagement of Costa Rican firms.

1.1. DGM solar PV projects: this is the most plausible possibility and therefore has become the leading method for solar PV technology diffusion in Costa Rica. The market for on-grid solar energy systems has seen much growth since ICE pilot tests at the beginning of this decade, and this importantly continues growing now that there is regulation in place given the government decree approved in 2015. This possibility has several facilitators and barriers associated as is shown in table 6.2 and figure 6.2. Thus, this possibility has three facilitators directly associated: the DGM decree, the availability of project financing and the fact of the highly motivated positive market demand. However, this possibility has also three barriers, the electric generation regulation, the incumbent energies impact that hinders many SMEs projects and the limited commercial viability of solar PV projects.

1.2. Increase the regional trading: this opportunity is directly open for the state-owned entity ICE, acting as the local representative in the regional trading market (MER). During the interviews, the actors from incumbent companies mentioned that the regional Infrastructure in Costa Rica is quite resilient and self-sustaining not necessarily so for neighboring regions where it is quite common to see countries in the regions having energy shortages. However, due to poor and inopportune energy management ICE has not been able de facto take advantage of this seemly market opportunity and in the past years, Costa Rica did not have a positive trade balance (more exports than imports) as shown in figure 6.1. Figure 6.1 shows how the local production heavily dependent on hydro energy is importantly weaker during the dry season, requiring importing energy from the region.

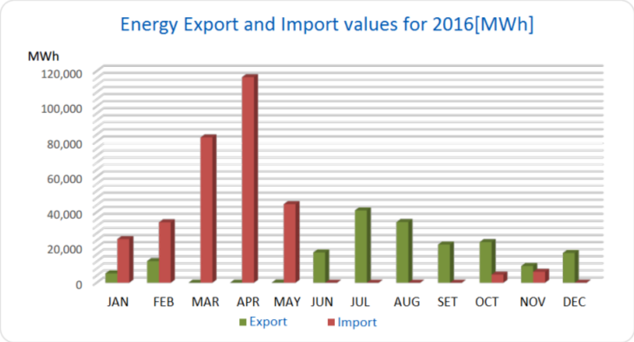

Figure 6.1. Costa Rica energy production vs. energy demand figures (CENCE, 2016)

Therefore, a change for the energy trading strategy is necessary to be more aligned to the energy supply increases needed during dry season and additionally to consider including intermittent energies such as solar PV and wind in combination to distributed storage technologies. The primary barrier associated locally is the lack of advanced and leading-edge knowledge on new energy storage technologies now viable on both sides of the meter. Minimizing this barrier would certainly guarantee greater grid stabilization that can significantly enhance the regional trading opportunities using solar PV or wind as an energy source.

1.3. Expansion outside the domestic market: to increase the size of the market, the emerging SMEs could additionally develop projects abroad in neighboring Costa Rica markets. Two SMEs executives interviewed (actors 3, 4) mentioned that only a few companies had expanded their operations into the markets of Central America, Colombia, and Puerto Rico. This additional possibility allows such companies to increase their business and profits further and thereby expand their knowledge expertise. The facilitators associated with this possibility are the solar PV project financing availability and the basic adaptive capacity. Moreover, the barriers associated with this possibility are the insufficient knowledge of regional markets and the weak global engagement.

Product upgrading type

The SMEs are currently focused on developing profits from the today's most successful solar PV product, which are that of grid-connected systems. In specific the grid-connected with non-battery storage systems have seen the highest customer demand based on their potential positive return on investment strongly associated with quite elevated electricity rates in Costa Rica. However, some companies' offerings also include products such as solar water heating, pool heating, and some limited off-grid solar systems mainly for deep rural areas installations. Furthermore, the incumbent companies are focused on developing utility-scale projects, mainly hydroelectric and at a lower scale in geothermal or wind energy thereby solar PV utility-scale plans are consistently left behind.

Therefore, the two possibilities proposed for this upgrading type are based on the current scenario for which their benefits have yet to be exploited. The firms and the government will thus need to minimize the existing barriers to achieve their technology diffusion. These two possibilities are meant to dig further into the technological and economic potential of such utility-scale solar PV projects and technology complements.

2.1. Utility-scale solar PV projects: currently this is a critical market opportunity mostly open to the incumbent companies (ICE and electricity distributors) in turn it is highly restricted to emerging SMEs developers. Thus such solar PV utility-scale projects could in fact be used as a profitable alternative energy source to complement hydroelectric energy plants that would result being most beneficial during the dry or drought months and years. State-owned ICE showed interest in such projects, but the projects were not initiated since the feasibility studies done at that technology and project investment price per kWh in 2013 showed low viability. However, this study considers that this situation has now changed given the dramatic drop in solar per kWh prices compared to hydro and thermal high capital costs investments and overall related per kWh costs; for which more recent studies would likely show different results.

According to this analysis, despite the quite broad potential of this opportunity, firms will have to overcome several barriers, for which currently, there are no active associated facilitators. Thus, the barriers associated are that of the state-owned companies that in fact do not actively favor utility-scale solar projects over that of incumbent energy sources type projects. Additionally, the electric generation regulations place important limitations in the concession bidding and evaluation process by private companies. Moreover, locally there are few or no companies with the advanced knowledge to fully develop this type of projects which therefore will further complicate the development process and thereby their commercial viability is under significant scrutiny.

2.2. Use technology complements: the intermittent characteristic of solar PV energy makes it unreliable in comparison to conventional energies such as fossil fuels or even hydro or thermal power. Thus, there is a real need to continue searching for technological development to reduce this technological downside. In the global market there are currently important technological solutions that have recently emerged that must be considered for implementation in Costa Rica such as the use of smart grids, storage technologies and related devices as grid batteries for both before and after the meters, all for better overall distributed energy generation.

The development of smart grid technology facilitates the integration of distributed intermittent energies such as solar PV into the distribution grid, enhancing and quite efficiently bringing an additional stability to the electricity distribution grid. Therefore, allowing to foster greater technology diffusion and thus firms growth (Valverde et al., 2015). The use of fast emerging and maturing storage technologies such as grid batteries and supercapacitor battery combinations are sharply increasing the power density including significant surge capacity and given the significantly dropping energy storage devices' prices thus an important increase in the distributed grid surge demand abilities and their related grid stabilization factors. Hence, the global actors using smart grid technology with such grid batteries are already representing major disruptive breakthrough technology changes in the energy industry. Ie. Australia with Tesla company contract offering a 100 MW grid distributed battery stabilization storage system with such technology implementation confidence as to offer a 100-day project installation and operational guarantee "or free**"** (Pressman, 2017).

However, aside from the fact that the Costa Rican government has scholarship programs to study smart grids topics in graduate and undergraduate programs abroad, this possibility has many associated barriers. The barriers associated are that the current knowledge conditions are not optimal, the commercial viability requires further study and the fact that the incumbent companies must adopt a more proactive and much more positive outlook towards such technologies integration despite the inherent higher risks.

Functional upgrading type

Two opportunities for firms are outlined within the functional upgrading types and thus the inherent advantages that these new activities bring to Costa Rican firms. The majority of these possibilities are mainly related to rapidly moving into newer activities. Therefore, proactively develop new business and services within the solar and renewable energy industry. Emerging companies within this Costa Rican industry are not considering moving into other value chain segments as a priority since they are focus mainly on daily operational results and the existing associated barriers further discourage them.

3.1. Inter-segment upgrading: in section 2.2, outlines the significant opportunities to upgrade performing activities from other value chain segments. In the case of Costa Rica, several of the incumbent companies are already carrying out business activities outside the electricity generation segment, such as those related to the transmission and distribution market segments. In the case of emergent SMEs, they are prohibited from moving into these two segments. Moreover, there are additional new segments from the solar PV industry that could be explored for both actors such as that of the manufacturing of solar PV equipment and their related batteries or other storage technologies. The possibility of moving into solar PV manufacturing has been already evaluated by SMEs actors 1 and 15, and also legislation has already been initiated to facilitate this process in the future. However, at this time, the economic benefits from exploring activities of equipment manufacturing are not entirely evident and therefore require further studies. Moreover, there are no real signs that companies can move into energy distribution and transmission activities in the short term given the existence of legislation barriers that currently block such entrance for additional companies.

3.2. Diversify company services: Incumbent and emerging SMEs alike are willing to expand the services they provide in Costa Rica. These types of options allow local companies to aggressively diversify into a more specialized technology-driven market with differentiated service offerings and thereby better control their own destiny thus assuring greater opportunities for continued profitable growth. SMEs and incumbent companies employees (actors 3, 19) provided several possibilities on how they can diversify the companies' services. Additionally, the analysis of current conditions in this study allowed to identify a total of five opportunities and those are described ahead.

First is that of offering more consultancy services on preliminary design and feasibility studies for solar PV projects. Second, the SME actor 4 suggested the possibility of providing industry certifications for energy efficiency and ecological systems based on current INTECO regulations. Third, is to actively develop installation and maintenance crews to be outsourced to other companies and thus reduce operational costs on these activities. Fourth, several SMEs described the possibility of performing added logistic operations to that of importing products on their own, thus bypassing current local intermediary wholesaler that presently only serve to add barriers due to their abnormally high-profit margins. Companies could relatively easily with little or no risk become direct competitors of such local wholesalers offering added strategic synergies while lowering overall prices. i.e., lower costs especially on specialized solar PV products for a given application or process. The final opportunity is related specifically to incumbent distribution energy companies; whereby they should reconsider their traditional business models and look for new energy business in more highly market differentiated models and more importantly considering strategic alliances with SMEs developers. Thus helping preserve and further consolidate their clients base.

These important possibilities have both facilitators and barriers associated. Regarding the facilitators, given at this time the financial support is in fact, available when firms are considering moving into these new activities. Additionally, the necessary adaptive capacity is already present for most of these opportunities. However, considering the related barriers, some SMEs participants have somewhat limited resources in terms of personnel or needed specialized experience to expand their businesses. Also, the factors of the poor industry documentation and the limited knowledge sharing practices must further be mitigated by the firms.

Intra-chain upgrading type

The emergent and complex nature of this industry makes it difficult for companies to have already enough expertise to upgrade into other value chain industries. Instead, the trend is in fact that many companies and stakeholders upgraded from other renewable energy industry. However, for the future, the upgrade to other renewable energy industries could also importantly represent a much greater opportunity.

4.1. Intra-chain knowledge, the energy developers are in fact currently taking advantage of their intra-chain renewable knowledge from hydroelectric and wind energy projects. Thus, the typical upgrading process is with no question actively occurring and this all towards solar PV rather than the other way around.

However, some elements as that of the learning from solar PV integration could in essence be applied and diversified into the transmission and distribution value chain segments or other related energy technologies. The current existing limitation for intra-chain upgrading is the lack of industry maturity and its related recent implementation. Therefore, this is a situation that brings the insufficient advance knowledge factor as a critical element to be able to more importantly move into other energy value chains.

Summary of Possibilities, Barriers, and Facilitators

Table 6.2 provides a summary of possibilities described in this section which is organized by upgrading model types. In this table, the various possibilities are all associated with their respective barriers and facilitators as shown in figure 6.1 The detailed description for each barrier and facilitator are outlined in section 6.2.

Table 6.2. Upgrading possibilities and associated barriers and facilitators

#	Possibility	Barriers	Facilitator
1.1	DGM solar PV projects	Incumbent companies Impact. Outdated & biased energy legislation. Limited commercial viability.	DGM executive decree. Projects financing availability. Positive market demand. Basic adaptive capacity.
1.2	Increase the regional energy trading	Insufficient advanced knowledge.	Regional electricity infrastructure
1.3	Expansion outside the domestic market	Insufficient advanced knowledge. Weak GVC engagement.	Projects financing availability
2.1	Utility-scale solar PV projects	Incumbent companies Impact. Outdated & biased energy legislation. Limited commercial viability. Insufficient advanced knowledge.	None
2.2	Use technology complements	Incumbent companies Impact. Outdated & biased energy legislation. Limited commercial viability. Insufficient advanced knowledge Limited Knowledge sharing	Government policies.
3.1	Inter-segment upgrading	Outdated & biased energy legislation. Insufficient advanced knowledge.	None
3.2	Diversify company services	Incumbent companies Impact SMEs limited resources Small domestic market and weak GVC engagement.	Government policies. Basic adaptive capacity.
4.1	Intra-chain energy knowledge	Insufficient advanced knowledge.	None

From summary table 6.2, and below figure 6.2 it is possible to see that there are in fact more barriers than facilitators that are associated with each upgrading possibility which is a direct reflection of how difficult it is for firms to upgrade based on current more complex emerging technologies and conditions.

Moreover, figure 6.2 shows the results from this case study, which are that of, the strategic links between the concept models, the added barriers and facilitators identified and finally how those are all interconnected to each given opportunity. Figure 6.2 further illustrates the active results from table 6.2 and the logic needed to determine the related possibilities based on the concept's analysis. Some barriers and facilitators are the results of a combination of concepts and others basically of just one. I.e., the small market with weak global participation is a combined reflection of the stakeholders current positioning in the GVC activities and the low performance realized from the Innovation System's Knowledge functions.

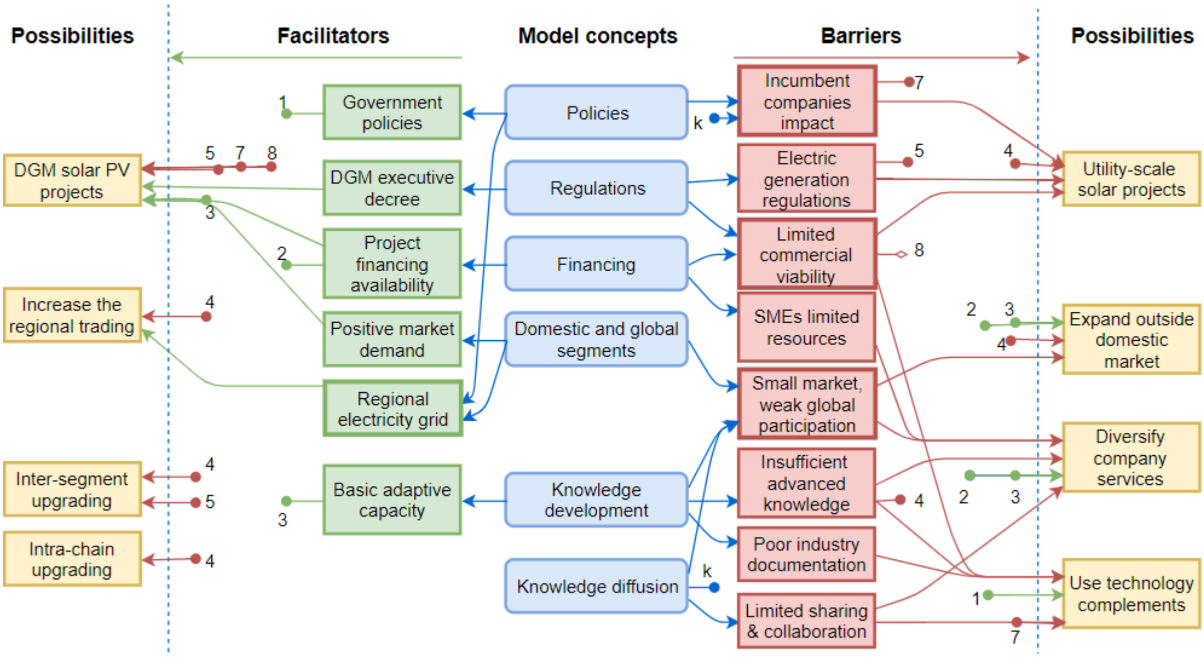

Figure 6.3 Case study barriers, facilitators and possibilities relationship.

6.3 Definition of Enriched Conceptual Model

This thesis attempts to develop a conceptual model that combines the concepts of Technological Innovation Systems (TIS) (Carlsson & Stankiewicz, 1991) theory and Global Value Chains (GVC) (Humphrey & Schmitz, 2002) perspective. Therefore this section deals with explaining how the conceptual model is integrated starting from the theoretical framework defined in section 2.3 of the literature review.

Model Integration and Findings

Figure 6.3 illustrates the improved conceptual model which consists of the same structural sections defined in the theoretical framework of section 2.3. The sections are: the value chain context, the knowledge functions, and the GVC upgrading. The main elements of this conceptual model figure are described herein below.

The pink box represents the value chain context which is formed by the entire global value chain segmentation for solar PV energy and the value chain institutional setting. Several segments of the entire value chain and the value chain institutional setting fall within the boundaries of the Technological Innovation System of solar PV energy.

The blue box represents the Knowledge functions section, in the figure, thereby related to the specific value chain segment of electricity generation. In this section of the model, it is proposed to analyze the performance of the solar PV firms related to knowledge development and knowledge diffusion as similarly done by Bergek et al. (2008).

The green box represents the potential upgrading possibilities for the firms. When the blue and pink boxes are examined, it is possible to determine the effects that such conditions provide to those possibilities. This effect is described in the analysis of barriers or facilitators in section 6.2.

The red dotted line represents the TIS structural boundaries which are positioned to represent the Costa Rica case. Within these boundaries, it is possible to find the structural elements of the value chain institutional setting. It is also possible to locate the value chain segments covered and among those, the firms within the Knowledge functions section. At last, the arrows and the signs (plus and minus) represent the direction and nature of the effect from the blue and pink blocks towards the upgrading possibilities of firms in the value chain.

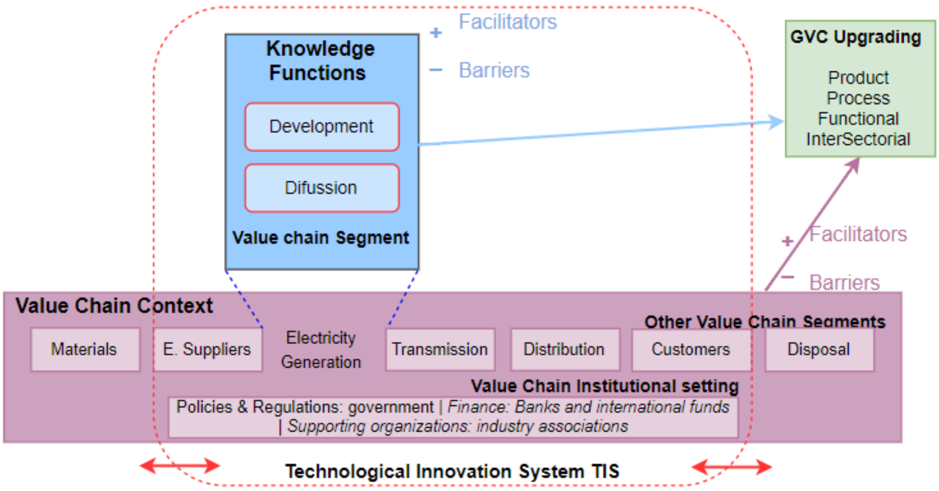

Figure 6.3. Enriched conceptual model definition

Differences and similarities

The differences and similarities between the initial theoretical framework developed in chapter 2 (see figure 2.5) and the final conceptual model illustrated in figure 6.3 are explained in this section. Thus regarding the similarities between the initial and the final model, relies mainly on structure, since both frameworks present the same structural components. They consist of the three main sections and subsections: the value chain context (value chain segment and institutional setting), the knowledge functions (development and diffusion), and the GVC upgrading (product, process, functional and intra-chain).

Regarding the differences, the first point to mention is that of the initial framework that only provided the central section's structure and did not illustrate how the concepts relate. Relative to this difference, the analysis proved that the value chain context and the Knowledge functions section create barriers and facilitators towards the third section of GVC upgrading, something that was previously an assumption of the initial framework. As well, the value chain context and functions sections could have a separate effect towards the firms upgrading but also the effect could be additionally combined. I.e.:, the creation of an R&D center modifies the institutional structure positively and would stimulate the knowledge development and diffusion increasing the upgrading opportunities for the firms.

Another difference between the initial and the final conceptual model is the stakeholders positioning and that of the accurate activity segmentation. Based on the defined structure, and the study case findings the final conceptual model can thereby accurately position the right stakeholders and institutions within the model components. Finally, the improved conceptual model can locate the coverage of the Technological Innovation System(TIS).

The following section describes in more detail the specific findings for each of these sections.

Findings Identification

The **value chain context** section from figure 6.3 contains three relevant components that influence the firms' upgrading possibilities. Those components are: the segmentation of the global value chain, the value chain institutional setting and finally the coverage of the technological innovation system. The structural aspects of GVC and TIS also intertwine in this section of the conceptual model.

As explained in section 2.3, this section therefore for structural analysis purposes goes beyond the typical TIS structure approach mentioned by Bergek et al. (2008). In essence, this section expands the TIS structural analysis incorporating elements of Global Value Chains by Gereffi & Fernandez-Stark (2016) such as that of the global activity segmentation and stakeholders positioning. The researcher considers that this allows broadening the firms' upgrading possibilities into that of a more global perspective, I.e., Instead of just looking into domestic upgrading opportunities the combination including the GVC perspective opens the more possibilities of penetrating the global market.

The added influence of the "*other value chain segments"* for the electricity generation companies create significant business opportunities and likewise could place barriers to development. I.e., as it was mentioned during the interviews, the equipment suppliers' are open to creating alliances with local SME and let them become their "brand ambassadors" and to the contrary, some electricity distribution companies consider the SME developers as a business threat and try to delay their solar PV projects.

The value chain institutional setting analysis determined the government policies, energy regulations, financing, and education conditions in which the firms from the electricity generation market participate. This analysis strictly follows the TIS approach used by Hekkert et al. (2011). It could therefore similarly be observed how the conditions could become barriers or facilitators for upgrading. Hence, it was recognized that the value chain institutional context conditions act as moderators for the firm's development since they influence directly or indirectly the upgrading opportunities.

The Technological Innovation System coverage and boundaries were determined in order to do the value chain context analysis. The red dotted rounded square in figure 6.1, shows that TIS covers the value chain institutional context organizations and value chain segments of equipment supply in terms of: electricity generation, electricity transmission, electricity distribution and service location. Several portions of the solar PV energy value chain are not covered by TIS since they are not currently being developed in Costa Rica. Hence, the Technological Innovation System is acting as a veil covering several components of the enriched conceptual model

The **knowledge functions** section is entirely grounded in the TIS literature using the analysis of Knowledge development and Knowledge diffusion as suggested by Hekkert et al. (2007). The authors emphasize these two functions be the most relevant for that of the emerging Technological innovation systems, and therefore it is considered in fact the case of solar PV energy in Costa Rica. The difference with authors' analysis in this conceptual model is that instead of locating the analysis in the Technological Innovation System per se, the analysis is focused on the value chain segment of interest.

The functions analysis in this conceptual model improves the understanding of the company's current knowledge performance. It determines if the type, amount, and quality of knowledge developed by Costa Rican firms are helping to increase the firm's upgrading possibilities. It also helps to define if the learning mechanisms can support the firm's growth. Furthermore, it was also possible to shed light on the fact that if the knowledge institutions provide the adaptive knowledge capabilities required from solar PV companies thereby integrate it into the new technology. It was found that the knowledge development and knowledge diffusion overall conditions are relatively not favorable for the solar PV TIS emergence.

As determined in this case, the electricity generation segment in terms of the GVC for solar PV energy is situated at the heart of this Technological Innovation System. Therefore, we consider that improvements associated with the Knowledge functions will further improve the technological system, the firms' development and also increases the possibilities for the value chain upgrading.

The upgrading possibilities in the conceptual model are as a consequence of being influenced by the value chain context and knowledge functions sections. According to the indicators analyzed in this section show that these other two sections manifest positive and negative influence towards the firms upgrading possibilities. Therefore, in the model, the plus and minus signs next to the arrows coming from both building blocks shows this bimodal effect from both components. However, is not possible to quantify the effect of those barriers and facilitators. For this study the magnitude of the effect is unknown, and it should, therefore, be studied in future research.

Moreover, given the upgrading results, would in fact, change the supply, the demand activities and the actors involved within the value chain. Hence, the upgrading decisions taken by firms would surely modify the TIS boundaries in the value chain. I.e., the functional upgrading or downgrading directly affect the TIS coverage in the value chain. Additionally, the product upgrading type would probably modify the TIS coverage given there are modifications in the firms' product portfolio. As an example, given a change in the supply that in turn modifies the left side boundary of TIS, whereby, if the companies from the electricity generation segment begin to manufacture equipment, the supply segment moves to the left and the TIS coverage as well. Therefore, the TIS coverage would increase or be reduced depending on the companies upgrading model type used.

6.4 Discussion

This section consists of the interpretation of the main findings of this thesis. It will cover the interpretation of the analysis for the value chain context and the knowledge functions. After that, it will further discuss the analysis of the global value chain upgrading possibilities and finally the definition of the conceptual model. These interpretations are based on the findings from the interview's analysis and are overall linked to the available literature. This discussion section also serves as a source of information to elaborate the practical and further research recommendations in the next chapter.

6.4.1 Interpretation of the Value Chain Context and Knowledge Function's Findings

This section starts discussing the limitations that firms are dealing with at the moment and what are the potential causes for those limitations. Next, the analysis moves to discuss the favorable conditions observed for firms from the value chain context and Knowledge functions concepts and how those conditions might have arisen. Lastly, an overall interpretation of the findings regarding these concepts is given.

The emerging conditions from Technological Innovations System and solar PV industry are represented in the type of limitations, and barriers found. The analysis of value chain context and knowledge conditions highlighted critical barriers that will limit the firms upgrading in the value chain as well as for the TIS emergence. Moreover, these types of barriers are usually prevalent in the emergence of renewable energy sources under typical energy lock-in scenarios from developing countries as outlined by Edsand (2017).

Discussion based on barriers Found

Regarding the value chain context, a significant finding to highlight is that within the relevant stakeholders from the energy sector in Costa Rica, there is no consensus that solar PV diffusion must be strongly supported. Despite the industry and demand push for integrating solar PV and therefore supporting the firms' development, there are still actors hesitant to move in this mode. This is noticeable in the existing unfavorable regulatory framework for energy generation and the lack of solar PV plans from incumbent energy distribution companies.

According to the TIS structure theory described by Bergek et al. (2008), the regulations must be aligned to promote the new technology diffusion, and as it was explained in section 6.1, this is not the case in Costa Rica. The current legislation that allows the solar PV utility-scale development restrict the developments of the project from private companies. Thus, leaving the technology diffusion in the hands of the Incumbent electricity distribution companies which are ultimately not fully engaged in other sources of energy besides hydro, wind or geothermal. Moreover, there is no concrete legislation for DGM development, only the norm granted by an executive decree. On top of that, this norm has essential limitations to the commercial viability of solar PV projects mainly intended to protect incumbent energy distribution companies.

The effect of the incumbent companies of limited Return of Investments (ROI) are mentioned in previous energy case studies as important barriers for firms upgrading and technology diffusion. Edsand (2017) argued in his research that incumbent companies play a decisive role in allowing or blocking emerging firm's growth. Moreover, Martin & Ryor (2016) outlined that when the return on investments is not favorable to clients, the reception of the technology and the upgrading possibilities of the firms are quite limited.

Furthermore, the knowledge functions analysis recognized limitations that also highlights the TIS emerging stages. Whereby, the conclusion is there is an overall deficiency of the knowledge performance of Costa Rican firms. The documentation practices are additionally scarce within the solar PV sector, which is manifested in the factors that: the development of only a mere handful of feasibility studies, R&D research, and the literal inexistent of patents development or filings. The learning mechanisms of "learning by doing" and "learning by searching" are actively used by emerging SMEs to sustain the essential knowledge capacity that drives the existing solar PV market.

From the Knowledge diffusion standpoint, the knowledge exchanged is quite limited and mainly tacit within the electricity generation segment. The type and quality of knowledge shared is associated primarily with design and installation of small solar PV systems. Moreover, the competition aspects and the fear of losing competitive advantage hinders peers collaboration, and therefore the knowledge exchange channels between industry and academia are relatively disengaged.

Furthermore, current training programs delivered by local Universities are relatively aligned to current market necessity, and this study considers it is enough to sustain the current market development. However, it does not necessarily directly contribute to the firms GVC upgrading in the future. It is considered that the country is significantly lacking in specialized training primarily related to specific knowledge as described by the barrier of Insufficient advanced knowledge from section 6.1.

Combined Effects Found

Moreover, some additional limitations are resulting from the combination value chain context and the knowledge components under analysis. This is the case of Costa Rica solar PV industry having significant limitations of an extremely small domestic market, which additionally has weak global ties. These conditions are critically limiting the benefits of being engaged on globalized value chains such as the strategic access to penetrating new market along with that of the pertinent need for increasing learning and knowledge and thereby opportunities as stated by Pietrobelli & Rabellotti (2011).

This combined effect is also especially noticeable for the factor the extend value chain coverage in Costa Rica. It was importantly observed that solar PV energy industry activities such as energy generation, transmission, and distribution started their emergence merely in the last decade while other segments such as the raw materials, manufacturing equipment, and disposal activities are nonexistent locally. Furthermore, the global link to those elements ~~is~~ are weak. The particular absence of the raw materials, manufacturing equipment segments can be reflected by the lack of local knowledge generation, while the absence of the disposal segment can be acknowledged as a consequence of the immature development of the solar PV industry in the country.

Discussion Based on Facilitators Found

To this point of discussion, the limitations found from the case study analysis have already been discussed. In section 6.1 related to facilitators found it was outlined that the government, industry associations, and universities already have taken several significant actions to mitigate some of these limitations and thereby further promote the solar PV technology technological systems emergence and thus overall support for local firms.

It was described that Costa Rica government had eliminated import taxes on solar PV systems with the intention to improve the commercial profitability of installed systems. The Environment and Energy Ministry (MINAET) has strategically implemented a national energy program to particularly identify areas for improvement regarding renewable energy, solar PV included. In parallel in 2015 government approved an executive decree to regulate the DGM, thereby creating important new opportunities to develop solar PV projects for the self-consumption market segment.

Additionally, local universities began providing engineering training relative to installation and design of smaller solar PV systems. Available local training is more than enough to cover the necessarily required knowledge capabilities to develop and appropriately address the current market demand. Hence, the industry organizations have started to incentivize the knowledge sharing among the public and also promoting additional stakeholders interactions. Finally, it is relevant that now is possible to obtain credit loans from local banks if clients are willing to install solar PV systems given it is a positive financial alternative. These facilitators were recognized in section 6.1 and are a relatively important positive sign if not in fact strategic for the development of the solar PV industry.

Finally, this study considers that the value chain context and the knowledge functions barriers are far outweighing the available facilitators, which as a result are highly hindering the overall firms' upgrading and the technology diffusion. To expedite the TIS emergence and increase the possibilities of upgrading in the value chain the effect of these barriers must be substantially minimized. As outlined by Chaminade & Vang (2008) the improvement of the Knowledge conditions within the value chain segments will appropriately allow for the emergence of TIS and firms' upgrading at a similar pace.

Discussion Based on Upgrading Possibilities Found

The GVC upgrading analysis is based on the upgrading models from GVC literature (Humphrey & Schmitz, 2002). This thesis analysis establishes how the firms' upgrading possibilities are influenced by the structural and functions performance conditions and based on those, it finally defines a list of upgrading possibilities for Costa Rican firms.

The most explicit possibility to grow in the domestic market is expanding the distributed generation model (DGM) based on solar PV energy for self-consumption. So far, no international firms are competing in this local domestic market due to its small size. However, this possibility also has several barriers that need to be overcome to develop this DGM model fully. This study, therefore, offers recommendations for this related opportunity within the upgrading potential for such firms.

The domestic competition in the solar PV energy market is strong among SMEs developers. However, since the market is still small and utility-scale projects are significantly restricted. Thus there are not many international companies interested in competing. Also, among the equipment suppliers, the competition is relatively minor, and their local presence is therefore limited. However, despite this relatively low competition factor from international firms, companies must pay close attention to the aspect of global competition and start building their knowledge capacity for the future given the circumstances might change.

There are also possibilities for local firms to participate in the global market such as an increase in regional energy trading. This is a direct opportunity for the incumbent state-owned energy company ICE. However, if the energy export process is expanded to include variable energies, thus emerging SMEs could also be involved and benefited.

6.4.2 Interpretation of the Conceptual Model Findings

The conceptual model combines concepts of Technological Innovation Systems (TIS) (Carlsson & Stankiewicz, 1991) theory and Global Value Chains (GVC) (Humphrey & Schmitz, 2002) to achieve the research objective defined in section 1.3 of this thesis. This model consists of three sections, the value chain context, the knowledge functions, and the GVC upgrading. The final model was developed in two main steps, the first was completed as part of the literature review from chapter three and thus defined the theoretical basis for describing the concepts and establishing the conceptual model structure and their respective indicators. The second step was completed in section 6.3 after incorporating the analysis findings from the individual interviews performed in Costa Rica.

This conceptual model considers the typical TIS institutional and structural analysis from Bergek et al. (2008) and expands the analysis further by incorporating the global activity segmentation and stakeholders positioning elements of Global Value Chains(GVC) perspective from Gereffi & Fernandez-Stark (2016). This addition is further considered for the broadening of the analysis to identify the firms upgrading possibilities thereby using a global perspective. Hence, the Technological Innovation System (TIS) is located within the global value chain, and it is acting as a veil covering several value chain segments and structural components of the enriched conceptual model (see figure 6.3).

The conceptual model also illustrates how the concepts relate to each other. In this case, the analysis proved that the base model sections, in fact, create barriers and facilitators towards the third section of GVC concepts for upgrading, something that was previously merely an assumption of the initial framework. Furthermore, the value chain context and functions sections could have had a separate related effect on the firms upgrading moreover the effect could in essence also be combined. Finally, based on the defined structure and the study case findings the final conceptual model can thereby accurately position the right stakeholders and institutions within the model components.

This combination is quite relevant since the TIS analysis lacks a broader perspective for such an analysis according to Markard & Truffer (2008). Hence, the segmentation of activities considering the global' industry dynamics done through the GVC perspective represents an critical asset to reducing the TIS limitation. Moreover, the GVC approach is quite limited for the institutional context analysis according to Pietrobelli & Rabellotti (2011). Therefore, the TIS emphasis on systems structure which thereby provides that a better understanding of the institutional context conditions for which given firms are embedded within represents a critical asset to enhance GVC approach. Therefore, this thesis follows Pietrobelli & Rabellotti (2011) suggestion, considering that the combination of both kinds of literature will in fact strengthen each other's weaknesses.

To conclude, the enriched conceptual model importantly proved its worth to illustrate a systemic approach based on structural and functional terms to identify the firms' barriers, facilitators, and upgrading possibilities. As a consequence, the study of these elements better allows the researcher to elaborate contextualized upgrading recommendations based on the very important Innovation Systems circumstances within a global value chain perspective.

6.5 Summary

In this chapter, the Solar PV TIS structure and Knowledge functions performance analysis based on figure 6.1 allowed identifying the existing firms' barriers and/or facilitators. Therefore, section 6.1 describes the relevant aspects of barriers and facilitators recognized for Costa Rican firms. A total of eight barriers and six facilitators were defined in section 6.1 and summarized in table 6.1.

The barriers identified are: the incumbent companies' impact, the outdated & biased electric generation legislation, the SMEs limited resources, the limited commercial viability of solar PV systems, the small domestic market and weak GVC engagement, the insufficient advanced knowledge from stakeholders, the poor industry documentation and finally the limited knowledge sharing and collaboration. On the other hand, the facilitators identified are: the Government policies, the DGM executive decree, the projects financing availability, the positive market demand, the regional electricity infrastructure and finally the basic adaptive capacity.

Furthermore, section 6.2 offered a description of the upgrading possibilities recognized given the model components and conditions. Those possibilities were divided into the four models for the firms upgrading: process, product, functional and inter-sectorial (Humphrey & Schmitz, 2002). A total of eight possibilities are given to firms, and their related connection to the barriers and facilitators as shown in table 6.2 and figure 6.2. the possibilities are the increase of the regional energy trading, the firms' expansion outside the domestic market, to diversify utility-scale solar PV projects, the use of solar PV technology complements such as batteries and smart grids, the inter-segment upgrading, to diversify company services and finally the intra-chain energy knowledge.

Section 6.3 defined the enriched conceptual model directed to address SRQ5 from section 1.4. It additionally provides the relationship between the main concepts and explains how they would generate barriers and facilitators for the firms upgrading. The enriched conceptual model provides a graphic representation of value chain context, knowledge functions and GVC upgrading sections from the theoretical framework described in section 2.3. Also, this model enables the analysis of the operational aspects of the Technological Innovation Systems related to Institutional structure and that of the performance of these functions.

Moreover, section 6.4 discussed the main findings from this study, combining the findings from value chain context and functions analysis and thereby linking those back to the literature. The findings and discussion from this chapter helps to address SRQ4 and SRQ5 and are used in the next chapter to provide a contextualized recommendation for firms in Costa Rica.

7. Conclusions and Recommendations

The previous chapter, *Results and Discussion* provided two of the major outcomes from the thesis, the conceptual model definitions and the identification of a group of barriers, facilitators, and facilitators for Costa Rican companies developing in the solar PV value chain, morever, elaborated a discussion of the research findings.

In this last chapter of the thesis, the research questions from section 1.4 are answered. After that, this chapter highlights the thesis contributions and following that describes the last outcome of this thesis which is the practical recommendations. The chapter continues describing the limitations observed during the elaboration of this thesis and concludes suggesting areas for future research associated with those limitations.

7.1 Answering the Research Questions

After developing the chapters from this thesis, it is now possible to answer each sub research question individually. Furthermore, the joint knowledge allows addressing the main research question that was proposed considering the research objective and the knowledge gap from the literature.

Sub research question 1. *What are the main elements to analyze firms' upgrading in the solar PV energy sector based on knowledge and emerging institutional context conditions?*

The main concepts defined to analyze firms' upgrading in the solar PV energy sector based on knowledge and emerging institutional context conditions are extracted from Technology Innovation Systems (Carlsson & Stankiewicz, 1991) and Global Value Chain (Humphrey & Schmitz, 2002) literature.

From TIS literature the main concepts used are shown in figure 2.2 and those are the Knowledge functions of development and diffusion and the TIS structural elements such as policies, regulations, research and education and industry organization. From the GVC literature, the main concepts used are shown in figure 2.1 and those are value chain segments, stakeholder positioning, Institutional context and upgrading models. The literature review in section 2.1 described the relevant concepts and as part of section 2.3 defined a framework to combine those concepts. Moreover, section 2.4 defined a set of indicators for that was used for the thesis analysis.

The combination of TIS with GVC is relevant since the TIS analysis lacks a broader perspective for analysis according to Markard & Truffer (2008). Hence, the segmentation of activities considering the global' industry dynamics done by the GVC perspective represents an asset to reduce the TIS limitation. Moreover, the GVC approach is limited for the institutional context analysis according to Pietrobelli & Rabellotti (2011). Therefore, the TIS emphasis on systems structure which thereby provides a better understanding of the institutional context conditions for which the firms that are embedded within, results in an asset to enhance the GVC approach. Therefore, the thesis follows Pietrobelli & Rabellotti (2011) suggestion and adapts it for the research objective, since it is considered that the combination of both kinds of literature would strengthen each other's weaknesses.

Sub research question 2: *"What are the value chain context conditions for Costa Rican solar PV energy firms?"*

The main components of the value chain context section of the conceptual model are the value chain institutional setting and the value chain segments. In chapter four, these components were analyzed for Costa Rican case study of solar PV energy firms.

Regarding the value chain institutional context described in section 4.1 it was observed that the financial support, regulations, policies, the educational solar PV institutions, and the market are emerging. Hence, the institutional structure, many institutional roles, and regulations are not fully established. The existing regulatory framework is considered outdated, highly biased in Hydroelectric, which makes it very difficult to develop utility-scale projects since it restricts the participation of private developers. However, the recent approval of executive decree improved the opportunities to develop solar PV projects self-consumption purposes.

Regarding the value chain segments described in 4.2, it was noticed that Costa Rica presents a value chain dominated by local dynamics and weak global ties. Most of the value chain segments and actors are positioned locally, and there is no connection to segments being developed abroad which makes it more of a domestic value chain. This lack of global engagement is limiting the access to penetrate new market along with that of increasing learning and knowledge opportunities which are the some of the benefits of engaging in GVCs as stated by Pietrobelli & Rabellotti (2011). Moreover, the domestic activities such as energy generation, transmission, and distribution are dominated by incumbent companies. The fact that incumbent companies dominate the domestic market produce a substantial adverse effect on the diffusion of solar PV energy technologies, the development of SMEs and in general the upgrading opportunities of the country. Moreover, the domestic activities such as energy generation, transmission, and distribution are dominated by incumbent companies which develops mainly hydropower project. This fact that incumbent companies dominate the domestic market produce a substantial adverse effect on the diffusion of solar PV energy technologies, the development of SMEs and in general the upgrading opportunities of the country since they lack legitimacy towards solar PV energy projects.

Sub research question 3: *"What are the knowledge functions conditions within the value chain segment of Costa Rican solar PV firms?"*

The conditions for knowledge development and diffusion functions of Innovations systems are described in chapter five of this thesis. It was possible to determine the knowledge conditions from the two main groups of firms (incumbent companies and the emergent SMEs) in the electricity generation segment. The individual interviews from these groups provided a deeper insight into how these firms are managing the knowledge.

In Costa Rica, the adaptive capacity is sufficient for the current early stage of technology diffusion in which the market is emerging. However, to upgrade to the next stage, it is necessary to make improvements in specific specialized Knowledge topics such as: high tech storage devices, smart grids, development of solar PV business models. So far, the learning mechanism has been exploited more often by emerging SMEs due to their active engagement on developing DG model systems while incumbent companies are still focused mainly on hydroelectric energy.

The knowledge diffusion has been promoted by the several industry associations creating networks of stakeholders and developing industry activities as energy congress and solar PV fairs. However, the Knowledge exchange is limited by competition aspects and the fear of losing competitive advantage. Moreover, the channels between industry and university are not active, and they function only on a specific project basis.

Finally, it is clear that the government is not taking the lead on increasing the Knowledge conditions and this is a must if firms and industry want to upgrade. Therefore, the industry associations should take this leading position and help to improve the knowledge development and diffusion to increase the engagement on the solar PV value chain.

Sub research question 4: *"What are the value chain upgrading barriers, facilitators, and possibilities for solar PV firms in Costa Rica?"*

The analysis of value chain institutional context elements and the TIS knowledge functions allowed extracting barriers, facilitators, and possibilities for solar PV firm's upgrading. Sections 6.1 and 6.2 are dedicated to describing those findings. A total of eight barriers and six facilitators were defined in section 6.1 and section 6.2 described eight possibilities, divided into the four categories for upgrading: process, product, functional and inter-chain.

Section 6.1 provided the barriers related mostly to the value chain context as: first is the negative impact by incumbent companies. Second, electric generation regulation that is not aligned with solar PV development. Third, the limited commercial viability of solar PV systems. Fourth, the SMEs are limited in resources to invest in training or innovation. Fifth, the small market and the weak global participation, etcetera. Moreover, from the Knowledge functions, the barriers associated are the poor Industry documentation, limited knowledge sharing, and collaboration along with insufficient advance knowledge.

Furthermore, in section 6.1 there are five facilitators mainly related to the value chain context concepts: first the government has several policies that promote the usage of solar PV energy. Second, an executive order enables the Distributed Generation Model (DGM) which opens the market for solar PV firms. Third, there are financing opportunities for the solar PV industry provided by banks and funding organizations. Fourth, there is a positive response from the market towards solar PV energy projects, and last is the existence of a regional infrastructure for energy transmission and trading. Furthermore, from Knowledge functions the facilitator identified was the availability of basic solar PV knowledge training for design and installations which enables market deployment.

Finally, in section 6.2 eight upgrading possibilities were identified and categorized according to the upgrading models from Humphrey & Schmitz (2002). The process upgrading possibilities for firms are three, continue the development of DGM for solar PV, increasing the regional energy trading, expanding outside the domestic market. Besides those, for product upgrading there is two: diversifying into utility-scale solar PV projects, and implementing technology complements for solar PV such as smart grids and distribution grid batteries. Additionally, there are two possibilities for firms' functional upgrading: To upgrade into other value chain segments beside electricity generation and Diversify the company energy services into new activities. Finally, one possibility for intra-chain upgrading that will be to move into other renewables development.

Sub research question 5: "*How does the institutional context integrate with firms' knowledge development and diffusion to identify firms' upgrading possibilities?"*

Chapter six defined the final conceptual model that integrated the concepts of Technological Innovations System (TIS) from Carlsson & Stankiewicz (1991) and Global Value Chain (GVC) Humphrey & Schmitz (2002) to help to answer this research question. The final conceptual model used as a structural basis the theoretical framework developed as in chapter 2 and it was improved with the findings from the analysis of value chain context and Knowledge development and knowledge diffusion functions.

The final conceptual model considers the typical TIS institutional and structural analysis from Bergek et al. (2008) and expands the analysis further by incorporating the global activity segmentation and stakeholders positioning elements of Global Value Chains(GVC) perspective from Gereffi & Fernandez-Stark (2016). This addition is further considered for the broadening of the analysis to identify the firms upgrading possibilities thereby using a global perspective. Hence, the Technological Innovation System (TIS) is located within the global value chain, and it is acting as a veil covering several value chain segments and structural components of the enriched conceptual model.

The descriptive analysis from chapters four and five proved that the value chain context and the Knowledge functions section create barriers and facilitators towards the GVC upgrading of firms. The value chain context and functions sections could have individually form barriers and facilitators for the upgrading of firms within the electricity generation segment. Moreover, since their components are intertwined, their development affects each other and further affects the upgrading possibilities in a combined manner. Therefore, the enriched conceptual model proved to illustrate a systemic approach based on structural and functional terms to identify the firms' barriers, facilitators, and upgrading possibilities.

Main research question: *"How do the knowledge development, knowledge diffusion, and context conditions affect Costa Rican firm's upgrading in the solar PV energy value chain?"*

The thesis analysis establishes how the Costa Rican firms' upgrading possibilities in the value chain are influenced by knowledge development, knowledge diffusion, and context conditions. Sections 6.1 and 6.2 describes Costa Rica firms' barriers, facilitators, and upgrading possibilities, moreover, in section 6.3 all those findings are discussed.

From this study analysis and discussion in section 6.4, it is clear that firms in Costa Rica are growing in emerging conditions of Technological Innovations System and industrial Global Value Chain. This puts then in disadvantage in a potential global value chain engagement since current Knowledge capabilities, and structural conditions are not sufficient to compete in the global market.

The context conditions are more likely to be hindering firms upgrading possibilities. The regulatory framework does not adapt to facilitate an integration of solar PV technology or their associated companies. The government policies are not highly attractive to minimize the limitations on commercial profitability. The value chain is merely domestic, the solar PV market is small and has weak connections globally. Moreover, the few incumbent companies within this domestic chain are focused on hydroelectric power development and lack legitimacy for solar PV which creates a barrier for SMEs and technology in general since they have so far enough resource to restrict the development from solar PV.

Similarly, the Knowledge conditions are hindering the firms upgrading possibilities. At this point of emergence, the TIS knowledge conditions are merely enough to satisfy the domestic market. The education institutions only provide basic training for solar PV development and lack specialized programs to take firms to the next level. There is an overall deficiency of the knowledge development performance: the documentation practices are scarce, the knowledge is exchanged primarily tacit. Moreover, the knowledge exchange is limited, because the fear of losing competitive advantage hinder peers collaboration. Finally, the knowledge exchange channels between industry and academia are relatively disengaged.

Considering these previous conditions is relevant provide firms and policymakers with recommendations and a systemic approach to develop further the country and firms capabilities.

7.3 Practical Recommendations

This section proposes specific recommendations considering the upgrading possibilities identified in section 6.2 and the corresponded barriers and facilitators found and described in section 6.1. The proposed recommendations are directed to policy makers, company executives and decision makers in Costa Rica on how to appropriately support the solar PV firms upgrading in the value chain.

Therefore, in order to increase the firms upgrading opportunities, this section suggests four recommendations derived from the overall analysis. The recommendations are listed at first and described next.

1. Create a solar PV Research and Development (R&D) center.
2. Updating the energy generation legislation to facilitate the small and utility-scale solar PV project developments,
3. To increase the global participation of solar PV firms.
4. To increase the participation of Incumbent energy distribution companies in solar PV projects.

1. Creation of a solar PV Research & Development Center

The Knowledge functions analysis of chapter five provided insights regarding the emerging knowledge conditions from the solar PV Technological Innovations System (TIS)(Carlsson & Stankiewicz, 1991). This analysis highlighted several barriers described in section 6.1.1 such as the poor industry documentation manifested for the lack of research and feasibilities studies. Furthermore, there is poor or otherwise limited knowledge sharing and collaboration within the industry, especially among firms and that of academia. Finally, the analysis outlines a lack of advance knowledge on specialized topics that would importantly support firms upgrading.

Therefore, it is recommended the creation of an R&D center aimed at centralizing the efforts to minimize and thereby mitigate the knowledge development and knowledge diffusion barriers described in section 6.1.1. Thus, the R&D center would certainly help to further develop the knowledge functions of the solar PV TIS thus increasing the firms' possibilities for upgrading. This study suggests at least three focus areas for the R&D centers: that of documentation, knowledge diffusion and training. First, this will help to improve the documentation practices of the industry and additionally support the creation of higher quality feasibility studies. Second, such a center would make it possible to better promote the interactive learning mechanisms within the solar PV industry both locally and globally. Moreover, create knowledge sharing channels between industry and universities. Third, delivering training will help to increase the experts' Knowledge on specific topics that are useful for future firms upgrading such as solar PV utility-scale development, smart grids design or development, DG energy trading, contextualized related financial capabilities and newer technologies implementation on battery storage are but some examples.

2. Update legislation to facilitate the small and utility-scale solar PV development

Section 6.1.1 outlines critical findings that Costa Rican regulations are in fact hindering the solar PV technology diffusion and firms upgrading as described in barriers 1 and 4. Whereby, current regulations for centralized and utility-scale projects increase the influence of Incumbent state-owned monopoly ICE and also that of the other electricity distribution companies thus, significantly restricting competition from other companies. Additionally, there is no legislation for small-scale DGM; there only exists regulations in the form an executive decree and this it most assuredly requires further improvements. This finding was outlined in our barriers discussion since it is quite evident that it is in fact limiting the commercial viability of solar PV projects at the expense of clients.

Therefore, considering the abovementioned conditions, the modification and restructuring of the regulatory framework for electric generation is strongly recommended. These modifications to the regulatory framework for energy generation should aim to support the development of solar PV projects by increasing the flexibility of the existing regulations. Hence, to increase this flexibility it is suggested to separate the management of conventional energies (including hydroelectric) from variable energies such as wind, solar PV, and biomass, etc. as similarly confirmed in the feasibility study of Echeverria & Monge (2017).

Furthermore, to increase this flexibility, it is recommended to implement separate regulations for centralized utility-scale development and small-scale DGM (based on the existing DG Norm). Additionally, the utility-scale regulation should minimize the restrictions on private energy producers to allow fair competition with incumbent distribution energy companies. Finally, the DGM regulation should reduce unnecessary roadblocks and improve the billing methodologies to accomplishing a tradeoff between distribution companies and prosumers' commercial expectations as observed in section 4.1.2

3. Increase global engagement of solar PV firms

Section 4.2 describes the findings that Costa Rica's solar PV value chain presents dominant domestic dynamics and the connection to global value chain activities are weak. Additionally, Costa Rican stakeholders are not part of several value chain segments' activities such as raw materials, equipment manufacturing, and equipment disposal. However, the solar PV activities developed in Costa Rica such as electricity generation, transmission, distribution, and service location (demand) have quite favorable conditions to start growing at the global level. The facilitators from section 6.2 showed an existing regional infrastructure for energy trading. Firms also have the strategic availability to access credit loans for solar PV projects, and last but not least, it is critically important there is more than enough knowledge in Costa Rica solar industry regarding technical aspects, especially as to installation and design.

Therefore, based on these conditions, this study recommends increasing the global participation from solar PV firms. This global participation undoubtedly increases the current market opportunities and thereby also gain new knowledge from this new more diversified global exposure as outlined by Pietrobelli & Rabellotti (2011). There are two accessible ways to begin an incremental participation in the global value chain.

The first is expanding firms' solar PV operations into neighboring regions. Companies should further co-develop projects with international companies having leading-edge technologies and longer-term financing capabilities, thus as mean to strengthen their company resources. Moreover, use the learning mechanisms of technology sharing and thereby "learn by doing" with other peers to gain this needed in-country technology knowledge and experience more quickly. The second is through maximizing the utilization of the regional energy market (MER). Through addressing the inherent opportunities of utilizing Costa Rica's electricity distribution strengths towards resolving of the Regional Energy Market (MER) weakness especially related to better help alleviate their frequent power outages. Finally, in the future, new grid energy distributed storage technologies must be implemented allowing the integration of variable energies such as solar PV as is done in the case of European countries and similarly in the United States (Martin, 2015).

4. Increase engagement of Incumbent Companies in solar PV projects

In section 6.1.1, the Incumbent energy distribution companies' impact is identified as a barrier. From the findings, it is evident in Costa Rica some of these companies are highly empowered by legislation (ICE, CNFL). They can define the energy expansions plans and based on their strong influencing positions as energy distribution companies this in fact, represents a barrier since most of their decisions are biased towards hydroelectric and wind projects. Additionally, the fact that these companies' activities cover several segments of the domestic solar PV value chain increase their negative impact on SME emerging companies and technology diffusion in the overall. Furthermore, in the past, the state-owned companies have substantially hindered the implementation of solar PV projects due to their quite evident lack of legitimacy in the solar PV energy and associated technologies.

Therefore, based on our findings it is highly recommended to endeavor to better work with Incumbent electricity distribution companies to significantly increase their knowledge and abilities. I.e, the legitimacy and therefore their overall participation in solar PV projects which will thereby facilitate the needed technology diffusion and firms upgrading abilities. Furthermore, incumbent companies and emergent SMEs can additionally profit from strategic alliances established through new business models such as “rooftop renting” or implementation of utility-scale projects in similar collaborations. Finally, Incumbent electricity generation companies must help to implement the use of technology complements such as smart grid and battery storage within the existing distribution grid.

7.4 Thesis Contributions

This thesis explores how the theory of Technological Innovations Systems (Carlsson & Stankiewicz, 1991) and the Global Value Chain (Humphrey & Schmitz, 2002) approach may be appropriately integrated to determine firm upgrading opportunities. It takes advantage of the existing analytical framework used for Technological Innovations Systems to study Solar PV firms in a Global Value Chain setting. Thus, applies the TIS structural and functional analysis within the solar PV chain segments focusing on specific indicators related to the Institutional context, value chain activity segmentation, stakeholder’s positioning, knowledge development, and knowledge diffusion. As a result, it is possible to determine Global Value Chain upgrading recommendations for firms in an emerging technological background.

The main theoretical contribution is that the analysis takes a different approach to what has been done in the literature to increase the understanding of technological emergence phenomenon and firms’ upgrading in developing countries. The study applies a simple model to analyze at firm level the TIS and GVC conditions and thus provide contextualized recommendations. In this way, the study differs from similar analytical studies that focus on niche markets and sociotechnical regimes (Schot & Geels, 2008). The GVC upgrading perspective allows to have a broader view of opportunities in comparison to a single niche market and moreover, the TIS perspective increases the understanding of the potential critical barriers that are difficulting to achieve the firm upgrading opportunities.

Moreover, the thesis results provide the insights from a case study done in a developing country from Latin America which has an emerging Technological Innovation System. Therefore, it follows the suggestion made by Pietrobelli & Rabellotti (2011) to apply this combined approach in developing countries in order to increase the learning and gain more insights from the expected benefits such as increasing competitiveness of firms and the developing country's growth.

Additionally, this energy case study is also different from others available in the literature (Bamber et al., 2014; Edsand, 2017) because the incumbent energy is not conventional such as fossil fuels and instead is a renewable energy as hydropower. This particular difference delivers new insights for the existing literature, noticing that the associated barriers to the lock-in effect from hydropower are similar than fossil fuels however the opportunities to develop a new energy source are less, based on the strong perceived benefits from existing Incumbent renewable energy.

Finally, the main practical contribution of this thesis is the identification of barriers, facilitators, and possibilities in structural and functional terms. The conceptual model defined provides a practical and straightforward mechanism to identify potential barriers and facilitators for companies' upgrading possibilities. Moreover, the final practical recommendation to company executives and policy makers were listed in section 7.3.

7.5 Reflection on Limitations

Several limitations are identified in this section after doing a critical analysis of the study results and the overall process followed. Some of the limitations were already minimized during the study and others remained. Therefore they will further be considered as suggestions for future research. The final four limitations items are outlined here and further described in more detail below

1. Information bias
2. Completeness of the analysis
3. Methodology process is unclear
4. Number of cases the study

1. Information bias: This is a typical limitation derived from the individual interview process that could reduce the study's internal validity if it is not mitigated. For this study, it was noted that indeed several actors' opinions differed from each other in respect to the barriers and facilitators identified. I.e., SMEs will argue that distribution companies will have an adverse effect on their solar PV projects and on the other hand the distribution companies provided a quite different opinion. Therefore, to minimize the information bias and increase the validity of the results, the data triangulation method was used. This triangulation was applied by interviewing different sectors of the value chain and also that from the Institutional context as explained in section 3.3. As a result, using this technique, it was possible to avoid skewed results to one specific actor. I.e., the results not skewed either to the incumbent companies or emerging SMEs side.

2. Completeness of the analysis: After doing a critical review of the study results, a couple of concerns arose regarding the completeness of the study based on the concepts used for information integration and analysis. I.e., should it be necessary to include the governance concept from the GVC literature? Moreover, should it be also necessary to include the rest of the seven TIS functions? Both concerns are directed to challenge the completeness of the results from this thesis. The first concern is rooted in the fact that the literature recognizes that governance as a central concept within the GVC analysis (Humphrey & Schmitz, 2002). Therefore, It is possible to think that leaving the governance aspect out of this type of study analysis would result in somewhat of a limitation. Moreover, the second concern is based on the fact the Technological Innovation System (TIS) has seven functions (Carlsson & Stankiewicz, 1991) to analyze its performance, and this study was focused on two instead of the seven. Therefore, it is justified to think that the findings might be somehow limited.

However, based on the current study results, it is obvious that an excellent depiction of the current TIS and GVC solar PV conditions in Costa Rica was in fact achieved even without using such concepts. Therefore, it is genuinely not clear to which degree the use of just these two functions is reducing the understanding of the whole TIS performance in Costa Rica. Thus, the same applies to the exclusion of the governance concept from the analysis.

Therefore, more research is necessary for this direction, to determine if the current analysis is sufficient, and is relatively providing satisfactory insights and recommendations for the upgrading of solar PV firms in Costa Rica.

2. Unclear methodology process: as outlined in the literature review section 2.3, this thesis is referenced in the TIS analytical framework. Despite this fact, this study does not define a precise methodology process to be used in the analysis section. Thus, if this combined perspective is used in the future by another researcher, it might be challenging to follow the same analytical steps used here. Additionally, this deficiency in the methodology process could be even associated with unclear and weak findings in this thesis. I.e., the findings regarding the learning mechanisms are weak, and also it is unclear for the combined effect of two or more barriers. Therefore, this study will recommend to strength this methodological aspect in future research applications.

3. The number of study cases analyzed: one of the clear limitations of this case study is that it focuses merely on one case study: Costa Rica. Hence, the study results cannot be easily generalized, except in relatively specific cases. Therefore, a potential case comparison would likely be limited to cases sharing similar conditions with Costa Rica. First, the case should be related to a developing country thus with limited technological, and innovation resources. Second, the electricity sector must be controlled by a state energy monopoly such as in Costa Rica. Third, the electricity generation supply should be dominated by one energy source, preferably hydroelectric as is the case in Costa Rica. Based on such conditions, the comparable countries in Latin America would be Nicaragua and Uruguay.

Moreover, based on this limitation it is considered quite relevant to perform this type of study in more countries thus be able to generate more accurate general conclusions. Therefore, this limitation will be a related consideration in the following section for future research.

7.6 Future Research Suggestions

In this last section of the thesis, the suggestions for further research are outlined here to continue improving this study and thus extend its contribution. Thus, these suggestions are for possible future research and are based on abovementioned related limitations for the methodology of the analysis, the completeness of the analysis and that of the reduced amount of cases available in the literature given this new proposed type of analysis.

This study considers it necessary to continue this type of combined research in developing countries as recommended by Pietrobelli (2011). This will support companies to increase their knowledge and thereby enhance their potential profits by additionally having greater access to global markets.

The future research studies in developing countries should be focused on two aspects. The first is to improve and properly document a methodology that allows understanding for the separate and also the combined effect of the concepts integration. Therefore, this is aimed at developing a robust methodology with structured and clear steps that would be easy to use and replicate in other developing countries cases.

Second, future research cases should test the completeness of this conceptual model proposal. Therefore, the studies must compare cases using the same concepts used in this study with further analyses of cases with missing concepts such as governance, and that of the rest of the seven TIS functions. Therefore, this study process is also aimed to test if the current conceptual proposal is robust enough or if it needs further improvements.

Therefore, increasing the number of cases using this combined approach will likely strengthen the results from the proposed conceptual model in this thesis. This will also make it possible to develop a more robust and systemic approach to determine the barriers, facilitators, and upgrading possibilities of firms in developing countries.

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Appendix Section

Appendix 1: List of Stakeholders and Contacts Interviewed

The following is a list of stakeholders of the case study. The interview code is used to reference then within the thesis. Also, the last column shows the actors interviewed from the emerging SMEs and incumbent companies.

Table A.1. List of stakeholders and contacts interviews

Value chain Segment	Company/Institution	Contact	Interviewee code
Electricity generation	PuraSol	Pierre Lambot	Interview 1 **(SME 1)**
Electricity generation	PuraVida Energy	Carolina Sanchez	Interview 2 **(SME 2)**
Electricity generation	Sunshine	Harold Steinworth	Interview 3 **(SME 3)**
Electricity generation	Yuxta Energy	Alberto Rodriguez	Interview 4 **(SME 4)**
Electricity generation	Matelpa	Luis Rojas/Jorge Corrales	Interview 5 **(SME 5)**
Suppliers	ABB (Inverters)	Jorge Murillo	Interview 6
Suppliers	Jinko (Solar Panels)	Juan Rodriguez	Interview 7
University	ITCR: CR Technology Institute-SESlab	Dr. Carlos Meza	Interview 8
University	UCR: Costa Rica University-Eperlab	Dr. Gustavo Valverde Mora	Interview 9
Consultant	Dyscresa	Mario Alabi	Interview 10 **(SME 5)**
Financing and Banks	Promerica Bank	Gustavo Calderon	Interview 11
Financing and Banks	BAC Bank	Irving Calvo	Interview 12
Financing and Banks	Sunshine company	Roberto Barzuna	Interview 13 **(SME 3)**
Trade and Industry Organizations	ACOPE: Costa Rican Agency for energy producers	Mario Alvarado	Interview 14
Norms and Legislation	INTECO: Costa Rican Institute for Technical Norms	Diego Cordero	Interview 15
Norms and Legislation	MINAET: Environment and Energy Ministry	Francisco Gomez	Interview 16
Norms and Legislation	ARESEP: Regulatory Agency for Public services	Victor Valverde	Interview 17
Transmission	ICE: Costa Rica Electricity Institute-Planning	Jorge Mario Montero	Interview 18 **(Incumbent 1)**
Distribution	CNFL: National Power and Light Company	Ivan Montes	Interview 19 **(Incumbent 2)**
Distribution	ICE: Costa Rica Electricity Institute-DG	Armando Cruz	Interview 20 **(Incumbent 1)**
Customers	Nala Kalu	Paulo Fernandez	Interview 21

Customers	Monteval developers	Alvaro Perez	Interview 22

Appendix 2: List of Relevant Stakeholders from Solar PV energy Industry in Costa Rica

As part of the value chain context analysis in chapter 4, the relevant actors and their roles were defined. This table summarized that analysis and it was not included in the thesis to reduce the length.

Table A1. Relevant stakeholder's description per sector. (source: interviews)

Value Chain Segments	Actor	Description
Financial support	BNCR: Costa Rica National Bank	Recently opened a portfolio for renewables energy projects
	PROMERICA Bank	First bank (since 2010) to provide green credits for solar PV project using "soft" interest rates, also in countries in the region. Sponsor of solar fairs
	BAC San José Bank	One of the leaders on the market providing customized credits based on the profitability of the project. Solar fairs sponsors
	IDB: Inter-American Development Bank	This international Bank finance renewable energy project directly or they function as a fund for a local bank.
	FMO, Dutch: Entrepreneurial development back	This international Bank finance renewable energy project directly or they function as a fund for a local bank.
	Sunshine Solar Energy	Private company that provides alternative funding for banks.
Industry & Engineering	ACESOLAR: CR Solar energy Association	Non-Profit Organization with the objective to promote solar energy in CR by bringing the private and public sector together.
	ACOPE: CR Energy Producers association	Non-Profit Organization with the objective to promote energy producer under law 7200.
	CICR: Chamber of Industry	Macro level board of Industry
	CFIA: Engineering & Architects Association	Brings together the Engineering sector.
Education	EARTH University	It is developing solar PV training programs in collaboration with RENAC.
	ITCR: CR Technology Institute Seslab	It has solar PV specialization training programs (yearly basis) and develops solar PV projects.
	UCR: Costa Rica University Eperlab	They have solar PV courses within their Bachelor specialization programs.
		A new Master program is scheduled for 2019.
	INA: National Technical Learning Institute	This is an autonomous institution from the Government in charge of technical training. So far has not developed solar PV training programs.
	RENAC: Renewables Academy	Academy based in Berlin, they deliver training for solar PV energy in collaboration with EARTH. Courses cover the whole value chain of renewable energy technologies and energy efficiency measures

	CFIA: Engineering and Architects Federation	They are organizing specialization training in collaboration with Solar Energy International.
	Solar Energy International	A nonprofit educational organization provides industry-leading technical training and expertise in renewable energy including solar PV.
Policy and Legislation	ARESEP: Public Services Regulatory Authority	Responsible for regulating all public services such as electricity generation. It defines all the electricity public service tariffs based on production cost principle.
	MINAET: Environment, Energy and telecommunications Ministry.	Institution responsible for managing all energy, environmental and telecommunications matters in Costa Rica. The DSE defines the policies and plans for the energy sector.
	DSE: Energy Sector Department	
	INTECO: Costa Rican Institute for Technical Norms	This private organization promotes the generation/adaptation of norms in CR. These norms could be used as standards.
Electricity generation segment	Incumbent energy producers	Companies that have been in the distribution generation market for several decades.
	Emergent SMEs	Emerging developers companies dedicated to solar PV small-scale projects
Transmission	ICE: Costa Rica Electricity Institute	State-Owned company responsible of the transmission and national energy supply.

This table shows the list of most relevant equipment suppliers doing businesses in Costa Rica. It provides a deeper insight about the major stakeholders and what is the link globally. The table is divided by the solar PV systems components

Table A2. Equipment suppliers in Costa Rica (source: interviews)

Component	Suppliers	Domestic	Headquarters	Manufactured
Solar Panels	Canadian Solar	Yes	Canada	Canada, China, Indonesia, Vietnam and Brazil
	Jinko	Yes	China	China(5), Malaysia, Portugal and South Africa
	Renesola	No	China	China, Poland
	Yingli Green Energy	No	China	United States, Spain and China
Inverters & micro inverters	Ginlong / Solis	No	China	China
	SMA Solar	No	Germany	Germany, China
	Enphase Energy	No	USA	USA
	Fronius	Yes	Austria	Austria, USA
	ABB	Yes	Switzerland	Finland, Spain, Italy
	Schneider Electric	Yes	France	Various
Batteries	Trojan Battery Company	No	USA	USA
	NorthStar	No	Sweden	USA, China
Racks & mountings	Chiko Solar	No	China	China
	Unirac	No	USA	USA
Surge Protectors	Midnite Solar	No	USA	USA
Charge Controllers	Victron Energy	No	The Netherlands	The Netherlands

This table provides information about the electricity distribution companies in Costa Rica. The information on the table is related to the area covered by each company, the percentage of clients and the sales percentage that those clients represent. ICE is the company that covers more area and his subsidiary CNFL is the company that has more density of clients. Two companies cover approximately 80% of the total sales and clients in Costa Rica.

Table A3. Energy distribution companies (CENCE, 2016)

Value Chain Segment	Electricity Distributor	Area [Km]	Clients [%]	Sales share [%]
Distribution	ICE: Costa Rica Electricity Institute	38715	43	41
	CNFL: National Power and Light Company	885	35	37
	Public service provider: JASEC	1103	6	6
	Public service provider: ESPH	104	5	6
	Cooperative: Coopeguanacaste	3915	4	5
	Cooperative: Coopelesca	4851	4	4
	Cooperative: Coopesantos	1275	2	1
	Cooperative: Coopealfaro	252	1	0.3

Appendix 3: Semi-Structure Interviews: GVC and Knowledge Functions

This appendix is related to the semi-structured questionnaire applied to all the stakeholders. This questionnaire provided the baseline of questions; however during the interviews other questions might have aroused depending on ongoing the discussion.

Introduction

1. Could you tell me, what is your educational background, to which company do you represent and which is your position in that company?
2. Which are your functions related solar PV in this company? Do you have to perform other activities besides solar PV?
3. Do you consider there are limitations or barriers for your company and the country at your value added segment of solar PV GVC?
4. Do you consider there are facilitators or strengths for your company and the country at your value added segment of solar PV GVC?

Related to solar PV Global Value Chain (GVC)

5. What types of activities does your company do about solar PV? How many employees are involved for Costa Rica for those activities? What type of financing do you have? Could you finance EPCs?
6. [I will show the GVC segmentation framework] from the different segments, which activities your company performs from this framework and in which countries?
7. Do you consider that your company could upgrade to perform other activities from this GVC framework? Would you like that?
8. Considering the solar PV system, which components are made by your company and which are being imported? Could your business manufacture those components? Please explain.
9. [I will show the GVC segmentation framework] considering your work segments, how are the major players, where are those actors geographically located for solar PV?
10. Does your company have strategic alliances with solar PV industry? Which are those types? If not, why you don't have those?

Knowledge Related

11. How would you describe the solar PV environment in CR and how affects your company stability?
12. Do you think that local knowledge institutions are matching the knowledge requirements for the solar PV firms/industry/research? How do you close the gap?
13. Within your company, to what extend the knowledge is documented?
14. Your company or other local stakeholder generates basic or applied knowledge through scientific articles, patents or applications? How could this process be improved in your firm and Costa Rica?
15. How long did it take you to acquire knowledge on solar PV field? To learn about solar PV business and technology which internal and external learning methods did you use and continue using (fairs, conferences, workshops, webinars, e-learning, books, scientific papers, customer and company visits)?
16. Does your business perform activities to diffuse solar PV knowledge to other firms, citizens or clients?

Appendix 4: Case study Protocol

The following is the case study protocol used to document the individual interviews. The documentation of the interviews is provided in a separate annex file.

GVC upgrading possibilities depending on knowledge context

CASE CONTACT DATA

Name of the company	Company name
Contact person	Company representative
E-mail of the contact person:	Email address
Website	www.<website>
Phone	+506 XXXX XXXX

COLLECTION OF EMPIRICAL DATA

Responsible researcher	Juan Carvajal
The research period	From 3.4.2017 to 1.6.2017
Research approach	Case Study
Data collection	Complete with used methods

Research data	**##**	**Documentation methods** none/memo/audio file/transcript/data file	**Documents available from**
Interview		Filling info	
Observation		Filling info	
Workshop		Filling info	
Meeting		Filling info	
Statistical data		Filling info	
...		Filling info	

Main theories used	Functions of Innovation Systems, Global Value Chain Upgrading

Data-analyses; use of codes etc.	Selective Coding
Software used for analyses	Not determined yet

VALIDATION AND REVIEW OF CASE REPORT

Validated by contact person	Yes/No/No yet
Reviewed by thesis supervisor	Yes/No/No yet

FIRM's BACKGROUND INFORMATION

Background characteristics	<Info from Interview or desk research>
Business Model	<Info from Interview or desk research>
Established in	<Info from Interview or desk research>
Number of employees	<Info from Interview or desk research>
Dedicated to Solar PV	<Info from Interview or desk research>
Installed capacity	<Info from Interview or desk research>
BtoB/BtoC/BtoG	<Info from Interview or desk research>
Lifecycle phase of SME	Mature and growing

FIRM's within Global Value Chain

Solar PV segment(s)	<Info from Interview or desk research>
Market area (geo)	<Info from Interview or desk research>
Market segment	<Info from Interview or desk research>
Activities performed	<Info from Interview or desk research>

FIRM's KNOWLEDGE CREATION

Knowledge documentation characteristics	<Info from Interview or desk research>.
Learning Methods	<Info from Interview or desk research>
Patents generation	<Info from Interview or desk research>
Attend to fair(type,qty)	<Info from Interview or desk research>
Written Scientific Articles	<Info from Interview or desk research>
Applications made	<Info from Interview or desk research>
Competency building characteristics	<Info from Interview or desk research>

FIRM's KNOWLEDGE DIFUSSION

Knowledge sharing characteristics	<Info from Interview or desk research>.
Types of alliances	<Info from Interview or desk research>
Publications	<Info from Interview or desk research>
Knowledge diffusion activities	<Info from Interview or desk research>

FIRM's UPGRADING on Value Chain

Firm is interested in upgrading	<Info from Interview or desk research>.
To which segment	<Info from Interview or desk research>
Activities performed	<Info from Interview or desk research>
Activities outsourced	<Info from Interview or desk research>
New activities	<Info from Interview or desk research>
Discontinued activities	<Info from Interview or desk research>

FIRM's BARRIERS

Knowledge Creation barriers	<Info from Interview or desk research>.
Knowledge diffusion barriers	<Info from Interview or desk research>
Upgrading barriers	<Info from Interview or desk research>
Other barriers	<Info from Interview or desk research>

COMMUNICATION VALUE OF THE CASE

Keywords	
Main message towards SMEs	
Lessons learned	

The study protocol was adapted from protocol version of ENVISION project website: http://www.envisionproject.eu/