Deep Dive into Peru’s Power-Generating Technology Costs until 2035

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Abstract
The desire to know what the future might bring has always been part of the human nature and as human beings, we have extrapolated that desire to most aspects of our surroundings. Energy is a basic need for human development, and thus, energy deployment has not been exempt from that desire. Nowadays, energy models have become a standard tool to assess many areas of the energy sector, including projections of future energy costs. Statkraft AS, in an attempt to strengthen its position within the emerging markets where it is present, has developed a power cost projection model based on macroeconomic indicators and capable to integrate learning rates from experience curves. The model seeks to provide the future energy costs (CAPEX & LCOE) of selected technologies, namely, onshore wind, solar PV and CCGT, until 2035. This study explores the model’s theoretical foundations and addresses its results within the Peruvian energy market.

Keywords: Energy technology, experience curves, energy models, renewable energy, LCOE.
Executive Summary

Statkraft AS is an state owned Norwegian energy company and an international leader on renewable energy generation. Through the company's Innovation Unit, they seek to strengthen their position in the emerging markets where they have operations. The current study is part of a bigger assessment that aims to compare energy costs from different energy technologies across Brazil, Chile, China, India, Peru and Turkey. As part of that overarching project, the main objective of this study was to obtain the future energy costs for onshore wind, solar PV and CCGT within the Peruvian market. Statkraft's interest in Peru emerged from the company's vision and objective of seeking to maintain itself as an international leader on power generation. Hence, an overview of the current and eventual future of the Peruvian energy market, can give the company an opportunity to develop competitive strategies to further enhance its presence within said market. With that in mind, Statkraft has developed a power cost projection model that aims to provide with costs projections for energy technologies (TOC & LCOE). Before addressing the theoretical foundations and macroeconomic indicators of the power costs projection model. In order to set the current context from which the cost projections will be elaborate, this study gives an overview of the Peruvian energy market.

Even though, more than 50% of the electricity production in Peru comes from renewable sources, the last ten years have seen an increasing growth of thermal technologies. Due to the Camisea gas fields, the country cut its dependency from oil imports and was able to fully meet the electricity demand growth. Nonetheless, there is no certainty of the amount of proven reserves in the country just yet. The Peruvian government has been, in the opinion of many critics, too optimistic regarding its capability to cover the domestic natural gas demand in the future. On the bright side, the last years have also shown a promising deployment of renewable energy technologies, namely, onshore wind and solar PV. Although, the market is still quite small, governmental will to expand it, has been observed.

Learning rates from experience curves for energy technologies have been an useful tool to assess the deployment of energy technologies for quite sometime now. The theory behind learning rates can be summarised by saying that with experience in doing the same thing, one tends to do it more it more efficiently ("learning by doing"). As part of this study, a literature review on learning rates from experience curves was conducted. From this review, two main conclusions can be drawn: (i) young technologies have a higher learning rate than mature technologies; and, (ii) the integration of learning rates in forecasting models may or may not have an impact on the cost decrease for energy technologies. Although, many authors argue the existence of local and global learning rates, this study takes the approach given by Neij (2008). Neij (2008) found empirical experience to state that learning occurs at a global level. In her paper, she also recommends the use of certain values for learning rates, differentiating them across technologies. After discussing Neij's (2008) findings with the other members of the project, the suggested rates were integrated into the power cost projection model.

As the model seeks to compare the differences between costs across countries from now to 2035, macroeconomic indicators and assumptions needed to be made. By applying the Balassa-Samuelson effect, which explains the relationship between non-tradable items (NTs) and the real exchange rate (RER), the model is able to develop a trajectory of prices for NTs from 2015 to 2035. Since one of the main project assumptions relies on the influence of NTs on price variations between technologies and across countries, by integrating the Balassa-Samuelson effect into the model, the calculations for the future costs projections are ready to be made.

After explaining the theoretical foundations of the model, the study elaborates on the “mechanics” of the model, i.e. it develops the formulas to calculate the future total overnight construction cost (TOC) per energy technology and the Levelised Cost of Energy (LCOE).
The inputs for the model to run and develop the future cost projections, are obtained from both primary and secondary sources. These inputs are composed of capital construction costs (CAPEX) and operation & maintenance costs (OPEX) from greenfield projects commissioned during 2014. Once the inputs are integrated in the model, the results of the TOC and LCOE projections for the studied technologies show the following trends:

- For the TOC, it can be stated that cost reductions are a direct effect from learning rates and for the Peruvian context, onshore wind technology ends as the more cost competitive technology in 2035.

- For the LCOE, the results show differences in the prices due to capacity factors for the renewable technologies; and, fuel prices & fuel net efficiency for CCGT.

It must be noted that energy models come in all sort of shapes and sizes. Although, the power cost projection model offers valid indicators to assess technology development and cost reductions, these indicators are not the only ones. Academic studies regarding the impact of policies in technology development are widely available in mature markets. However, besides IRENA (2014), no other sectorial, or governmental organisation has undertaken similar studies for the Peruvian context. Certainly, this is a gap worth exploring in future research endeavours.
# Table of Contents

**LIST OF FIGURES** ................................................................................................................................. II

**LIST OF TABLES** ................................................................................................................................. II

**ABBREVIATIONS (IF REQUIRED)** ........................................................................................................ III

1. **INTRODUCTION** ............................................................................................................................. 1
   1.1. BACKGROUND .................................................................................................................................... 1
   1.2. PROBLEM STATEMENT AND MOTIVATION ...................................................................................... 1
   1.3. RESEARCH FOCUS ............................................................................................................................ 2
       1.3.1. Objective ..................................................................................................................................... 2
       1.3.2. Research Questions ................................................................................................................... 2
       1.3.3. Target Audience ......................................................................................................................... 2
   1.4. LIMITATIONS AND SCOPE .............................................................................................................. 2
   1.5. METHODOLOGY .............................................................................................................................. 3
       1.5.1. Benchmark costs and supply chain data collection ........................................................................ 3
       1.5.2. Analytical Framework ................................................................................................................ 3
       1.5.3. Modelling and Analysis of the Results ....................................................................................... 4
   1.6. THESIS OUTLINE ............................................................................................................................ 4

2. **OVERVIEW OF THE PERUVIAN ELECTRICITY MARKET** .............................................................. 5
   2.1. ENERGY SECURITY - CONCEPTS USED ........................................................................................... 6
   2.2. THE NATURAL GAS INDUSTRY ....................................................................................................... 7
   2.3. NON CONVENTIONAL RENEWABLE ENERGY TECHNOLOGIES ................................................... 8
   2.4. THE WAY FORWARD? ...................................................................................................................... 10

3. **LITERATURE REVIEW - EXPERIENCE CURVES FOR ENERGY TECHNOLOGIES** ......................... 12
   3.1. DEFINITION OF EXPERIENCE CURVES ......................................................................................... 12
   3.2. EXPERIENCE CURVES FOR ENERGY TECHNOLOGIES .................................................................... 14
       3.2.1. Onshore Wind ............................................................................................................................ 15
       3.2.2. Solar Photovoltaic (PV) ............................................................................................................ 16
       3.2.3. Combined Cycle Gas Turbine - CCGT ..................................................................................... 16
   3.3. GLOBAL VS LOCAL LEARNING - “RECOMMENDED” EXPERIENCE CURVES .............................. 17

4. **POWER COST PROJECTION MODEL** ............................................................................................... 19
   4.1. ENERGY MODELS - GENERAL ASPECTS ....................................................................................... 19
   4.2. STATKRAFT’S POWER COST PROJECTION MODEL - THEORETICAL FOUNDATIONS .................. 20
       4.2.1. Levelised Cost of Energy - LCOE ............................................................................................. 20
       4.2.2. Non Tradable Items - NTIs ...................................................................................................... 22

5. **THE MODEL IN A NUTSHELL - MODEL DYNAMICS & RESULTS** .................................................. 27
   5.1. CALCULATIONS FOR TOC AND LCOE ......................................................................................... 27
   5.2. PROJECTIONS RESULTS AND SENSITIVITY ANALYSIS .............................................................. 28
       5.2.1. Model Inputs: Benchmark Costs - Onshore Wind, Solar PV and CCGT .................................... 28
       5.2.2. Model Results and Sensitivity Analysis .................................................................................... 30

6. **CONCLUSIONS AND FURTHER RESEARCH OPPORTUNITIES** .................................................. 33

**BIBLIOGRAPHY** ..................................................................................................................................... 34
List of Figures

Figure 2-1: Demand growth of the last 10 years covered by energy produced from natural gas.

Figure 3-1: An example of an experience curve in linear (a) and log (b) scales.

Figure 4-1: Global LCOE from April-June 2013 (USD/MWh)

Figure 5-1: TOC projections per technology until 2035

Figure 5-2: LCOE projections per technology until 2035

List of Tables

Table 2-1: Summary of the main features of the Peruvian power market:

Table 2-2: Results of the first and second auction (excluding results awarded to biomass energy production):

Table 3-1: Suggested learning rates per energy technology

Table 4-1: Differences between top down and bottom up models.

Table 4-2: Major NTs (energy sector) in Different Economies - Global Price Level Comparison

Table 5-1: Model Inputs per Technology

Table 5-2: CAPEX & OPEX projections per technology until 2035

Table 5-3: LCOE projections per technology until 2035
Abbreviations (if required)

BCG - Boston Consultancy Group
CAPEX - Capital cost
CCGT - Combined Cycle Gas Turbines.
IDC - Interest during construction
LCOE - Levelised cost of energy
LNG - Liquified natural gas
NTs - Non tradable goods and services
OC - Owner's cost
OCC - Overnight construction cost
OPEX - Operational and maintenance cost
PPP - Purchasing Power Parity
PR - Progress ratio
REN21 - Renewable Energy Technology Network for the 21st Century
RER - Real exchange rate
TOC - Total overnight construction cost
WACC - Weighted average cost of capital
1. Introduction

“Prediction is very difficult, especially if it's about the future.”
Nils Bohr (1885 - 1962), Nobel laureate in Physics 1922

1.1. Background
Statkraft AS, a state owned Norwegian company, is the largest producer of renewable energy in Europe, with a total annual power production of 56 TWh. In 2003, Statkraft started its operations in Peru, and since then it has been operating eight hydropower plants, which accounts for 3.5% of Peru's energy production. As of today is the fifth largest electricity producer in the country. With a growing interest on emerging markets, Statkraft seeks to strengthen its position as a leading international provider of renewable energy in Peru (Statkraft, 2014).

To accomplish such objective, the Technology Analysis Department, as part of the Innovation Unit provides the company with the analysis of trends in power generating technologies. This thesis is part of a bigger study that comprises emerging markets with Statkraft’s presence, namely: Brazil, Chile, China, India, Peru and Turkey. The analysis is geared towards different technologies in different markets, focusing on costs of the four main power generating technologies coal, gas, solar PV and onshore wind1 (Statkraft, 2014).

1.2. Problem Statement and Motivation
Within the Peruvian energy market, it is an common observation that mature technologies are more cost competitive than newer technologies, which currently, makes fossil based generation cheaper than renewable based generation. It is thus, noteworthy to study this spread and project if this gap between renewables and non renewables widens or narrows in the future; considering that technological costs not only differ with technology but also with the situation of the country.

For instance, through Statkraft’s previous analysis, it has been observed that Combined Cycle Gas Turbines (CCGT) plants in Western Europe cost1 1.31 M$/MW while those in India cost 0.662 M$/MW. This effect is due to underlying supply chain in both locations. So while the biggest cost component for a CCGT plant are the turbines, which are produced by two of the major manufacturers in the world: General Electric (GE) and Siemens, the Indian plants built the turbines domestically under license GE reducing costs.

Considering this, Statkraft deemed important to analyse how technology costs evolve for the same technologies in different emerging countries. Taking into account that technology costs also evolve as a result of experience curves and that costs of power generation varies, not only with technologies but also from country to country, Statkraft has developed a Cost Projection Model, in order to obtain and analyse future cost projections (Total Overnight Construction Costs - TOC & Levelised Cost of Energy - LCOE) until 2035. The Power Cost Projection model not only captures learning rates from experience curves, but also, from an economic perspective2, the variations on Non-tradable goods and services (NTs)3 across countries.

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1 For the case of Peru, coal generating technologies are out of the thesis scope.
2 One can assume that the model is based in a question such us: why does the cost of technology varies across countries.
3 Good and services such as land, construction services, utilities, labour and so on.
1.3. Research Focus

1.3.1. Objective
The overarching objective of this study is to collaborate with Statkraft’s Innovation Department in the analysis and comparison of future cost projections for energy technologies in the different emerging markets. The main objective of this paper is to present an overview of the Peruvian Energy Market, to later obtain and analyse the future projections (from 2015 to 2035) for TOC and LCOE for onshore wind, solar PV and CCGT power plants in Peru. The thesis observes the evolution of energy technology costs in Peru, under the lenses of experience curves. In order to achieve the objectives, benchmark capital (CAPEX) and operational (OPEX) costs for the above mentioned power generating technologies are collected; and, a literature review on experience curves is carried out.

1.3.2. Research Questions
In order to address the overall objective the following research questions have been formulated:

• What will be the power generating technology costs for Peru in 2035?
• What will the shape of the future energy system be and what technologies will make up the system?

1.3.3. Target Audience
The following actors are the main target audience for this paper:

• Statkraft’s Innovation Unit - Technology Analysis Department: This unit provides the company with technology analysis on technology development, costs and trends, as well as on early phase business concepts.

• Fellow Master Thesis Students at Statkraft - As mentioned before, this thesis is part of an overarching project which aims to analyse future costs projections for energy technologies in Brazil, Chile, China, India and Turkey. Another five Master students, each one from the mentioned countries, have addressed the research questions and framed them in the context of their own countries.

1.4. Limitations and Scope
In order to answer the research questions, the study seeks, as a starting point, to obtain, organise, calculate and analyse the benchmark CAPEX and OPEX costs for onshore wind, solar PV and CCGT greenfield, utility level, energy projects within the Peruvian Energy Market. Once the CAPEX and OPEX are obtained/calculated, these values will be presented as inputs for the Power Cost Projection Model.

The thesis also analyses how learning rates from experience curves, for the above mentioned energy technologies, impact on the cost reductions per technology. As for the economic perspective of the Power Cost Projection Model, this study refers to the paper written by Shubham Gupta regarding the variations on NTs across the emerging markets part of the overarching project sponsored by Statkraft.

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4 Shubham Gupta is a Statkraft Master Student and a MSc (candidate) in Economics and Business Administration from NHH - Norge Handelshøyskole and HEC Paris. As part of Statkraft's project, he was in charge of analysis for India's Power Generation Technology Cost
The original overarching project design by Statkraft included four different scenarios, which were intended to examine alternate pathways for the future of energy. The scenarios, developed by Statkraft's Innovation Unit, were based on technological development, economic growth, climate focus and regiment, innovation and security of supply, as well as demand and demographics. However, due to time constraints and by Statkraft's initiative, the scenarios were removed out of the project's scope. Only a base scenario is considered in the Power Cost Projection Model and it is defined by the country's specific macroeconomic indicators.

The study analysed data gathered mainly from secondary sources. One of the limitations in gathering data from primary sources was related to the lack of reliability of the documents issues by the Peruvian Government. For instance, when trying to collect data regarding benchmark CAPEX costs from onshore wind and CCGT greenfield projects, the author encountered that original documents produced by: the Peruvian Energy Agency (OSINERGMIN), the Ministry of Energy and Mines and the Peruvian Private Investment Promotion Agency (PROINVERSION) had inconsistent information. Moreover, due to the lack of variety in academic papers regarding the Peruvian Energy Market, Chapter 2 is based mainly on governmental reports, international organisations' papers, NGO's reports and journalistic investigations.

1.5. Methodology

The approach undertaken for this study was suggested by Statkraft and it is in the form of a case study. It is both, a qualitative and quantitative analysis of the Peruvian electricity market and its future projections for certain power generating technologies. Although, large hydropower is one of the main sources of energy production in the Peruvian electricity market, this technology was taken out of study scope, due to Statkraft's familiarity with this technology. The idea behind this study was to explore the cost projections of specific “new” technologies within the Peruvian context and, for the purposes of Statkraft's overarching project, compare the Peruvian results with the findings from Brazil, Chile, China, India and Turkey.

The necessary information to data and academic literature to address the research questions was collected over a three months period. Additionally, as part of the Statkraft's comprehensive project, a kick off meeting in Oslo, Norway was carried out at the beginning of the project. After that, in order to follow up on the research and discuss the rationale between the differences among the all the countries in the project, weekly online meetings with all the team members and Statkraft's supervisors were conducted.

The research design was proposed by Statkraft and is as follows:

1.5.1. Benchmark costs and supply chain data collection

The first part of the research was dedicated to collect data on onshore wind, solar PV and CCGT greenfield, utility scale, energy projects. This first step allowed the author to re-gain familiarity with the Peruvian energy market, as well as, gave the other team members a general overview of the current trends in technology deployment. The main sources of data sets were provided by the Peruvian authorities. Although, as it was mentioned before, some of this primary sources contained unreliable and inconsistent information. In those cases, assumptions based on regional and global benchmark costs were made. As for the supply chain and technical characteristics of the studied power generating technology systems, the data sets were obtained from the Peruvian Energy Agency (OSINERGMIN).

1.5.2. Analytical Framework

The second part of the study was targeted to develop an analytical framework based on learning rates from experience curves for power generating technologies. The aim to use experience curves as an analytical framework responded to: (i) the possibilities offered by
experience curves to assess costs developments for energy technologies; and; (ii) the design of the Power Cost Projection Model. Information from secondary sources, academic literature, books, publications from international organisations (IEA, OECD, IRENA, etc), financial services reports (Bloomberg) and internet searches, was collected for the assessment of experience curves for energy technologies.

1.5.3. Modelling and Analysis of the Results
Lastly, the inputs gathered during the first part of the research, along with the suggested learning rates from the experience curves for the selected energy technologies were input in the Power Cost Projection Model. In order to answer the research questions, this last stage was divided in 2 phases:

- Analysis of each of selected energy technologies in comparison with all countries, i.e. cost development of onshore wind in all countries5.

- Analysis of all the selected energy technologies per country, i.e. comparison of the costs development for all technologies in Peru.

1.6. Thesis Outline
The report is organised as follows:

Chapter 1: Shows the study in context, allowing the reader to get into the topic and explains its relevance and research methodology.

Chapter 2: This chapter gives an overview of the Peruvian Electricity Market. It also stresses the analysis into the country’s current ‘readiness’ to foster a serious attempt to deploy sustainable energy projects.

Chapter 3: Based on the relevant available literature, this chapter goes in depth over the learning rates for experience curves from the selected energy technologies. It also examines the challenges of these rates and their effects of cost developments. The chapter concludes with recommended rates to be used as inputs for the Power Cost Projection Model.

Chapter 4: This chapter gives an overview of energy models to later explain the theoretical remarks Power Cost Projection Model developed by Statkraft, in order for the reader to understand the macroeconomics behind the TOC and LCOE calculations and projections until 2035.

Chapter 5: Presents the “mechanics” of the model. This chapter is a continuation of the previous one, but it is focus on the real calculations made by the model and the results. It also provides a sensitivity analysis of the results.

Chapter 6: Lastly, this chapter seeks to state the closing remarks on the Peru’s projected energy costs and pointing out recommendations for future research.

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5This stage is not included in this report, since is part of Statkraft’s overarching project and out of the scope of this specific study.
2. Overview of the Peruvian Electricity Market

In December 2014, Lima, the Peruvian Capital, hosted the 20th session of the Conference of the Parties for the United Nations Framework Convention on Climate Change (COP 20). Many around the world followed the events of the conference with great interest, mainly due to the fact that whatever it would happen in Lima, it will affect tremendously the path to a climate change agreement in Paris this year (COP 21).

The Peruvian Government did not miss the opportunity to present their achievements related to environmental governance and when it came to energy issues, the Peruvian government presented the newest National Energy Plan 2014-2025. This document has been considered as part of this literature review and essentially addresses the policy considerations and investment projects related to basic national energy objectives. One of its highlights is perhaps the goal to achieve 5% of energy production from non-conventional renewable sources by 2021. Along with the energy produced by hydroelectric plants, the Peruvian Government aims to have a 60% share of renewable energy in the national production matrix by 2021.

Table 2-1: Summary of the main features of the Peruvian power market:

<table>
<thead>
<tr>
<th>Generation</th>
<th>Transmission</th>
<th>Distribution</th>
<th>Free Consumers</th>
</tr>
</thead>
<tbody>
<tr>
<td>42 companies</td>
<td>10 companies (main grid)</td>
<td>21 companies/4 privates.</td>
<td>216 free consumers</td>
</tr>
<tr>
<td>74% private sector</td>
<td>100% private</td>
<td>41% costumers “belong” to private distributors.</td>
<td>41 “big users” - (Big user &gt;10MW).</td>
</tr>
<tr>
<td>113 power plants</td>
<td>806 substations</td>
<td>Regulated Distribution Tariff - non industry.</td>
<td>Purchase energy from</td>
</tr>
<tr>
<td>7.81 GW effective</td>
<td>16,533 km of lines from 130 to 500kV.</td>
<td>Tariff is updated every 4 years.</td>
<td>a generator or distributor.</td>
</tr>
<tr>
<td>capacity</td>
<td>Regulated public service with open access.</td>
<td>Monopoly within the concession areas.</td>
<td>51% are supplied by</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>generators and 49% by</td>
</tr>
<tr>
<td>52% hydro</td>
<td>Planned development.</td>
<td></td>
<td>distributors.</td>
</tr>
<tr>
<td>42.6% natural gas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.7% onshore wind</td>
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<tr>
<td>1.0% solar PV</td>
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<tr>
<td>Two contracting</td>
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<td>environments:</td>
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<td>Free market</td>
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</table>

Source: (OSINERGMIN, 2014)

However, in the author's opinion, two events that did not echoed among the public, darkened the Government’s ‘good will’. The first one is related to the conference venue itself. Newly built and powered exclusively with diesel generators, it contributed to place this conference as the one with the largest carbon footprint of any other UN climate meeting. The organisers failed to connect the venue with the Peruvian electricity grid, which is mainly powered (52%) by hydro-energy. The second event is related to something that happened a few days after the conference. The conference stated as one of its main pledges to meet the climate goals a significantly ramp-up on renewable energy and energy efficiency. However, on a contradictory note, the Peruvian Government announced that twenty-six oil blocks were ready to be offer in an international bid. Moreover, the Peruvian Government also stated that they expect to find

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6 As defined by the Peruvian regulation (Legislative Decree 1002), non-conventional renewable sources encompass Solar PV, Wind and Biomass. Hydropower sources of more than 20MW of installed capacity are excluded from this category.

more oil reserves and aim to drill between 40 and 50 exploratory wells per year⁸.

2.1. Energy Security - Concepts Used

Guaranteeing a constant flow of energy is a priority for governments’ administrations around the world, and the Peruvian administration is not an exception. A myriad of policies and policy instruments have been conceived in order to address the key threats to energy supply: price of energy and its availability. Events like tension in the Middle East or the lack of energy production sources in some countries can significantly affect the price of energy. It is also widely known, that an uninterrupted provision of electricity ensures market and investment effectiveness. However, energy security does not only restrain to that, for instance, if we think about the sovereignty of estates, the supply of fuels is vital for armies and transportation.

The International Energy Agency (IEA) defines energy security as “the uninterrupted availability of energy sources at an affordable price”. This availability is one of their main objectives and the foundation of its establishment back in 1974. That being said, as for today, fossil fuels are still the main source of energy in the world, and it does not come as a surprise that oil security remains a cornerstone of the IEA. However, with the acknowledgement about the limited availability of conventional fossil fuels, the need of more comprehensive sources of energy (i.e. renewables) arose.

Despite the fact that, there is a common understanding about the ‘basics’ of energy security, the discourse, its implementation and threats vary from country to country. Among the “basics” factors of the energy security, the IEA states, “long-term energy security is mainly linked to timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.”

It is undeniable that climate change plays an important role within the concept of energy security. However, with the release of the latest IPCC report and the last COP20 in Lima, an urgent call of awareness has been made. The overall world temperature is increasing, and drastic measures need to be taken, especially for the poorest of the world. In reference to the report, it points out the urgent need to redirect investments in all sectors, especially within the energy sector, towards more climate-friendly technologies (IPCC 2014).

As stated before, one of the major issues mentioned by the report, refers to energy production and use of fossil fuels. The report states that investments on electrical power plants functioning on fossil fuels need to decline by about 20% within the next 20 years, in order to meet climate change targets. The IPCC has issued a clear warning: the longer countries delay this aggressive change, the more difficult it would be to limit the increase of temperature (IPCC 2014). Therefore, investments and research in renewable energy production needs to increase aggressively from current levels.

Climate change effects and meeting future energy needs are two interlaced and urgent policy challenges for nations throughout the world. For instance, in Europe, Germany has stated as its strategy to invest and promote renewable sources of energy. The German Energiewende aims to reduce Germany’s dependency on energy imports. Thus making the country less vulnerable to the rising prices of fossil fuels, to political influence from outside its borders and understanding energy security as the reflection on the availability of affordable energy for its growing demand (Morris and Pehnt, 2012). The fact that the reliance on foreign sources of energy is a “threat” to Germany’s energy supply was shown during the winter of 2011-2012.

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⁸ Peru tiene 26 lotes de petróleo listos para convocar a licitaciones (Peru has 26 oil plots ready to start a bidding process) : http://www.americaeconomia.com/negocios-industrias/peru-tiene-26-lotes-de-petroleo-listos-para-convocar-licitaciones?utm_source=dlvr.it&utm_medium=facebook
During that period of time, Russia reduced imports to Germany by as much as 30% due to a long cold spell within the Russian territory. When referring to this episode, Morris and Pehnt point out that “renewables and energy conservation can reduce the dependence of countries that consume energy on countries that provide energy resources. Over the past few decades, this dependency has constantly increased. Reducing this dependency would also promote global peace; after all, wars over resources and the “oil curse” are directly related to the problems that many politically fragile regions face.”

Several discussions have been developed regarding the ‘threats’ to energy security, and most of them conclude in more or less the same issues. In 2009 Watson and Scott grouped what are perceived as main energy security threats in four categories: (i) Fossil fuel scarcity and external disruptions including international terrorism; (ii) Lack of investment in infrastructure; (iii) Technology or infrastructure failure; and, (iv) Domestic (UK-based) activism or terrorism.

In the Peruvian context, the fact that proven reserves of natural gas are available within the borders of the country has shaped its energy market in a peculiar way. In previous years, almost 98% of the electricity demand was covered by the hydropower production. However, during the last ten years, the demand growth has been covered with natural gas. Hence, the demand share covered by hydro-energy was reduced in almost 50%. As in any other modern economy, fossil fuels still occupy a major role in the Peruvian energy market.

Figure 2 - 1: Demand growth of the last 10 years covered by energy produced from natural gas.

2.2. The Natural Gas Industry

The commissioning of the Camisea natural gas fields was Peru’s major catalyzer to reduce its dependence on imports and positioned the country as an exporter of liquefied natural gas (LNG). According to Spencer, from a history track as an oil exporter country, during the 1980’s, Peru became a net importer. The main reasons behind this were a combination of a highly state-dominated management of the country’s energy sector during the 1960’s and the lack of important reserves discoveries over the next years (Spencer, 2010; Tamayo et al, 2014).

The Royal Dutch Shell discovered the Camisea natural gas (Amazon basin) fields in the 1980’s. However, it took approximately twenty years to develop the project and bring natural gas into the Peruvian market. After the discovery, Shell pursued deployment entitlements for the fields, however the company could not reach to an agreement with the Peruvian government. Due to
this, Shell quit its activities in Peru in 1988. Nonetheless, the country was unable to both: attract investors and collect funds to develop the fields. The project, thus, remained untapped. Later in 1994, the country opened up the project for bids, but according to Spencer, “major potential bidders wanted the government to resolve its conflict with Shell first. Two years later, after renewed discussions, Peru granted a 40-year concession to a Shell-Mobil consortium. Nonetheless, the consortium terminated the project in 1998 because of still-irreconcilable differences between the companies and the Government of Peru”. It was not until 2000, after a series of legislative changes that Peru signed contracts for the development, transportation and distribution of the Camisea natural gas. In 2004, almost twenty years after its discovery, the Camisea project started its commercial production (Spencer, 2010).

It is noteworthy to mention some of the legislative changes that allowed the development of the project. Alba states that gas supply to the local and international markets have different requirements. Whereas the local market involves lower investments, exports can only be developed once the local market supply is adequately secured and guarantees from proven reserves. In order to develop both markets, Alba describes how an ad-hoc regulatory framework put in place comprised ceiling gas prices for the production of the gas field destined to cover the domestic market (Block 88). For the transport, a cross subsidy for the first Camisea pipeline was put in place, in order to determine electricity tariffs and to ensure its economic feasibility (Alba, 2012).

Both Alba and Spencer agreed on the benefits brought to the Peruvian economy by the deployment of the Camisea natural gas fields. The National Energy Plan 2014 -2025 confirms these benefits: “From 2003-2013 the Gross Domestic Product increased by 86%, electricity production by 92% while hydrocarbon production increases by 260%. Final national consumption of these energy resources increased by 92% for electricity while for liquid and gas hydrocarbon aggregates it increased by 100%. This is the highest growth in economic activities and in energy demand shown over the last decades due to an increase in private infrastructure investment, as well as to social investment developed by the State” (Ministry of Energy and Mines, 2014).

On the investors’ side, Alba points out how the project has brought high profits to the developers. So far, the project has reimbursed the initial investments and is in a net earning period. Between 2002 and 2011, earnings before taxes accumulated by the developers were over US$ 4,900 million. Moreover, projections show that by 2040 the developers will obtain an internal rate of return of approximately 37% (Alba, 2012). Nonetheless, from the date of the project’s commissioning until today, as stated by both Alba and Spencer, no one has seriously considered the impact on international natural gas prices that the exploitation of shale gas in the USA could produce. The variation on prices would definitely impact the country and investors earnings from their exports.

Furthermore, as stated by Spencer, it is argued that Peru does not have enough reserves to both supply the domestic market and also to satisfy its exporting commitments (i.e. Mexican market). As Camisea gas fields hold nearly 90% of the country’s natural gas reserves and 40% of these reserves are already compromised to exports, a prospective unavailability of gas reserves comes as a major issue for the country’s energy supply (Leung and Jenkins, 2014). Leung and Jenkins conducted a cost benefit analysis for a series of scenarios on the availability of the resource and their results show that: (i) there are indications that gas deposits were misclassified; and, (ii) there are not enough reserves to secure exports without affecting the domestic market.

2.3. Non Conventional Renewable Energy Technologies

As previously mentioned, historically electricity generation in Peru has come from renewable sources (mainly from hydropower plants). With the commissioning of the Camisea project, the share of hydropower production has been reduced in almost 50% (Figure 2-1). Although, fossil fuels availability still play a determinant role on the domestic supply, concerns about the
impacts of its deployment on the environment have emerged in the Peruvian society. On top of that, the Peruvian economy has rapidly expanded in the last years, due to investments in the mining and infrastructure sectors. Therefore, the Ministry of Energy and Mines has estimated that electricity demand will grow at an average annual rate of 8.8% per year up to 2017. According to the International Renewable Energy Agency – IRENA, Peru has to invest in bringing an additional capacity of 4300MW (including 1400MW from large-scale hydro and 600MW non-conventional renewable sources). This increase would account for investments of more than $5 billion USD by 2016 in electricity generation from renewable sources (IRENA, 2014).

It is within this context that a growing interest in sources of energy friendlier to the environment has appeared. Taking this into account, in 2008 the Peruvian government issued the Legislative Decree 1002, which promotes investments for electricity generation by using non-conventional renewable sources, namely: solar PV, wind, biomass, geothermal and small hydropower plants with an installed capacity of less than 20MW (Ministry of Energy and Mines, 2014; OSINERMING, 2014).

Regarding, renewable energy resources in general including large-scale hydropower projects, the IFC has encountered that sources like “solar, wind, biomass, hydro energy, and others, have significant potential in Peru. However, only 4.7% of the hydro energy potential, 0.65% of the wind potential, 6.1% of the biomass potential, and less than 1% of the solar potential is currently being exploited. Accordingly, there is high potential to increase the use of renewable electricity and to decrease dependence on fossil fuels (in 2010, 56% of electricity generation came from with hydropower, and 44% from natural gas and oil derivatives). Doing so will diversify the energy matrix and contribute to the mitigation of climate change, for which the Government of Peru has made international commitments” (IFC, 2011).

Although, in general the context seems favourable to develop renewable electricity sources, the process is rather slow. The highest energy demand comes from the industrial sector, which accounts for almost 80% of the country’s electricity consumption. Moreover, domestic tariffs for electricity consumption in Peru are subsided by the Government, placing them among the lowest tariffs in Latin America. Thus the percentage of the population that gets a constant flow of energy is not encourage to use it efficiently (IFC, 2011; IRENA, 2014).

Anyhow, through Legislative Decree 1002, Peru has implemented renewable energy auctions, which so far have helped promoting biomass, wind, solar PV and small hydropower plants. Up to date, there has been three energy auctions, where the first two (2010 and 2011) awarded almost 1400 GWh/year of renewable power from solar, wind and biomass and 281 MW from small hydro, attracting total investments of almost USD 1.5 billion.
Table 2-2: Results of the first and second auction (excluding results awarded to biomass energy production):

<table>
<thead>
<tr>
<th>Technology</th>
<th>Project name</th>
<th>Power offered (USD/MWh)</th>
<th>Power to be installed (MW)</th>
<th>Plant factor (%)</th>
<th>Energy awarded (GW/h)</th>
<th>Date of commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Auction (2010)*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Marcona</td>
<td>65.6</td>
<td>32.0</td>
<td>53</td>
<td>148.0</td>
<td>25.04.2014</td>
</tr>
<tr>
<td>Wind</td>
<td>Talara</td>
<td>87.0</td>
<td>30.0</td>
<td>46</td>
<td>120.0</td>
<td>03.09.2014</td>
</tr>
<tr>
<td>Wind</td>
<td>Cupisnique</td>
<td>85.0</td>
<td>80.0</td>
<td>43</td>
<td>302.0</td>
<td>03.09.2014</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Panamericana</td>
<td>215.0</td>
<td>20.0</td>
<td>28.9</td>
<td>51.0</td>
<td>31.12.2012</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Majes Solar</td>
<td>222.5</td>
<td>20.0</td>
<td>21.5</td>
<td>38.0</td>
<td>31.10.2012</td>
</tr>
<tr>
<td>Solar PV</td>
<td>20T Solar</td>
<td>223.0</td>
<td>20.0</td>
<td>21.4</td>
<td>37.0</td>
<td>31.10.2012</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Tacna Solar 20T</td>
<td>225.0</td>
<td>20.0</td>
<td>26.9</td>
<td>47.0</td>
<td>31.10.2012</td>
</tr>
<tr>
<td>Second Auction (2011)**</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind</td>
<td>Tres Hermanas</td>
<td>69.0</td>
<td>90.0</td>
<td>52.0</td>
<td>415.0</td>
<td>In construction***</td>
</tr>
<tr>
<td>Solar PV</td>
<td>Moquegua FV</td>
<td>119.9</td>
<td>16.0</td>
<td>30.5</td>
<td>43.0</td>
<td>31.12.2014</td>
</tr>
</tbody>
</table>

Source: Adapted from OSINERGMIN (2014)
* The price ceilings for wind and solar PV were 110.0 and 269.0 USD/MWh respectively. ** The price ceilings were not disclose. ***Expected for 31.12.2015.

The third auction process (2013) was according to the Peruvian government and IRENA, even a bigger success than the two previous auctions. It resulted in the award of 16 hydropower projects with a total energy supply of 1278 GWh/year (IRENA, 2014).

### 2.4. The Way Forward?

Although official documents show encouraging numbers, they fail to provide scenarios in where the availability of natural gas could be threatening for the country’s energy supply. The National Energy Plan 2014-2025 was prepared under very optimistic assumptions, namely: (i) economy will grow at an average rate between 4.5% and 6.5% a year; (ii) energy prices will follow the trends of world prices, with the exception of gas; (iii) resource availability based on the current existence of production reserves (natural gas, hydro, and non conventional renewables) (Ministry of Energy and Mines, 2014). This fact leaves the future energy supply under a veil of uncertainty. The Peruvian government also acknowledges its dependency on fossil fuels and it is aware of the fact that this dependency will continue. But then again, the government does not provide a ‘back up’ plan for a scenario without the availability of cheap natural gas for electricity production. If the country does not increase further its efforts to create a competitive market for non-conventional energy sources, in the future the country could go back to its state of dependency on oil imports. This, in a long term scenario, could pressure Peru’s energy security, and thus its economic stability.

The Peruvian government has scheduled a fourth auction process for August 2015, which it is expected to grant 1300GWh/year, a bigger and more ambitious capacity than the ones granted in the last three previous auctions. This is indeed a promising step towards a more transparent and efficient procurement of renewable energy. Peru has taken important steps to foster renewable energy auctions, and according to IRENA, it is currently one of the leading countries that have developed and held successful auctions. Nonetheless, there are still a myriad of opportunities to further enhance and provide a secure energy mix.
3. Literature Review - Experience Curves for Energy Technologies

Technology learning is one of the main drivers behind the development of energy technologies available in different energy systems and as a consequence is also a key driver for the reduction of production costs (Junginger et al, 2008). Conventional power technologies in use today have already been continuously enhanced over the years, in both technology and cost efficiency. As opposed to many renewable/clean fossil fuel energy technologies and energy saving technologies which have remain with higher production costs. Junginger et al, state that as some of these technologies are still novel, “their technological development and resulting cost reduction occur at relatively high speeds compared to the conventional technologies”. In recent times, one of the approaches to analyse, both past and future energy production cost reduction is the experience curve approach (Junginger et al, 2008).

3.1. Definition of Experience Curves

In 1968, the Boston Consulting Group, after performing a cost analysis for a major semiconductor manufacturer, stated that the company’s production cost per unit would fall by an expected amount for each doubling of “experience” or accumulated production volume. According to BCG, in real terms, one should expect to have a 20 to 30 percent of cost reductions. These results had evident implications for businesses. For instance, not only one’s own costs could be projected, but, given market’s information, competitors’ cost are also susceptible to be estimated. (Henderson, 1968).

Nonetheless, BCG also noted that reductions in costs do not necessarily occurred automatically with the increase of the volume produced. The reductions, as expected, were also related to “competent management”, when seeking ways to manoeuvre costs downs as their production volume expands. Hence, production costs are most likely to be reduced under internal pressure. However, Henderson mentioned as well that these costs “variances” shown in experiences curves are probably better interpreted in changes on cash flows. Thus, costs shall include every kind of cost required to deliver the product to the final user, from intangibles to R&D, sales expense, advertising and so on (Henderson, 1968).

As the author stated, “any failure of the producer to relate any one of these cost elements properly to the other will have a degrading effect on the cost performance in serving the end user”, implying that anyone who fails to achieve the “optimum combination of all cost elements compared to his competitors’ combination” is susceptible to be eliminated from the market. In BCG’s view, this is the main reason of why the experience curve works and what differentiates it from the learning curve⁹. On the same note, Henderson states that another important factor to interpret experience curves is the product’s growth rate. Whereas the production of said product does not grow, the rate of cost decrease progressively decelerates and approaches zero (Henderson, 1968).

Although, vast literature about experience curves is available, some authors use experience and learning curves indistinctly. For instance, McDonald & Schrattenholzen, define “learning curves” as as concept developed from the premise of “learning by doing”. The most common formulation states that a unit cost decreases by a constant percentage for each doubling of experience, the authors called this ‘constant’ the ‘learning rate’. The rationale behind this, is quite similar to the one used by Henderson, since experience accumulates with time, thus unit costs for a given technology decreases with time. On the other hand, if the technology is left unused, it can cause loses in the experience, hence costs per unit could rise (“forgetting by not

⁹The learning curve as an economic concept was introduced in the late 1930’s by Theodore Paul Wright. It analyses the cost reductions related to labor and production (man-hours per unit).
doing”). Bottom line, the more a technology is used, the biggest the incentive to deploy it more. (McDonald & Schrattenholzen, 2001).

Considering that it is common understanding that a distinct attribute of an experience curve is the constant percentage of costs’ reductions with each doubling of the total production units, predominantly, the experience curve is expressed using the following equation (Neij, 1999):

\[ C_{\text{CUM}} = C_0 \cdot \text{CUM}^b \]

Where:

- \( C_{\text{CUM}} \) = Cost per unit - function of output
- \( C_0 \) = Cost of the first unit produced.
- \( \text{CUM} \) = Cumulative production over time
- \( b \) = Experience index\(^{10}\).

According to Neij, the concept of experience “should not be regarded as an established method or theory, but rather as correlation phenomenon, which has been observed for several technologies”. This probably responds to the fact that experience curves are based on a large range of parameters which might fluctuate in a short period of time. Hence, it is only after many doublings of production that a pattern can be identified (Neij, 1999).

On the same line, Neij states that the cost reduction for a technology is a function of the cumulative production of said technology, which will rely on market demand. Since market demand will depend on the cost and performance of the technology in comparison to mature technologies, in the long term, cost reductions will be limited by “physical limits in technology development, cost limits and market potential”. Whereas, in the short and medium term, cost reductions will be limited by existing market barriers and “the rate at which manufacturers are able to reduce costs through additional production” (Neij, 1999).

Nonetheless, it is worth noting that research has shown that cumulative production may not only lead to a cost reduction, but in some cases it may lead to an increase on the costs. This situation can be encountered when, for instance, the “total cost cannot be reduced (by product standardisation, process specialisation, scale effects, labour rationalisation, etc.) as fast as costs trends of non-

\[ (1-2^b) \]

The value \( (2^b) \), known as the progress ratio (PR), which is used to show the cost reduction progression within different technologies, i.e., a PR of 80%, shows that costs were reduced by 20% with each doubling of the cumulative production (Neij et al, 2003).

\(^{10}\) According to Neij, “the experience index is used to calculate the relative cost reduction, \((1-2^b)\), for each doubling of the cumulative production”. The value \( (2^b) \), is known as the progress ratio (PR), which is used to show the cost reduction progression within different technologies, i.e. a PR of 80%, shows that costs were reduced by 20% with each doubling of the cumulative production (Neij et al, 2003).
standardised products”. Thus, as Neij points out, experience per se does not cause cost reductions, but it rather gives opportunities for cost reductions.

Although, in theory the experience curve is drawn as a straight line on a log-log scale (see Fig. 1), it has been observed that some experience curves show “discontinuities, or a distinct break”. According to Neij, these break downs may be shown as a result of major technological changes (radical improvements), which could lead to believe it is necessary to use two different experience curves. However, Neij states that the distinction within these discontinuities is “subtle and often somewhat arbitrary” (Neij, 1999).

Moreover, Neij also points out that, despite the fact that historical trends in cost reductions represented by experience curves have been, and are still used, to analyse future cost reductions; an study based on experience curves “must also be complemented by an analysis of the underlying technology development and market forces causing and limiting cost reductions” (Neij, 1999). However, for the purposes of this study (see Chapter 4 - Power Cost Projection Model), an assessment of available experience curves are taken as an analytical framework to explore the possibilities of cost development of energy technologies for electricity generation (Neij, 2008).

3.2. Experience Curves for Energy Technologies

From the late 1960's onwards, experience curves have come to be used in a more widespread way than learning curves, especially when it comes to the analysis of future energy costs and the eventual introduction and commercialisation of new energy technologies. This responds to nature of the analysis used by experience curves, which refers to reductions on the total costs (labour, capital, administrative), sources of costs reductions related to changes in production (incremental innovations, scaling effects) product changes (redesign & standardisation) and changes in input prices (Neij, 1997; Neij, 1999, Jamasb, 2007).

As stated by Neij, in order to show cost reductions in energy technologies by using experience curves, there is a need for an initial market, i.e. new technologies that would provide opportunities by “learning by doing” and “learning by using”. Whether these markets are deployed “through early adopters, niche markets, or governmental policy measures”, it is expected that after some time, new energy technologies with “a high initial cost may be competitive with already established technologies” (Neij, 2008). Neij also argues that the use of experience curves for cost analysis of non-standardised products manufactured, both, globally and locally, could lead to uncertainties and variation on the results, especially if they are used to forecast long term projections (Neij et al. 2006).

Although, as pointed out by Neij using experience curves analysis “is only suitable under conditions of low uncertainty and for series of incremental innovations” (Neij et al. 2006), it is noteworthy to appoint the observations made by Jamasb, regarding how experience curves are “context-dependent and driven by model specification, variables used, and aggregation level”. Experience curves can also vary due to the timeframe in which they were measured and their different technical characteristics. Thus, there is not an unique experience curve for a given technology; and, moreover there is a significant variation within empirical experience curves estimates per energy technology (McDonald and Schrattenhoizer, 2001; Jamasb 2007).

An important contrast is noted by Neij, when analysing experience curves for conventional technologies (mostly characterised by large facilities) and renewable energy technologies (smaller scale and modular). Due to their technical characteristics, conventional technologies “require extensive construction in the field”, whereas renewable energy technologies are more likely to offer the opportunity “for factory-based automatic production, and much less site construction”. Renewable technologies are thus comparable to mass-production technologies, and consequently, experience curves for conventional technology plants have presented a cost
increase over the years; as opposed to renewable technologies, which “have shown a more progressive trend”. As presented by Neij, this evidences greater possibilities for cost reductions for wind turbines and PV modules, than for conventional power plants (Neij, 1997).

The next sections of this chapter will present the experience curves studied in the literature for the following technologies: Onshore wind, solar photovoltaic (Solar PV), and combined cycle gas turbines (CCGT).

### 3.2.1. Onshore Wind

From the mid-1970's, significantly development has been carried out within wind energy systems. Historical trends show progress in wind technology as a “continuous chain of incremental improvements, based on a familiar design, rather than as radical shifts to new designs” (Neij, 1997). However, according to the literature review carried out by Azevedo et al., a myriad of studies, from early 1990’s to now have estimated a very large span of experience rates, almost between -3% and 35% (Azevedo et al., 2013). The literature consulted included some of the authors mentioned in previously in this study: McDonald & Schrattenholzer, 2001; Neij et al., 2003; Nemet, 2006; Junginger et al., 2008; Neij, 2008; Lindman & Söderholm, 2012. The majority of these studies focus mainly on Europe and North America, nonetheless their scope varies in several aspects, such as energy systems components, time frame & areas of study, just to mention a few.

For instance, Neij et al. divide the experience curves in types in accordance to “perspectives” and “systems approaches”. When referring to “perspectives”, the authors distinguished between “production” and “market”, where the first one describes the learning process supported on the manufacturers’ production, i.e. production of wind turbines by manufacturer; and, the latter takes “the market, or different countries as the basis for the experience process” (Neij et al., 2003). In the case of “systems approaches”, experience curves can be sorted per components of the wind power system i.e. wind turbines, installed wind turbines, etc. Thus, as explained by Neij et al., it is noteworthy to understand that “the learning system of wind power is an aggregated system of several individual learning systems”, which includes learning systems for: wind turbines, siting and wind capture and maintenance (Neij et al., 2003).

Moreover, Lindman & Söderholm found that choices of geographical boundaries on the systems studied, constitutes an important factor for experience curves in wind power. The authors also differentiate between global and local learning. They also observed that when the studies take a global approach the experience curves tend to be significantly higher, as opposed to the studies performed with more restricted geographical scope (national). This finding, as they state “is further complicated by the fact that technology learning in wind power (and presumably in other renewable energy technologies as well) is deemed to have both national and global components” (Lindman & Söderholm, 2012).

In terms of LCOE, Neij conducted a study of wind turbines in Denmark, based on the “specific electricity production of wind turbine in Denmark” (Neij et al., 2003). The study showed an experience curve of 17% (PR of 83%). Due to the nature of the study (LCOE based) these curves include, among others, the development costs of wind turbines, cost related to installations and O&M costs (Neij, 2008). Thus, as Neij et al. appoint this result “indicates that the greater the number of sources of experience (learning) included in the experience curve, the larger the cost reduction” (Neij et al. 2003).

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11 For more details on LCOE, see Chapter 4 of this study.
3.2.2. Solar Photovoltaic (PV)

Solar PV is considered by many the fastest growing energy technology by far (REN21, 2014; Nemet, 2006). According to the REN21, Solar PV has accomplished a 53-fold increase on its global capacity from 2004 to 2013 (REN21, 2014). PV modules, depending on the type of solar cells, can be classified in two categories: (i) single or multi-crystalline (wafer-type); and, (ii) thin film12 (van der Zwaan & Rabl, 2004; Azevedo, 2013). As stated by Azevedo et al., currently “wafer type technologies still achieve higher efficiencies (12%-15%), than thin film (6%-11%), but there is a consensus that thin film technologies offer the best long term perspective for low production costs” (Azevedo et al. 2013). PV system CAPEX costs include both, the cost of the modules and costs for the balance of system (BOS). BOS costs include all the other system components different than the modules, which, among others, include electrical installation, inverters, support structure, land acquisition, and so on (van der Zwaan & Rabl, 2004; Neij, 2008). According to Azevedo et al. and Nemet, the BOS could double the overall cost of the PV system.

As presented by Neij, from the analysis of several literature studies, PV systems show a range of experience curves that go from 10% to 47%. According to the author, the differences may respond to the scope of the analysis (types of technologies, time periods and geographical areas). However, most studies state a 20% to 10% experience rate for PV modules (van der Zwaan and Rabl, 2002; Schaeffer et al., 2004; REN21, 2014). In the case of BOS, Schaeffer et al. argue that experience and prices are determined by the local market, as opposed to PV modules which respond to global developing. BOS will thus develop a different learning rate and it will vary among different geographical locations (Schaeffer et al., 2004).

Regarding the results presented by Schaeffer et al., Neij stated that, apart from experience curves, the most important sources of cost reductions for the PV systems referred in this study are associated with: the cost of silicon - 8%, increase in plant’s efficiency - 14% to 17% and the scale of plants - 25% (Nemet, 2006; Neij, 2008). Although, as stated above, BOS rates might differ from country to country, Neij points out that studies show an approximately 20% learning rate, for both PV modules and BOS systems (Neij, 2008).

3.2.3. Combined Cycle Gas Turbine - CCGT

It was on the 1940s, that natural gas started being used for power generation; however, it was not until the 1970s, when the first gas combined cycle plants were built. Due to the oil embargo in the 1970s, the construction of natural gas-fired power plants did not develop (Azevedo et al., 2013). As appointed by Azevedo et al. natural gas-fired power plants finally developed during “the late 1990s and early 2000s when gas prices were low and efficient combined cycle power plant costs fell” (Azevedo et al. 2013).

Combined Cycle Gas Turbine are known as advance fossil-fuel technologies, and although the introduction of such technology will increase the installation costs of the power plant, according to Neij, these costs may decrease over time (Neij, 2008). Whereas there is vast literature regarding experience curves for renewable technologies, studies on experience curves for CCGT plants are much limited. Based on a study perform by Claeson (2000), Neij states that according to prices of CCGTs during the 1990s, an experience curve indicating a 25% learning rate can be drawn (Neij, 2008). Although, natural gas prices have a bigger impact on future electricity production costs, than investment costs and the use of specific experience curves13; Neij et al. suggest an experience curve of 10% for the future cost projections (Neij

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12 Although, PV technologies can also be categorised according to their applications (central station PV and rooftop), this study will only focus on wafer type - central station PV technologies.

13 The authors also identified the improvement of thermal efficiency as an issue of great relevance for future cost reductions in CCGT plants (Neij et al. 2006).
3.3. Global vs Local Learning - “Recommended” Experience Curves

Most authors agree on the lack of exactness of experience curves, and rather recommend to take them as “best guesses” (Neij, 2008); and, as stated by Wene, “whenever experience curves are used for benchmarking, for predictions or for scenario analysis it is obviously very important to use cumulative global outputs if the learning is global and regional cumulative outputs if the learning is regional” (Wene, 2000).

Even though, energy technologies show different development paths as a response to a variety of factors, such as geographical location, economic development and so on; as pointed out by Dittmar, “international interactions and cooperation play an important role in the context of technological learning. This holds especially true if there global markets and import and export activities are of relevance. Global competition promotes global information and learning-by-doing, that is, production is local but learning is global” (Dittmar, 2006). To illustrate this statement, one can refer to the study conducted by Neij et al. (2003), which shows that, over time, wind power learning has developed into an international system.

A similar phenomenon can be identified for Solar PV. When analysing Wene’s study (2000), Dittmar observed that a global experience curve for Solar PV, between 1982 and 1997, showed a learning rate of 18%, when measuring performance (US$/kWp) and cumulative sales (MW). Whilst, for an European experience curve the learning rate was 35%, based on the same factors: performance (€/kWh) and cumulative electricity production (TWh).

Evidently, the european curve appears to be steeper than the global rate; however, to explain this, Wene states the following: “One explanation is the change in PV applications in the period 1985-1995 from remote systems to grid-connected systems, which have substantially reduced cost for Balance of System (BOS), exaggerating the experience effect. Another explanation is that the EU was a late starter in 1980 compared with the US and Japan, and could rely on importing experience on PV during the 1980s. The latter explanation illustrates the distinction between global and regional experience curves. Both explanations indicate that the high rate of learning cannot be maintained, and that future progress ratios for electricity from PV in EU will depend on the global progress ratio for PV modules.” (Wene, 2000).

Nonetheless, as explained before, it is important to bear in mind that technologies usually comprise many subsystems. For instance, in the case of Solar PV systems, there are two learning processes, one for PV modules and one for BOS, and although PV modules respond to global learning processes, BOS is bound to local conditions (Junginger et al., 2008). Hence, as a whole system, the European experience represents both, global and local learning processes (Dittmar, 2006).

Although, experience curve analysis is complex, for the purposes of this study, it is necessary to provide with recommended rates for every technology. The rates will be taken from the study conducted by Neij (2008) and are summarised in the following table:
Table 3-1: Suggested learning rates per energy technology

<table>
<thead>
<tr>
<th>Energy Technology</th>
<th>Learning Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore wind generated electricity</td>
<td>17%</td>
</tr>
<tr>
<td>Solar PV generated electricity</td>
<td>20%</td>
</tr>
<tr>
<td>Advance fossil fuel - CCGT</td>
<td>10%</td>
</tr>
</tbody>
</table>


These rates will be later used as inputs for the Cost Projection Model, in order to project the LCOE per energy technology.
4. Power Cost Projection Model

“Essentially, all models are wrong, but some are useful.”

4.1. Energy Models - General Aspects

Models have a long history of development and nowadays energy models have become standard instruments in energy planning, management and forecasting. Energy models have evolved greatly and now a myriad of models are available. Although, it is difficult task to single out all types of models, Jeebaraj & Iniyan (2006) on their study attempted to provide an empirical classification of energy models. One of these categories corresponded to “Forecasting models”, which they briefly defines as models that have been structured using variables such as population, income, price, growth factors and technology. On the same note, Dittmar states that an energy model classification cannot be exact, due to the existence of “hybrid” kind of models (Dittmar, 2006).

However, Dittmar refers to the available literature on energy modelling and argues that a basic attempt to classify models could broadly divide energy models depending on the approach these use: top down or bottom up. The author points out that a top down approach model use a “macroeconomic view on the entire economy either on regional, national or international scope”. This model represents a holistic view of the economy and how the energy sector, as part of the economy, interact in it. Hence, the level of detail of the energy system within the model is rather “rudimentary” (Dittmar, 2006).

As opposed to top down models, bottom up models are usually provide a comprehensive overview on the energy system. This model shows the technological characteristics of the system in detail. According to Dittmar (2006), the model “typically follow ‘process-engineering’ or ‘engineering-economic’ approaches, i.e. available technologies and forecast technologies of energy systems are explicitly considered with respect to their techno-economic parameters”. Moreover, bottom up models can apply simulation techniques, which explore eventual “future developments of energy systems determined by means of extrapolation methods” (Dittmar, 2006).

As mentioned before, it is difficult to state a certain classification of energy models, and as models get more and more sophisticated, the same happens with the differences between one model and another. In the case of the top down - bottom up models some differences have vanished, and recently designed “hybrid” models include elements of both approaches. However, Dittmar identified the most important remaining differences between both approaches, and these can be found in the table below:

<table>
<thead>
<tr>
<th>Table 4 -1: Differences between top down and bottom up models.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Top down</strong></td>
</tr>
<tr>
<td>“Economic approach”</td>
</tr>
<tr>
<td>Focus on the entire economy</td>
</tr>
<tr>
<td>Represent economy-wide feedback effects</td>
</tr>
<tr>
<td>Cannot explicitly represent technologies</td>
</tr>
<tr>
<td>Capture available technologies adopted by the market in production functions</td>
</tr>
<tr>
<td>Capturing observed market behaviour</td>
</tr>
</tbody>
</table>

*Source: Adapted from Dittmar, 2006.*
4.2. Statkraft’s Power Cost Projection Model - Theoretical Foundations

The Power Cost Projection Model was designed by Statkraft to identify cost evolution for each of the selected technologies in this study, namely: onshore wind, solar PV and CCGT. In order to fulfil the objective and answer the research questions of this study, the model was developed under two economic premises:

(i) Wene (2000) states that price is perhaps the most important measure of performance for new energy technologies. Nonetheless, cost of power generation technologies varies not only from technology to technology, but also from one geographical location to another; and,

(ii) Young technologies learn faster from market experience than old technologies with the same learning rates (Wene, 2000). Hence, integration of learning rates into energy models is an important factor to analyse technology change and scenario planning (Neij, 2008).

The first premise sets a very straightforward, yet complex question: why does technology costs vary across countries? To answer that, the model uses the Levelised Cost of Energy (LCOE) as an indicator. For instance, LCOE for wind power varies, sometimes dramatically, from country to country, although, 63% of the CAPEX from wind onshore projects is allocated to the turbines. According to Statkraft, these technologies show different costs across markets. Also, these differences might be driven largely due to local labour costs and local Non-tradable goods and services (NTs) costs.

The second premise, referring to learning rates from experience curves for the technologies under this study were addressed in the previous chapter. Hence, the next subsections of this chapter aim to give a brief look at the main characters and components of the LCOE, and the theory of NTs, to better understand the dynamics of the model.

4.2.1. Levelised Cost of Energy - LCOE

In general terms the LCOE can be defined as the cost incurred to generate one unit of electricity and is typically expressed in unit currency/kWh (the currency used is US Dollars and the costs will be expressed in USD/kWh or USD/kW as is applicable). Perhaps one of the main perks of LCOE indicators is its capability to show a cost comparison between different technologies. Moreover, when it is used as an indicator in forecasting models, LCOE can show the development of the energy system and the price of electricity in a certain market (WEC, 2013).

Figure 4-1: Global LCOE from April-June 2013 (USD/MWh)
Branker et al. (2011) argue that the LCOE methodology, as an “abstraction from reality”, aims to remove biases between the technologies being analysed. They also define LCOE as a benchmarking tool for assessing energy technologies and their cost-effectiveness. For that, the it considers “the lifetime generated energy and costs to estimate a price per unit energy generated” (Branker et al. 2011). One of the key components of LCOE is the cost of finance, which tends to vary by location and technology (WEC, 2013). Although, technologies such as onshore wind and solar PV are widely taken as “low risk” and might get “more favourable financing terms” (WEC, 2013), due to their “capital intensive nature”, the weighted average cost of capital (WACC), selected to evaluate any particular project, has an important effect on the LCOE (IRENA, 2012).

Figure 4-2: LCOE ("common") Formula. Source: Adapted from IRENA, 2012.

\[
LCOE = \frac{\sum_{t=1}^{n} \left( I_t + M_t + F_t + E_t + D_t \right)}{\sum_{t=1}^{n} \left( 1 + r \right)^t}
\]

Where:

- \( I_t \) = Investment costs (CAPEX) in the year \( t \)
- \( M_t \) = Operations and maintenance costs (OPEX) in the year \( t \)
- \( F_t \) = Fuel costs in the year \( t \)
- \( E_t \) = Emissions cost in the year \( t \)
- \( D_t \) = Decommissioning costs in the year \( t \). Often defined as zero
- \( G_t \) = Generation in the year \( t \)
- \( r \) = Discount rate (e.g. WACC)
- \( n \) = Economic lifetime for the system/plant (construction time plus commissioning and decommissioning time)

As stated by IRENA (2012), when developing a model with an LCOE approach, many possible trade-offs need to be considered. However, the approach taken in the model developed by Statkraft is rather simple, bearing in mind that the model has to be applied to different technologies and different countries. As for the LCOE components used in the model, the definitions given by Statkraft are presented in the following box:

**Box 4-1: Components of the LCOE - Statkraft’s Power Cost Projection Model**

**Capital Cost (CAPEX):** The total investment required to build a project. The model refers to this as the “Total Project Cost” (TPC) and for this study, TPC splits intro three components as below:

- **Overnight Construction Cost:** The cost incurred if the entire project was built overnight. It includes, cost of the equipment and materials, labour, EPC services, Balance of Plant (BOP) and contingencies. The discounted cash flow methodology, for plants that take more than one year to construct, will followed.

- **Owner’s Cost:** Represents all costs borne by the owner to make the plant functional. These can vary broadly but typical cost headers would be costs associated with royalties, fees, licences, field study, cost of inventory, property taxes, property development (e.g. developing housing quarters for employees of the plant) etc. Owner’s cost are also expressed in USD/MW.

- **Financing Costs:** Costs incurred as a function of the capital employed in the project. Typically these include, Interest During Construction (IDC) and other costs escalations (e.g. inflation).
As mentioned before, the LCOE methodology offers comparisons not only across technologies, but also across different regions. One of the key contributors for the variations observed in the LCOEs across/within countries are NTs. The next subsection will explain the nature of NTs and their integration into the model.

4.2.2. Non Tradable Items - NTs

Non-tradable items are often defined as those goods and services which are produced and consumed within a domestic market, thus these items are not subject to international competition. Items, such as land, construction services, utilities, labour, etc. are commonly considered as NTs. These items are a core component of CAPEX and OPEX in energy projects. Since the price of NTs are given by local market equilibrium, the cost of these items have significant variations from country to country. In order to show this, the following table has the price index for the major NT services in different countries (Gupta, 2015).

---

**Operation and Maintenance Cost (OPEX):** The OPEX is the cost required to keep the plant up and running. Typically, the numbers quoted as OPEX cost are annual, i.e. the total O&M cost incurred in the year. OPEX costs change every year due to changes in costs of materials, labour etc. and would typically be expressed with an associated escalation rate. It has two components described below:

- **Fixed OPEX cost (FOM):** This is the fixed cost that is incurred each year. This includes salaries and wages and other fixed components and is expressed in USD/MW.

- **Variable OPEX cost (VOM):** This is the variable cost component and is expressed in USD/MW/h.

**Fuel Costs:** Fuel costs are the amount of fuel required to generate one unit of electricity and and expressed in USD/MWh. Fuel costs should also include cost of transportation of the fuel. These costs are a function of the energy content or the Net Calorific Value (NCV) of the fuel as well as the plant efficiency. The higher the NCV and higher the efficiency, the lesser fuel is required to produce one unit of electricity. Fuel costs also change each year.

Table 4-2: Major NTs (energy sector) in Different Economies - Global Price Level Comparison

<table>
<thead>
<tr>
<th>Economy</th>
<th>Housing, water, electricity, gas and other fuels</th>
<th>Transport</th>
<th>Communication</th>
<th>Miscellaneous goods and services</th>
<th>Machinery and equipment</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>56.1</td>
<td>65.5</td>
<td>50.9</td>
<td>73.6</td>
<td>102.8</td>
<td>68.9</td>
</tr>
<tr>
<td>India</td>
<td>29.8</td>
<td>56.4</td>
<td>32.0</td>
<td>46.6</td>
<td>88.2</td>
<td>41.9</td>
</tr>
<tr>
<td>Norway</td>
<td>210.0</td>
<td>215.2</td>
<td>132.2</td>
<td>214.4</td>
<td>132.8</td>
<td>296.5</td>
</tr>
<tr>
<td>Brazil</td>
<td>118.0</td>
<td>133.0</td>
<td>239.7</td>
<td>96.6</td>
<td>144.3</td>
<td>88.0</td>
</tr>
<tr>
<td>Peru</td>
<td>51.4</td>
<td>68.5</td>
<td>106.8</td>
<td>49.3</td>
<td>123.5</td>
<td>84.0</td>
</tr>
<tr>
<td>United States</td>
<td>136.7</td>
<td>91.6</td>
<td>137.6</td>
<td>107.5</td>
<td>85.5</td>
<td>203.9</td>
</tr>
</tbody>
</table>

Source: Adapted from Gupta, 2015

As seen in the in the table, the variations across countries are considerable and price levels are much lower for emerging economies (India and Peru for instance), which influences directly in the LCOE variations. Hence, in order to perform the cost projections up to 2035, the model needs to use the price development of NTs from 2015 to 2035. This is undoubtedly a major challenge for the model. However, in order to define a suitable indicator to follow NTs price developments, Gupta (2015), as part of the overarching project lead by Statkraft, conducted a study on the on the theoretical foundations on NTs and analysed the drivers behind price developments across countries. Gupta’s findings are presented hereunder:

- The fact that NTs are not exposed to international competition responds to their nature, as they are to trade/transport between one place to the other. As opposed to commodities (i.e. oil, coal, chemicals, etc) utilities, construction services, education services, etc. can not be traded/transported. Hence, the price of NTs is set by local market equilibrium, whereas the price of tradable items responds to international supply, demand equilibrium and is subject to Purchasing Power Parity (PPP) principles. Nonetheless, it is challenging to divide tradable and NT items, as most traded items have NTs components.

- The Big Mac index developed by The Economist, shows how ‘identical internationally traded items’ (beef, lettuce, onions, etc.), which prices are set by PPP principles, have notorious variations in their market price compared to their PPP level, due to NTs. To sell a Big Mac it is necessary to procure NTs services (leasing space, utilities, etc.), and the prices for them (determined locally) are higher in high income countries. When extrapolating this situation into a more intensive capital sector like energy, the impact becomes critical.

- The Balassa- Samuelson effect states that prices of NTs cause variations from PPP because of differences in productivity across countries and sectors. According to this, the differences in productivity across sectors influences directly on the increase of relative

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14 As stated by Gupta, consumer price index (CPI) and whole price index (WPI) are commonly use, but they are not recommended for this study, since they represent a combination of both NT and tradable items.

15 “Purchasing power parites calculated as a ratio of consumer goods prices for any pair of countries would tend to approximate the equilibrium rates of exchange (...) when equilibrium rates prevailed, changes in relative prices would indicate the necessary adjustments in exchange rates” Balassa, 1964. *The Purchasing-Power parity doctrine: a reappraisal.*

16 In 1964, both Balassa and Samuelson (separately) proposed similar theories regarding the effects of NTs on PPP. For more details, see: Balassa (1964): *The Purchasing-Power parity doctrine: a reappraisal.* and Samuelson (1964): *Theoretical notes on trade problems.*
prices for NTs “(vis-à-vis tradable) as the productivity of tradable sector increases”. These assumptions are made under the premise that NTs productivity is similar across countries and shows minimal variations over time, as opposed to the productivity of tradable sectors, which varies significantly from high income to low income countries. Since both sectors, traded and NTs, compete in the same labour market, if the productivity of the trade sector increases, so do wages levels, which causes inflation in the prices of NTs, as its productivity level remains constant. As a consequence, this inflates the overall price index (CPI or WPI) of the country.

As presented by Gupta (2015), the Balassa-Samuelson effect is the initial point to set a theory for the relationship between NTs productivity levels and real exchange rate (RER) for a low income country in relation to a high income country. In theory, this effect attributes the difference in income levels between countries to the differences in productivity across them. If so, variations in RERs can be associated to variations in NTs prices and the productivity level of a country.

Although many research works have been conducted, both in favour and against the relationship between variations in NTs and RER, after his literature review (Engel, 1997; Engel, 1999; Betts & Kehoe, 2008; Kakkar & Ogaki, 1999), and corroborating the high correlation between prices of NTs and RERs, Gupta concludes with the following statement:

“(…) there is high level of correlation between relative prices of NTs and RERs. Further, the countries in focus viz. Brazil, Chile, China, India, Peru and Turkey are developing countries witnessing rapid growth in productivity of their tradable sectors; therefore, it is more likely that the Balassa-Samuelson effect would be more effective; and; relative prices of NTs would exhibit strong relationship with RERs for the currencies of these countries relative to USD (United States is a high income developed country therefore must have different trajectory of relative prices of NTs as compared to these 6 nations), respectively (…). Lastly, based on Kakkar and Ogaki’s (1999) analysis that there exist a co-movement between relative prices of NTs and RERs in the long run, we can construe that if we can project RERs (relative to US) to 2035 for 6 focus countries, the development trends of RERs will be close enough to any other method used for forecasting price development trends of NTs for these 6 emerging markets up to 2035.” (Gupta, 2015).

Nonetheless, it is important to bear in mind that other supply and demand factors, such as fiscal stimulus, shift in consumer preference with higher income level, and other country specific and global macroeconomic events, namely, trade liberalisation, global supply shocks, nominal exchange rate movements are also key contributors in the relative price movement of NTs. Although, the Balassa-Samuelson effect assumes markets (including capital and labor) are perfectly competitive and mobile. In real terms, markets are not always perfectly competitive.

De Gregorio et al. (1993), as cited by Gupta (2015), on their study regarding the contribution of productivity differences on NTs prices, found that faster growth in total factor productivity of tradable sector as a key contributor of high inflation in NTs. Moreover, the study encountered a simultaneous increase in the price of NTs and increase in share of NTs for 8 out of the 14 OECD countries assessed. According to Gupta, this suggests a significant role of both, supply side and demand side factors, such as government spending.

17 Gupta refers particularly to the findings of Kakkar & Ogaki (1999) and Bette & Kehoe (2008). Both studies analysed the co-movement between prices of NTs and RERs and found strong evidence of this relationship. Kakkar & Ogaki, studied the relationship between USA, Italy and UK - using CPI and GDP deflators to construct RERs- and the relationship between USA, UK, Japan and Canada - using consumptions deflators to construct RERs and ratios of implicit deflator of service consumption to non-service consumption. For both methods, they found that on the long term scenario, the relationship between RERs and NTs co-movements exists. On the same note, Bette & Kehoe analysed the same relationship for 1225 country pairs from 1980 to 2005 and found that variations in NTs prices contribute with almost 1/3rd to variations in RERs.

24
Based on the assessment of other studies linking prices of NTs to capital intensiveness of the sectors, and also linking RER and relative price movement of NTs to terms of trade, Gupta concludes that “besides productivity differential other supply and demand side factors do influence the relative price movement of NT goods and in turn real exchange rates. However, the extent of these depend on number of factors viz: level of price administration of non-tradable items economy openness and trade liberalisation, terms of trade, nature of government spending, market exchange rate management” (Gupta, 2015).

Having addressed the macroeconomics behind the model, the next chapter provides the “mechanical” dynamics of the model. It attempts to show how the calculations and interactions inside the model were done and presents the results for Peru.
5. The Model in a Nutshell - Model Dynamics & Results

After explaining the theoretical foundations of the Power Cost Projection Model, this chapter aims to provide with the “mechanics” of the model and the actual use of its indicators. As explained at the beginning of this study, the model seeks to offer two particular results: LCOE and TOC projections from 2015 to 2035. In order to do so, the formulas for the calculations of TOC and LCOE will be given. The last part of this chapter will present the results and a sensitivity analysis for Peru.

5.1. Calculations for TOC and LCOE

As previously stated TOC will be expressed in US$/MW and among its components includes, EPC (engineering, procurement, construction) costs, land acquisition, mechanical and electrical equipments, labour and permits that are necessary for building a power plant. This constitutes, as explained in the previous chapter, a combination of NTs and traded goods. The formula to obtain the TOC in the model is presented below:

\[
\text{TOC} = [\text{TOC}_g \times \text{GLR}_{\text{cum}} \times \text{Global PPP Scaling Factor}] + [\text{TOC}_l \times \text{LLR}_{\text{cum}} \times \text{Local PPP Scaling Factor}]
\]

Where:
- \(\text{TOC}_g\) = the global TOC component.
- \(\text{TOC}_l\) = the local TOC component.
- \(\text{GLR}_{\text{cum}}\) = the global cumulative learning rate.
- \(\text{LLR}_{\text{cum}}\) = the local cumulative learning rate.
- Scaling factors = the PPP/RER values on the global and local basis that integrates the price increase followed by the Balassa-Samuelsson effect.

When doing this calculation, there are two major factors to take into account: the global and local learning rate. Although, some literature distinguishes learning rates between local and global, and also offer different PR for each one (so does the model), from the literature review conducted in this study, the author has concluded that there is evidence that learning is global\(^{18}\). For the case of the Peruvian market, the model used the learning rates recommended by Neij (2008) and that are presented in Table 3-1 of Chapter 3. Thus, in the model the same learning rate (global) is used for both inputs (local & global learning rate).

For the case of the goods and services acquired for the project, the TOC differentiates them between “global and local components”. As stated in the previous chapter, different prices are shown across countries due to the variations on NTs prices. The local component is given by the sum of all the NTs, namely, labour, utilities, land acquisition, permits, etc. The global component are all the other goods traded in the the international market (usually turbines and panels).

To calculate the effect of learning rates; the suggested learning rates per technology were multiplied by the global and local cost components. Later it is necessary to adjust prices for the future projections, which it is done by scaling PPP to RER, based on the macroeconomic presented in the previous chapter. As a result of this, it cannot be assure that that costs will always be reduced overtime, if the price adjustments surpass the learning effect then the cost might increase overtime.

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\(^{18}\) See Section 3.1. of Chapter 3.
Although, the LCOE comes as a different indicator in the model, it is connected to the TOC as both indicators share components for their calculations. The LCOE is expressed in US$/MWh and its formula is described below:

\[
\text{LCOE} = \sum_{k=1}^{N} \left[ \frac{I(k) + FOM(k) + VOM(k) + FC}{N \cdot \text{yr}} \right]
\]

Where:
- \(I_k\) (US$/MWh) = the construction cost (TOC * IDC) divided to total generation in a year and spread over the economic lifetime of the power plant.
- \(FOM_k\) ($/MWh) = the discounted fixed OPEX which is then divided to discounted annual generation.
- \(VOM\) ($/MWh) = the variable OPEX scaled by PPP/RER.
- \(FC\) ($/MWh) = the fuel costs which is extrapolated to 2015-2035 then divided to efficiency rate.
- \(N\) (yr) = the economic lifetime of the power plant.

For the LCOE calculation, the process is rather more complex than the one used by the TOC. In addition to the TOC component, the LCOE has to account fuel costs, variable OPEX and fixed OPEX. All of the components need to be projected to 2015-2035 by extrapolating them with WACC, scaling factor (PPP/RER), plant’s capacity factor and availability over the construction time of the power plant.

During the data collection period, components such capacity factor, availability, construction time and TOC were gathered and were ready to input into the model. WACC for the Peruvian case was sourced from Bloomberg and provided by Statkraft to the author.

5.2. Projections Results and Sensitivity Analysis

This subsection starts by presenting the data gathered during the first part of the project, which was used as inputs to the model. It will also explain what assumptions were made when data was not available or lacked consistency. The second part will introduce the projections results for TOC and LCOE, along with the sensitivity analysis.

5.2.1. Model Inputs: Benchmark Costs - Onshore Wind, Solar PV and CCGT

In order to get the CAPEX and OPEX costs for the assessed technologies, as stated in Chapter 1, data collection from primary and secondary sources was conducted. The model only allowed data from greenfield projects, which for the case of CCGT was challenging. Currently there is only one CCGT plant (‘built from scratch’) in operation in the country. The other CCGT plants currently in operation were converted from one cycle to combined cycle. These plants are outside of the scope of the study, due to the fact that their cost structure would no reflect all the contents needed for the TOC calculations. In the case of onshore wind and solar PV, all operating projects are greenfield projects. As stated before, the Peruvian market for these technologies is still quite small. Currently there are only five solar PV and three onshore wind plants in operation.

One of the main sources for CAPEX costs was the Peruvian Private Investment Promotion Agency - PROINVERSION. It is very common among private infrastructure investors to sign an agreement with the Peruvian Government through PROINVERSION in order to get tax
benefits during the construction of their projects. In order to access the benefit, a detailed investment schedule shall be submitted to PROINVERSION. This document is usually the cash flow for the project during its construction years. Although, this source may seem consistent, the author found that in some cases, when the data was contrasted with reports sent by the investors to the Peruvian Energy Agency - OSINERGMIN, the total project investment cost would not match. In those cases, benchmark costs from other regions were carefully discussed between the author and Statkraft, before being assumed as valid inputs to the model. Sources for global benchmark costs were: Bloomberg, IRENA, World Energy Council and the IEA. It is important to add that all the plants (regardless the technology) were commissioned between 2012 and 2014; and, only data from plants commissioned during 2014 was taken as inputs for the model.

In the case of OPEX costs, the task of data collection was rather more challenging. As it can be inferred, OPEX costs are not usually publicly displayed, due to their major importance for the competitiveness and efficiency of the projects. Hence, a similar process to the one conducted for CAPEX assumptions was carried out. For the case of CCGT, the Total OPEX cost was assumed to be a 3% of the OCC, from which 80% corresponds to the fixed OPEX and 20% to the variable OPEX. For onshore wind and solar PV, only fixed OPEX costs were assumed. Hence, for onshore wind the OPEX cost was assumed to be 2% of the total OCC (OCC plus Owner’s costs minus the IDC). Lastly, for solar PV, OPEX costs were sourced from the World Energy Council (see details Table 5-1).

Table 5-1: Model Inputs per Technology

<table>
<thead>
<tr>
<th>General</th>
<th>Technology</th>
<th>Onshore Wind</th>
<th>Solar PV (trackers)</th>
<th>Solar PV (no-trackers)</th>
<th>CCGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>WACC</td>
<td>7.6%</td>
<td>7.6%</td>
<td>7.6%</td>
<td>7.6%</td>
<td>7.6%</td>
</tr>
<tr>
<td>TOC (MUSD$/MW)</td>
<td>2.11*</td>
<td>2.42</td>
<td>2.08</td>
<td>1.49</td>
<td></td>
</tr>
<tr>
<td>Learning rate (%)</td>
<td>17%</td>
<td>20%</td>
<td>20%</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Global component (% of TOC)</td>
<td>85%</td>
<td>78%</td>
<td>28%</td>
<td>89%</td>
<td></td>
</tr>
<tr>
<td>Local component (% of TOC)</td>
<td>15%</td>
<td>22%</td>
<td>22%</td>
<td>11%</td>
<td></td>
</tr>
<tr>
<td>Fixed OPEX (k$/MW)</td>
<td>42.20</td>
<td>50.00**</td>
<td>20.00**</td>
<td>33.83</td>
<td></td>
</tr>
<tr>
<td>Variable OPEX (USD$/MWh)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.14</td>
<td></td>
</tr>
<tr>
<td>Unit size (net capacity - MW)</td>
<td>47*</td>
<td>16</td>
<td>16</td>
<td>534</td>
<td></td>
</tr>
<tr>
<td>Economic lifetime (years)</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>Fuel net efficiency (%)</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>55%</td>
<td></td>
</tr>
<tr>
<td>Capacity factor (%)</td>
<td>43%</td>
<td>29%</td>
<td>21%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Availability (%)</td>
<td>98%</td>
<td>99%</td>
<td>99%</td>
<td>85%</td>
<td></td>
</tr>
<tr>
<td>Construction time (years)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>


The agreement is known as “Recuperacion anticipada de IGV”, which aims to give back to the investor all the IVA paid to Government during the construction of their projects (PROINVERSION, 2014).

Among its competences, OSINERGMIN shall supervise the fulfillment of energy concession contracts between privates and the Peruvian government. When acquiring the IVA tax benefit, investment schedules become part of the concession contract (OSINERGMIN, 2015).

Variable OPEX costs are usually related to fuel efficiency and fuel prices. For renewables this costs equals zero.
5.2.2. Model Results and Sensitivity Analysis

This section presents the projections of the TOC and LCOE, and proceeds to answer the research questions stated at the beginning of this study.

- What will be the power generating technology costs for Peru in 2035? and What will the shape of the future energy system be and what technologies will make up the system?

As presented by the model, the TOC costs for Peru in 2035 are summarised in the following table:

Table 5-2: CAPEX & OPEX projections per technology until 2035

<table>
<thead>
<tr>
<th>General</th>
<th>Technology</th>
<th>Onshore Wind</th>
<th>Solar PV (trackers)</th>
<th>Solar PV (no-trackers)</th>
<th>CCGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>2035</td>
<td>2035</td>
<td>2035</td>
<td>2035</td>
<td>2035</td>
</tr>
<tr>
<td>CAPEX</td>
<td>TOC (MUSD$/MW)</td>
<td>1.09</td>
<td>1.25</td>
<td>1.08</td>
<td>1.40</td>
</tr>
<tr>
<td>OPEX</td>
<td>Fixed OPEX (k$/MW)</td>
<td>21.82</td>
<td>25.87</td>
<td>10.35</td>
<td>31.75</td>
</tr>
<tr>
<td></td>
<td>Variable OPEX (USD$/MWh)</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.37</td>
</tr>
</tbody>
</table>

If the results are compared to the inputs in Table 5-1, it can be observed that major variations occur with the costs of onshore wind and solar PV with no tracking systems. Right behind these results, the costs for Solar PV with tracking systems show good prospects as well. On the other hand, the costs for CCGT do not show noticeable variations. The differences between the significance of the variations across technologies responds mainly to the effects of learning rates. Although, globally onshore wind and solar PV are not considered “new technologies”, for the Peruvian energy market, the experience deploying these technologies on a utility level, is rather new. However, considering that in Peru, most of the cost components for these technologies are determined by the international market; and, as stated before, this study was done under the understanding that learning is global, it can be argued that these costs in theory follow the global trend of lower costs for onshore wind and solar PV. The same rationale can be applied for CCGT, which is considered as a mature technology (lower learning rates) and most its cost components are traded internationally.
Deep Dive into Peru’s Power Generation Technology Costs until 2035

For the case of LCOE, the results of the model can be observed in the following table and figure:

Table 5-3: LCOE projections per technology until 2035

<table>
<thead>
<tr>
<th>Technology</th>
<th>Onshore Wind</th>
<th>Solar PV(trackers)</th>
<th>Solar PV (no-trackers)</th>
<th>CCGT</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCOE - 2015</td>
<td>67.41</td>
<td>106.53</td>
<td>113.39</td>
<td>42.97</td>
</tr>
<tr>
<td>LCOE - 2035</td>
<td>35.85</td>
<td>55.12</td>
<td>58.68</td>
<td>70.73</td>
</tr>
</tbody>
</table>

Figure 5-2: LCOE projections per technology until 2035

On a first glance, the LCOE projections follow the trend started by the TOC projections. It can be observed that onshore wind has the most attractive LCOE deployment. Solar PV with and without trackers show an interesting trend as well; however, it appears that both technologies have “switch places” with respect to the TOC projections. Finally, CCGT presents itself as the most expensive technology in 2035, as opposed to its situation in 2015, where the model shows it as the cheapest. These results might respond to a number of reasons; however, in the author’s opinion, the main causes are elaborated hereunder:

- Onshore wind: For renewable energy technologies, the capacity factor constitutes a major input to its productivity. The more wind or sun the technology is expose to, the better. The model considers a ±25% sensitivity range for all inputs per technology, and when observing the results projected under capacity factor, these show the highest sensitivity. As previously mentioned, there are only three onshore wind plants currently in operation in the country, and they are geographically located in an area with strong winds, hence the capacity factor (43%) for these plants is rather high. The model assumes that all future plants will have the same capacity factor; however, this might now be case in 2035. The Peruvian government seeks to increase the share of non-conventional renewables sources within its market. Thus there is a possibility that, with a bigger deployment of the technology, future plants might be located in areas with less strong winds and consequently with a lower capacity factor.

- Solar PV - with and without tracking systems: The same principle stated for onshore wind, regarding capacity factor, applies for solar PV. However, an interesting twist is shown by the model. In general, the LCOE correlates directly with the TOC. As it can be observed for onshore wind and CCGT: the higher the TOC, the higher the LCOE. However, in the case of solar PV with tracking systems, the “extra” capacity factor, given by tracking devices, compensates (29%) for the higher TOC, with “extra” productivity, and thus with a
lower LCOE. Again, as it was the case with onshore wind, the model shows the highest sensitivity under capacity factor inputs.

- CCGT: In the case of CCGT, the major inputs influencing the LCOE are fuel costs and fuel net efficiency. Currently natural gas is available and cheap in Peru; however, the model shows that fuel prices will increase towards 2035. Expensive fuels force thermal power plants to be more efficient in its production. As explained in Chapter 2, although there is no certainty of the amount of natural gas proven reserves to supply the domestic demand, the Peruvian government has not considered the possibility of fuel supply shortage in the future. If a back up plan for fuel supply shortage is not addressed, the scenario presented by the model might lead into a dependency from oil and natural gas imports. Taking into account that the demand growth has been covered by thermal technologies for the last ten years, dependency from foreign fuels might threaten the country’s energy security.
6. Conclusions and Further Research Opportunities

Following the structure of the study, this chapter seeks to wrap up the main findings encountered during the research period and propose future research opportunities on the topic. In that sense, the most important outputs from this research can be summarised as follows:

- It is important to acknowledge the advantages from an assessment based on learning rates. From the findings of this study, it can be concluded that learning rates, indeed offer opportunities to accomplish cost reductions. This has a vital importance, specially in markets such as the Peruvian, which as for now it is still quite small. By combining assessments based on learning rates and the influence of policies (i.e. feed in tariffs), the Peruvian market could boost the development of renewable energy sources.

- From the LCOE projections, Statkraft has the opportunity to assess future strategies to enhance its competitiveness within the country. By seeing the trends on CCGT, which currently covers almost 40% of the electricity demand, one could conclude that energy supply in the country may face shortages in future. This fact can be seen as both, a threat and an opportunity. From the perspective of the company, it could be an initial step for a long term plan to extend its business within the market; and, from the government perspective, it could an opportunity to assess the diversification of its energy matrix.

Last but not least, and perhaps most importantly, one has to bear in mind that the model and methodology provided in this study, is one of many. It shall not be taken as a set theory and it shall also be re-evaluated and updated when necessary.
Bibliography


