MSc Program
Renewable Energy in Central and Eastern Europe

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Development of small hydropower plants in Peru. Regulatory Framework, Opportunities, Challenges and Risks.

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Bernhard Pelikan

Reinhard Wagner

a9909780

Vienna, 23.11.2015

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Affidavit

I, **Reinhard Wagner**, hereby declare

1. that I am the sole author of the present Master Thesis, "*Development of small hydropower plants in Peru. Regulatory Framework, Opportunities, Challenges and Risks*", 114 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, 23.11.2015 ________________________

Date　　　　　　　　Signature

Abstract

The core objective of this master thesis is to analyze (i) the global development of the hydropower sector, (ii) the potentials, challenges and opportunities of the electricity and hydropower sector in Peru and (iii) to come to a conclusion if the development of small hydropower plants (sHPPs) in Peru is a viable business opportunity for project developers and investors from a risk-return perspective, taking into account the technical potential, the stability of the country, the regulatory framework and economic and financial considerations.

This question has been answered by means of a diligent literature and internet research. Furthermore, a case study with regard to the development of sHPPs in Peru has been analyzed, including inter alia the calculation of the internal rate of return (IRR) and the net present value (NPV). Finally, the challenges, risks and market barriers, but also the strengths, opportunities and potentials with regard to the development of sHPPs in Peru for project developers and investors have been discussed in detail.

Concluding, it can be stated that the small hydropower sector in Peru is very interesting and promising for local but also foreign project developers and investors. Even though several risks, challenges and market barriers remain, the development of sHPPs in Peru can be considered as a viable business opportunity for project developers and investors. However, a collective assessment of the economic and financial feasibility of sHPPs in Peru is not possible, as an investment decision can only be taken individually, based on the specific site conditions of the project and the experience, risk appetite and available resources of the project developers and investors.

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List of Abbreviations

AC	Alternating current
BOO	Build Own Operate
BOOT	Build Own Operate Transfer
CCGT	Combined Cycle Gas Turbine
CO_2	Carbon dioxide
DC	Direct current
DSCR	Debt Service Coverage Ratio
ECL	Electric Concessions Law
EJ	Exajoule
E&M	Electro-mechanical
EPC	Engineering, procurement and construction
ESCO	Energy Service Company
FIRR	Financial Internal Rate of Return
FIT	Feed in Tariff
FLH	Full Load Hours
GDP	Gross Domestic Product
GHG	Green House Gases
GRP	Glass-reinforced Plastic
GW	Gigawatt
GWh	Gigawatt Hour
HPP	Hydro-electric power plant
IRR	Internal Rate of Return
kW	Kilowatt
kWh	Kilowatt Hour
LCA	Life Cycle Assessment
LCOE	Levelized Costs of Electricity
MW	Megawatt
MWh	Megawatt Hour
NPV	Net Present Value
O&M	Operation and Maintenance
PE	Polyethylene
PEN	Peruvian Nuevo Sol
PJ	Petajoule
PV	Photovoltaics
PPA	Power Purchase Agreement
RE	Renewable Energy
sHPP	small Hydro-electric Power Plant
TPES	Total Primary Energy Supply
TU	Technical University of Vienna
TW	Terawatt
TWh	Terawatt Hour
USD	United States Dollar
VAT	Value Added Tax
WACC	Weighted Average Cost of Capital

1. Introduction

This master thesis is dealing with two main topics: hydropower and Peru. More specifically, this thesis is analyzing the development of small hydro power plants (sHPPs) in Peru, including possible challenges, potentials and barriers.

Hydropower has been used by human mankind since thousands of years. The generation of electricity by hydro power sources, however, started at the end of the 19th century in Europe and the US, when a water turbine was coupled to the recently invented electric generator. Since then, hydropower delivered electricity to homes and industries and today is a mature, proven and cost-efficient technology that contributes a bigger share to the global electricity production than any other renewable energy source. Hydro-electric power plants nowadays exist in various sizes, types and designs, with an installed capacity ranging from some kW to power plants like the Three Gorges dam in China with 22.5 GW.

Peru is located in western South America, bordered by Ecuador, Colombia, Brazil, Bolivia, Chile and the Pacific Ocean. "*Peruvian territory was home to ancient cultures spanning from the Norte Chico civilization, one of the oldest in the world, to the Inca Empire, the largest state in Pre-Columbian America*" (reegle.info, 2015). After the conquest by the Spanish Empire in the 16th century Peru became independent in 1821. Today, Peru is a representative democratic republic with agriculture, fishing, mining, and manufacturing as main economic activities.

Peru has a significant potential with regard to renewable energy technologies. The recently conducted *Peru's Business and Investment Guide 2015/2016* from E&Y (2015) mentions a potential of up to 69,000 MW for hydropower plants, up to 22,000 MW for wind power plants, up to 3,000 MW for geothermal power plants and, as nearly elsewhere, an indefinite potential for solar and biomass projects.

However, so far Peru has not used its renewable energy resources on a large scale (except large hydro power plants, which do not account as a renewable technology according to the classification of Peru if they exceed 20 MW). This is however changing as Peru has adopted a strong regulatory framework during the last decades and nowadays is one of the leading countries with regard to renewable energy auctions globally. At the moment of writing this thesis, Peru is conducting its fourth renewable energy auction, tendering up to 1,300 GWh for biomass, wind and solar projects and 450 GWh from hydropower projects up to 20 MW. This will further boost the share of renewable sources in the electricity mix of Peru, which so far is dominated by large hydro plants and thermal sources – mainly from the *Camisea* natural gas fields, located around 430 kilometers east of Lima.

1.1. Motivation

The main reason why I am writing this master thesis is twofold. On the one hand, I wanted to improve my knowledge about hydropower and dig somewhat deeper into this fascinating subject. On the other hand, I wanted to write about a topic that is somehow related to my professional work. Given these assumptions, it was soon obvious that I will write about the potential and challenges of hydropower in a developing country. As I was in contact at the time of starting this thesis with a project developer, who is just developing a sHPP in Peru, I took the opportunity and decided to write my master thesis about the Peruvian electricity sector and the development of sHPPs in Peru.

This master thesis thus fulfills my personal interest in hydropower and also creates an additional value by improving my knowledge and skills which are relevant for my daily tasks and responsibilities. Furthermore, the thesis represents a valuable source of information for academics and scientist, but also project developers, investors, banks and any other person interested in the hydropower sector of Peru. This is due to the fact that all information provided in this report has been diligently researched and includes the latest available information about the renewable energy and especially hydropower sector in Peru.

1.2. Core objective and core questions

The core objective of this master thesis is to analyze (i) the global development of the hydropower sector, (ii) the development of the electricity sector and the potential, regulatory framework and economic feasibility of small hydro power plants in Peru and (iii) to come to a conclusion if the development of sHPPs in Peru is a viable business opportunity for project developers and investors based on the results from the preceding research.

As such the first part is dedicated to a general overview about hydropower and includes the following questions: *How did the use of hydropower evolve in human* *history? What is the energy source for hydropower development? What is the global potential and installed capacity of hydropower? Which types and classifications of hydropower plants exist? What are the main components of a hydropower plant? What are the main cost factors and levelised costs of electricity (LCOE) of hydropower and what are the main aspects when it comes to financing hydropower plants?*

Part two of this thesis is dealing with the electricity sector and the development of sHPPs in Peru. The main question in this chapter thus include: *How did the energy and electricity sector evolve in Peru over the last decades? Which technologies contribute to the current energy and electricity supply in Peru? What is the potential and installed capacity of renewable energy technologies and especially hydropower in Peru? How elaborated is the regulatory framework for renewable energies in Peru and who are the key actors in the Peruvian electricity sector? How is the electricity sector structured in Peru and what are the different possibilities to sell electricity (spot market, free market, regulated market and auction market)? What are the requirements for participating at renewable energy (RE) auctions and what have been the results from the RE auctions conducted so far? Which conditions have to be fulfilled in order to operate a sHPP in an economic viable way and which financing opportunities are available for sHPPs in Peru?*

After having answered the above mentioned questions, we come to the point when we - hopefully - can answer the core question of this thesis, which is:

- *Is the development of sHPPs in Peru a viable business opportunity for project developers and investors from a risk-return perspective, taking into account the technical potential, the stability of the economic and political situation, the regulatory framework of the electricity sector and economic and financial considerations?*

This question is also analyzed on the basis of a concrete case study in Peru, including realistic cost estimates, revenues and profitability. However, due to the individual nature of each hydropower project, based on the specific site conditions of the respective plant, this thesis can only analyze the general and legal framework conditions and discuss the economic results of the case study. A decision to invest in a capital-intensive and long-term project (which both applies when it comes to hydropower) can only be taken individually, based on experience, risk appetite and available resources, especially when the proposed plant is far away from one’s place of origin.

1.3. Main literature

As the internet provides abundant sources of documents and data nowadays, the main literature, information and data for this thesis was researched in the World Wide Web. Especially the internet sites and reports from the Intergovernmental Panel on Climate Change (IPCC), International Energy Agency (IEA), World Bank (WB), International Renewable Energy Agency (IRENA), Inter-American Development Bank (IDB), European Small Hydropower Association (ESHA), etc. provide up to date background information for the theoretical analysis with regard to the development of the hydropower sector.

Databanks used for this master thesis include inter alia:

- World Bank database (http://data.worldbank.org)
- IEA Statistics (http://www.iea.org/statistics/)
- IDB Energy database (*http://www.iadb.org/en/topics/energy/energy-innovation-center/energy-database,8879.html*)
- Global Climatescope (*http://global-climatescope.org/en/*)
- Clean Energy Info Portal – reegle (*http://www.reegle.info*)

Additional information was researched from the library of the TU Vienna, mainly in order to get a general overview about hydropower. In this regard, especially the books from Kaltschmitt and Streicher (2009) and Pedraza (2015) were very useful.

The above mentioned sources were also important for the second part of this thesis, which analyses the electricity sector and the development of small hydro power plants in Peru. However, for the second part especially the website, reports and data from the Peruvian Ministry of Energy and Mines (MINEM), the Supervisory Organization for Investment in Energy and Mining (OSINERGMIN), the Committee for the Economic Operation of the Electric System (COES) and the Peruvian Investment Promotion Agency (PROINVERSIÓN) were extremely helpful and provided the most reliable and up to date information.

With regard to the case study of a sHPP in Peru presented in part three, the data and information was received directly from the project developer. This information and data includes the idea, basic design and necessary permits of the proposed sHPP. Furthermore, different economic scenarios and calculations have been provided as well. However, due to confidentiality reasons, the exact name and location of the project will not be disclosed.

1.4. Structure of the master thesis

This master thesis is structured in five parts. After the introduction (chapter 1) follows a general description about hydropower (chapter 2). Then, the energy and electricity sector of Peru is analyzed in detail, with a specific focus on hydropower (chapter 3). After these theoretical parts, the next part constitutes the practical part of this thesis, in which a case study of a sHPP in Peru will be discussed (chapter 4). In the conclusions (chapter 5), the core question of this master thesis, which has been formulated in the introduction, will be discussed based on the findings from the previous parts. Finally, the references and the annexes have been included at the end this master thesis.

1.5. Method of approach

With regard to the theoretical parts of this thesis (chapter 2 and 3), the main information and data has been researched during a literature research about hydropower and the electricity and hydropower sector of Peru. This literature research includes scientific books from the library of the TU Vienna, but also a thorough research in the World Wide Web. There are plenty of renowned and well-done internet sites and data bases dealing with renewable energy and hydropower and these resources were also included in this thesis. As the electricity sector of Peru has undergone significant changes in the last years, the focus during the research was on up to date reports and reliable sources.

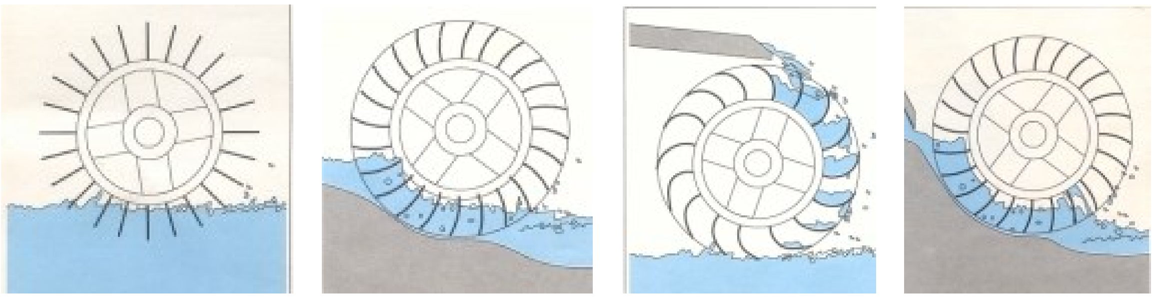
The practical part of this thesis (chapter 4) is based on information and real data from a sHPP, which has been received from a project developer. This case study is also presented in order to verify the information provided in the theoretical parts. As such, the economic and financial viability of sHPPs in Peru will be discussed and includes inter alia the calculation of the internal rate of return (IRR) and the net present value (NPV). Finally, the actual risks with regard to the development of sHPPs in Peru for project developers and investors will be discussed in detail.

In the concluding part (chapter 5), an analysis of the challenges, risks and market barriers, but also the strengths, opportunities and potentials with regard to the development of sHPPs in Peru will be conducted. Based on this, the core question of this master thesis will be discussed and answered to the best of my knowledge and belief.

2. Hydropower

2.1. The history of hydropower

Using hydropower has a long tradition. Hydropower has been used in China, Egypt and Mesopotamia thousands of years ago and already in the Roman Empire and Antique Greece the kinetic energy of the rivers was used to power sawmills and flour mills. "*Waterwheels were used in Greece as early as 100 B.C. to grind grain. Water from a stream flowed into a horizontal paddle wheel that contained numerous buckets mounted on a vertical shaft*" (Cech, 2010).



vertical waterwheel | undershot waterwheel | overshot waterwheel | breastshot waterwh.

Figure 1.1. Different kind of waterwheels. Source: wasserkraftverband.de (2015)

The first water wheel in Europe were installed around 500 AC.[1] One of the earliest and simplest form was the classical vertical waterwheel, where the blades are dipped horizontally into the water. This type is only using the kinetic energy of the water and thus were highly inefficient. The next development, from 900 AC on, was the undershot waterwheel, which is making use of a small head between the water inlet and the water outlet. This type of waterwheel is thus using the kinetic energy of the current, but also gravity and the pressure of water. The overshot waterwheel, on the other hand, is a water wheel that was rotated by falling water striking the buckets from the top. This type, which was developed around 1,400 AC, is using mainly the potential energy or gravity (weight of the water). "*The British engineer John Smeaton was the first to determine the efficiency of water wheels using a series of model tests in 1759. He found that over shot wheels had efficiencies of more than 60%, whereas undershot wheels only reached 30%*" (Müller, n.y.). Breastshot water wheels were rotated by falling water striking the buckets at the center of the wheel's edge. They were less efficient than overshot wheels, but more efficient than undershot wheels.

[1] This part is mainly based on Neumayer (2008), rwe.com (2015) and wasserkraftverband.de (2015).

Other forms of water wheels included the backshot wheel, the hydraulic wheel, the suspension wheel and rim-gears. "*Water wheels were used as mechanical power sources for flour and mineral mills, textile and tool making machines, wire drawing and hammer works, oil mills or water supplies, to generate electricity and for other purposes*" (Müller, n.y.). According to Cech (2010), by 1800, there were around 500,000 watermills in Europe.

At the end of the 18th century new technological interventions spurred the further development of hydropower. Johann Segner was the first who used the reactive force of water and constructed the first water-jet (Segner wheel). Nearly at the same time John Smeaton built the first large waterwheels out of cast iron, which were much more durable and achieved a much higher output.

In 1827 Benoit Fourneyron, a French engineer, developed a high efficiency outward flow water turbine. Unlike a waterwheel, the water thereby was directed tangentially through the turbine runner causing it to spin, which improved power output significantly.

Another breakthrough of hydropower came with the development of the electric generator, which was discovered by Michael Faraday in 1831. Sir Charles Wheatstone, Werner von Siemens and Samuel Alfred Varley developed independently the dynamo-electric machine in 1866, which was capable of delivering power for industry.

In 1849 James B. Francis further developed the design of Benoit Fourneyron and created the so called Francis turbine, which is still widely used nowadays, with around 90% efficiency. According to IPCC (2011), the world's first hydroelectric project was installed in Cragside, England in 1870. In 1880 the first industrial use of hydropower to generate electricity occurred in Grand Rapids, Michigan, when a water turbine powered some lamps for a theatre and surrounding stores. "*The breakthrough came when the electric generator was coupled to the turbine and thus the world's first hydroelectric station (of 12.5 kW capacity) was commissioned on 30 September 1882 on Fox River at the Vulcan Street Plant, Appleton, Wisconsin, USA, lighting two paper mills and a residence*" (IPCC, 2011, cited by usbr.gov, 2015). Only a few years later, in 1886, the first HPP in Austria was completed in Scheibbs with 130 kW.

In 1890 the American engineer Lester A. Pelton developed the so-called Pelton turbine and in 1913 the Austrian Professor Victor Kaplan developed the Kaplan turbine. “*By 1920 hydroelectric plants already accounted for 40 per cent of the electric power produced in the United States*“ (ieahydro.org, 2015).

At the beginning of the 20th century, the first storage HPPs were built and after the Second World War (especially between 1955 and 1970), hydropower was further expanded in Europe and the whole world.

2.2. The source of hydropower

The source of hydropower is based on the hydrological cycle. Water is continuously moving on, in and above the Earth and is changing from liquid to vapor to ice and back. In general, the solar radiation which hits the earth’s surface is absorbed by the surface of the sea or land and, by heating up the surface, is evaporating the available water. The vapor rises in the air and condensates into clouds as the temperature falls. The clouds move around globally and precipate either as snow, hail or rainfall. The precipitation is either stored in glaciers or falls into the sea or onto land, where, due to gravity, it flows as surface runoff over the ground. Water is then either transported back to the sea directly by a river or infiltrates the ground, where it may be stored for some time, before it finally again enters the oceans. There and all the way long, it is again evaporated by the incoming solar radiation into the atmosphere.

The sun is thus driving the hydrological cycle, which in itself embeds a huge potential energy. However, only a limited part of this potential energy can be exploited technically and economically by humankind. Kaltschmitt and Streicher (2009) stated that only 0.02% or 200 EJ/year are stored as kinetic or potential energy in the rivers and lakes globally. “*It is the flow of waters in rivers that can be used to generate hydropower, or more precisely, the energy of water moving from higher to lower elevations on its way back to the ocean, driven by the force of gravity*” (IPCC, 2011).

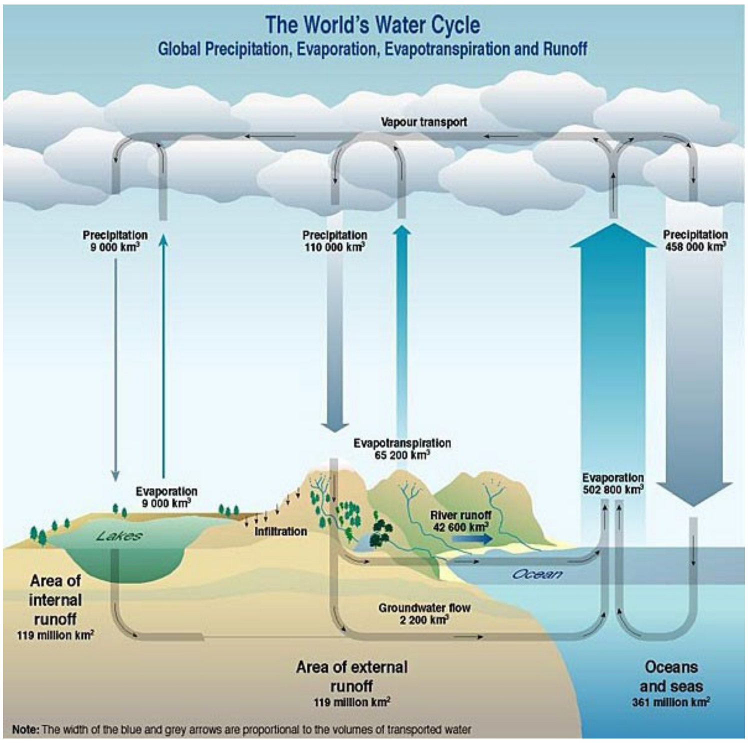


Figure 1.2. The world's water cycle. Source: oceanworld.tamu.edu (2015)

2.3. Energy conversions, calculations and losses of hydropower

In order to use the energy of water and generate electrical energy, the energy is converted several times in a HPP.

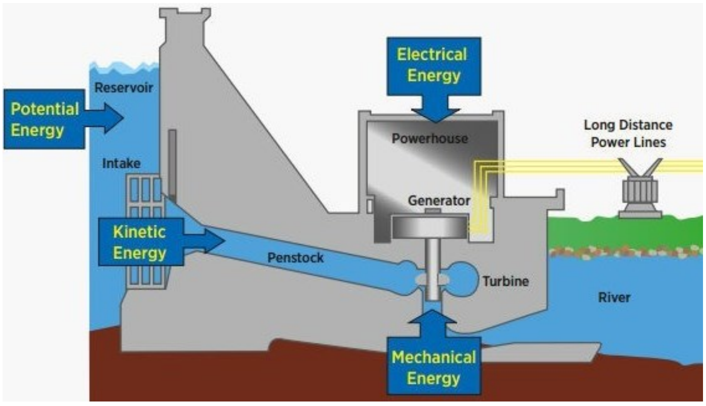


Figure 1.3. Energy conversion in a HPP. Source: sites.uoit.ca (2015)

First, the potential energy of the water in the reservoir is converted into kinetic energy when the gates are opened and the water is flowing through the penstock due to gravitational forces. When the water is spinning the turbine, the energy is converted into mechanical energy. The electrical generator, which is connected to the turbine, finally converts the mechanical energy into electrical energy.

The power potential (capacity) of a hydro power plant is calculated by the following equation:

$$\mathbf{P = \eta \cdot \rho W \cdot 10^{-3} \cdot g \cdot Q \cdot H\ [kW]}$$

η: coefficient of efficiency (turbines, generator)
ρW: density of water = 1000 kg/m³ = constant
g: acceleration due to gravity = 9.81 m/s² = constant
Q: available stream flow / discharge (m³/s)
H: head drop (m)

As ρW and g are constant, it is obvious that the available stream flow (m³/s) and head drop (m) are the decisive factors for the power output of a HPP. In fact, the "*power output from the scheme is proportional to the flow and to the head*" (ESHA, 2004).

As a rule of thumb, the following formula can be applied: **P = 7.8 · Q· H [kW]**

The annual energy output of a hydro power plant can be calculated with the following formula:

$$\mathbf{E_a = T \cdot Pa\ [kWh]}$$

T: operating hours per year
Pa: rating capacity according to the rating discharge Qa
Qa: rating discharge is the design discharge of a hydro power plant

Hydroelectric power generation is the most efficient method of large scale electric power generation without inefficient intermediate thermodynamic or chemical processes or heat losses. However, the combined efficiency of hydro power generation (η_{total}) include inter alia water energy extraction losses, mechanical losses and electrical losses.

The conversion efficiency of a hydroelectric power plant depends mainly on the turbine used (modern turbines have efficiencies up to 95%). Most modern hydroelectric power plants show overall efficiencies between 80-90%, and advanced large hydropower systems can have overall electricity generation efficiencies up to 95%. Smaller plants up to 5 MW normally have efficiencies between 80 and 85% (mpoweruk.com, 2015).

Losses can be summarized in the following way (Source: wiki.uiowa.edu, 2015):

- incomplete extraction of available water energy,
- water energy loss from wall friction,
- turbine losses,

- mechanical losses between the turbine and generator systems,
- losses from generator inefficiencies, and
- losses from transformer and other power conditioning inefficiencies.

The following figure shows typical energy losses in a run-of-river HPP (unfortunately only available in German).

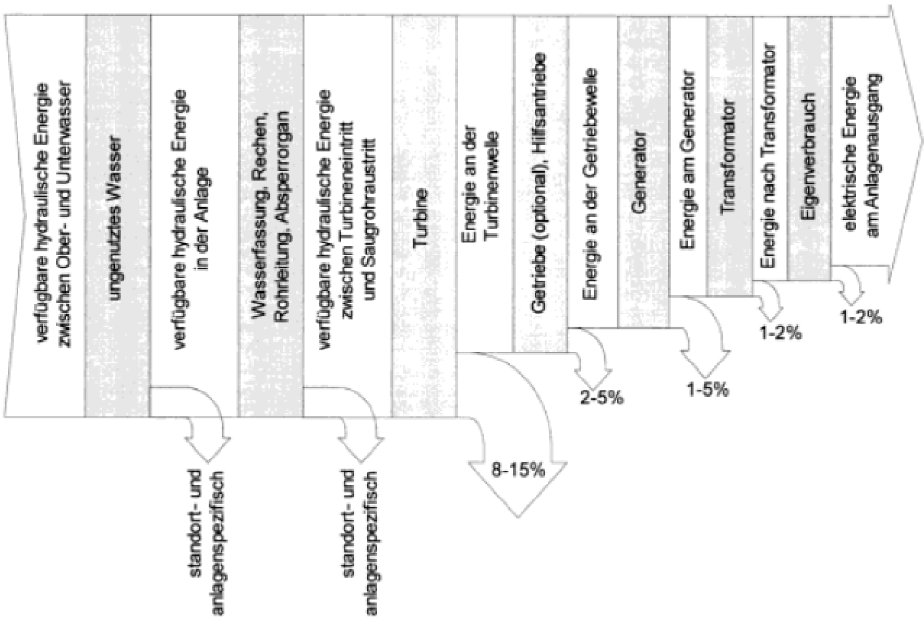


Figure 1.4. Energy losses in a run-of-river HPP. Source: Kaltschmitt and Streicher (2009)

2.4. The potential and installed capacity of hydropower

According to IPCC (2011) the **theoretical potential** for hydropower generation was estimated by IJHD (2010) as 39,894 TWh/year (144 EJ/year).[2]

The global **technical potential** is estimated at 14,576 TWh/year (52,47 EJ/year), which corresponds to an estimated installed capacity of 3,721 GW (IPCC, 2011, cited by IJHD, 2010). However, the IEA (2010) stated that the overall technical potential is estimated to be more than 16,400 TWh/year. The following figure shows the technical potential for each world region including the percentage of the so far undeveloped technical potential in 2009.

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[2] According to IPCC (2011) another study from Rogner et al. (2004) estimated the theoretical potential for hydropower generation to be 41,784 TWh/year (147 EJ/year).

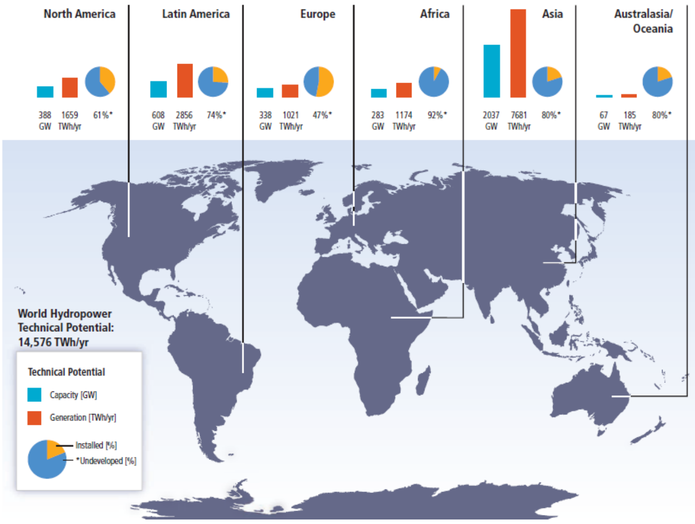

Figure 1.5. Regional hydropower technical potential in terms of annual generation and installed capacity and percentage of undeveloped technical potential in 2009. Source: IPCC (2011) cited by IJHD (2010)

The global **economic potential** depends on various factors, like pricing, regulatory framework and energy supply, which can change considerably over time. A detailed assessment on the economically feasible potential for hydropower is thus not really possible or realistic.

The global **installed capacity** of hydropower in 2009 was 926 GW, producing 3,551 TWh/year (IPCC, 2011). According to IHA (2015a), in 2014, 39 GW of new capacity have been installed globally, bringing the world's total installed capacity at the end of 2014 to 1,055 GW (excluding pumped storage plants). IHA (2015a) estimates the total installed pumped storage capacity at the end of 2014 at 139 GW, bringing total hydro capacity to 1,194 GW on a global level. Total hydropower generation was estimated at 3,900 TWh in 2014 by IHA (2015a). The following tables show the distribution of new and total HPP capacities per country/region.

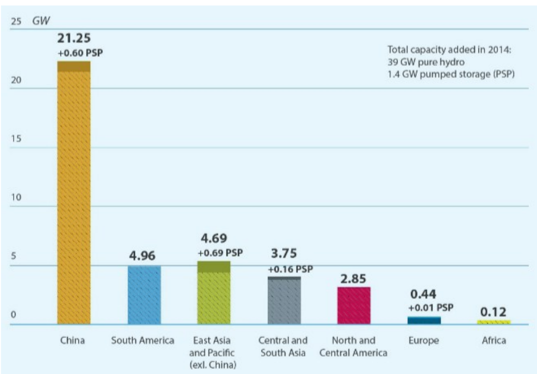

Figure 1.6. Distribution of new capacity added by region, including pure hydropower and pumped storage (PSP). Source: IHA (2015a)

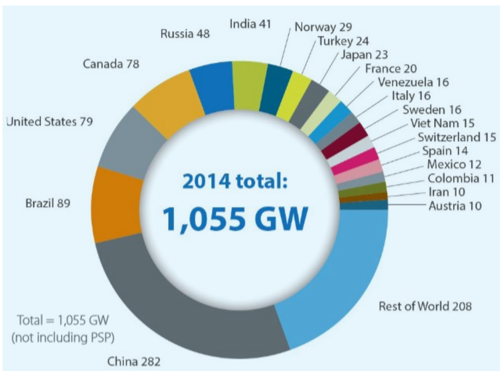

Figure 1.7. Global total of pure installed hydropower capacity (GW) by country in 2014 (excl. pumped storage). Source: IHA (2015a)

As can be seen in Figure 1.6. and 1.7. China is leading the way and added 21.85 GW of new capacity in 2014. Malaysia added 3.34 GW, Brazil 3.31 GW, Canada 1.72 GW, India 1.20 GW and Turkey 1.35 GW. For the coming years, significant additional capacity is either under construction or in the planning stages, demonstrating the continued growth of hydropower.

According to the WSHDR (2013a), the global **installed capacity of sHPPs up to 10 MW** was estimated to be around 75 GW in 2011/2012. The potential of sHPPs up to 10 MW on the other hand is around 173 GW. More than 65% of this potential is located in Asia, around 16% in Europe, around 13% in the Americas and around 5% in Africa.

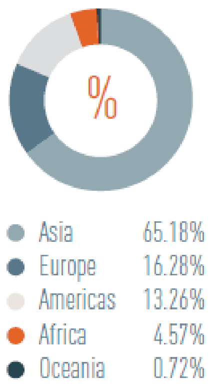

Figure 1.8. Global distribution of small hydropower resource potential up to a capacity of 10 MW. Source: WSHDR (2013a)

According to the WSHDR (2013a), South America "*has an estimated small hydropower potential of about 9,465 MW (for plants up to 10 MW), of which 1,735 MW has been developed*".

In general, a huge potential can be found in existing infrastructure schemes that so far do not generate electricity. "*Only 25% of the existing 45,000 large dams are used for hydropower, while the other 75% are used exclusively for other purposes (e.g., irrigation, flood control, navigation and urban water supply schemes)*" (IPCC, 2011).

2.5. Classification of hydropower plants

2.5.1 Classification by size and head

A clear classification of HPPs by size is difficult as no global definition of "small" or "large" HPPs exists. On the contrary, different countries use different definitions to distinguish small from large HPPs. The table below shows the various definition of sHPPs in different countries.

Table 1.1. Definition of sHPPs by installed capacity in different countries.
Source: IPCC (2011)

Country	Small-scale hydro as defined by installed capacity (MW)	Reference Declaration
Brazil	≤30	Brazil Government Law No. 9648, of May 27, 1998
Canada	<50	Natural Resources Canada, 2009: canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/renewables/small_hydropower.html
China	≤50	Jinghe (2005); Wang (2010)
EU Linking Directive	≤20	EU Linking directive, Directive 2004/101/EC, article 11a, (6)
India	≤25	Ministry of New and Renewable Energy, 2010: www.mnre.gov.in/
Norway	≤10	Norwegian Ministry of Petroleum and Energy. Facts 2008. Energy and Water Resources in Norway; p.27
Sweden	≤1.5	European Small Hydro Association, 2010: www.esha.be/index.php?id=13
USA	5–100	US National Hydropower Association. 2010 Report of State Renewable Portfolio Standard Programs (US RPS)

sHPPs rather tend to be run-of-river facilities, but also this is no general rule. "*Hydropower comes in manifold project types and is a highly site-specific technology, where each project is a tailor-made outcome for a particular location within a given river basin to meet specific needs for energy and water management services*" (IPCC, 2011). As there, for example, also exist sHPPs which include storage facilities, the definition of HPPs by size is rather arbitrary.

A classification by head (= difference between upstream and downstream water levels) is mostly decisive for the choice of the turbine. Kaplan and Bulb turbines are mostly used for low head, Francis turbines for medium head and Pelton turbines for high heads. However, the "*classification of what 'high head' and 'low head' are* [also] *varies widely from country to country, and no generally accepted scales are found*" (IPCC, 2011).

Majumder and Ghosh (2013) classify HPPs according to the availability of water head in the following way:

- ''Low head'' hydro-electric plants (less than 30m) generally utilize heads of only a few meters or less. They may utilize a low dam or weir to channel water, or no dam and simply use the water flow.
- "Medium-head" hydro-electric plants (30–300m) normally consist of a dam and a reservoir in a mountainous area.
- "High-head" hydro-electric plants (300-1000+m) generally utilize a dam to store water at an increased elevation. The use of a dam to impound water also provides the capability of storing water during rainy periods and releasing it during dry

periods. This results in the consistent and reliable production of electricity, able to meet demand. Most large hydro-electric facilities are of the high-head variety.[3]

sHPPs can also be classified according to the head. If the head is dominant (head ≥ 10 m), it is called a small high head power plant and if the discharge is dominant (head ≤ 10 m) it is called a small low head power plant.

2.5.2. Classification by type of HPP

HPPs can be classified according to the operation and type of flow. In general, there exist the following types: Run-of-river, storage (reservoir), pumped storage and in-stream HPPs.[4] All types vary from very small to very large scale, depending on the topography of the surrounding and the hydrology of the watershed.

Run-of-river HPPs use the natural flow of rivers, often without having any storage possibilities even though short-term storage (hourly, daily) might be included. "*This type of hydropower plant show fluctuations in energy production induced by low flow or overflows periods, whereas reservoir power plants can store water (i.e., energy) over long time periods and generate a steady supply of electricity, relatively independent from variations in short-term inflows*" (Pedraza, 2015, cited by Lehner et. al, 1998).

Run-of-river HPPs can either be placed directly in the flow of the river (see Figure 1.8.) or a part of the water is diverted to a channel or penstock to spin the turbine (see Figure 1.9.).

[3] ESHA (2004) mentions the following classification according to the head: High head = 100 m and above; medium head: 30 – 100 m and low head = 2 – 30 m.
[4] energy.gov (2015) classifies HPPs as impoundment (storage), diversion (run-of-river) or pumped storage HPP. Pedraza (2015) classifies HPPs as run-of-river power plants, pondage and reservoir power plants and pumped power plants.

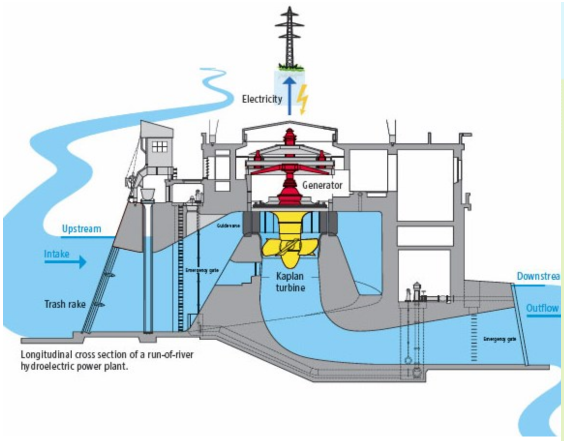

Figure 1.9. Longitudinal cross section of a run-of-river hydroelectric power plant. Source: rwe.com (2015)

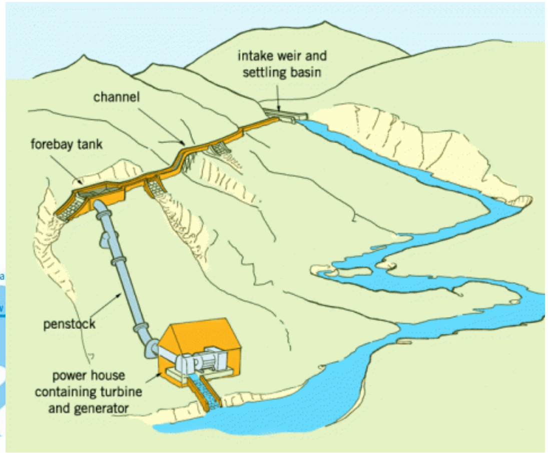

Figure 1.10. Typical run-of-river HPP with diversion structure. Source: practicalaction.org (2015)

Run-of-river HPPs can also be constructed as cascades, often with a reservoir-type HPP upstream. "*The combined cascade of dams and reservoirs allows an optimized electricity generation and may also be used to absorb excess energy when reducing river flow, thereby strongly enhancing the storage function from the upper reservoir*" (Pedraza, 2015). As run-of-river HPPs do not include large dams, etc. they are normally cheaper and environmentally friendlier than storage HPPs.

Storage (reservoir) HPPs can reduce the dependence on the variability of the inflow by means of a reservoir, so that the water can be stored and used at a later time. Reservoirs are often lakes or inundated river valleys, which include a dam and tunnels or pipelines. The design of the HPP and the reservoir is thus mainly influenced by the surrounding topography.

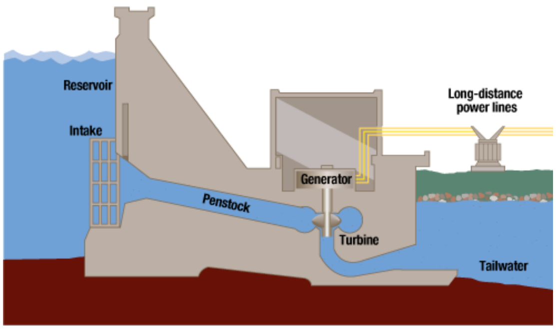

Figure 1.11. Typical storage hydropower plant. Source: tva.gov (2015)

The turbine is normally located at the bottom of the dam or further downstream, "*allowing it to take full advantage of the pressure created by the dam. The amount of* *water moving through the turbine can be controlled, allowing the Reservoir hydro system to vary the amount of electricity it produces*" (whyhydropower.com, 2015).

Pumped storage HPPs use excess or cheap electricity – normally at night – to pump water from a lower reservoir to a reservoir at a higher elevation. When electricity is needed, water is released from the higher to the lower reservoir producing additional capacities at peak times. "*Although pumped-storage sites are not net producers of electricity — it actually takes more electricity to pump the water up than is recovered when it is released — they are a valuable addition to electricity supply systems. Their value is in their ability to store electricity for use later when peak demands are occurring. Storage is even more valuable, if intermittent sources of electricity, such as solar or wind, hook into a system*" (Pedraza, 2015).

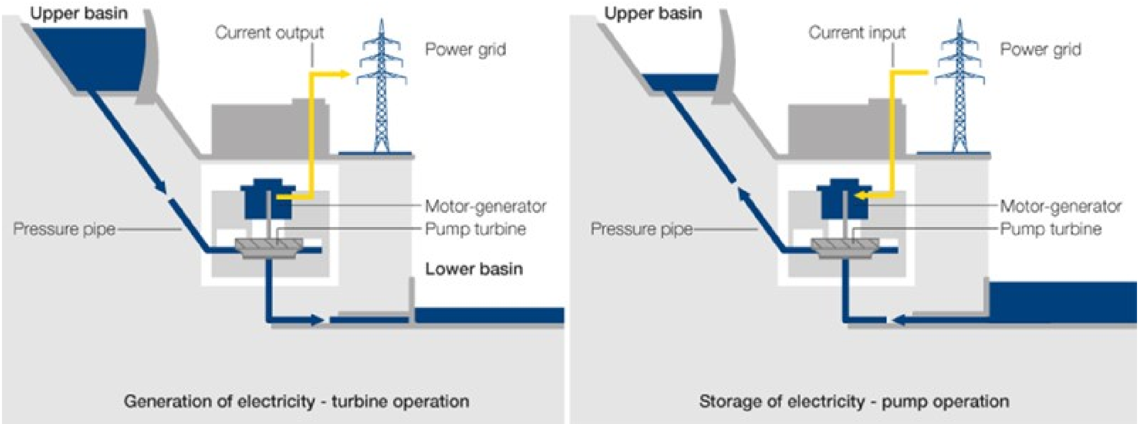

Figure 1.12. Operation principle of pumped storage HPPs. Source: www.thehea.org (2015)

Storage HPP help tremendously in maintaining a balanced grid. These include inter alia the possibility of backup and reserve power in order to respond to emergency situations, quick-start capability to provide electricity within a few minutes, black-start capability in order to restore the power system after a black-out, regulation and frequency response (in order to regulate active power), voltage support (in order to regulate reactive power) and spinning reserve to stabilize the dynamic behavior of the grid. "*Hydropower can help with grid stability, as spinning turbines can be ramped up more rapidly than any other generation source*" (IRENA, 2012).

Yang (2010) mentioned that the following two main types of pumped hydro exist: (1) pure or off-stream pumped-storage HPPs, which rely entirely on water that was previously pumped into an upper reservoir as the source of energy and (2) combined or pump-back pumped-storage HPPs, which use both pumped water and natural stream flow water to generate power. Pumped-storage HPPs however always require suitable terrains with significant elevation difference between the two reservoirs and significant amount of water resource. The construction is mostly complex and might need several years before completion.

According to thinkprogress.org (2015) the biggest pumped storage HPP is the Bath County Hydro Pumped Storage Facility in the US with 3,030 megawatts of installed capacity.

In-stream technologies: Small turbines can also be used in places where weirs, canals or barrages already exist. Basically, these HPPs work like run-of-river HPPs.

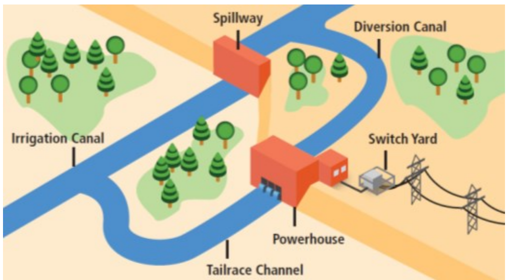

Figure 1.13. Typical in-stream hydropower plant using existing facilities.
Source: IPCC (2011)

Another form of in-stream technologies are hydrokinetic turbines, which capture the energy of currents and tides (these types are thus not relying on the potential energy of the hydraulic head, but on the kinetic energy of the water flow). Instream hydrokinetic power generation has the advantage that dams, diversions or reservoirs are not necessary, thus also reducing costs and the ecological footprint. Hydrokinetic turbines can be used in free-flowing rivers and waterways as conduits and canals. "*The principal difference between tidal and river/ocean current turbines is that river and ocean currents flows are unidirectional, whilst tidal currents reverse flow direction between ebb and flood cycles. Consequently, tidal current turbines have been designed to generate in both directions*" (IPCC, 2011).

2.5.3. Other classifications of HPPs

Majumder and Ghosh (2013) also mention a classification of HPPs according to the nature of the load.

- “Peak Load Plants” are used to supply power at the peak demand phase. The pumped storage plants are this type of plants and normally have efficiencies between 60–70%.
- “Base load plants” provide a steady flow of power regardless of total power demand by the grid. These plants run at all times through the year except in the case of repairs or scheduled maintenance.

In general, Majumder and Ghosh (2013) provide the following overview with regard to a classification of HPPs:

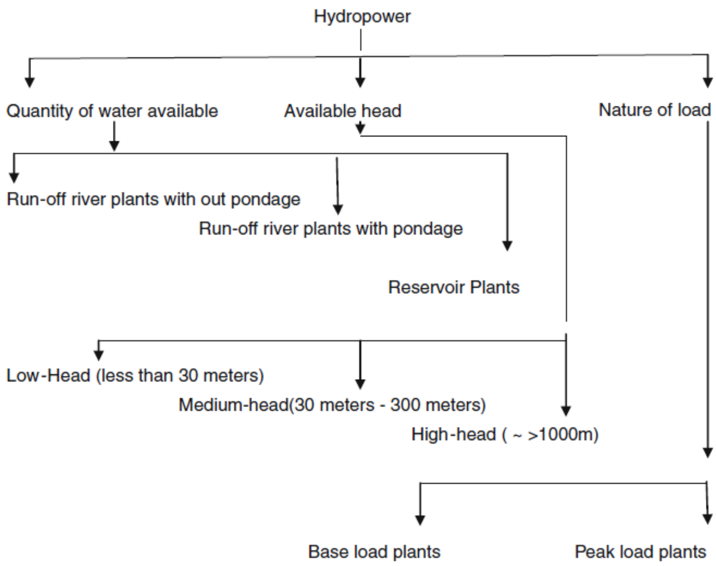

Figure 1.14. Overview of classification of HPPs. Source: Majumder and Ghosh (2013)

HPPs can be further classified according to the transmission system (isolated or connected to the grid), according to the purpose (single or multiple purpose) and according to the hydrological relation (single or cascade).

2.6. Components of hydropower plants

As there exist different types of HPPs and each HPP is unique in itself due to the specific site conditions, different HPPs can have different components. Storage and pumped storage HPPs need a dam and reservoir for storing the water or potential energy, while diversion HPPs (run-of-river) do not require dams or reservoirs but commonly have a weir. Instream-technologies can be placed directly in the river, without the need for any weirs, dams or reservoirs.

In general, the components can be classified as either electro-mechanical equipment or civil infrastructure. The electro-mechanical equipment consists of the turbine, drive system, generator, control systems, switch gear, power and current transformers, etc. "*Many small hydropower systems, particularly micro hydropower, are sold as "water-to-wire" packages*" (wyomingrenewables.org, 2015), which means that the manufacturer will supply all of the electro-mechanical equipment as a package according to the specifications and interconnection requirements (but without the civil infrastructure). The civil infrastructure consists of the dam, reservoir, intake structure, penstock, powerhouse, grid connection, the required infrastructure (access road, etc.), etc.

Dam: The basic function of a dam is to hold back water in order to create a reservoir. In general, there exist the following types of dams: gravity dams, embankment dams, arch dams and buttress dams (other dams include the spillway dam, masonry dam or timber dam). The selection of the proper dam depends mainly on the local topography and geotechnical conditions. Dams are normally made of earth and clay, gravel or rock, stone masonry, wood, metal, concrete or concrete reinforced with steel. New large dams are normally either Concrete Faced Rockfill Dam (CFRD) or Roller Compacted Concrete Dams (RCC-dams). ESHA (2004) stated that according to "*the ICOLD (International Committee of Large Dams), a dam is considered "small" when its height, measured from its foundation level to the crest, does not exceed 15 m, the crest length is less than 500 m and the stored water is less than 1 million cubic meters*". As dams pose a significant threat to environment and health, they should be checked regularly, including monitoring and control systems.

According to NEED (2013) a "*dam is either an overflow or non-overflow dam. An overflow dam allows excess water to spill over its rim. A non-overflow dam uses spillways – channels going through or around the dam – to control the pressure and potential energy of water behind the dam*". sHPPs, which are often run-of-river HPPs, normally only divert a small portion of the river flow and the remaining flow continues to flow over it. "*Such a structure is commonly known as a weir, whose role is not to store the water but to increase the level of the water surface so the flow can enter into the intake*" (ESHA, 2004). Weirs and spillways can be either fixed or mobile structures, gated or ungated and exist in various forms and types.

Reservoir: The water reservoir is behind the dam and stores the water. The height of water in the reservoir decides how much potential energy the water possesses.

Energy dissipation structure: As the flow after the spillways or weirs can have a quite high velocity and turbulences, this may cause severe erosion. In order to dissipate the energy, stilling basins, baffled apron drops, plunge pools or chute cascades are commonly used. "*Most of these structures dissipate the flow energy by the formation of a hydraulic jump, which dissipates a lot of energy over a relatively short distance*" (ESHA, 2004).

Intake structure: Intake structures are gates built on the inside of the dam and are typically the highest point of a HPP. The gates release the water flow from the reservoir to the penstock or canal. According to ESHA (2004) intake structures can be classified as power intakes or conveyance intakes. Power intakes supply the water as pressurized flow directly to the turbine via a penstock (often encountered in lakes and reservoirs). Conveyance intakes on the other way supply the water as free surface flow to other waterways (power canal, flume, tunnel, etc.) and finally in a power intake (often along rivers and waterways). The following types of conveyance intakes exist along rivers: lateral, frontal and drop intakes.

Intakes normally include trashracks to prevent possible floating debris and bedload transport from entering. Trashracks are normally constructed from metal, stainless steel or plastic bars. "*The maximum possible spacing between the bars is generally specified by the turbine manufacturers. Typical values are 20-30 mm for Pelton turbines, 40-50 mm for Francis turbines and 80-100 mm for Kaplan turbines*" (ESHA, 2004).

Sediment traps: As the intake structures normally do not prevent suspended sediment transport, this is done by sediment traps which are located downstream of the intake. "*The main objective of such a trap is to avoid sedimentation of downstream structures (canals, shafts, etc.) as well as to limit the possible damage of sediments on the hydro mechanical equipment. A sediment trap is based on the principle of diminishing the flow velocities and turbulence*" (ESHA, 2004).

Penstock: The penstock is either a closed conduit or pipe which conducts the water to the turbines and powerhouse. The water in the penstock possesses potential energy due to its height and kinetic energy due to its motion. "*Penstocks can be installed over or under the ground, depending on factors such as the nature of the ground itself, the penstock material, the ambient temperatures and the environmental requirements*" (ESHA, 2004). If the penstocks are buried, they "*must be carefully painted and wrapped to protect the exterior from corrosion, but provided the protective* *coating is not damaged when installed, further maintenance should be minimal*" (ESHA, 2004). Nowadays, there exist a lot of different materials for the construction of penstocks. According to ESHA (2004), for larger heads and diameters, fabricated welded steel is the best solution and spiral machine-welded steel pipes can be considered due to their lower price. Steel or ductile iron pipes are preferred for high heads. "*For smaller diameters, there is a choice between: manufactured steel pipe, supplied with spigot and socket joints and rubber "O" gaskets, which eliminates field welding, or with welded-on flanges, bolted on site* […]*; plain spun or pre-stressed concrete; ductile iron spigot and socket pipes with gaskets; cement-asbestos; glass-reinforced plastic (GRP); and PVC or polyethylene (PE) plastic pipes*" (ESHA, 2004). Penstocks are characterized by the following factors:

- Material (selected according to the ground conditions, accessibility, weight, jointing system and costs),
- Diameter (selected to reduce frictional losses within the penstock to an acceptable level),
- Wall thickness (selected to resist the maximum internal hydraulic pressure, including transient surge pressure that will occur) and
- Type of joint (ESHA, 2004)

Powerhouse: The powerhouse accommodates the generator, turbine and control systems. "*The size and configuration of the powerhouse is dictated by the equipment configuration and landscape of the site*" (wyomingrenewables.org, 2015). Generally, larger HPPs need more civil infrastructure and micro HPPs may not need any powerhouse at all. "*Since hydro turbine and generator equipment has substantial weight, properly designing the powerhouse foundation and structure to handle the loads to which it will be subjected must be considered*" (wyomingrenewables.org, 2015). Also, the turbine's discharge channel to the tailrace must be considered in the design of a powerhouse. "*Reaction turbines discharge water through a tailrace incorporated directly into the powerhouse foundation; whereas, an impulse turbine powerhouse discharges the tailwater directly into an open air excavation rather than a tailrace*" (wyomingrenewables.org, 2015).

In the following part, the main parts of the electro-mechanical equipment of a HPP are described in detail:

Turbines: In the turbine the kinetic energy of the water is converted into mechanical energy (rotation of the turbine blades and shaft). Due to the differences in head and discharge, which lead to differences in water pressure and speed, different turbines exist. In principle, there exist two different kind of turbines: impulse and reaction turbines.

Impulse turbines use a jet of water and fire it through a narrow nozzle at the turbine blades, which makes them spin around (the water pressure is converted into kinetic energy by constant "impulses"). Impulse turbines have bucket-shaped blades, which catch the water and direct it off at an angle or back the way it came. "*An impulse turbine can be open to the atmosphere and only needs a casing to control splash. Impulse turbines are generally well suited for high head, low flow applications*" (wyomingrenewables.org, 2015). Impulse turbines direct the water flow tangential to the turbine wheel and generally need less maintenance than reaction turbines.

Reaction turbines turn around as the water flows through and past its blades. The water pressure thus applies a force on the turbine runner blades which decreases at the end of the turbine. "*The turbine runner blades are fully immersed in water flow and must be encased in a pressurized housing. Reaction turbines are generally suited for lower head, higher flow applications*" (wyomingrenewables.org, 2015). While the water is hitting the blades and bouncing off in an impulse turbine, the blades in a reaction turbine are moving more smoothly as a reaction to the traversing water flow.

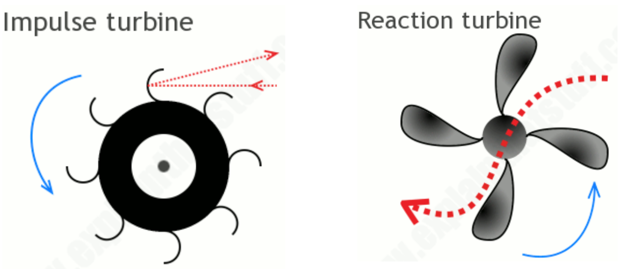

Figure 1.15. Difference between impulse and reaction turbines.
Source: explainthatstuff.com (2015)

In general, different turbines may be suitable for a specific location. However, as the efficiencies and range of the turbines can vary greatly, an experienced manufacturer should be contacted. "*The design flow for smaller systems, such as a pump-as-turbine, may also be dictated by standard, "off-the-shelf" turbine sizes*" (wyomingrenewables.org, 2015).

Figure 16 shows the application ranges concerning head and flow for different turbines. In general, it can be stated that Kaplan turbines are rather suitable for low heads, Francis turbines for medium heads and Pelton turbines for high head.

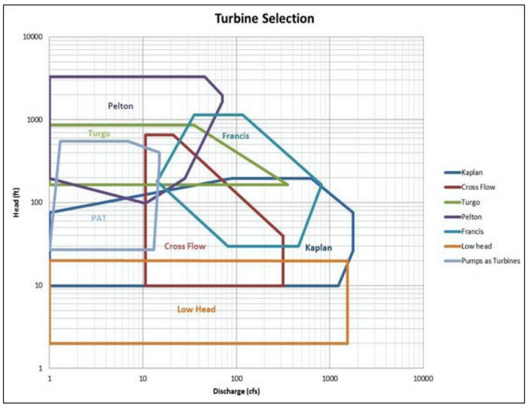

Figure 1.16. Turbine selection chart.
Source: Colorado Energy Office (2013)

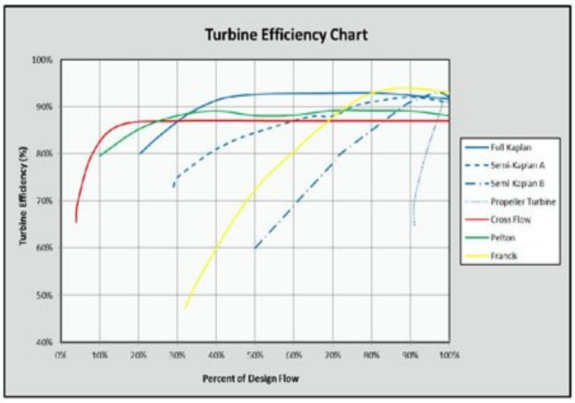

Figure 1.17. Turbine efficiencies chart.
Source: Colorado Energy Office (2013)

Figure 17 shows the efficiencies of different turbines. "*Generally, a flatter efficiency curve represents a turbine that can operate under broad ranges of head and flow. Curves that are steeper and narrower are indicative of a turbine designed for more focused ranges of operation*" (wyomingrenewables.org, 2015).

Subsequently, the most common turbines will be described.

Impulse turbines can be either Pelton turbines, Turgo turbines or cross flow turbines.

Pelton turbines are normally used for medium and high head. They use one or more water jets to inject the pressurized water on the buckets of the turbine. The design of the jets and buckets is very efficient, leading to efficiencies of up to 90%.

Turgo turbines are very similar to Pelton turbines, but are commonly used for higher flows and lower heads than Pelton turbines. "*The main physical differences between the two relate to the flow path of water through the turbines and the cup shape on the runners*" (wyomingrenewables.org, 2015).

Cross flow turbines typically consist of two or more inlet guide vanes, which can be adjusted based on the specific flow conditions. The water thereby flows through the blade channels from the outside to the inside and then from the inside to the outside. As can be seen in Figure 17, the cross flow turbines are able to have a consistent efficiency over a high range of flow rates. This means that cross flow turbines are well suited for seasonal flows and partial load. Further positive aspects are the self-cleaning design and thus also low maintenance and long life time. "*Typical power outputs range from 5 kW to 100 kW, though they can actually be up to 3 MW on the very largest systems*" (wyomingrenewables.org, 2015).

Reaction turbines can be either Francis, Kaplan or Pump-as-turbines.

Francis turbines has fixed runner blades and adjustable guide vanes and is typically used for medium head. "*The inlet water flow is always radial, and the outlet is axial through a draft tube. The water enters the turbine by the spiral scroll case and flows through adjustable guide vanes or wicket gates, whose function is to control the water flow into the runner and adapt the inlet angle of the flow to the runner blades angle*" (wyomingrenewables.org, 2015). The guide vanes or a butterfly valve can be used to shut down the system in case of emergency. Efficiency of a Francis turbine has a higher peak, but a narrower operating range than other turbines. Francis turbines are the most widely used turbine in the world and can also be used for pumped storage HPPs.

Kaplan turbines are normally used for low head and large volumes of water. As the pitch, runner blades and inlet guide vanes of Kaplan turbines are highly adjustable, efficiency is very high. The water flow which passes through the inlet guide vanes create shaft power of the propeller-like turbines. Kaplan turbines are often more expensive than other turbines, but the flexibility and higher efficiency is often an additional asset. "*Kaplan turbines that have both adjustable inlet guide-vanes and adjustable rotor blades are known as being "double regulated" or full-Kaplan turbines. The variant of Kaplan turbines that only have adjustable inlet guide-vanes or adjustable rotor blades are known as semi-Kaplans*" (wyomingrenewables.org, 2015).

Pump-as-turbines use a centrifugal pump running in reverse, thus they are working de facto like a reversed motor. Pump-as-turbines are generally working fixed flow, meaning they are either running or switched off depending on the available flow. As the turbine is shut down when the flow is too high, these types are not suited for variable flow conditions. When the flow rate is constant on the other hand, Pump-as-turbines can be an affordable alternative to other turbines.

Pelton turbine Kaplan turbine Francis turbine

Figure 1.18. Pelton, Kaplan and Francis turbines. Source: koessler.com (2015)

Generator: The primary function of the electrical generator is to convert the rotation of the shaft into electrical energy. "*The basic process of generating electricity in this manner is to rotate a series of coils inside a magnetic field or vice versa. This process leads to the movement of electrons inside conductors, which produces electrical current*" (Wagner and Mathur, 2011). Most generators, except very small ones, produce alternating current (AC), which can be easily connected to the transformer. Very small systems may also use direct current (DC) generators, but here inverters are necessary to convert the DC into AC power. In general, there "*are two main types of generators: induction and synchronous. Induction generators rely on the electric grid to control the speed and frequency; synchronous generators monitor grid frequency and voltage and automatically adjust generation to match*" (wyomingrenewables.org, 2015).

Transformer: "*The transformers and power house of a hydro power plant act as an interface between the electric generator and the power transmission lines*" (Wagner and Mathur, 2011). The transformers increase the voltage generated by the electrical generator into very high voltage electricity. This is necessary, because losses can as such be reduced significantly during the transmission of power over long distances.

Control systems: Control systems are normally supplied together with the generator and turbines as a water-to-wire package. In general, there exist controls for the grid interconnection, which synchronize voltage and frequency and emergency shut down systems, which disconnect the generator in case of emergency situations. In case of off-grid applications, a load management system or governor is needed in order to distribute the generated electricity and balance the varying loads.

2.7. Economics of hydropower plants

The cost factors of a hydropower plant can be divided in the following two groups:

- **Civil works:** include the costs for the construction of the dam and reservoir, the tunnel, canal, powerhouse, grid connection, the required infrastructure (access road, etc.), engineering, procurement and construction (EPC) and project development costs (including planning, feasibility studies, permits, fees, etc.).

- **Electro-mechanical (E&M) equipment**: includes the turbines, generators transformers, monitoring and control systems, cables, etc. including transport costs and import levies (if applicable)

In general, it can be stated that the costs for the electro-mechanical equipment are rather stable due to the maturity of the technology. In contrast, the costs for the civil works are highly site specific and thus can vary significantly (including long lead-times for permitting, planning and feasibility studies).

For large scale HPPs the main costs normally refer to civil works, while the E&M costs tend to be lower. "*However, for hydropower projects where the installed capacity is less than 5 MW, the costs of electro-mechanical equipment may dominate total costs due to the specific costs of small-scale equipment*" (IRENA, 2012).

Another cost factor are the expenses for operation & maintenance. These normally include fixed O&M costs (personnel costs, administration, insurance, etc.) and variable O&M costs (equipment costs/maintenance). Maintenance costs, however, normally only include minor refurbishments like rewinding the generator or overhauling the turbine, but not the replacement of the whole equipment or the reconstruction of the penstock, etc.

Further critical factors influencing the economic feasibility of HPPs include the capacity factor, the economic life of the plant and the cost of capital (discount rate).

A common way to calculate (and compare) the costs of hydropower projects is to levelise the costs of electricity generation (LCOE). The LCOE is based on the discounted cash flow method, which discounts the financial flows over the lifetime of a project by taking into account the time value of money. The following shows a simplified formula, which is used to calculate the LCOE of renewable energy projects (Source: IRENA, 2012).

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

LCOE = the average lifetime levelised cost of electricity generation;
I_t = investment expenditures in the year t;
M_t = operations and maintenance expenditures in the year t;
F_t = fuel expenditures in the year t;
E_t = electricity generation in the year t;
r = discount rate; and
n = economic life of the system

The LCOE thus calculates the average costs per kWh produced (including investment costs, O&M, fuel costs (if applicable) and the costs of capital) over the lifespan of the project. LCOE calculations for real projects, however, are much more detailed and also include taxation, subsidies, inflation, etc. The advantage of the LCOE is that it allows to compare different power generation technologies from an economic perspective.

Regarding hydropower projects, investment costs are typically high, while O&M costs are rather low. Fuel prices are often zero, however sometimes a fee for the utilization of the water right might have to be paid. Due to the capital-intensive technology, the discount rate – or more precisely the weighted average cost of capital (WACC[5]) – is an important factor influencing the LCOE.

The following table shows the typical installed costs in USD/kW, O&M costs, capacity factor and LCOE of hydropower projects, assuming 10% cost of capital.

Table 1.2. Typical installed costs and LCOE of hydropower projects (IRENA, 2012)

	Installed costs (USD/kW)	Operations and maintenance costs (%/year of installed costs)	Capacity factor (%)	Levelised cost of electricity (2010 USD/kWh)
Large hydro	1 050 – 7 650	2 – 2.5	25 to 90	0.02 – 0.19
Small hydro	1 300 – 8 000	1 – 4	20 to 95	0.02 – 0.27
Refurbishment/upgrade	500 – 1 000	1 – 6		0.01 – 0.05

Note: The levelised cost of electricity calculations assume a 10 % cost of capital

According to IRENA (2012) the costs of large HPPs normally are between 1,000 and 3,500 USD/kW, but might increase if transmission lines and substantial infrastructure facilities have to be built. Refurbishments and upgrades of already existing HPPs on the other hand are the most cost-effective options with installed costs between 500 and 1,000 USD/kW and an LCOE between 0.01 and 0.05 USD/kWh.

O&M costs for large HPPs are in the range of 2% – 2.5% of the investment costs/year. For sHPPs, O&M costs vary between 1% – 4% of the investment costs/year, with

[5] "*Weighted average cost of capital (WACC) is the average after-tax cost of a company's various capital sources, including common stock, preferred stock, bonds and any other long-term debt. By taking the weighted average, the WACC shows how much interest the company pays for every dollar it finances. The internal rate of return (IRR), on the other hand, is the discount rate used in capital budgeting that makes the net present value (NPV) of all cash flows (both inflow and outflow) from a particular project equal to zero. It is used by companies to compare and decide between capital projects. For example, a company may evaluate an investment in a new plant versus expanding an existing plant based on the IRR of each project. The primary difference between WACC and IRR is that where WACC is the expected average future costs of funds (from both debt and equity sources), IRR is an investment analysis technique used by companies to decide if a project should be undertaken. A close relationship exists between WACC and IRR, however, because together these concepts make up the decision for IRR calculations. In general, the IRR method indicates that a project whose IRR is greater than or equal to the firm's cost of capital should be accepted, and a project whose IRR is less than the firm's cost of capital should be rejected*." Source: *investopedia.com* (2015)

higher costs for mini and pico-HPPs. The study from Ecofys (2011) mentions average O&M costs of around 35 Euro/kW/year for large HPPs and around 40 Euro/kW/year for sHHPs (i.e. around 40,000 Euro per MW installed).

In any event, it is advisable to include an item for unforeseen costs in the economic calculation of HPPs. As mentioned in IEA (2000b), the "*amount depends on the developer's "gut feeling*"".

2.7.1. Economics of small hydropower plants

sHPPs normally have slightly higher investment costs than large HPPs due to the lack of economies of scale.[6] This trend can also be observed within sHPPs. However, sHPPs are often cost competitive compared to other technologies, depending on the specific site conditions. "*The LCOE range for small hydropower projects for a number of real world projects in developing countries evaluated by IRENA was between USD 0.02 and USD 0.10/kWh, making small hydro a very cost competitive option to supply electricity to the grid, or to supply off-grid rural electrification schemes. Very small hydropower projects can have higher costs than this and can have an LCOE of USD 0.27/kWh or more for pico-hydro systems*" (IRENA, 2012).

The diversity of the cost factors for sHPPs, which is due to the individual nature of the respective site, is shown very well in the following figure. Electro-mechanical costs can thus vary between roughly 20% and 50% and infrastructure and connection and transmission costs can have a quite high impact.

[6] Another reason why large HPPs are economically more interesting than sHPPs is because the typical lifetime for a sHPP is around 40 years, while it can be between 40 and 80 years for large HPPs (however, this is not really affecting the LCOE significantly).

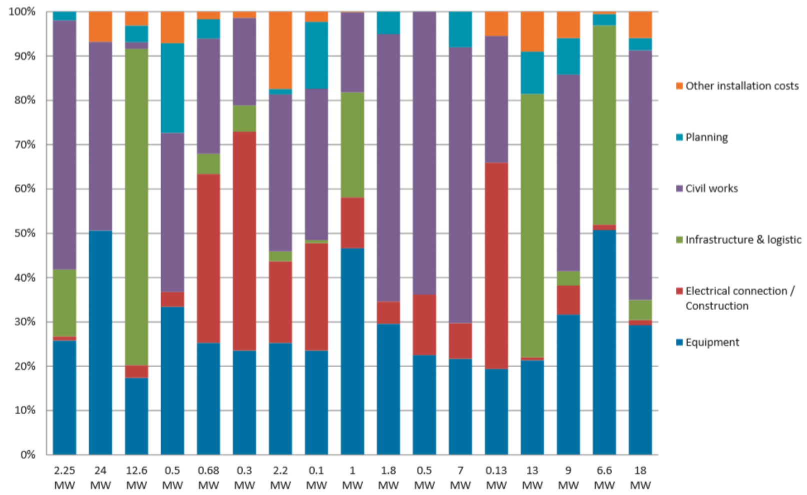

Figure 1.19. Cost breakdown for different sHPPs in developing countries (IRENA, 2012)

According to ARE (2014) with regard to sHPPs it “*is generally considered that location and site preparation determine around 75% of project costs against only 25% for the equipment*“.

Table 1.3. Cost factors of sHPPs in %. Source: ARE, 2014

Element of investment	Participation up to (%)
Hydrotechnical construction	60
Turbines	25
Building	5
Electrical equipment	10
Cost of exploitation	0,5

With regard to sHPPs, costs may be reduced by using local materials and skills as much as possible.

As hydropower is such a mature technology, significant cost reductions are unlikely in the near future. Taking into account that the best sites for hydropower are probably already in use, hydropower costs are expected to remain more or less on the same level as today (at least in the short term). Economically feasible options, however, are available due to the possibility of refurbishments and upgrades of existing HPPs and by exploiting existing dams which have so far not be used for electricity production.

Another important issue with regard to the economic feasibility of HPPs are government incentives (feed-in-tariffs, investment subsidies, tax benefits, etc.).

2.8. Financing of hydropower plants[7]

HPPs typically have high upfront costs and low O&M costs. Obtaining external financing for a HPP project is thus mostly necessary, though sometimes difficult to find.

The next part describes the key players with regard to the development of HPPs. Generally, it can be stated, that the "*parties involved will vary, depending on how the project is financed. A large hydropower utility may design, construct and finance a new hydropower project with a minimum of involvement from other parties. In most cases however, the project will involve several parties*" (IEA, 2000a).

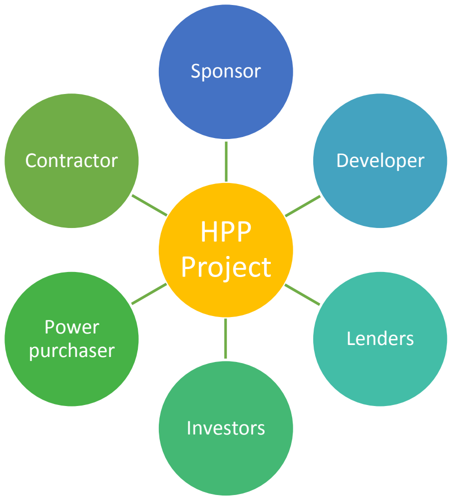

Figure 1.20. Key players with regard to the development of HPPs. Source: own figure

Sponsor: The sponsor is either the government, a utility or a private company that is promoting the hydropower project.

Developer: The developer has the responsibility to develop the HPP (incl. securing permissions and licenses, negotiating prices with suppliers, signing contracts with contractors, negotiating financing with banks and securing power purchase agreements with the purchasers).

Lenders: Lenders may be either private, commercial banks or specific organizations like the World Bank. Especially in developing countries, local banks may have too little

[7] This chapter is mainly based on own experience and on IEA (2000a), *Financing of Small-Scale Hydropower Projects*.

knowledge with regard to financing HPPs and thus associate high risk with such projects. In these cases, the World Bank (for public sector projects) or other specialized financial institutions (like the International Finance Corporation IFC, who acts a private sector arm of the World Bank) may provide financing. Lender normally provide the majority of the financial resources needed (~ 70%).

Investors: The investors provide the equity capital for the project (~ 30%). As the investors take a high risk when investing in a project, they expect profits and a strong influence on the project. Investors may include private individuals, power utilities, financial institutions, equity funds, industrial companies or (local) governments. Equity capital is subordinated to loans from financial institutions and thus is much less secured / riskier.

Power purchaser: The power purchaser is normally either the national or regional power utility, a distribution company, a power broker or company that is directly buying the electricity for own use. The parties (seller and buyer of electricity) normally conclude a power purchase agreement (PPA), which regulates inter alia the price per kWh, the amount of electricity to be sold and penalties in case the conditions defined in the PPA are not fulfilled.

Contractor: Contractors are normally engineering companies who either construct a part or the whole HPP. As it is generally easier to deal with only one party, a general contractor, who is responsible for all aspects of engineering, procurement and construction (EPC), might be hired. The general contractor is then responsible for the completion of the HPP (“turnkey contract”), including the settlement with possible sub-contractors, suppliers, etc.

There exist different possibilities to finance HPPs, depending on the financial strength of the sponsor and the different financing options available in the respective country.

Own funds: The sponsor or developer may have sufficient reserves to finance the project. However, considering the high upfront costs for HPPs, this is rarely the case (for very small HPPs, however, it might be possible). Furthermore, sponsors normally are keen to increase their own profits and to diversify their risks and thus try to obtain financing from banks.

Co-development with a partner: If the sponsor does not have enough own funds, he might develop the project in a joint venture with a financially strong partner who either provides equity capital and/or offers security for bank loans (assets/property).

Furthermore, partnerships might be suitable to bring additional expertise into the company or project (engineering, finance, etc.). Another example might be the inclusion of the land owner, who either receives shares, royalty payments or electricity supply in exchange for the use of his land and energy source, respectively.

On balance sheet financing – ordinary bank loans: On balance sheet financing means that the loan from the bank (normally around 70% of the total investment costs) is secured by assets or property owned by the sponsor or developer. If sufficient security is available, ordinary bank loans are generally considered to be simpler, thus the costs for financing can be reduced. This option, however, is normally only available for companies with sufficient financial resources and is more difficult to obtain for smaller, financially weaker companies.

Limited recourse project financing: While an ordinary bank loan (on balance sheet) is secured by the assets of the company, the repayment source of project finance is based on the future cash flow of the project. As the lenders are thus relying on the future performance of the project, they will require detailed technical reports undertaken by independent experts, long-term power purchase agreements (PPA) and experienced suppliers and contractors (including fixed-price turnkey contracts with regard to engineering, procurement and construction (EPC)). Furthermore, the lenders will probably include contractual arrangements that make it possible to exercise a tight control over the project, including stepping in and operating the plant in case of non-performance, a blanket pledge of all assets and assignment of rights under the contract. As project finance includes complex contractual arrangements, it is rather difficult for small projects which only have limited investment costs and financial resources. IEA (2000a) mentions also the following important aspects and cost factors with regard to limited recourse project financing:

- "*Initial arrangement fee. The financiers will require an up-front fee for covering the arrangement expenses of financing.*
- *Undertakings. The lenders may restrict the payment of dividends to shareholders. This is done in order to provide a buffer against unforeseen problems and may amount to half a year of debt service.*[8] *Payment of dividends may also be cancelled in case the project is performing badly.*

[8] A typical financial covenant by the lenders would normally include a Debt-Service Coverage Ratio (DSCR = Net Operating Income / Total Debt Service) of minimum 1.4.

- *Conditions precedent. A number of conditions must be met before the loan can be drawn. Normally this requires that all contracts be to the bank's satisfaction, that all permits are in place, the existence of a favourable review from an independent technical consultant, all insurances in place, etc.*
- *Fees to external experts. The financiers will require all fees to external legal and technical advisers to be paid by the developer*."

Leasing: The Oxford Dictionary defines leasing as: "*A contract by which one party conveys land, property, services, etc. to another for a specified time, usually in return for a periodic payment*" (*oxforddictionaries.com*, 2015). In general, leasing is classified as either operating leases or financial (capital) leases. An operating lease is more or less like renting where payments are considered operational expenses (and the asset being leased stays off the balance sheet). In contrast, a capital lease is rather like a loan (the asset is treated as being owned by the lessee so it stays on the balance sheet). An operating lease is rather short-time, where the lessor assumes most of the responsibilities of ownership including insurance, maintenance, service, etc. "*A financial lease (capital lease) is a long-term contract by which the lessee agrees to pay a series of payments that in sum will exceed the purchase price of the asset, and provide the lessor with a profit. The lessee takes on the fundamental ownership responsibilities such as maintenance, insurance, property taxes, etc. Normally the agreement is not cancellable by either party, but may provide clauses that allow cancelling should certain circumstances occur. Upon termination, the asset is returned to the lessor*" (IEA, 2000a).

Table 1.4. Difference between capital and operating lease. Source: *diffen.com*, 2015

	Capital Lease	**Operating Lease**
Lease criteria - Ownership	Ownership of the asset might be transferred to the lessee at the end of the lease term.	Ownership is retained by the lessor during and after the lease term.
Lease criteria - Bargain Purchase Option	The lease contains a bargain purchase option to buy the equipment at less than fair market value.	The lease cannot contain a bargain purchase option.
Lease criteria - Term	The lease term equals or exceeds 75% of the asset's estimated useful life	The lease term is less than 75 percent of the estimated economic life of the equipment

	Capital Lease	Operating Lease
Lease criteria - Present Value	The present value of the lease payments equals or exceeds 90% of the total original cost of the equipment.	The present value of lease payments is less than 90 percent of the equipment's fair market value
Risks and Benefits	Transferred to lessee. Lessee pays maintenance, insurance and taxes	Right to use only. Risk and benefits remain with lessor. Lessee pays maintenance costs
Accounting	Lease is considered as asset (leased asset) and liability (lease payments). Payments are shown in Balance sheet	No risk of ownership. Payments are considered as operating expenses and shown in Profit and Loss statement
Tax	Lessee is considered to be the owner of the equipment and therefore claims depreciation expense and interest expense	Lessee is considered to be renting the equipment and therefore the lease payment is considered to be a rental expense

Paying-back by delivering electricity: A company with considerable energy needs may finance a HPP and agree to be paid back with electricity (or other goods and services). As this is an alternative to paying the debt in cash, the developer can also avoid lengthy financing negotiations with banks.

Suppliers' credit: In a lot of cases the suppliers may also provide financing for their equipment. This kind of credit allows the buyer to receive the products and paying for them later in accordance with the terms and conditions. The developer thus can pay back the costs for equipment with his future earnings. The conditions are subject to negotiation on a case by case basis. According to geekwise.com (2015), supplier credits have "*many benefits for both the supplier and the customer. For the customer, the establishment of a line of credit means it is possible to order what is needed now and pay for it incrementally while earning a return from the use of the items ordered. For the supplier, extending the line of credit means that steady flows of revenue are created, assuming that all customers who are granted supplier credit make timely payments on their outstanding balances*."

Public participations / crowdfunding: Crowdfunding is generally defined as "*the practice of funding a project or venture by raising many small amounts of money from a large number of people, typically via the Internet*" (forbes.com, 2015). Crowdfunding has experienced a growing relevance in the last years with regard to the financing of renewable energy projects, especially photovoltaics and wind. In the meantime, hundreds of crowdfunding platforms have been established, raising hundred millions of Euros annually.[9] Even though crowdfunding is also suitable for large projects, it is especially interesting as a financing option for smaller projects and sHPPs.

Build Own Operate (BOO): Even though BOO is not a specific financing alternative (also in these cases the developer will actually use one of the financing options described above) it should be noted as one way to develop a HPP. Here the owner of the energy source grants a concession to use the source to a developer, who pays a fee to the owner for the right to plan, construct and operate the HPP. Another possibility is Build Own Operate Transfer (BOOT), which thus includes also the transfer to the original owner after a specified time period. With regard to HPPs, BOOT is one way for governments of developing countries to accelerate the development of HPPs.

Which financing option is finally applied, depends on the specific project and the financial strength of the developer, as mentioned above. Regarding project finance, the risk of the developer is limited to the equity capital, but he also has to accept a tight control by the financing institutions, has to pay a price for reducing the risk and pay high arrangement costs.

Co-development with a partner is always a good option for HPPs and especially for sHPPs. This should help bring additional technical and financial strength into the project, preferentially at early stage.

When approaching a bank for financing, it is advisable to be able to show that sufficient technical knowledge and reference projects are available. Furthermore, the available energy resource should be verified by long-term studies and all contractual arrangements (EPC, PPA, O&M, land use, shareholder agreement, etc.) should be in place. A detailed information memorandum about the project including a financial analysis and modelling must be available as well.

Limited-recourse project financing might be difficult to secure for sHPPs as the size of the debt is too small compared to rather high arrangement costs and the costs associated with the security structure. However, it should be possible for HPPs with an installed capacity of minimum 5 MW.

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9 Two of the most important crowdfunding platforms for renewable energy projects are Abundance - *https://www.abundancegeneration.com/* - and Mosaic - *https://joinmosaic.com/*.

sHPPs generally face problems in obtaining financing due to the lack of economies of scale. “*For a large project the feasibility study normally accounts for 1 – 2 % of total costs, while for a small project it may well amount to 50 % of the cost*” (IEA, 2000a, cited by Breeze, 1997). Furthermore, as the revenues are much smaller, the feasibility of the sHPP is much more cost-sensitive and thus includes higher risks. Off-grid sHPPs normally are not able to obtain a PPA, which makes project finance nearly impossible.

IEA (2000a) mentions some possibilities to improve the financing situation for sHPPs:

- Public incentives: loans, grants, FITs, PPAs, investment subsidies, tax reliefs, etc.
- Cost reduction: joint development of several projects in an area, ongoing co-operation among key parties involved in the development process and simplifying legal procedures
- Risk reduction: government guarantees, high quality stream flow data, stepwise development of projects and creating legal certainty

Other important aspects include capacity building, publicly financed centers which provide professional advice, equity funds, business angels, match-making of investors and developers, etc.

3. Peru

3.1. Background and key statistical data

After Brazil and Argentina, Peru is the third largest country of South America with around 1.28 million square kilometers. "*Peruvian territory was home to ancient cultures spanning from the Norte Chico civilization, one of the oldest in the world, to the Inca Empire, the largest state in Pre-Columbian America*" (reegle.info, 2015). After the conquest of the Spanish Empire in the 16th century and the establishment of a Viceroyalty, Peru regained its independence in 1821. Today, Peru is a constitutional republic with 25 regions and 31.2 million inhabitants (estimation 2015 by EY, 2015). Significant mineral and energy resources can be found inter alia in its tropical forests at the Amazon Basin, the highlands of the Andes and the Pacific coast. However, the vast renewable energy potential (sHPPs, wind, solar, biomass and geothermal) is still largely untapped in Peru.

The economy has grown rapidly during the last years in Peru. As can be seen in Figure 2.1. the GDP of Peru increased significantly during the last decade, reaching USD 204 billion in 2014. Furthermore, public debt (in % of GDP) decreased from 46% in 2000 to only 19.7% in 2014. "*Market-friendly policies with sound fiscal management and a commitment to macroeconomic stability have contributed to sustained economic growth*" (IRENA, 2014). Currently, Peru has an investment grade rating of BBB+ from Standard & Poor's and Fitch Rating and of A3 from Moody's. The main economic sectors are industry, mining, agriculture, trade and energy and its main exports include copper, gold, zinc, textiles and fish meal (ARE, 2014).[10]

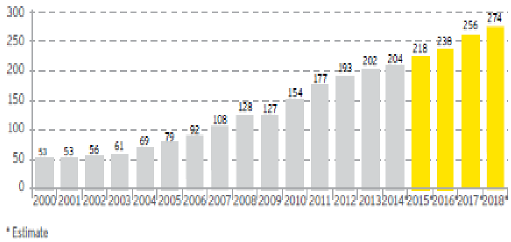

Figure. 2.1. GDP of Peru (USD billion).
Source: Central Reserve Bank of Peru (BCRP), cited by EY (2015)

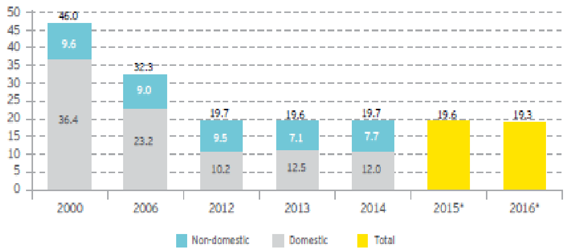

Figure. 2.2. Public debt (% of GDP).
Source: Central Reserve Bank of Peru (BCRP), cited by EY (2015)

[10] "*Peru is one of the world's largest exporters of gold, silver and copper, particularly to China. In fact, the demand pull from Chinese manufacturers is so strong that the strength of Peru's overall economy is closely correlated with the health of the Chinese manufacturing sector*" (ITA, 2014).

The growth of the Peruvian economy also led to a significant increase in energy demand. "*Energy production has grown at an average rate of 6.7% in the past 10 years, led by thermal generation, which grew by an average annual rate of 14.6%, while hydro energy grew 2.7%.*" (ProInversion, 2015). Furthermore, the "*Ministry of Energy and Mines (MINEM) has calculated that electricity demand will grow at an average rate of 8.8% per year up to the year 2017*" (IRENA, 2014).

In the following table, some key indicators for Peru are presented and compared with the respective data for Austria (2012).

Table 2.1. Key indicators for Peru and Austria in 2012. Source: own table, according to data from iea.org (2015)

Key indicators (2012)	**Peru**	**Austria**
Population (millions)	29.99	8.43
GDP (billion 2005 USD)	127.56	337.69
GDP PPP (billion 2005 USD)	310.15	306.34
Energy production (Mtoe)	23.35	12.80
Net imports (Mtoe)	-2.14	21.57
TPES (Mtoe)	21.70	33.11
Electricity consumption (TWh)	36.53	71.72
CO2 emissions (Mt of CO2)	45.82	64.73
TPES / population (toe/capita)	0.72	3.93
TPES / GDP (toe/thousand 2005 USD)	0.17	0.10
TPES / GDP PPP (toe/thousand 2005 USD)	0.07	0.11
Electricity consumption / population (MWh/capita)	1.22	8.5
CO2 / TPES (t CO2/toe)	2.11	1.96
CO2 / population (t Co2/capita)	1.53	7.68
CO2 / GDP (kg CO2/2005 USD)	0.36	0.19
CO2 / GDP PPP (kg CO2/2005 USD)	0.15	0.21

3.2. Historical development of the electricity sector

In its beginnings, the Peruvian energy sector was developed by private individuals; Peruvian petroleum producers were important for the whole continent and hydropower development started "*in the early years of the previous century*" (ESMAP, 2011). A system of concessions was established by Law No. 12378 in 1955 and the National Tariff Commission aimed to guarantee the profitability of investments (IBP, 2015). However, "*the military governments of the 1970s dedicated their efforts to nationalizing the industries, taking almost total control of the energy industry*" (Honda, J.A., 2010).

Until the early nineties, the electricity sector in Peru was thus controlled by the state and based on vertically integrated power utilities (see Figure 2.3.). "*Two of them – Electroperu and Electrolima – provided about two thirds of Peru's electricity services through the national interconnected system* […]*. Nine regional companies provided the rest to isolated power systems* […]" (Vagliasindi and Besant-Jones, 2013).

Due to economic problems, low electricity tariffs[11] and political interventions in the state-owned power sector in the 1980s, investments were scarce and the overall conditions of the electricity sector hardly favorable. "*Consequently, in 1990 only 45 percent of the population had access to electricity (a much lower proportion than in neighboring countries), the power supply was insufficient to cover demand, and power losses in the distribution segment were high – more than 20%*" (Vagliasindi and Besant-Jones (2013). This is also confirmed by Maurer and Barroso (2011), who mentioned: "*Limited investments in maintenance and the destruction of infrastructure by terrorist groups led to a power crisis in the 1990s. Existing supply covered only 74 percent of the demand requirements and distribution losses were over 20 percent. Less than half of the population had access to electricity*".

Based on the reforms implemented in Chile already in 1982, the Peruvian government subsequently adopted the Electric Concessions Law (LEC - law no. 25844) in 1992 and the Supreme Decree (No. 009-93-EM) in 1993 in order to unbundle generation, transmission and distribution and to attract the interest of private investors and companies by means of a new concession regime for electricity. Furthermore, the LEC established a supervisor (OSINERGMIN) and a grid operator (COES) for the electricity sector. Private investment in the power sector increased significantly in the years after the reforms (1996-1999), but slowed down again between 2000 and 2004.

According to Mastropietro et al. (2014), after the reform in 1992 the electricity market was based on bilateral contracts between generators and distributors. The tariffs were capped by the regulator at the so called "*busbar*" energy tariffs, i.e. based on the expected average marginal price. However, when the real marginal costs of the generators increased without adjustments in the tariffs of the regulated consumers, the generators canceled their contracts with the distributors (Maurer and Barroso, 2011). This led to a dangerously low reserve margin of the system (which further

[11] "[...] *the electricity tariffs were chosen using political rather than technical criteria, so the fact that they didn't cover even 30% of the average operating costs comes as no surprise. This was precisely what made the* [public] *companies lose USD 426 million, USD 302 million and USD 38 million in 1989, 1990 and 1991, respectively*". (Honda J.A., 2010)

deteriorated due to a water shortage in 2004) and finally to the adoption of the "Law to Secure the Efficient Development of Electricity Generation" (Law No. 28832) in 2006, which again brought significant adjustments for the electricity market in Peru.

"*The most important changes were (1) establishment of an obligatory competitive auction mechanism to contract the supply to distribution companies that is gradually replacing the original system of administered tariffs in the regulated market; (2) formalization of transmission planning nationwide and a bidding process for building and operating* […]*; (3) changing the governance of COES* […]*; (4) the pass-through of auction prices as part of the regulated generation tariff; and (5) stabilization of remuneration for* […] *transmission facilities*" (Vagliasindi and Besant-Jones, 2013).

The ultimate goal of the reforms implemented by the Peruvian government, however, was to guarantee the security of electricity supply for the country.

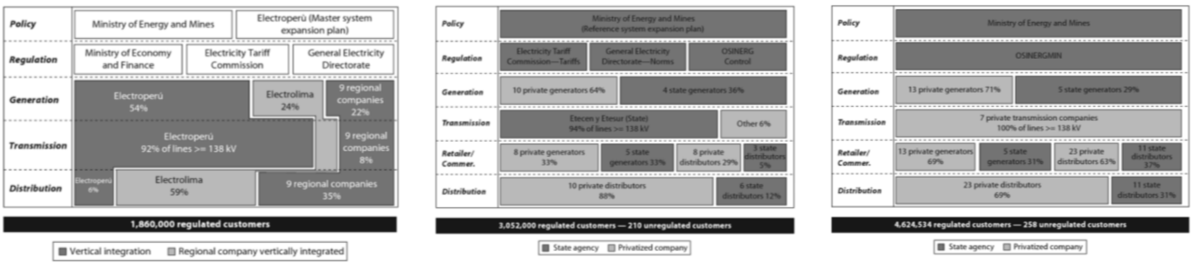

Figure 2.3. Taxonomy of the power sector in Peru (left: 1990, middle: 1998, right: 2008).
Source: Vagliasindi and Besant-Jones (2013)

Nowadays, around 70% of generation and distribution and 100% of the transmission sector is privatized. This is also confirmed by Mwenechanya (2013) who states: "*As a result, the private sector now generates 80% of the electricity, is responsible for more than 50% of the distribution and controls the operation of the interconnected system*."[12]

According to Vagliasindi and Besant-Jones (2013) the reforms had significant impacts on the performance of the electricity sector, including enhanced access to electricity (nowadays around 90%), improved security of supply (distribution losses decreased

[12] reegle.info (2015) mentions that: "*65% of the generation capacity, almost all the transmission capacity and 2 distribution companies that serve the capital of Peru has been privatised. The Government still owns a 1 GW hydro-electric plant that represents 30% of the total generation capacity and several regional distribution companies. Off-grid systems are operated by the government*".

to 8.2% in 2008), better service quality for customers and financial stability for the private companies participating in the market.

3.2.1. Electricity auctions

As one of the most important changes of the Law No. 28832 to "Secure the Efficient Development of Electricity Generation" from 2006 was the introduction of a competitive auction mechanism, this system will be discussed shortly. According to Maurer and Barroso (2011) the main principles of the Peruvian electricity auction system include:

"*a) The expected demand of regulated users should be fully contracted by distributors, at least for the next few years. This is monitored and enforced by the regulatory agency.*

b) Distributors should call for supply auctions at least three years before their demand requirement, and with a contractual duration of no less than five years, which would be insufficient for developing medium to large-scale hydro plants.

c) Distributors design and manage their own auctions (including the selection of the demand to be contracted and the auction mechanism), but the process is subject to general approval and supervision by the regulator (Osinergmin) and should follow the specific guidelines set forth in the regulations.

d) Distributors can combine their demands to participate jointly in a supply auction. Free users can request that their demand be incorporated into a supply auction organized by a distributor.

e) The regulator establishes a price cap for each auction, above which no offer would be accepted. The maximum price is only revealed if a given auction "round" does not cover all the demands put out to tender and at least one bid received is rejected because it is higher than the maximum price.

f) In case the situation described in (e) occurs, a new tender is called (i.e., a new auction round). There is no restriction for participating in a new invitation to bid for the same process: if a company participates in the first invitation to bid, it is not obliged to continue participating. Participation in the first invitation to bid does not oblige companies to participate in the second invitation to bid."

As can be seen, the intention was to strengthen the contracting by distribution companies in the forward market in order to ensure security of electricity supply for regulated users. Furthermore, the price of the auctions should become the main factor for the tariffs (however, the remuneration for generators is still divided in a regulated capacity payment and a variable payment based on the delivered electricity; see chapter 3.7.) and the contracts awarded during the auctions are indexed to local fuel prices, inflation and exchange rate (Maurer and Barroso, 2011).

Peru has conducted several electricity auctions during the last years. As the results in the first few years after the adoption of Law No. 28832 in 2006 were not always promising, some adaptions were introduced during 2008 and 2009, including the introduction of technology specific auctions and a discount factor of 15% for HPPs, which should serve as an additional incentive (Maurer and Barroso, 2011). All these measures finally led to a steady increase of the installed generation capacity of Peru. Furthermore, the procedures and mechanisms established during that time also had a significant impact on the renewable energy auctions, which were implemented in Peru from 2009 until nowadays and which will be discussed in detail in chapter 3.7.4.

3.3. Current energy and electricity supply

As can be seen in Figure 2.4. the total primary energy supply (TPES) in Peru is dominated by fossil fuels (natural gas, coal and oil), which accounted for 75% of the TPES in 2011. Bioenergy made up 15% and large hydro 9% of TPES, respectively. Other renewable energy technologies (including wind and solar) only had a share of 0.03% of TPES. Furthermore, the table shows the remarkable growth rate of TPES, which nearly doubled in Peru within 20 years (from 408 PJ in 1990 to 805 PJ in 2010). Consumption of energy in 2011 was dominated by the transport sector (38%), followed by the industrial sector (28%) and the residential sector (25%).

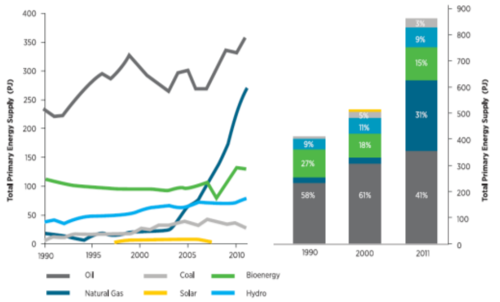

Figure 2.4. Total primary energy supply by fuel in Peru. Source: IEA, cited by IRENA (2014)

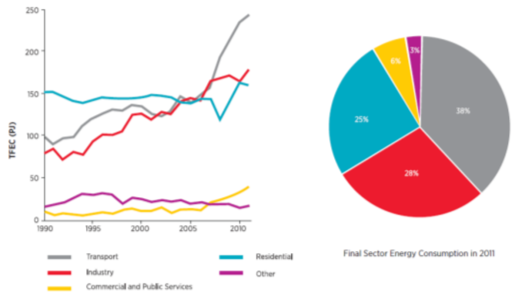

Figure 2.5. Total final energy consumption by sector in Peru. Source: IEA, cited by IRENA (2014)

The electricity sector, on the other hand, is dominated by hydropower and natural gas. As can be seen in Figure 2.6. large HPPs accounted for 54.63% of all electricity produced in Peru in 2012. Thermal electricity production (mainly natural gas) made up 43.54% of the electricity production and renewable energy provided the remaining 1.83% (sHPPs accounted for 1.23% - according to EY (2015) the figure for sHPPs up to 20 MW increased to 1.45% in 2013). Table 2.2. shows that this situation is not expected to change significantly at least in the short term.

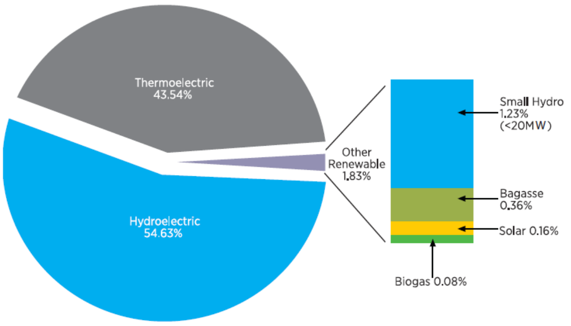

Figure 2.6. Electricity production by technology in Peru in 2012. Source: ProInversión (2013), cited by IRENA (2014)

Table 2.2. Estimation of the annual generation for 2015 and 2016 by electricity source. Source: COES, cited by EY (2015)

Source Type	2015		2016	
	GWh	%	GWh	%
Hydraulic	26,717	50.2%	31,210	52.3%
Natural Gas	23,632	44.4%	25,709	43.1%
Coal	628	1.2%	829	1.4%
Biomass	42	0.1%	42	0.1%
Wind	986	1.9%	988	1.7%
Solar	256	0.5%	257	0.4%
Residual	270	0.5%	231	0.4%
Diesel	692	1.3%	447	0.7%
Total	53,223	100%	59,713	100%

Source: Report Economic Operation Committee for the National Interconnected System (COES-SINAC) (COES) / DP- 01-2013 "Diagnostic Report of Operating Conditions of the SEIN 2015-2016" - COES

According to the latest information available from COES SINAC, the share of renewable energy generation in the SEIN further increased to 3.1% in 2014, mainly due to the renewable energy auctions which were conducted in the years before (see chapter 3.7.4.). The production of electricity from sHPPs reached 672.97 GWh in 2014, an increase of 16.71% compared to 2013. Furthermore, in 2014 the first wind turbines were connected to the national electricity grid in Peru.

Table 2.3. Sources of electricity generation by type in Peru in 2013 and 2014. Source: COES SINAC (2015)

TIPO DE GENERACIÓN		2013		2014		VARIACIÓN	
		GW.h	PARTICIPACIÓN %	GW.h	PARTICIPACIÓN %	GW.h	(%)
HIDROELÉCTRICA		20 551,96	51,81%	20 329,94	48,64%	-222,02	-1,08%
TERMOELÉCTRICA		18 118,15	45,67%	20 160,94	48,24%	2 042,78	11,27%
RECURSOS ENERGÉTICOS RENOVABLES	HIDROELÉCTRICA	576,60	1,45%	672,97	1,61%	96,37	16,71%
	BAGAZO	194,62	0,49%	146,11	0,35%	-48,51	-24,93%
	BIOGÁS	31,17	0,08%	30,32	0,07%	-0,85	-2,73%
	SOLAR	196,93	0,50%	199,30	0,48%	2,38	1,21%
	EÓLICO		0,00%	256,31	0,61%	256,31	
TOTAL		39 669,43	100,00%	41 795,89	100,00%	2 126,46	5,36%

It is interesting to have a look at the historical data of electricity production in Peru. As can be seen in Figure 2.7. hydropower always had a dominant share in the production of electricity (with values up to 80 – 90 %) in the past. However, the start of the "*large Camisea gas fields in central Peru's Ucayali basin* [in 2004] *increased the production of natural gas tenfold in the last decade*" (ITA, 2014).

According to MINEM (2014), cited by IRENA (2014), the total installed generating capacity connected to the National Interconnected Electric grid (SEIN) in 2013 "*consisted of 23 hydropower plants with a total capacity of 3 270 MW and 32 thermal power stations with a total capacity of 5 260 MW*". However, hydropower still had a slightly higher electricity output (in GWh) as thermal plants are rather used for peak times and dry seasons. Power plants in Peru can be either connected to the SEIN (87%) or for self-generating companies (13%), mainly large industries and mines.

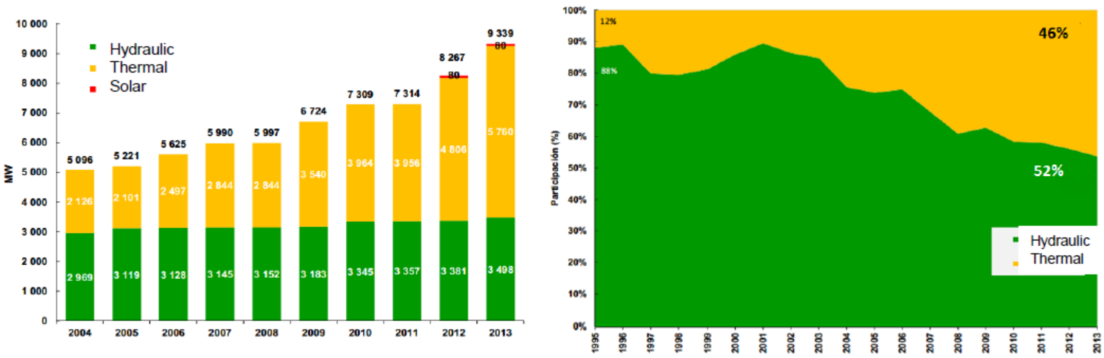

Figure 2.7. Power installed in the electric market by technology in MW (left) and distribution of the energetic matrix of Peru (right). Source: MINEM, cited by ProInversion (2015)

According to americaeconomia.com (2015), the total installed capacity in Peru (power plants connected to the SEIN and for own use) increased to 11,284 MW at the end of 2014 (up from 6,016 MW in 2004). Furthermore, it is reported that the pipeline projects will add 4.4 gigawatts (GW) of new capacity by 2019; a further increase of around 40% compared to 2013 (rumbominero.com, 2015).

3.4. Potential of hydropower and renewable energy technologies

The potential for hydropower has been diligently researched in the "*Atlas of the Hydroelectric Potential of Peru*" ("*Atlas del Potencial Hidroeléctrico del Perú*"), which was published by the Republic of Peru together with the World Bank and the Global Environment Facility (GEF) in 2011.

The atlas, which is assessing the national water resources for hydro-electric power generation in the range of 1 – 100 MW, concludes with the following results:

Table 2.4. Theoretical and technical potential for hydropower in Peru in MW. Source: own table based on Republic of Peru (2011)

Theoretical Potential (MW)				Technical Potential (MW)			
	Total	Excluded	Usable		Total	Excluded	Usable

Pacific	37,451	7,949	29,502	Pacific	11,402	2,671	8,731
Atlantic	197,221	57,900	139,321	Atlantic	86,971	26,345	60,627
Titicaca	1,191	5	1,186	Titicaca	87	0	87
Total	**235,863**	**65,854**	**170,009**	**Total**	**98,460**	**29,016**	**69,445**

As can be seen, the total theoretical potential for HPPs between 1 and 100 MW was calculated at 235,863 MW, mainly located in the Atlantic region. However, as protected areas, locations with a concession in force and some buffer zones were excluded, the usable theoretical potential was calculated at 170,009 MW.

The technical potential for hydropower is also mainly located in the Atlantic region of Peru (87.3%). The total technical potential for HPPs in the range of 1 – 100 MW was calculated at 98,460 MW, of which 29,016 MW were excluded. The usable technical potential was thus reported at 69,445 MW.

The study further provides results for each department, region and river basin and also lists up the 100 most promising hydropower projects in Peru, which have been researched in the course of the study.

Regarding sHPPs with an installed capacity of up to 20 MW, exact studies and data could not be found and it seems that detailed measurements have not been conducted. Also ESMAP (2011) mentioned that "*there is no solid basis for estimates of the technical potential of small hydropower (<20 MW)* […] *because of the lack of inventories of such resources.*" However, the same study later indicates that "*Peru's significant small hydropower potential, defined as plants with capacity less than 20 MW, is conservatively estimated at over 1,600 MW*" (ESMAP, 2011).[13]

Moreover, the WSHDR (2013) states: "*There are possibilities for incorporation of small hydropower projects in existing hydraulic structures (at reservoir outlet works, canal drop structures, etc.). Assuming a similar ratio of total installed capacity to irrigated areas in Peru as in Chile, Peru possibly has a potential of 510 MW for small-*

[13] It should, however, be mentioned that the World Small Hydropower Development Report (WSHDR, 2013) stated: "*The gross small hydropower potential (up to 20 MW) is 170,000 MW, while both the technical and economic potential is reported as 69,445 MW in a questionnaire by the Ministry of Energy*". As the WSHDR (2013) also presents a table indicating that that out of a potential of 69,445 MW, 3,514.02 MW of sHPPs below 20 MW have already been installed (in fact the total installed capacity of HPPs in Peru was around 3.514 MW in 2013), this strongly leads to the impression that the person filling out the questionnaire just stated the total potential and technical potential for HPPs instead of the potential for sHPPs up to 20 MW. WB (2010) mentions that the only comprehensive evaluation of hydro resources in Peru was done in 1979 and concluded with the following results: theoretical potential 206,107 MW and technical potential 58,404 MW. These estimates slightly increased in the "*Atlas of the Hydroelectric Potential of Peru*" (Republic of Peru, 2011).

to medium hydropower plants that could be incorporated into existing irrigation infrastructure".

The incorporation of sHPPs in existing hydraulic structures has several advantages, including "[…] *easy access, limited geotechnical uncertainties, minimal civil works, and hence, short implementation times*" (ESMAP, 2011). Furthermore, ESMAP (2011) mentions that around 30% of all sHPPs built between 1998 and 2006 have utilized existing irrigation structures.

Peru thus has a significant hydrological potential. However, also with regard to other renewable energy resources, Peru has been endowed with a huge potential. As such, the recently published "*Peru's Business and Investment Guide 2015 – 2016*" from Ernst & Young (EY, 2015) mentioned that Peru has one of the highest ratios of renewable energy reserves measured as technical potential / installed capacity.

Table 2.5. Technical potential, installed capacity and technical potential / installed capacity in Peru (MW). Source: MINEM, cited by EY (2015)

Energy Type	Total Power (MW)	Country's Installed Capacity (MW)	Total Power / Capacity (Times)
Hydraulic	69,000	2,954	23
Wind	22,000	142	155
Solar	Indefinite	80	-
Biomass	Indefinite	27.4	-
Geothermal	3,000	0	to be exploited

Source: Ministry of Energy and Mines (MINEM) / Prepared by EY

This is also confirmed by Mendoza (2012), cited by IRENA, 2014: "*Hydropower potential has been estimated at 70 000 MW, mostly concentrated in the Cuenca del Atlántico*"[14] and Mwenechanya (2013): "*For wind, out of an estimated of 22,000 MW usable potential, only 0.65% has been exploited. Similarly the usage of solar and biomass potential is 1% and 6.1%, respectively* […]".

Local renewable energy sources present huge opportunities and benefits for Peru and the countries in the region. According to Mastropietro et. al. (2014), the most important advantages of Renewable Energy Sources for electricity (RES-E), especially wind, solar, and biomass in South America include:

- "*RES-E represent the opportunity to diversify the current generation mix, in many cases heavily based on hydropower. Furthermore, some of them, as wind and biomass, present seasonalities which are complementary to hydro periodicity* […].

[14] IFC (2011) stated that only 4.7% of the hydrological potential is currently exploited in Peru.

- *The comparatively short construction times of RES-E turn them into a valuable alternative to avoid under or over procurement, especially taking into account the demand growth rates in the region and the long lead times demanded by hydro plants.*
- *RES-E are often the most efficient solution to improve the access to electricity*[15] *for a large number of people living in the numerous isolated areas in the region.*"

Furthermore, "*the high proportion of large-reservoir hydro plants in these systems provides an abundant storage and fast ramping capability that mitigates the extreme impact of the intermittency and non-dispatchability of RES-E technologies*" (Mastropietro et. al., 2014).

Apart from using an indigenous energy source, which protects our environment and further diversifies the energy mix of Peru, RE technologies also attract local and foreign investments. The IFC has estimated the renewable energy generation and investment potential in Peru from 2012 to 2020, which shows a huge potential in the years to come.

Table 2.6. Renewable energy generation and investment potential from 2012 to 2020. Source: IFC (2011) cited by ITA (2014)

Renewable Energy Source	Potential Cumulative Demand	Total Investment Potential Lower Margin (USD)	Total Investment Potential Upper Margin (USD)
Photovoltaic	540 MW	$1,350,000,000	$1,620,000,000
Wind	1,800 MW	$3,240,000,000	$3,600,000,000
Small Hydroelectric	2,000 MW	$3,000,000,000	$3,600,000,000
Biomass	1,800 MW	$3,240,000,000	$4,500,000,000
TOTAL	**6,140 MW**	**$10,830,000,000**	**$13,320,000,000**

So far, Peru has achieved to attract the interest of local and international renewable energy developers and investors. "*In 2012 alone, Peru almost doubled its cumulative investments* [in renewable energy technologies] *from the previous six years – reaching $1.2 billion (which was mostly in the wind sector)*" (ITA, 2014). According to global-climatescope.org (2015), US$ 3.4 billion have been invested in renewable energy projects in Peru between 2008 and 2013, thereof US$ 773m in 2013 alone (evenly divided between wind and sHPPs).

[15] Mwenechanya (2013) also mentioned: "*Additionally, renewable sources offer the only solutions for electrifying rural communities that are far from the grid, in which an inhospitable landscape means expensive line construction costs*".

3.5. Regulatory Framework

1992 - Electricity Concessions Law (*Ley de Concesiones Eléctricas*, Law No. 25844). This decree vertically separated the electricity industry into generation, transmission and distribution and enabled the participation of the private sector in the Peruvian energy system.

1997 - Antimonopoly and Antioligopoly Law of the Electrical Sector (*Ley Antimonopolio y Antioligopolio del Sector Eléctrico*, Law No. 26876). "*This new law limits horizontal integration between companies in the generation, transmission and/or distribution businesses to 15% of the total market. Companies also may not hold more than 5% of the market in any one sector*" (IBP, 2015). Besides, this law foresees that companies who want to sell shares or merge need an approval from Indecopi, the consumer protection institute.

2006 - Law for Efficient Generation Development (Law No. 28832). "*The Law for Efficient Generation Development aims to guarantee efficient electricity generation, reducing the vulnerability of the Peruvian electrical system to price volatility and long blackout periods. It also provides the assurance of a competitive electrical tariff to consumers*" (IRENA, 2014). The main element of Law No. 28832 was the introduction of auctions for the procurement of electrical supplies to regulated consumers.

2008 - Legislative Decree for the Promotion of Investment in Electricity Generation with Renewable Resources (*Decreto Legislativo de Promoción de la Inversión Para la Generación de Electricidad con el Uso de Energía Renovable*, Legislative Decree No. 1002) and its Regulations. This degree promoted renewable energy resources like biomass, wind, solar, geothermal, tidal and hydropower (with an installed capacity of less than 20 MW) as a national priority. Decree No. 1002 set the target that up to 5% of the national energy demand should be covered by the above mentioned renewable technologies (reviewed every 5 years) and guaranteed a priority dispatch for RE technologies by COES until the above mentioned target has been reached. In case of RE auctions, the winning projects are entitled to enter into a 20 year PPA with the government, which provides long term stability and security for project developers, investors and banks. As an additional incentive for renewable energy technologies, Decree No. 1058/2008 "*introduced a scheme of accelerated depreciation equal to 20% per year (this means a 5-year tax postponement) for all the investments on machines, equipment and constructions of RES-E projects*"

(Mastropietro et al., 2014). Finally, the sale of electricity from renewable energy sources is entitled to early Value Added Tax (VAT) recovery.

2011 - Regulations for the generation of electricity from renewable energies (Supreme Decree No. 012-2011-EM). "*Regulates the provisions of Legislative Decree Nº 1002 (described above) and establishes the administrative procedure for RER tenders and for the award of concessions for RER electricity generation*" (IFC, 2011).

The National Energy Policy of Peru 2010 – 2040 (*Política Energética Nacional del Perú 2010 – 2040*) has been passed in November 2010 (Decree No. 064-2010-EM). It sets national energy policy targets and aims to promote renewable energy and energy efficiency and a diversification of the energy sources in order to strengthen the security of supply. According to a presentation from OSINERGMIN (export-erneuerbare.de, 2015), the target until 2040 is to have an energy mix of 40% hydro, 40% natural gas and 20% RE technologies. Mwenechanya (2013) mentioned that the "*aim of the objectives is to develop an energy sector that has minimum impact on the environment*.

The National Rural Electrification Plan 2013 – 2022[16] (Plan Nacional de Electrificación Rural 2013 - 2022) aims "*to raise the rural electrification rate from 87% to 95% by 2016*" (IRENA, 2015).[17] In order to achieve this goal, a call for auction was announced on November 7, 2014 for 500,000 off-grid PV systems. "*With this auction, Peruvian Government expected to cover 1,832 districts in 194 provinces and 24 regions in Peru.*" (global-climatescope.org, 2015). The auction was won by Ergon Peru SAC, who concluded a 15-year contract including construction, installation, operation, maintenance and replacement. Already in August 2015 a minimum of 2,000 off-grid PV systems should be installed in rural areas. Commercial operation is expected on December 31, 2018.

As can be seen, Peru is working hard to establish a favorable investment climate in the country. This holds especially true for renewable energies. "*In fact, recent legislation suggests that Peru's energy mix will begin to diversify in earnest, as government incentives and rising consumer demand drive the development of new renewable energy projects across the country*" (ITA, 2014). This has also been

[16] Before, the Plan Nacional de Electrificación Rural 2011 – 2020 was in place, which objective was to increase the electrification rate up to 88.4% by the year 2020 (ARE, 2014)
[17] According to IRENA (2015), the national electrification rate already increased from 55% in 1993 to 87.2% in 2012.

acknowledged by various publications such as the Climate Scope[18], which ranked Peru 4th out of 26 countries in the Latin American and Caribbean Region with regard to the investment climate for clean energy (Climatescope, 2013). The global assessment (Climatescope, 2014), which compares the investment climate and policies for clean energy investments ranks Peru 11th out of 55 emerging markets in Africa, Asia, and in Latin America and the Caribbean. Furthermore, the Industry & Analysis (I&A) department of the International Trade Administration of the US stated: "*Peru ranked eighth in I&A's 2014 Renewable Energy Top Markets Report, which examined potential export markets for the sector through 2015*" (ITA, 2014). The Doing Business Report 2015 from the World Bank Group (WBG, 2014) ranked Peru's business environment as 35th out of 189 countries. With regard to Latin American and Caribbean countries, Peru ranked second after Colombia (rank 34) in the Doing Business Report 2015.

3.6. Key actors in the electricity sector

MINEM - *Ministerio de Energía y Minas del Perú* (Ministry of Energy and Mines of Peru). "*MINEM is the cornerstone of the institutional framework for renewable energy in Peru*" (IRENA, 2014). The Ministry formulates policies and regulations with normative and supervision powers, acts as a grantor of electrical rights in representation of the Peruvian State, initiates RE auctions and signs electricity supply contracts. Within MINEM the following divisions are relevant for renewable energy:

- *Dirección General de Electricidad* (DGE) - Directorate-General for Electricity[19]
- *Dirección General de Electrificación Rural* (DGER) - Directorate-General for Rural Electrification
- *Dirección General de Hidrocarburos* (DGH) - Directorate-General for Hydrocarbons
- *Dirección General de Asuntos Ambientales Energéticos* (DGAAE) - Directorate-General for Energy-Related Environmental Affairs

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[18] "*The Climatescope is a unique country-by-country assessment, interactive report and index that evaluates the investment climate for climate-related investment worldwide*". Source: *global-climatescope.org* (2015)

[19] According to IRENA (2014), the functions of DGE include: "*Grants the rights to carry out electricity-related activities. This includes the promotion of power projects, governance of central government policies on electricity subsector development, and proposals for Peruvian electricity standards.*"

Even though MINEM is the main national authority with regard to renewable energies, regional governments also play a significant role. They "*are responsible for formulating, implementing, evaluating, monitoring and managing energy plans and policies within their own boundaries, in line with national policies and sector plans. In addition, they are responsible for granting generation concessions for plants with an installed capacity of 500 kilowatts (kW) - 10 MW*" (IRENA, 2014).[20] Furthermore, they are responsible for rural electrification programmes and land use planning (identification of suitable sites).

OSINERGMIN - *Organismo Supervisor de la Inversión en Energía y Minería* (Supervisory Organization for Investment in Energy and Mining). According to EY (2015), OSINERGMIN is "*responsible for supervising and controlling compliance with legal and technical provisions of activities developed by companies in the electricity and hydrocarbons subsectors, as well as compliance with legal and technical regulations related to the conservation and environmental protection. It is also in charge of quality and quantity control of fuels and higher prerogatives as part of its power to impose sanctions*." As such, OSINERGMIN can be called the State regulatory agency in the energy sector, with powers of control and supervision of electrical activity including tariff setting powers[21] and the authority to regulate the sector (including conducting RE auctions) and to settle disputes between electricity market participants.

COES SINAC - *Comité de Operación Económica del Sistema Interconectado Nacional* (Committee for the Economic Operation of the Electric System). COES is a nonprofit private entity, designed to coordinate the secure and efficient operation of the National Interconnected Electric Grid (*Sistema Eléctrico Interconectado Nacional* - SEIN), ensuring the best use of the available energy resources. It is also the Spot Market administrator and directs the operation of the electric transmission grid. Furthermore, it "*approves any pre-operative studies of projects that are to be connected to the SEIN, acts as an intermediary and regulates power purchase agreements*" (ITA, 2014). Its members are generation, transmission and distribution companies and large consumers.

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[20] "*For projects under 500 kW, concessions are not required, article 2 and 3 of Law Decree N° 25844*" (IRENA, 2014).
[21] The *Gerencia Adjunta de Regulación Tarifaria* (GART) - Office for Tariff Regulation (a division of OSINERGMIN) calculates and proposes the electricity tariffs in Peru.

PROINVERSIÓN - *Agencia de Promoción de la Inversión Privada* (Peruvian Investment Promotion Agency). ProInversión is a public entity attached to the Ministry of Economy and Finance (MEF) with the mission to promote investment in the private sector and to boost Peru's competitiveness and sustainable development. ProInversión offers its services free of charge and provides inter alia information about incorporating a business in Peru, identifying investment opportunities, learning about the processes of public-private partnerships, etc. According to EY (2015), ProInversión supports investors in the following three stages.

Table 2.7. Services of ProInversión. Source: EY (2015)

Pre-Incorporation	Incorporation	Post-Incorporation
‣ General information service: macroeconomic data, legal framework, tax system, etc. ‣ Specific information service, at the request of the potential investor. ‣ Preparation of agendas with: potential partners, suppliers, clients, authorities, associations, unions, etc.	‣ Guidance on obtaining municipal permits and licenses for the establishment of an industrial or commercial business. ‣ Contact and accompaniment to the regions and potential production zones. ‣ Advisory on migratory processes for entry and residence of business people.	‣ Establishment of a network of contacts with public and private companies. ‣ Guidance for the expansion of the business. ‣ Identification of administrative barriers.

Furthermore, according to the *Anuario Estadístico de Electricidad 2013* (MINEM, 2014), 57 generation companies are participating in the Peruvian electric market and 73 companies are producing electricity for own use.

With regard to hydropower, 39 companies (136 HPPs - 3,451 MW - 21,709 GWh) were generating electricity for the market and 17 companies (37 sHPPs - 106 MW – 610 GWh) for own use in 2013.

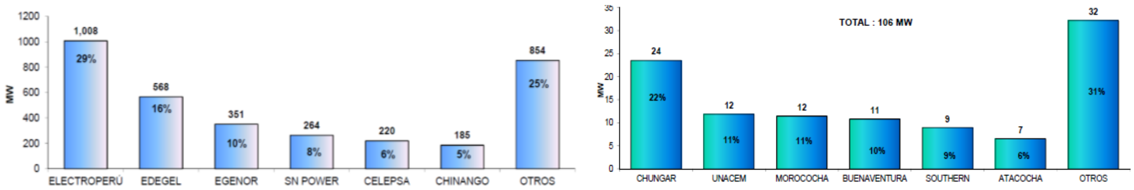

Figure 2.8. Installed hydro capacity by company in the Peruvian electricity market (left, total: 3,451 MW) and for own use (right, total: 106 MW) in 2013. Source: MINEM (2014)

According to MINEM (2014), of the 39 hydro companies producing for the electric market, 16 companies had more than 20 MW installed capacity and 23 companies were operating sHPPs below 20 MW. Hydro projects for own use were all below 20 MW in 2013 (except from *Empresa Administradora Chungar S.A.C.* with 23.56 MW).

Regarding renewable energy companies in the planning, engineering and supply sector, IFC (2011) stated: "*There are currently 26 project developers with technical capability to manage renewable energy projects in the Peruvian market. In addition, there are 24 companies that supply renewable energy technologies, from turnkey systems to individual pieces of equipment.*" Besides, there exist the following business associations related to renewable energy: *Asociación Peruana de Energías Renovables* (APEGER), *Asociación Peruana de Energía Solar* (APES), *Sociedad Nacional de Minería Petróleo y Energía* (SNMPE) and *Asociación de Consumidores Intensivos de Energía* (ACIDE).

3.7. The Peruvian electricity market

In general, the Peruvian electricity market consists of the spot market, the free market, the regulated market and the auction market, as can be seen in Figure 2.9.

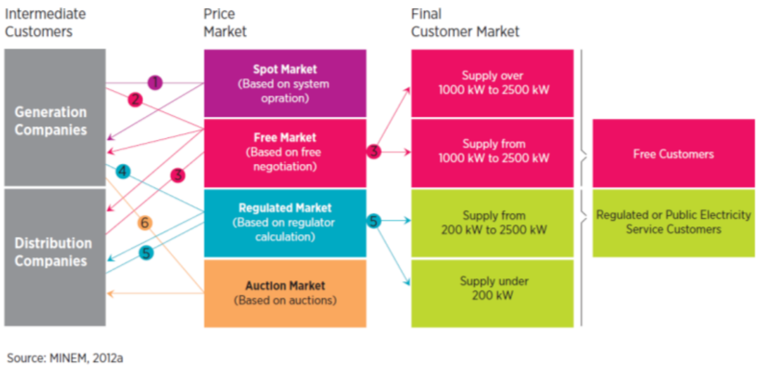

Figure 2.9. Electricity market in Peru. Source: IRENA (2014)

Electricity generators thus can sell their electricity on the spot market (1) or on the free market, which is based on open negotiations (2). "*The free market applies to transactions between generation and distribution companies as well as distribution to final* [large] *customers*" (IRENA, 2014). In the regulated market (3), on the other hand, generators can sell their electricity to distribution companies at a price set by OSINERGMIN; the distributors then sell the electricity to final regulated users (up to a demand of 2.500 kW) based on the rates of the regulated market. Finally, electricity can be sold via auctions (4) from generation to distribution companies.

The revenues for power plant operators in the Peruvian electricity market consists of the following two components:

1) Fixed monthly capacity fee (*Precio de Potencia*): This fee depends on the installed generation capacity and is adjusted by OSINERGMIN on an annual basis. The applicable capacity fee can be found on the website of OSINERGMIN.

2) Variable fee for the produced electricity: The price for the electricity produced depends in which market the electricity is sold (see below). In general, the following opportunities exist:

- Electricity sales on the spot market
- Power Purchase Agreements with a distribution company or large consumer
- Renewable energy auctions ("Subasta")

Finally it should be mentioned that the Peruvian electricity sector distinguishes between two types of consumer: regulated and large (free) consumers. The price for regulated consumers is fixed and based on consumption. Large consumers on the other hand can negotiate the price with their supplier. Consumers with an annual peak demand of up to 200 kW are defined as regulated consumers by law. Consumers between 200 kW and 2,500 kW peak demand are allowed to choose being either a regulated or large consumer. Consumers with an annual peak of more than 2,500 kW are defined as large (free) consumers.

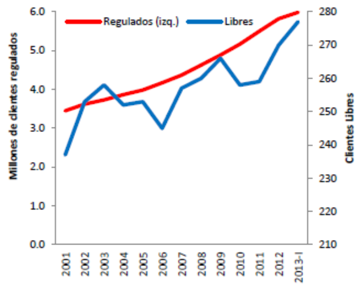

Figure 2.10. Number of regulated and free consumers in Peru. Source: OSINERGMIN (2013)

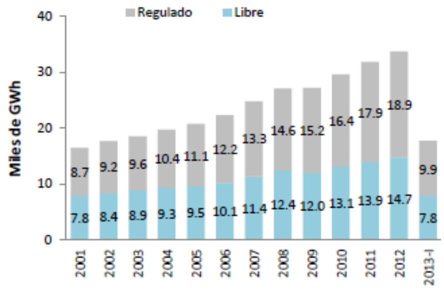

Figure 2.11. Sale of electricity in GWh to regulated and free consumers in Peru. Source: OSINERGMIN (2013)

According to the latest available Monitoring Report of the Electrical Market ("*Reporte Semestral de Monitoreo del Mercado Eléctrico*") from OSINERGMIN (2013), Peru had around 6 Mio. regulated and 277 large consumers. Electricity consumption, however, was much more evenly divided between these groups – free consumers bought 44% and regulated consumers 56% of the total electricity sold in the first half of 2013.

3.7.1. Spot market

The spot market exchanges electricity for immediate demand between generators who are connected to the SEIN. "*The "spot market" is typically used to transfer electricity between generators on an "as needed" basis, as distributors are barred from buying directly from the market. However, revisions to who can enter Peru's spot market are expected in 2016*" (ITA, 2014). The spot market and real-time dispatch of generation supply is managed by the COES.

The spot price for electricity is calculated every 15 minutes based on the marginal cost values[22] to supply the given demand. The spot price is thus cost based and also zonal. COES (2015) explains that the variations of the marginal costs are directly related to the behavior of the hydrological basins exploited by the generation system, the operational discharge strategy for reservoirs and lakes as well as the availability of more efficient thermal units.[23] Also EnerSur (2014) mentioned in this regard that the "*volatility of the spot price is mainly driven by hydro conditions, gas transport availability, main plants availability and high voltage transmission restrictions*".

ESMAP (2011) further describes that COES "*dispatches on the basis of "audited" variable costs, which are submitted monthly by the generators (except that gas generators may provide a yearly price). The marginal cost is therefore simply the cost of the most expensive unit in the system*." The spot market is thus described as classic power pool, determined by the difference between the contracted quantities and demand. This situation is however advantageous for sHPP developers as the "*procedure makes it likely that small hydro will be dispatched at all times largely mitigating any off-take risk because uncontracted power will invariably be taken at the system marginal cost*" (ESMAP, 2011).

According to BTG (2015) "*the average spot price at the Santa Rosa bar (Lima) was ~US$16/MWh* [in May 2015]*, the lowest average for the month since 2001*". As can be seen in Figure 2.12. spot prices changed significantly over time. As such, the average spot prices on a yearly base were as low as 15.9 US$/MWh in 1999, but then increased steadily (2000: 21.6 US$/MWh, 2001: 21.9 US$/MWh, 2002: 27.2

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[22] Vagliasindi and Besant-Jones (2013) explain: "*The marginal energy price is a fluctuating value determined by the operating cost of the most expensive generating unit needed to cover the peak demand at a specific moment.*"

[23] "*Las variaciones de los costos marginales estan directamente relacionadas con el comportamiento hidrológico de las cuencas aprovechadas por el sistema de generación, la estrategia operativa de descarga de los embalses y lagunas asi como la disponibilidad de las unidades termoeléctricas mas eficientes*" (COES, 2015).

US$/MWh, 2003: 38.1 US$/MWh). Between 2004 and 2008 spot prices reached an absolute peak compared on an annual basis (2004: 68.6 US$/MWh, 2005: 63.4 US$/MWh, 2006: 68.1 US$/MWh, 2007: 38.3 US$/MWh, 2008: 88.7 US$/MWh). After that, spot prices decreased again (2009: 32.0 US$/MWh, 2010: 21.5 US$/MWh, 2011: 23.6 US$/MWh, 2012: 32.4 US$/MWh, 2013: 26.5 US$/MWh, 2014: 24.6 US$/MWh). In 2015, spot prices have so far (January-May) even further decreased to an average of 15.4 US$/MWh.[24] As already explained before, the reason for the increase of the spot prices around 2004 were "*due to limited hydro production and delays in the expected implementation of new generation*" (ESMAP, 2011), which finally resulted in the new legislation of 2006.

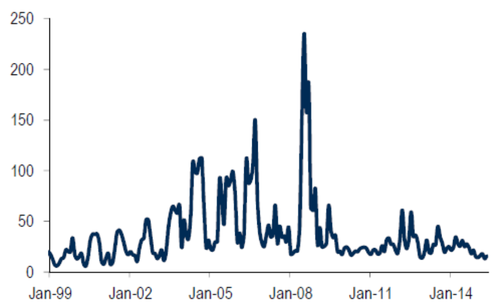

Figure 2.12. Historic average spot prices at the national grid (SEIN) in Peru. Source: COES SINAC, cited by BTG (2015)

However, it should be mentioned that the general opinion expects energy prices to increase in the years to come.

"*According to energy analysts, the price of energy is expected to rise in future. Peru is currently experiencing artificially low prices for natural gas since pricing for the block currently in use (Block 88 of the Camisea project) does not include the exploration costs it incurred, creating market distortions and barriers to the promotion and implementation of renewable energy and energy efficiency projects. When current sources are depleted (in roughly 20-30 years from now), natural gas from other blocks will command a much higher price that includes the full cost of exploration*" (IFC, 2011).

This will – at least in the long run – have a significant effect on the spot prices, but also on the prices negotiated in PPAs with distribution companies and large consumers (see next chapters).

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[24] Annex 6 provides detailed information about the spot prices in Peru from 1999 up to May 2015 (Source: BTG, 2015).

3.7.2. Free or wholesale market

At the free or wholesale market, generators can either sell electricity to distribution companies or directly to large final consumers (mainly mines and industries). Prices, time frames and other terms and conditions are negotiated bilaterally and documented in power purchase agreements (PPAs), "[…] *which are not regulated by the Peruvian Government*" (ITA, 2014).

According to the *Anuario Estadístico de Electricidad 2013* (MINEM, 2014), the average price for electricity sold in the free market was 6.7 USD cent / kWh from generators and 9.0 USD cent / kWh from distributors in 2013.

Table 2.8. Average electricity prices in USD cent/kwh from generators and distributors in the free market from 2000 to 2013. Source: own table based on MINEM (2014)

	00	01	02	03	04	05	06	07	08	09	10	11	12	13
Generators	5.2	4.5	4.5	4.5	5.2	5.5	5.6	5.4	6.7	5.7	5.4	6.0	6.5	6.7
Distributors	5.3	5.4	5.2	5.3	5.4	5.7	5.4	5.4	6.2	6.6	6.9	7.8	8.1	9.0

Finally, it is important to note that "[…] *generators are able to inject or withdraw from the Peruvian spot market in order to uphold the contracts they have signed with their customers in the wholesale market*" (ITA, 2014).

3.7.3. Regulated market

The regulated market includes most of the electricity consumers, generators, transmission companies and distributors in Peru. "*In this market, distributors are required to ensure power supply through contracts with generators, and are bound to provide electricity to everyone that requests it within their concession zone*" (ITA, 2014).

According to estore.enerdata.net (2015), the "*price of electricity is US$8.4c/kWh for industry and US$14.1c/kWh for the residential sector (2013). The prices are readjusted twice a year by the regulatory body OSINERGMIN, with an additional revision every 4 years*."[25] The *Anuario Estadístico de Electricidad 2013* (MINEM,

[25] ITA (2014) stated (based on information from OLADE and UNIDO, 2011): „*In 2010, on average, the users' end price was composed of 50.8% from generation costs, 36.4% from distribution costs, and 12.8% from transmission costs. Bloomberg New Energy Finance indicated that the average retail rate in Peru is generally much lower than in neighboring countries: on average, Peruvian consumers are paying $107/MWh versus $177/MWh for the Latin America and Caribbean region*."

2014) stated that the average price for electricity sold in the regulated market was 12.2 USD cent / kWh in 2013 (2012: 12.2 USD cent / kWh and 2011: 11.1 USD cent / kWh).

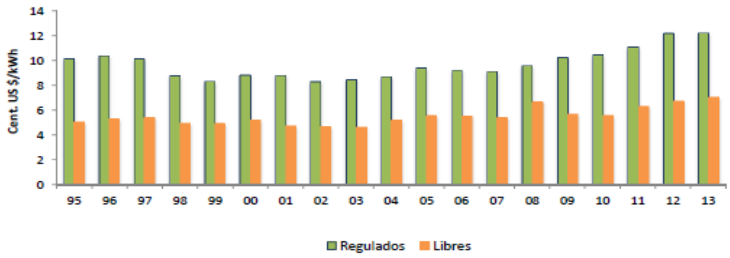

Figure 2.13. Evolution of the average electricity price (USDcents/kWh) in the regulated and free market between 1995 and 2013. Source: MINEM (2014)

Prices in the regulated market are adjusted by OSINERGMIN (split into peak times / off-peak times and by the different regions of Peru) and can be downloaded at its website. PPAs in the regulated market are normally concluded for 10-20 years.

It should be mentioned, however, that AHK (2014) states that a prerequisite for a PPA with OSINERGMIN is the capability to provide base load to the grid. This means that solar and wind energy can so far not enter into a PPA with the regulator (except in the auction market described below). sHPPs and biomass projects are considered as eligible for PPAs in the regulated market.

3.7.4. Renewable energy auctions

3.7.4.1. Background

Renewable energy auctions have emerged as an essential policy instrument for many countries in order to develop additional power-generation capacities, attract competition and spur renewable energy technologies. According to IRENA and CEM (2015) the "*number of countries that have adopted renewable energy auctions increased from 6 in 2005 to at least 60 by early 2015*".

In South America, regulatory reforms always aimed to attract additional investments in order to cover the increasing demand. "*In order to achieve this goal, the countries in the region which in the eighties and early nineties opted for market-oriented schemes, have rebuilt in the last decade their regulatory frameworks around long-term auctioning*" (Mastropietro et al., 2014).

Nowadays, different approaches and methodologies with regard to energy auctions have emerged. Mwenechanya (2013) distinguishes between First-Price Sealed-Bid Auctions (bidders submit sealed bids simultaneously, lowest price wins), Descending Clock Auctions (auctioneer sets price and receives bids indicating the quantities to be supplied at that price – if the quantities exceed the future demand, the auction is repeated with a lower price until the price matches quantity – all bidders are paid according to the clearing price) and Pay-as-bid or Discriminatory Auctions (auctioneer collects bids starting with the lowest bid until the required quantity has been reached – all bidders below the clearing price are paid according to their financial offer).[26]

Mwenechanya (2013) mentioned that Peru adopted in principle the Pay-as-bid or Discriminatory Auction design, but "*adapted it through a strong reliance on of* [sic] *financial guarantees instead of technical and financial due diligence procedures. By so doing Peru achieved a simplicity that is one of the strong points of its auction system*" (Mwenechanya, 2013).

3.7.4.2. Process and key actors involved

The key actors involved in the auction process are MINEM, OSINERGMIN-GART and COES. According to IRENA (2014), "*MINEM defines the structure of the auction, the quantity of energy requested and the allocation of that amount among the various renewable energy technologies (i.e., the ministry sets a cap according to technology).*" global-climatescope.org (2015) mentions that MINEM evaluates every two years in August the necessity to call for auctions. Furthermore, MINEM is responsible for the award of contracts and signs PPA contracts and concessions. OSINERGMIN-GART is responsible for the operational process and proposes the price cap for each technology. "*The price set takes a number of factors into consideration, such as the type of technology, project cost, cost of capital and reasonable rate of return*" (IRENA, 2014). In fact, the main criteria during the evaluation of the bids are the price per MWh and the capacity to cover the energy demand (AHK, 2014.) The maximum prices for the first auction were determined by OSINERMIN based on studies from international consultants (depending on the specific technology, investment costs, variable costs, grid connection costs, an investment horizon of 20 years and a rate of return of

[26] Detailed information about the design of renewable energy auctions can be found in: IRENA and CEM (2015), *Renewable Energy Auctions – A Guide to Design*.

12%).[27] The winning projects enter into a 20 year PPA and are obliged to supply the specified electricity into the grid (if the generators underperform, they have to pay a penalty, see below). COES is supporting MINEM with regard to information about the needed power and the status of the grid infrastructure. Furthermore, an auction or steering committee is established, which is comprised of representatives of MINEM and OSINERGMIN. "*The Auction Committee sets the maximum price applicable to each quota, but keeps these values confidential*" (Mwenechanya, 2013). After all bids have been received, they are opened and evaluated by price (from lowest to highest). Those bids which exceed the maximum price are rejected. In case the energy offered in the bids (in MWh) is less than the required energy, all bids are accepted. In case the energy offered in the bids (in MWh) exceeds the requirements, "*the Committee may accept partial bids (partial adjudication) or call for a second round of the auction*" (Mwenechanya, 2013).

The contractual conditions of a PPA awarded through the auction process include: a guaranteed purchase for 20-year from commercial operation date, denominated in US Dollars and indexed to inflation (including a Sovereign investment grade country as counterparty).

3.7.4.3. Results of the first renewable energy auction

In June / August 2009 the first call for auction was announced by MINEM. On October 15, 2009 OSINERGMIN officially started the call for auction (from this day on generators could buy the bidding document package ('Bases')), requesting in total 1,314 GWh/year from the following renewable energy sources: biomass (813 GWh/year), wind (320 GWh/year), solar (181 GWh/year) and small hydro (500 MW in total; up to 20 MW installed capacity). The deadline for registration of participants was December 21, 2009 and for submission of the sealed bids January, 18 2010. Already on February 12, 2010 the winning projects were selected and awarded (global-climatescope.org, 2015).

[27] The "*mechanism considers a premium on the top of the market price in order to guarantee a 12% rate of return, which must be assigned through competitive bidding and it is settled once a year*" (Mastropietro et al., 2014).

However, the first renewable energy auction call from 2010 finally covered only 68% (887 GWh/year) of the total energy required from biomass, wind and solar. Regarding sHPPs, only around one third of the quota (162 MW from 500 MW) was fulfilled.

Table 2.9. Results of the first call of auction. Source: OSINERGMIN (2010), cited by IRENA (2014)

	Biomass	Wind	Solar	Total
Energy required (GWh/year)	813	320	181	1 314
Energy awarded (GWh/year)	143	571	173	887
Percentage awarded	**18%**	**178%**	**96%**	**68%**
Small Hydropower				
Power required (MW)		500		
Power awarded (MW)		162		
Percentage awarded		32%		

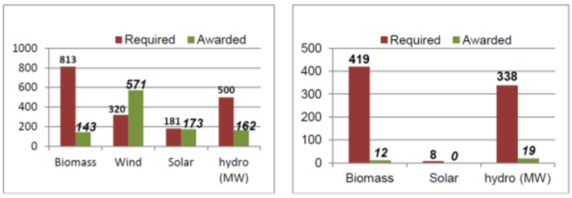

Figure 2.14. Results of the first and second call of auction. Source: Mwenechanya (2013)

As the first round did not lead to the expected results, a second call for auction was announced on March 16, 2010 by OSINERGMIN, requesting the remaining 427 GWh[28] from the first call (419 GWh/year from biomass and 8 GWh/year from solar) and 338 MW of small hydro up to 20 MW. However, in June 2010 only 12 GWh/year of biomass and one sHPP project with 19 MW were awarded (all other projects submitted offers above the maximum price). "*At the end of the two rounds of the auction contracts were signed for 899 GWh per year from wind, biomass and solar PV; and 181 MW from 17 hydro plants*" (Mwenechanya, 2013). The following table shows the maximum or ceiling price of the first auction together with the average awarded price per technology.

Table 2.10. Maximum and average awarded prices of the first RE auction. Source: own table based on IRENA (2014), Mwenechanya (2013) and global-climatescope.org (2015)

	Maximum / ceiling price 1st call (2nd call)	Average awarded price
sHPPs[29]	USD$ 0.074/kWh (USD$ 0.064/kWh)	USD$ 0.06/kWh
Wind	USD$ 0.11/kWh (-)	USD$ 0.08/kWh
Biomass	USD$ 0.12/kWh (USD$ 0.055/kWh)	USD$ 0.08/kWh
Solar	USD$ 0.269/kWh (USD$ 0.221/kWh)	USD$ 0.22/kWh

Even though the first auction did not fully fulfill the quota set my MINEM it achieved a competitive business environment and efficient prices (in average 24% below the maximum price). Furthermore, the auction provided valuable lessons learned for the promotion of renewable energies for the Peruvian government and had a significant economic impact for the country. "*This first auction attracted investments of nearly*

[28] "*In the case of wind energy, an additional 251 GWh/year was awarded during this auction. Wind energy prices were very competitive and the quota for biomass was not covered. Thus wind energy bids offering a price below the biomass cap were contracted*" (IRENA, 2014).
[29] "*In the case of small hydro projects, all awards were won by national companies, two of which were joint ventures with foreign partners*" (IRENA, 2014).

USD 1 billion. Total investments for nine projects in biomass, solar and wind amounted to USD 675 million while investments on 17 hydroelectric projects attracted investments of nearly USD 303 million" (IRENA, 2014).

3.7.4.4. Results of the second renewable energy auction

A second auction took place in 2011 for 1,300 GWh/year. However, as can be seen in Table 2.11. at the end of the auction only 1.153 GWh/year were contracted, including 1 biomass project (2 MW - 14.02 GWh), 1 wind project (90 MW - 415.76 GWh), 1 solar project (16 MW – 43 GWh) and 7 sHPPs (102 MW - 679.93 GWh).

Table 2.11. Results of the second RE auction. Source: OSINERGMIN (2010), cited by IRENA (2014)

	Biomass	Wind	Solar	Total
Energy required (GWh/year)	828	429	43	1 300
Energy awarded (GWh/year)	14	416	43	473
Percentage awarded	**2%**	**97%**	**100%**	**36%**
		Small Hydropower		
Power required (MW)		681		
Power awarded (MW)		680		
Percentage awarded		100%		

Table 2.12. Average awarded prices of the second RE auction. Source: own table based on IRENA (2014) and Mwenechanya (2013)

	Average awarded price
sHPPs	USD$ 0.053/kWh
Wind	USD$ 0.07/kWh
Biomass	USD$ 0.10/kWh
Solar	USD$ 0.12/kWh

The second RE auction attracted local and international investments of around 0.5 billion USD. Furthermore, prices "*between the first auction in 2009/2010 and the second in 2011 fell by 11% for hydro, 14% for wind, 9% for biomass and 46% for solar PV*" (IRENA, 2014) and showed competitive values compared to global averages. According to AHK (2014) the maximum ceiling price was more or less the same as the average awarded price.

3.7.4.5. Results of the third renewable energy auction

In 2013 OSINERGMIN announced the third call for auction requesting renewable energy generation from agroindustrial biomass waste (320 GWh/year) and sHPPs (up to a total of 1,300 GWh/year).

Finally, 19 sHPPs (240 MW) were contracted with a total generation of 1,278.06 GWh/year (only one biomass applied, but did not meet the requirements). According to global-climatescope.org (2015) the average price awarded was USD 0.05655/kWh.

3.7.4.6. Fourth renewable energy auction - ongoing

On December, 12 2014 MINEM published a preliminary call for auction requesting renewable energy generation from the following sources: 573 GWh of wind power, 415 GWh of solar energy and 312 GWh of bioenergy (125 GWh from forest waste, 125 GWh from agriculture solid waste, 31 GWh from urban solid waste incineration and 31 GWh from solid urban waste biogas). Additionally, 450 GWh/year are requested for sHPPs below 20 MW. According to the public announcement from September 3, 2015 by OSINERGMIN, the registration of participants is possible until October 30, 2015. Offers should be sent until December 18, 2015 and the results of the auction will be published on January 29, 2016 (osinerg.gob.pe, 2015). The auction will be officially closed at the end of April 2016. The detailed auction schedule can be seen in Table 2.13.

Table 2.13. Schedule of the fourth renewable energy auction. Source: garrigues.com (2015)

	Phases	Dates
a.	Publication of auction notice	09/03/2015
b.	Registration of participants	09/04/2015 - 10/30/2015
c.	Sale of the auction rules	09/07/2015 – 09/11/2015
d.	Any interested bidders who have acquired the auction rules may make suggestions and request information concerning the rules	09/07/2015 – 09/22/2015
e.	Publication of the revised auction rules	10/06/2015
f.	Any interested bidders who have registered and handed over their petition for participation and acquired the rules may submit their qualification and bid envelopes	12/18/2015
g.	Publication of the bidder list	11/01/2016
h.	Public opening of bid envelopes and award to the successful bidder	01/26/2016
i.	Publication of auction results	01/29/2016
j.	Closing date	04/29/2016

With the fourth renewable energy auction ongoing, Peru has not only contracted several hundred MW of renewable energy, but also gained experience in this field. "*Peru has taken significant steps in the development of renewable energy auctions and is currently one of the leading countries that have developed and held successful auctions*" (IRENA, 2014).

3.7.4.7. Requirements for participating at auctions

All documents, rules and requirements are available on the website of OSINERGMIN (*Link*, 07.09.2015) and developers can register online for the auction (*Link*, 07.09.2015).

In order to participate in the auction, the rules ("bases") must be obtained from the Deputy Tariff Office of the OSINERGMIN. "*The bidder must purchase the bidding document package (called 'Bases'), which outlines the auction details and requires bidders to submit project data (including nominal capacity to be installed, the capacity factor, measurement records, location of the project, and distance from grid), and other sworn statements*" (climatescope.com, 2015). The price of the bases for the fourth renewable energy auction is US$ 5,000.00.

Moreover, it is important to mention that the auction system in Peru relies heavily on financial guarantees, which have to be provided by the project developers.

"*Peru uses stringent guarantees in order to: i) ensure projects come online on time due to the urgency of demand, and ii) to reduce transaction costs for the auctioneer. In addition to strong pre-operational guarantees (e.g. USD 50,000/MW bid bond and USD 250,000/MW construction bond in the 2013 auction), Peru has designed an original approach to contract bonds, whereby any shortcoming in the contracted amount of electricity results in a reduction of the guaranteed tariff by the same percentage for that year*" (IRENA, 2015).[30]

From a technical perspective, however, only some basic data and a prefeasibility study are necessary and the administrative barriers are very low. As such, a market entry by new participants is much easier than in other countries. (GIZ, 2015)

"*The auction process obviates the necessity for many of the standard requirements for market entry such as feasibility studies, planning permits or lengthy legal documentation. The process relies rather on stringent and substantial financial guarantees at every stage, thus placing on the prospective investor the responsibility of determining project feasibility and viability and of securing all the necessary permits, including environmental impact approvals*" (Mwenechanya, 2013).

The main decision criteria with regard to the evaluation of the bids during the auctions in Peru is the price/kWh. Furthermore, the electricity has to be delivered within a specified time frame (normally within two/three years) after the auction. In case of the fourth renewable energy auction, the projects must be brought to commercial

[30] It should be noted that IRENA and CEM (2015) mentioned: "*In Peru's auction that started in 2009, bidders are required to deposit several guarantees, including a bid bond of USD 20,000/MW of capacity installed which is lost if the bid is won but the bidder fails to sign the contract. At a later stage, a performance bond of USD 100,000/MW of capacity installed is required.*" The same figures are stated in GIZ (2015).

operation at the end of 2018 and the termination date for the PPAs is at the end of 2038.

Power purchase agreements are set at fixed prices for a duration of 20 years. The generator is paid in regular monthly rates for the energy produced, according to the short-term marginal costs paid to all generators in the SEIN. The additional premium over the regular tariff is passed on to end-users, incurred in regular *peajes de conexión* (connection tolls), which are established annually by OSINERGMIN. The payment of the premium to generators, which is also managed by OSINERGMIN, is paid monthly the year after a given year, according to the awarded auction tariff (climatescope.com, 2015). In case more electricity is produced, this is sold at the market price.

3.7.5. Penalties

With regard to penalties, Mastropietro et al. (2014) mentions that Law No. 28832 foresees that the difference between the contracted and actually produced energy is calculated by OSINERGMIN according to the short-term market price, i.e. the power and energy not delivered as contracted must be replaced and procured at the short-term price by the generator.

However, with regard to renewable energy auctions (Legislative Decree N° 1002), an explicit penalization scheme has been introduced in case the generator fails to supply part of the energy as contracted. In this case, the "*penalisation factor used is equal to the percentage of the missing energy over the contracted one and it is multiplied by the total remuneration received for that year. This explicit penalisation is collected in the following year settlement*" (Mastropietro et al., 2014).

Furthermore, IRENA and CEM (2015) mentioned the following penalization scheme with regard to delays during construction and/or operation during RE auctions:

"*If delays occur in the construction phase for two consecutive quarters, penalties are deducted from the deposited guarantee. In the case of delays to the start of commercial operation of the plant, the performance bond is increased by 20% over the outstanding amount from the date of verification. The project developer may request to postpone the date of the commercial operation provided that it is within a defined deadline and no longer than three months. If the accumulated delay exceeds* *one year from the date specified in the bid, the government can choose to accept postponing the deadline accompanied by an increase in the performance bond by 50%. If it chooses not to, the contract is fully terminated.*"[31]

3.8. Economic and financial viability of sHPPs in Peru

Assessing the economic and financial viability of sHPPs in general is a difficult task, as each hydropower plant is unique in itself, depending on the specific location, changing regulations and financing opportunities. However, it is possible to discuss the main conditions, which have to be fulfilled in order to operate a sHPP in a financially viable way. These conditions mainly refer to the tariff level, other available energy resources in the country and its institutional and regulatory framework, but also include the load factor, the availability and costs of equity and debt finance, loan tenor, etc.

ESMAP (2011) mentions that until recently the development of sHPPs in Peru "*has not been financially viable because the financial cost of generation was set by the cost of gas-based generation at a lower price for natural gas from Camisea*". The calculation from the study was based on 2008 gas prices from the Camisea fields, which were set at 1.3 – 1.39 USD/mmBTU and at 2.13 – 2.24 USD/mmBTU if delivered to electricity generators near Lima. The total generation costs for a combined cycle gas turbine (CCGT) plant close to Lima thus resulted to just 3.2 USD/kWh in 2006 and to 4.3 USD/kWh in 2008.

sHPPs were thus confronted with average prices of 3.5 US cents/kWh in the regulated market (via a PPA with a distribution company) at that time. Based on realistic economic data from existing sHPPs in Peru, the study thus concludes: "*At an average price for gas-based generation of 3.5 US cents/kWh, a 17.5 percent financial rate of return (FIRR) on equity, a 10-year loan period and a 70 percent load factor, the maximum capital cost that is financially viable for a hydro project is around US$850/kW*" (ESMAP, 2011). Under these conditions it was hardly possible to

[31] GIZ (2015) mentions in this regard: "*In addition, authorities have established penalties for construction delays. They range from 20% plus on the construction guarantee to contract termination or extension combined with 50% plus on guarantee payments for delays of more than one year.*"

successfully operate a sHPP and in fact none of the nine sHPPs examined in the study was financially viable given the assumptions described above.

However, the study also mentioned that gas prices would soon increase as Peru became an exporter of liquefied natural gas (LNG) at that time, which would lead to prices set by the international market. Based on realistic costs for natural gas of 4 USD/mmBTU and capital costs of 1.15 USD/kW, the total generation costs of CCGTs would increase to 5.6 USD/kWh. Under these assumptions, four of the above mentioned nine sHPPs would achieve a financial rate of return (FIRR) on equity of minimum 17.5 percent and "*the allowable capital cost for small hydro increases to US$1,400/kW*" (ESMAP, 2011).

The study further examines the necessary conditions in order to meet the minimum financial expectations described above. This is especially interesting for this thesis, as the results can be directly compared with the recent auction prices for sHPPs in Peru. If the current (2015) auction prices are in the range described in the ESMAP study, this would indicate that it is nowadays economically and financially viable to operate sHPPs and that the government of Peru has set the correct steps and changes in the regulatory framework in order to exploit the hydro-electric potential of the country.

The main question is thus, which tariff is required as a function of capital costs and load factor in order to achieve a FIRR of 17.5%. The table below shows, which combinations of load factor and capital costs are feasible at 2008 prices of 3.5 USDcents/kWh (shaded area left at the bottom) and at prices of 6 USDcents/kWh (unshaded area in the middle with bold entries). As can be seen, a project with a capacity factor of 75% and capital costs below 1,700 USD/kW would be viable based on a realistic price of 6 USDcents/kWh.

Table 2.14. Tariff required as a function of load factor and capital cost (USDcents/kWh). Source: ESMAP (2011)

Load Factor	Capital Cost ($/kW) 900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
35%	7.2	7.9	8.6	9.3	10.0	10.7	11.4	12.1	12.9	13.6	14.3	15.0
40%	6.3	6.9	7.6	8.2	8.8	9.4	10.0	10.6	11.2	11.9	12.5	13.1
45%	5.6	6.2	6.7	7.3	7.8	8.4	8.9	9.4	10.0	10.5	11.1	11.6
50%	5.1	5.6	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5
55%	4.6	5.0	5.5	5.9	6.4	6.8	7.3	7.7	8.2	8.6	9.1	9.5
60%	4.2	4.6	5.0	5.4	5.9	6.3	6.7	7.1	7.5	7.9	8.3	8.7
65%	3.9	4.3	4.6	5.0	5.4	5.8	6.2	6.5	6.9	7.3	7.7	8.1
70%	3.6	4.0	4.3	4.7	5.0	5.4	5.7	6.1	6.4	6.8	7.1	7.5
75%	3.4	3.7	4.0	4.4	4.7	5.0	5.3	5.7	6.0	6.3	6.7	7.0
80%	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.5
85%	3.0	3.3	3.6	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2
90%	2.8	3.1	3.4	3.6	3.9	4.2	4.5	4.7	5.0	5.3	5.5	5.8

Source: Authors' calculations, 2008.

However, a lot of other factors are also influencing the financial viability of sHPPs. One of the assumption included in the calculation above was a loan tenor of 10 years. "*Extension of tenor by 5 years (from 10 to 15 years) is equivalent to a 5 percent increase in load factor, or an increase in the allowable capital cost by about US$100/kW*" (ESMAP, 2011). That means that the FIRR would increase from 14.6% to 18% if the loan tenor is extended from 10 to 15 years, as can be seen in Figure 2.15. Furthermore, the debt service coverage ratio (DSCR) would also increase significantly during the first years in case of a tenor of 15 years, no matter whether financed with constant principal payment or as an annuity (see Figure 2.16.).

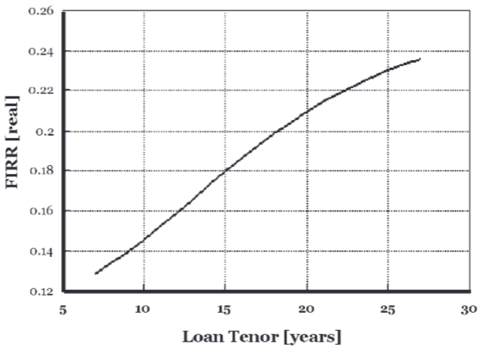

Figure 2.15. Impact of loan tenor on FIRR
Source: ESMAP (2011)

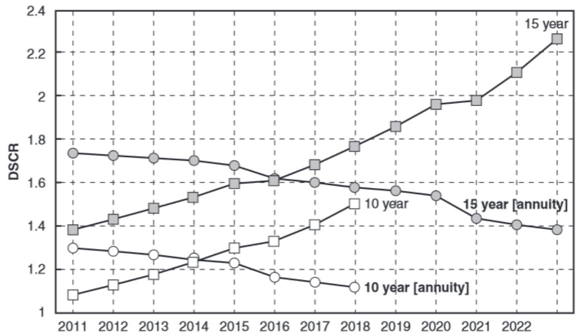

Figure 2.16. Impact of loan tenor on DSCR
Source: ESMAP (2011)

Based on the example from the ESMAP study, the extension of the loan tenor to 15 years alone would thus render projects with a load factor of 75% and capital costs up to 1,800 USD/kW viable, based on a realistic price of 6 USDcents/kWh.

Table 2.17. Impact of loan extension to 15 years on feasible combinations of load factors and capital costs (USDcents/kWh). Source: ESMAP (2011)

Load Factor	Capital Cost ($/kW) 900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000
35%	6.7	7.4	8.0	8.7	9.3	10.0	10.6	11.2	11.9	12.5	13.2	13.8
40%	5.9	6.4	7.0	7.6	8.1	8.7	9.3	9.8	10.4	11.0	11.5	12.1
45%	5.2	5.7	6.2	6.7	7.2	7.7	8.2	8.7	9.3	9.8	10.3	10.8
50%	4.7	5.2	5.6	6.1	6.5	7.0	7.4	7.9	8.3	8.8	9.2	9.7
55%	4.3	4.7	5.1	5.5	5.9	6.3	6.7	7.2	7.6	8.0	8.4	8.8
60%	3.9	4.3	4.7	5.1	5.4	5.8	6.2	6.6	6.9	7.3	7.7	8.1
65%	3.6	4.0	4.3	4.7	5.0	5.4	5.7	6.1	6.4	6.8	7.1	7.4
70%	3.4	3.7	4.0	4.3	4.7	5.0	5.3	5.6	5.9	6.3	6.6	6.9
75%	3.1	3.4	3.7	4.0	4.3	4.6	4.9	5.2	5.6	5.9	6.2	6.5
80%	2.9	3.2	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.8	6.1
85%	2.8	3.0	3.3	3.6	3.8	4.1	4.4	4.6	4.9	5.2	5.4	5.7
90%	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4	4.6	4.9	5.1	5.4

Source: Authors' calculations, 2008.

The ESMAP study further calculates the effects if carbon finance at a price of USD 15/ton CO_2 is included, besides a loan tenor of 15 years. Under these assumptions, projects with a load factor of 75% and a purchase price of 6 USDcents/kWh would be viable with capital costs of 2,000 USD/kW. However, as the market for carbon finance did not develop as expected, this option is not further discussed here.[32]

The examples of the loan tenor and carbon finance should however just underline the sensitivity of each parameter for the economic and financial viability of sHPPs and hence the necessity to study, calculate and if possible optimize each detail of the project. As such, sHPPs with costs of 2,000 USD/kW and more might be economically and financially viable in Peru if e.g. different financing conditions are applied, the project is developed in a portfolio of sHPPs (which saves costs on feasibility studies, etc.) or if the developers and/or investors accept a FIRR of around 10%.

3.9. Availability of financing for sHPPs in Peru

As already mentioned in part one of this thesis, the availability of financing depends heavily on the entity requesting/granting financing and the type of finance. As such, a "*small hydro projects for which major companies are willing to provide balance sheet guarantees will encounter few difficulties in finding finance* […]" (ESMAP, 2011). However, this issue is getting much more difficult when it comes to project financing and in case the balance sheets of the company are not as strong. ESMAP (2011) mentions that in the first decade of the 2000s banks have only rarely provided project financing for sHPPs and included one example, where "*the first phase required 100 percent cash collateral, making this in effect a project with 100 percent equity*" (ESMAP, 2011).

However, since then the regulatory framework has changed significantly and the guaranteed prices for 20 years in USD, which were offered in the renewable energy auctions, definitely gave some comfort to generally risk-averse bankers. This means that local banks nowadays are more open with regard to sHPP project financing. However, the terms and conditions (pricing, loan tenor, etc.) of the local banks are still hardly favorable for the development of sHPPs. "*Although debt finance is available in*

[32] With regard to carbon prices, the recently published report *State and Trends of Carbon Pricing* by the World Bank (WB and Ecofys, 2015) mentions: "*The existing carbon prices vary significantly—from less than US$1 per tCO_2e to US$130 per tCO_2e* […]. *The majority of emissions (85 percent) are priced at less than US$10 per tCO2e, which is considerably lower than the price that economic models have estimated is needed to meet the 2°C climate stabilization goal recommended by scientists.*"

principal, in actual fact developers would be unlikely to receive project financing for 12 to 15 years at competitive rates" (ESMAP, 2011).

Apart from local banks, International Financial Institutions (IFIs) like the International Finance Corporation (IFC) or the Inter-American Development Bank (IDB) may also provide financing for sHPPs in Peru. However, it should be obvious that banks often prefer larger deals as the transaction costs "*for a 200 MW CCGT near Lima are little different than that of a 5 MW hydro*" (ESMAP, 2011), especially if the sHPP is located in a remote area.

National and regional Development Banks like the Development Bank of Latin America (CAF)[33] or the Development Bank of Peru (COFIDE)[34] also have a focus on renewable energy projects and might have specific programs targeting some of the challenges related to the development of small hydropower in Peru. Moreover, there exist specialized financial institutions like the *Corporación Interamericana para el Financiamiento de Infraestructura* (CIFI)[35], which provides financing and advisory services to small and medium sized, private sector infrastructure companies in Latin America and the Caribbean.

Furthermore, also European Development Banks just recently announced its first financing activities in the small hydropower sector of Peru. As such, the Deutsche Investitions- und Entwicklungsgesellschaft (DEG) arranged a USD 59 million financing package in 2015 together with the Dutch Development Bank (FMO), the Development Bank of Austria (OeEB) and the Development Bank of Peru (COFIDE) for two sHPPs with 19 MW and 8.4 MW.[36]

Finding equity might be even harder for rather small project developers, depending on the specific location and the status quo with regard to permits and feasibility studies. Besides "*family, friends and fools*", private equity, venture capital and infrastructure funds specialized in renewable energy projects may be interested since the regulatory framework is favorable and environmental concerns are nowadays on the top of the agenda. Furthermore, some of the Development Banks mentioned above also offer equity capital, including the Nordic Development Funds like the

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[33] *http://www.caf.com/* (22.10.2015)
[34] *http://www.cofide.com.pe* (22.10.2015)
[35] *http://www.cifidc.com/* (21.10.2015)
[36] See: *https://www.deginvest.de/DEG-Documents-in-English/About-DEG/Responsibility/Investment-related-information/201507_Genandin_EN.pdf* (21.10.2015) and *http://www.hydroworld.com/articles/2015/08/union-group-arranges-us-59-million-in-financing-for-two-peruvian-hydropower-projects.html* (21.10.2015)

Norwegian Investment Fund for Developing Countries (NORFUND) or the Finnish Fund for Industrial Cooperation Ltd. (FINNFUND). However, the requirements and standards from International and European Development Banks and Funds are normally quite high and developers without a strong track record and financial backing would hardly be able to obtain debt and/or equity capital.

3.10. Founding a company in Peru[37]

The establishment of companies in Peru is governed in the Peruvian General Corporation Law (LGS). In general, it can be stated that (i) companies are required to be constituted by at least two partners or shareholders (individuals or corporations, Peruvian or foreign), (ii) a minimum capital is not required for the establishment of a company and (iii) all companies must have a status, name, subject and address.

Necessary steps before start of operation.

- Elaboration of the statutes and the social constitution, notarially certified at the public notary of Lima and registered at the public records of Lima (~ 7 business days).
- Request for the taxpayer registration (~ 5 business days).
- Before start of operation at a specific site, the operating licenses have to be obtained (see below).

Furthermore, in case the general manager of the company is not a Peruvian national, a work visa has to be requested (either in Peru or in the country of origin).

In general, there exist the following four types of companies in Peru:

- Stock Company
- Closed Stock Company
- Opened Stock Company
- Limited Liability Company[38]

The best choice with regard to the selection of the appropriate company type depends highly on the specific activities performed, shareholder structure, etc. However, with

[37] This chapter is mainly based on OeEB (2012).
[38] For further information, see OeEB (2011) and E&Y (2015)

regard to a single HPP in the range of up to 20 MW ONG Progreso Panamericana (OeEB, 2012) recommends to establish a Closed Stock Company (SAC in Spanish) due to the fact that this type allows a tighter control over the company than the other possibilities. As such the number of shareholders is limited to 20 and the shares are not registered at the public register of the stock market. Furthermore, shareholders have preferential rights to acquire shares before they are offered to third parties.

3.10.1. Costs of starting a company

When registering a company as Closed Stock Company a minimum capital of around US$ 380 (1,000 Nuevos Soles) is necessary in order to start operations. The costs for registration for a project in the range of 20 MW are estimated at US$ 3,000 and the taxpayer registration and accounting books are estimated at US$ 500. Furthermore, bank accounts in United States Dollars and Nuevos Soles have to be opened, with costs of around US$ 500. Finally, a contingency of US$ 500 is included, bringing the total costs to US$ 5,380.

Table 2.18. Initial expenses and monthly operational and administrative costs for starting a company in Peru. Source: own table based on OeEB (2012)

Initial Expenses		**Operational costs (monthly)**		**Administrative costs (monthly)**	
Concept	**Amount in US$**	**Concept**	**Amount in US$ (*)**	**Concept**	**Amount in US$ (*)**
Initial Capital	380	General Manager	5,000	Rent (Office of 120 m2)	2,500
Registration Costs	3,000	Project Engineer	2,300	Telecommunications	500
Accounting Registration	500	Administrator	1,700	Consumables & Office supply	400
Bank account opening	1,000	Accountant	1,500	Logistics Costs	2,000
Other initial expenses	500	In-house Lawyer	2,300	Courier Expenses	600
Total	**5,380**	Secretary	800	**Total**	**6,000**
		Messenger	400		
		Total	**14,000**		

(*) The total costs include taxes, fees, etc.

The monthly costs for the recommended initial staff and the monthly administrative costs are also estimated by ONG Progreso Panamericana (OeEB, 2012). Furthermore, they recommend to consider around US$ 15,000 for office design and office equipment. In general, however, it should be stated that the costs mentioned in Table 2.18. are just rough estimations and can vary significantly in reality, depending on the specific circumstances of the project.

3.11. Required permits and concessions for a HPP up to 20 MW

According to ONG Progreso Panamericana (OeEB, 2012) the following permits and concessions are necessary for the development, construction and operation of a HPP:

Municipal Permits:

- Fit Out License: A permit that allows the property to be fitted out for construction.
- Construction License: A permit which authorizes construction after a technical evaluation by the Municipality.
- Construction Conformity: Confirms the construction by the Municipality once the construction is completed.
- Operating License: An authorization by the Municipality to carry out commercial operation in a designated area.

National Permits:

By the Ministry of Energy and Mines

- Concession for power generation: A permit that allows to enter into the power generation business with a specific project.[39]
- Easement: A permit that allows the holder the use of public and third party goods for public service and the right for easements to carry out activities of electrical generation or transmission.

By the Ministry of Culture

- Certificate of non-existence of archeological artifacts (CIRA, by its Spanish acronym): A certificate issued by the Ministry of Culture indicating there are no archeological artifacts at the specific location.
- Archeological Monitoring Plan: A plan to be issued to CIRA before starting with any of the excavation on the project land.

By the Regional Government

- Detailed Technical and Safety Inspection: Certifies the holder that the inspection about safety rules was successful according to the size of the project area.

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[39] A detailed description of the conditions and requirements in order to obtain the concession is stated below.

By National Water Authority

- Water use authorization: Permits the use of water for execution of works in the project area.
- Water use license: Permits the use of water for hydropower generation. This license will be granted automatically after verification that the works were executed according to the characteristics, specifications and conditions of the approved technical file.

By COES

- Approval of the pre-operability study: Determines whether it is feasible to connect the new project to the national electric grid. It must be carried out according to the technical procedures of COES.
- Approval of the operability study: Determines whether the new facilities will have adverse effects on the operation of the national electric grid in terms of stability of the system, overloading of lines and transformers, protection and coordination mechanisms, etc. The study must also be carried out according to the technical procedures of COES.
- Approval of commercial operation: Permits the participation of a power generation company in the market.

By the National Service of Protected Natural Areas (SERNANP, by its Spanish acronym)

- Permit to perform electric activities in a protected natural area (if applicable).

SERNANP is the public agency that directs and establishes the criteria for the conservation of natural and protected areas. SERNANP carries out its work in coordination with regional and local governments and property owners.

Concession for power generation: In order to obtain the Concession for power generation, the following documents have to be submitted to the Ministry of Energy and Mines (MINEM) according to ONG Progreso Panamericana (OeEB, 2012):

- Application form
- Legal identification and address of the applicant, accrediting in the registry of the public records office and identification of legal representatives.

- Affidavit of compliance of technical and environmental standards, as well as conservation standards of cultural heritage.
- A descriptive report and complete and signed plans of the project, with at least feasibility studies.
- A timetable, indicating the beginning of works and the commercial operation date. It is important to consider gaps in the execution of works, because the supervision is made on the basis of this timetable.
- A project budget.
- Technical information for statistical purposes, consisting at least of the following: installed capacity, number of generation units, type of each generation unit, model of each generation unit, monthly hydrological data, design data, location plans, diagrams of works, point of connection to the national grid.
- A stand by letter of credit equivalent to 1% of the budget of the project with a limit of 500 tax units[40] (equivalent to approximately US$ 670,000), in order to guarantee the correct execution of works.
- Verifiable proof of investor's commitment to furnish funds for execution of works.
- A favorable report issued by a qualified Risk Rating Company with respect to the financial solvency of the investor.
- The pre-operability study approved by COES.
- A copy of the water use authorization.
- A specification of required easements.
- A demarcation of the concession area in UTM PSAD 56 coordinates.

When all documents are available, the concession should be granted in ninety calendar days. However, ONG Progreso Panamericana (OeEB, 2012) mentioned that this process may take between four to six months. The approval of the concession is then published in the Peruvian Official Newspaper "*El Peruano*" and must be signed by both parties within approximately two weeks after publishing.

[40] A Peruvian tax unit is equivalent to S/. 3,600 (approximately US$ 1,340).

4. Case study - a sHPP in Peru

In this chapter, a sHPP which is currently in the development phase will be analyzed. Due to confidentiality reasons, however, the exact name and location of the project will not be disclosed.

4.1 Basic idea and design

Basically, the idea is to use the hydro-energetic potential of a drop height of a supply channel of an existing irrigation system in Peru. As the irrigation channel is already in place, the technical realization is supposed to be rather simple. In fact, only a short diversion channel leading to the power house, which contains the turbine, the generator and control systems, has to be built. However, in comparison to other diversion type hydro plants, the construction of a water catchment, spillway, desander and penstock is not necessary. Furthermore, the main access roads are already existing and the connection to the medium-voltage grid is possible within 30 meter.

Figure 3.1. Irrigation channel
Source: project developer

Figure 3.2. Ramp construction of the channel
Source: project developer

The water supply for the irrigation system comes from a storage reservoir with a capacity of more than 300 million m^3. The reservoir is filled during months with high precipitation and used for agricultural purposes during times with low precipitation.

Hydrological data and records of the irrigation canal are available since 1995 and have already been purchased by the developer.

In the following table, the main parameters (including installed capacity, electricity production, investment costs, etc.) of the proposed sHPP can be found.

Table 3.1. Main parameters of the proposed sHPP. Source: project developer

Drop height	4.8 m
Discharge	12 l/s
Installed capacity	485 kW
Capacity factor	66%
Electricity production	2.8 GWh
Commissioning date	2017
Investment costs	970,000 USD

4.2. Legal status, permits and land rights

In order to develop and operate a sHPP in Peru, a closed stock company (*Sociedad Anonima Cerrada - SAC*) was founded in Peru during 2014.

As mentioned previously, the electricity concessions law from 1992 specifies that a concession (and some of the permits mentioned in chapter 3.12) are not necessary for the construction and operation of a sHPP below 500 kW. As such ESMAP (2011) mentioned: "*It is important to note that regulations of the Electricity Law apply only to systems with demand/capacity of 500 kW or more. Smaller systems are free of regulations under the Electricity Law, but are subject to other sector regulations, and requirements from regional or local authorities (like permits and authorizations), which are usually not standardized*".

According to information from the project developer, the following permits and authorizations had to be obtained:

- Water permit
- Construction permit
- Approval of the grid connection
- Permit for the use of the canal bank
- Certificate of non-existence of archaeological remains

Water permit: The procedure for obtaining the water permit is divided in the following four steps: i) the approval to conduct the water study, ii) the approval of the water study, iii) the water construction permit and iv) the water permit.

First of all, the implementation of the water study (i) has to be authorized by the local water authority (*Autoridad del Agua Local - ALA*).

In order to get an approval of the water study (ii), the necessary studies (hydrological, topographic, geological, geotechnical and soil mechanics studies) have to be prepared and submitted to the local water authority ALA.

After the approval of the water study, the water construction permit must be requested (iii). However, the approval by the water authority ALA is not a prerequisite for the start of construction and can also be applied during construction of the project.

After full completion of the project (commissioning) the water permit is issued (iv).

Construction permit: The application for the construction permit can only be submitted to the municipality after approval of the water study by ALA (see step ii above). The Peruvian law stipulates that the construction permit is agreed tacitly, if the municipality does not rule on the application within 25 days from filing the application.

After that day, the construction can be started.

Approval of the grid connection: First, the request for the elaboration of a study to extend the grid connection must be submitted to the regional grid operator. Upon approval of this request, the study can be implemented. After approval of the study by the regional network operator, the project can be safely connected to the grid.

Permit for the use of the canal bank: The permit for the use of the canal bank must be granted by the canal operator. Canal operators in Peru are financially independent public corporations, which are organizationally attributed to the local government. The main task of the canal operator is to optimize the use of the water in the rivers and the entire irrigation system of the region. The canal operator has the exclusive right to use the bank of the canal system. A permit is thus required to use the canal (breakthrough of the canal wall for inflow and outflow channels) and the canal bank. The formal request for this permit may also only be filed after approval of the water study by ALA (see step ii above).

Certificate of non-existence of archaeological remains: Finally, a certificate of non-existence of archaeological remains (*Certificado de Inexistencia de Restos arqueológicos - CIRA*) has to be requested at the Ministry of Culture**.** CIRA certifies that there are no serious concerns with regard to the respective project from an archaeological perspective.

Furthermore, the developers decided to conduct an environmental declaration (*Declaracion del Impacto Ambiental – DIA*), even though this would not have been necessary according to the laws of Peru. The results of the study indicated that there would be no permanent or considerable negative impacts to the villages close to the proposed project location. The creation of short and long term employment opportunities was positively mentioned in the report.

Finally, the project developer has secured the leasehold of the property for 99 years from the owner, an association of local authorities. The leasehold further guarantees the right of way and the necessary land use rights during construction. The leasehold has been entered in the official land register of Peru (*Registro de Predios*) and also entitles the transfer of rights to third parties.

4.3. Economics

Construction costs

The construction costs for the proposed sHPP show typical values compared to similar small hydropower plants. As such the electro-mechanical equipment makes up 61.7% of the total costs. The civil and general works are estimated at 28.2% and other costs (including site supervision and a 15% contingency for cost overruns during construction) at 10.1%. The total construction costs are estimated at 970.000 USD or 2.000 USD/kW. Site supervision is divided into local supervision (first row) and international supervision (second row).

Table 3.2. Construction costs. Source: project developer

Construction costs: (485 kW)	**USD**
Mechanical & Electrical	
Hydromechanical equipment	62.500
Mechanical equipment (Turbine, etc.)	330.000
Electrical equipment (Generator, etc.)	120.000
Transport and installation	50.000
Transmission Equipment	26.500
Site assembly, testing and commissioning	10.000
	599.000
Civil and general works	
General Works	8.500
Canal and forebay	21.000
Channel Equipment	22.500
Powerhouse and discharge channel	221.250
	273.250
Total direct costs	**872.250**
Site supervision	19.574
Site supervision	29.563
Other costs	7.500
Contingency (15% of civil and general works)	41.114
Total indirect costs	**97.750**
Total construction costs	**970.000**

Costs for operation & maintenance

Costs for operation & maintenance are estimated at around 17% of the monthly revenues. This figure is calculated conservatively and also includes administrative costs and various payments and fees to public authorities.

Table 3.3. Costs for operation & maintenance. Source: project developer

O&M	%	5,0%
Administration	%	2,0%
Guard	%	2,0%
Insurance	%	0,5%
Canal usage fee	%	2,0%
Land tax	%	1,0%
Payment to COES	%	1,0%
Payment to OSINERGMIN	%	0,5%
Power from the grid	%	0,1%
Miscellaneous (5kg of oil/month, etc.)	%	2,0%
Water usage fee	*US$/MWh*	0,412

Costs for O&M amount to around 2.3% of investment costs/year, which is in line with typical values discussed in chapter 2.7.

Other costs

Besides construction and O&M costs, the project developer had to bear the costs for project development (project studies, land rights, etc.). Due to confidentiality reasons these will not be further disclosed (but they are included in the economic analysis described below).

Furthermore, the value added tax (VAT) of 18% must be pre-financed and will just be refunded partly at commissioning and partly during the first three years of operation. However, for the sake of this thesis, the VAT issue is not further considered in the economic analysis.

Electricity sales / revenues

After a review of the electricity market in Peru, it was chosen to apply for the fourth renewable energy auction of Peru, which is currently ongoing (see chapter 3.7.4.6.). If successful, the developer will enter into a PPA with MINEM, which would guarantee a fixed tariff for 20 years. Furthermore, even though the payments are done in the local currency Nuevo Sol (PEN), they are calculated in USD equivalent and adjusted to inflation. Comparing the results of the last auctions, a guaranteed purchase price of around 55 USD/kW seems to be realistic.

In case the project will not be considered eligible during the auction, the produced electricity will be sold via the regulated market. This fall back option was already discussed with the regional utility, who would be happy to integrate more capacities due to the increased electricity demand from local mining and extractive companies (as mentioned above, distribution companies in Peru are obliged to contract the expected demand of the next five years).

Scenarios

The economic calculation includes the following three scenarios:

Base case: This scenario foresees to sell the produced electricity to the regional utility via a long-term PPA ("regulated market"). Furthermore, it assumes a 10% lower tariff compared to the current tariff. This would result at an average purchase price of 37 USD/MWh and an additional capacity payment of 5.96 USD/kW.

Auction case: If the participation at the auction is successful, a guaranteed purchase price of 55 USD/MWh can be secured. The capacity payment would amount to 5.96 USD/kW, as in the base case. After the end of the auction price in 2038 (20 years), the electricity will be sold to the regional utility under the conditions described above ("base case").

Sensitivity case: This scenario plans to sell the electricity to the regional utility via a long-term PPA, assuming a 15% lower tariff ("regulated market", as in the base case). This would result at an average purchase price of 34.9 USD/MWh and an additional capacity payment of 5.96 USD/kW. Furthermore, an annual devaluation of 3% of the PEN compared to the USD was applied over the whole calculation period.

The following assumptions are further included in the three scenarios:

- Commissioning in January 2017
- 100% equity, thus avoiding any interest rate and liquidity risks
- Discount factor/WACC: 8%
- Investment horizon (lifetime) of 40 years (sHPPs often run 60-80 years)
- An annual tariff increase of 3% (the tariff increase was never less than 3% during the last ten years)

Taking into account the costs, revenues and assumptions described above, the sHPP would generate a positive IRR and NPV in all three scenarios described above (see Table 3.4.).

Table 3.4. IRR and NPV. Source: project developer

		Base case	Auction case	Sensitivity case
IRR	%	11,7%	14,3%	8,1%
NPV	(USD ´000)	552	877	16

4.4. Timeline

As can be seen in Table 3.5. nearly all project studies have already been completed and most of the permits will be obtained in the next few weeks and months. Furthermore, the land rights have been secured and the M&E equipment has been ordered. An important step will be outcome of the RE auction, as this will determine the scenario and hence the economic and financial viability of the project. Construction is planned to start in 2016 and commissioning beginning of 2017.

Table 3.5. Timetable. Source: project developer

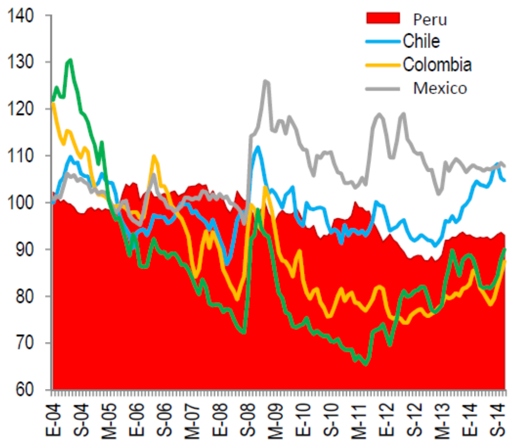
		Q1-15	Q2-15	Q3-15	Q4-15	Q1-16	Q2-16	Q3-16	Q4-16	Q1-17	Q2-17
Feasibility Study	√										
Hydrological Study	√										
Geological Study	√										
Topographic Study	√										
Environmental Declaration	√										
Archeological Study	√										
Water permit					■						
Approval of the grid connection study					■						
Grid connection approved						■					
Land rights	√										
Permit for the use of the canal bank					■	■					
Construction permit						■					
RE Auction & PPA				■	■	■					
Ordering M&E equipment	√										
Construction phase						■	■	■	■		
Commissioning									■	■	

4.5. Risks

Currency risk

As the revenues for this project are paid in PEN, the main risk for a EUR investor is the currency risk. If the PEN devaluates compared to the USD or EUR, respectively, the profitability of the project could decrease significantly. However, as can be seen in Table 4.4. the PEN has been the least volatile currency in the whole Latin American region during the last 10 years.

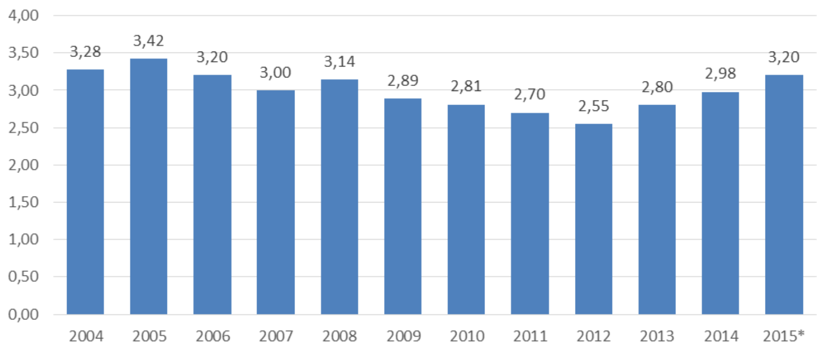
Table 3.6. Currency exchange rate fluctuations in Latin America (2004-2014).
Source: ProInversion (2015)



To this effect also E&Y (2016) mentioned recently, that the PEN is one of the most stable currencies worldwide: "*According to estimates as of the end of 2014, the Nuevo Sol is one of the least volatile currencies in the world, exhibiting firmness in the face of international market and currency fluctuations*".

Due to the stability of the PEN there were also no major fluctuations against the USD. Over the last 10 years, the PEN has moved from 2.53 to 3.45 USD. The all-time low of the PEN against the USD since its introduction in 1991 was reached in 2002 at 3.65. The stability of the PEN is primarily due to a responsible economic policy as well as the political stability in Peru.

Table 3.7. Exchange rate PEN versus USD at the end of each year.
Source: own table based on Bloomberg.com (2015)



This risk is thus considered rather low, even though currency fluctuations will have a certain impact on the profitability of the project.

Cost overruns

Just as in any infrastructure project, there is a risk of cost overruns or timeouts. Cost overruns must be financed with additional resources and timeouts lead to higher construction costs and a possible loss of income. In case additional cash is not available, this might lead to a failure of the project.

However, as the costs of the electro-mechanical equipment, which can be estimated accurately based on experience and ongoing negotiations with suppliers, account for more than 60% of the total costs, this risk can be considered also as rather low. Also, because the developer took into account sufficient reserves in the cost and time schedule, including a 15% contingency on civil and general works. Furthermore, he committed to make an additional contribution of up to USD 100,000 in the event of cost overruns during construction.

Technical and operational risks

Engineering, production and assembly errors at the proposed project may lead to significant delays and cost overruns. Furthermore, a poor commercial and/or organizational management of the power plant may have negative impacts on the profitability as well.

The planning and design of the project, however, will be done by experienced developers in close cooperation with technical experts and universities. Furthermore, the local Managing Director, who is also financially involved in this project, has long-term know-how with similar projects in the region. He will also take care that all contracts include guarantee and warranty provisions in accordance with international standards and that the usual insurances are taken out. However, a complete protection against these risks is not possible.

Regulatory and fiscal risks

The technical concept and the commercial operation of the planned power plants are based on the applicable energy laws and regulations of Peru as well as on assumptions about the applicable tax law. Changes in these conditions can be adopted by public authorities on one side and could lead to stranded costs, additional investments and operating costs and lower profits.

Hedging these risks is only possible as far as they can be qualified as political risks (see below).

Political risks

Political risks such as expropriation, unrest, civil war and other political developments may lead to a partial or total loss of the invested capital.

Various insurance providers can hedge these risks with a coverage ratio up to 100%.

Natural events and force majeure

Peru is located in a tectonically active earthquake zone. An earthquake can lead to a destruction of the power plant or the irrigation channel. Apart from the eventual residual value of some parts of the plant, this may lead to a total loss of the invested capital. This also applies to other natural events such as floods, storms, etc.

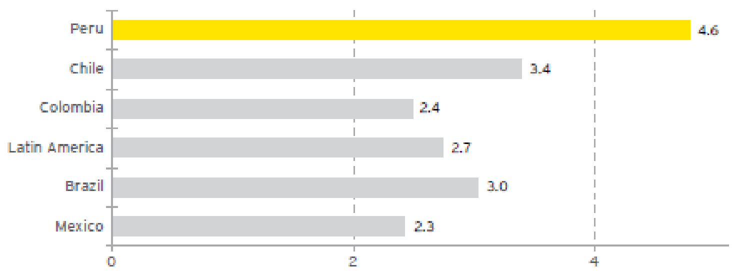
Insurances (such as business interruption insurances and insurances against natural events) can only partially hedge these risks.

4.6. Opportunities

Strong economic development

As described in chapter 2, Peru has managed a sustained economic growth during the last decades through market-friendly policies, a sound fiscal management and macroeconomic stability. This trend has also been recognized by international investors, who in 2013 invested more money in Peru than in any other Latin American country (in % of GDP, as can be seen in Table 4.6.).

Table 3.8. Direct Foreign Investment in Latin America in % of GDP in 2013.
Source: E&Y (2015)



Stable regulatory framework in the energy and electricity sector

Peru has elaborated a stable regulatory framework in the energy and electricity sector since the 1990ies (see chapter 2). With regard to renewable energies, the *Legislative Decree for the Promotion of Investment in Electricity Generation with Renewable Resources* (No. 1002, 2008) and the *Regulations for the generation of electricity from* *renewable energies* (Supreme Decree No. 012-2011-EM) have significantly improved the legal certainty for investors and developers of energy projects in Peru. Furthermore, the renewable energy auctions implemented by Peru during the last years have yielded guaranteed purchase prices which are considered sufficient for a viable development of sHPPs in Peru.

Track record of the developer and its partners

The developer and its partners have a comprehensive track record with regard to the development of renewable energy projects (sHPPs, wind, biomass and solar PV) in Europe and Latin America. Moreover, the local Managing Director has significant experience with regard to the development of sHPPs in Peru and is currently developing a comparable plant in the region. Last but not least, the whole project team of the proposed sHPP has ample experience in the development, financing, construction and operation of sHPPs.

Cooperation with Technical Universities, engineering companies and technical consultants

The developer is working in close collaboration with renowned institutes, consultants and engineering companies. The main focus will be the layout and detailed design of the proposed sHPP, but also includes project management and monitoring of the costs and construction schedule. The cooperation with experienced international companies definitely mitigates at least some of the risks mentioned above.

Local network and support

As mentioned above, the project profits from the local experience and know-how of the Managing Director, who has been working on the development of HPP in Peru since decades. Furthermore, he is a member of the community and has supported the villagers with his technical know-how several times. Finally, the association of local authorities as owner of the land already approved the leasehold of the property and is actively supporting the project.

5. Conclusions

In the introduction of this thesis, several questions have been raised which have been addressed in the previous chapters. Before answering the core question of this thesis, the findings of the chapter about hydropower (part 2) and the electricity sector in Peru (part 3) will be summarized and discussed shortly. Subsequently, the challenges, risks and market barriers, but also the strengths, opportunities and potentials with regard to the development of small hydropower in Peru will be elaborated. Based on this information, the core question of this master thesis will be answered.

About hydropower

With regard to hydropower, we have seen that water is constantly moving through a global hydrological cycle, evaporating from oceans, rivers and lakes, forming clouds, precipitating as snow or rain and then flowing back into the oceans. The energy of this hydrological cycle is driven by the sun and was used by human mankind since thousands of years in order to grind grain, for hammer works, textile making, etc.

The flowing water – or to be more precise, the kinetic energy of the flowing water when it moves downstream – can be used as mechanical energy or further converted into electrical energy by means of an electric generator. This happened the first time at the end of the 19^{th} century, when new innovations and developments resulted in the construction of the first HPPs in the US and Europe. The decisive factors which determine the capacity of a hydropower plant are the available flow (m/s) and the head drop (m). All hydropower plants show some losses during operation, however, modern facilities have efficiency levels of 90% and more.

The *Renewables 2015 Global Status Report* (REN21, 2015) mentioned: "*In 2013, hydropower accounted for an estimated 3.9% of final energy consumption*". 78.3% of the global final energy consumption at the end of 2013 was still provided from fossil fuels, 2.4% from nuclear power and 19.1% from renewable sources (thereof 9% from traditional biomass and 10.1% from modern renewable energy technologies). However, with regard to electricity production the same report stated: "*By year's end* [2014]*, renewables comprised an estimated 27.7% of the world's power generating capacity. This was enough to supply an estimated 22.8% of global electricity, with hydropower providing about 16.6%.*"

The global theoretical potential for hydropower plants was estimated at 39,894 TWh/year (144 EJ/year) and the global technical potential at 14,576 TWh/year (52.47 EJ/year) or 3,721 GW (IJHD, 2010 cited by IPCC, 2011). According to IHA (2015a), the world's total installed capacity of HPPs at the end of 2014 was 1,055 GW (excluding pumped storage plants). The study further estimates the total installed pumped storage capacity at the end of 2014 at 139 GW, bringing total hydro capacity to 1,194 GW globally. Total hydropower electricity generation was estimated at 3,900 TWh in 2014 by IHA (2015a). "*Worldwide average growth rates of hydroelectricity generation in the future are estimated to be about 2.4 % per year up to 2020*" (Pedraza, 2015).

There exist various different classifications of HPPs, inter alia according to the type, size or available head. Moreover, hydro power plants can be isolated (often in remote areas), connected to the grid, can have multiple purposes or constructed as cascades. However, in general it has to be stated that each HPP is unique due to the specific circumstances of the specific location. As such, a clear classification of hydropower plants is often difficult, also because single countries use different classification schemes.

The main parts of a hydro-electric power plant include the electro-mechanical equipment (the turbine, the generator, control systems, switch gear, cables, power and current transformers, etc.) and the civil infrastructure (the dam, reservoir, intake structure, penstock, powerhouse, grid connection, the required infrastructure, etc.). Some parts, like the turbine and generator, will always be necessary as they represent the key operating principle of a HPP. However, as mentioned above, the specific location determines which type of plant can be constructed and which parts will be needed accordingly. As such a pumped storage HPP needs a dam and reservoir for storing the water or potential energy, while diversion HPPs (run-of-river) do not require dams or reservoirs but commonly have a weir. Instream-technologies on the other hand can be placed directly in the river, without the need for any weirs, dams or reservoirs.

The costs for a HPP are generally divided in investment costs (the costs for the electro-mechanical equipment and the costs for the civil infrastructure) and expenditures for O&M. According to IRENA (2012) the investment costs of large HPPs are in a range between 1,000 and 3,500 USD/kW, but might increase if transmission lines or additional infrastructure facilities have to be built. The LCOE for large HPPs is normally between 0.02 and 0.19 USD/kWh and between 0.02 and 0.27 USD/kWh for sHPPs. Refurbishments and upgrades of already existing HPPs are the most cost-effective options with installed costs between 500 and 1,000 USD/kW and a LCOE between 0.01 and 0.05 USD/kWh. O&M costs are generally low and in a range between 1% - 4% of the investment costs/year for sHPPs and between 2% -2.5% of the investment costs/year for large HPPs.

Obtaining financing (equity and debt) is always an important prerequisite during the development process of a HPP. There are different opportunities available in the market. However, in general all of them (private investors, financial institutions, etc.) will require sufficient technical knowledge and a strong track record from the project developer. Furthermore, long-term measurements of the hydrological resource, detailed project studies, land rights, all necessary contractual arrangements (EPC, PPA, O&M, shareholder agreement, etc.) and a detailed financial model of the proposed project must be available.

About Peru

The Peruvian electricity sector was originally developed by private individuals and the first hydropower plants were constructed "*in the early years of the previous century"* (ESMAP, 2011). However, the military governments of the 1970s succeeded in nationalizing the electricity sector, with severe consequences with regard to security of supply, access to electricity and the profitability of the sector.

The first reforms were implemented in 1992. The electricity sector was unbundled and private investors were allowed to acquire concessions and to participate in the market. The "*Law to Secure the Efficient Development of Electricity Generation*" from 2006 was another cornerstone in the development of the electricity sector of Peru. Nowadays, around 70% of generation and distribution and 100% of the transmission capacity is owned by the private sector.

Historically, Peru has relied heavily on HPPs for the production of electricity. However, since the start of operation at the *Camisea* natural gas fields in 2004, thermal electricity production has increased significantly. As such, the share of large hydro represented 48.64% of electricity production in 2014, followed closely by thermal sources with 48.24%. The total installed capacity in Peru has increased to 11,284 MW at the end of 2014, nearly doubling within one decade. Furthermore, another 4.4 GW of new capacity will be added until 2019 according to recent projections.

Peru has a significant potential with regard to renewable energy sources. As such the usable technical potential for HPPs in the range of 1 – 100 MW was calculated at 69,445 MW in the recently published "*Atlas of the Hydroelectric Potential of Peru*". Moreover, a technical potential of 22,000 MW from wind power, 3,000 MW from geothermal sources and good conditions for solar power and biomass have been reported. So far, however, only a small share of these renewable resources has been used. The percentage of RE technologies in the national grid of Peru (SEIN) increased to 3.1% at the end of 2014 (compared to 2.52% at the end of 2013 and 1.83% at the end of 2012). The share of sHPPs, which are classified as renewable sources if they do not exceed 20 MW, was reported at 1.61% or 672.97 GWh in 2014.

This increase is based on a stable regulatory framework, which has been established during the last years. The "*Legislative Decree for the Promotion of Investment in Electricity Generation with Renewable Resources*" from 2008 and its regulations from 2011 promoted RE technologies as a national priority, guaranteed a priority dispatch in the SEIN and established the use of RE auctions. Those projects which succeed during the auction process enter into a PPA with the government of Peru for 20 years, with guaranteed prices denominated in USD and indexed to inflation.

The key actors in the Peruvian electricity sector include on the one hand the Ministry of Energy and Mines of Peru (MINEM) and the Directorate-General for Electricity (DGE). On the other hand, the Supervisory Organization for Investment in Energy and Mining (OSINERGMIN), the Committee for the Economic Operation of the Electric System (COES SINAC) and the Peruvian Investment Promotion Agency (PROINVERSIÓN) also have important control and support functions, tasks and responsibilities.

The Peruvian electricity market consists of the spot market, the free market, the regulated market and the auction market. The spot market is managed by COES SINAC and exchanges electricity for immediate demand between generators connected to the SEIN. The price in the spot market is calculated every 15 minutes and based on the marginal cost to supply the given demand. The free or wholesale market applies to electricity sales from generators to either distribution companies or large final consumers (mainly mines and industries). Prices, time frames and other terms and conditions are negotiated bilaterally and are not regulated by the government. The regulated market includes most of the consumers, generators, distributors and transmission companies of Peru. Prices in the regulated market are determined by OSINERGMIN and adjusted regularly. Finally, an auction market has emerged in various South American countries during the last decade in order to ensure competitive electricity prices and security of supply for final consumers. The prices offered during RE auction in Peru are technology-specific and are based on the Pay-as-bid mechanism. Furthermore, OSINERGMIN determines a price ceiling and a generation cap for each technology and auction.

Peru so far has conducted three on-grid RE auctions during the last five years, which resulted in the construction of 882 MW from biomass, wind, solar and small hydropower below 20 MW. Moreover, one RE auction for 500.000 off-grid PV systems was announced in 2014. At present, Peru is conducting the fourth on-grid RE auction, whose results are expected for end of January 2016. The requirements for participating at RE auctions are low from a technical and administrative perspective (as such only some basic data and a prefeasibility study have to be submitted), but include substantial and stringent financial guarantees (like bid and construction bonds) and penalties in case of delays or under-performance.

Assessing the economic and financial viability of sHPPs in Peru in general is hardly possible, because each hydropower plant is unique and depends inter alia on the specific location, changing regulations and available financing opportunities. However, the main conditions, which have to be fulfilled include among others things an adequate tariff regime, a stable institutional and regulatory framework, the installed capacity, load factor and LCOE of the specific plant, the availability and acceptable costs of equity and debt finance, the loan tenor, etc.

Financing is in principle available in Peru, but depends very much on the track record and creditworthiness of the borrower, the experience and risk appetite of the lender and the type of finance requested. Local banks, however, so far have hardly offered project finance for sHPPs on favorable terms with regard to pricing, loan tenor, etc. International Financial Institutions (IFIs), the Development Bank of Latin America (CAF), the Development Bank of Peru (COFIDE) and also European Development Banks do provide equity and debt capital for sHPPs. However, their requirements and standards are normally quite high and developers without sufficient own funds and track record would most probably not be able to obtain debt and/or equity capital.

Challenges, risks and market barriers

Related to the development of small hydropower in general[41]

Hydrology risk: Even though proper hydrological measurements might have been done, several dry years can have a significant impact on the viability of a project due to less than expected electricity generation. Banks will insist on long-term measurements from reliable sources.

Construction and completion risk: A construction and completion risk is inherent in any infrastructure project. Banks may as such require the involvement of an experienced engineering, procurement and construction (EPC) company, providing turnkey solutions. Main risks involve delays, cost overruns and litigations.

Operational risk: Mechanical problems and operational failures may lead to breakdowns and lengthy operational interruptions.

Price risk: If the project can demonstrate a long-term PPA, the price risk is not really a problem. However, if all or parts of the generated electricity is sold via the spot market, price changes do occur and can have a negative impact on the viability of the project. Banks may require that a certain percentage (50% and more) is covered by a PPA.

Offtake risk: Offtake risks include failures of the off-taker due to transmission line failures, congestion or for reasons of dispatch. However, these risks are generally considered as low, especially for sHPPs and in times of increasing electricity demand.

Related to the development of small hydropower in Peru

Some of the risks related to the development of hydropower in Peru have already been mentioned in the case study of this master thesis (chapter 4). These included inter alia the currency risk, regulatory and fiscal risks and political risks. As they have already been discussed, they will not be analyzed in detail now.

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[41] This part is mainly based on ESMAP (2011)

Below, several additional challenges, risks and market barriers with regard to the development of small hydropower projects in Peru, which have been stated in various publications and reports, will be further discussed.

Natural gas prices: Various sources mentioned the low price for natural gas from the *Camisea* fields as main obstacle with regard to the development of HPPs in Peru. *"The most fundamental constraint to developing Peru's hydro potential has been the low tariff faced by generators, which is a consequence of the low domestic price of natural gas"* (ESMAP, 2011). Natural gas prices averaged *"around $1.50 per million British thermal units (MMBtu), far below its economic value and pricing elsewhere around the world"* (ITA, 2014). However, as discussed in the course of this thesis, natural gas prices are expected to rise substantially in the future. This will also have positive effects on the prices in the spot market, but also in the regulated and free market. Furthermore, the RE auctions guarantee a fixed tariff for 20 years, which is a clear incentive for the development of renewable energy projects.

Local administration: Some sources mentioned complicated procedures and unnecessary delays regarding authorizations and permits as a real challenge and obstacle. As such Jochamowitz (2012) stated: *"The Peruvian government and its vetting and assessment process are also often a source of delay and frustration, particularly for firms lacking experience navigating the assessment and approval processes"*. In this regard also the IFC (2011) reported *"unclear environmental standards, in some cases, overlapping responsibilities of regulatory agencies, and lengthy procedures for the award of concessions"*. This further includes problems with water rights and the early recovery of VAT. In general, sHPPs should always be developed in cooperation with local partners as this may mitigate many of the challenges described above. In fact, experience and know how about the local market and its regulations and procedures is a prerequisite for entering any market.

Infrastructure and transmission lines: Even though the electricity infrastructure has developed substantially in Peru during the last decades, various regions are still not connected to the national grid. *"Regions in the Amazon and Andes may have substantial potential for renewable energy development on a large scale. However, these areas still lack sufficient infrastructure and connectivity for transmitting energy from generation centers to the population centers of the country"* (Jochamowitz, 2012). Various hydropower projects will thus require significant investments with regard to transmission lines and infrastructure.

Availability of financing: “*Additionally, the limited availability of low cost financing, especially from local banks, has slowed investment and reduced the attractiveness of renewable energy* […]” (ITA, 2014). This holds especially true when it comes to long-term project finance on easy terms. *“Without involvement of the government in assisting access to project financing for small hydro, it is unlikely that non-recourse project financing can be achieved, and the present 100 percent collateral/corporate guarantee requirements of the commercial banks will remain a major barrier to all but large corporate sponsors”* (ESMAP, 2011). Even though this situation is changing slowly due to the guaranteed tariffs offered during the recent RE auctions and the availability of international, regional and national development banks, financing is still a major challenge for a lot of project developers without sufficient own funds and/or experience. The reasons for this situation refer among other things to the limited experience of local banks and the high transaction costs for banks when it comes to financing sHPPs in remote areas.

Interest and lobby groups: AHK (2014) mentioned that some political interest and lobby groups are trying to impede or at least slow down the process of the RE auctions in Peru, even though MINEM is in principle obliged to call for an RE auction every two years. As such it might be possible, that RE auction will be delayed or stopped at all.

Strengths, opportunities and potentials

Related to the development of small hydropower in general

Renewable energy source: Small hydropower uses a renewable energy source – water – which is continuously available due to the hydrological cycle.

Environmental friendly: Even though emissions are released during the construction phase of sHPPs, neither heat nor noxious gases are produced during operation.

Proven and mature technology: The technology used in sHPPs is a mature, proven and cost-effective technology that offers reliable and flexible operation.

Long lifetime: sHPPs have a long lifetime and many existing plants have been in operation for more than half a century and are still operating efficiently.

High efficiency: Hydropower plants achieve efficiencies of 90% and more, making it the most efficient energy conversion technology.

No fuel costs and low O&M costs: Hydroelectric energy generally has no fuel cost and only low operating and maintenance costs.

Suitable for base load power: Small run-of-river hydropower plants are normally operated as base-load power plants. Furthermore, hydropower normally offers a means of responding within seconds to changes in load demand and plays a major role in power system management.

Rural electrification: Small hydropower offers a unique opportunity for bringing electricity to remote areas, which are so far not connected to the national grid.

Related to the development of small hydropower in Peru

Some of the opportunities related to the development of hydropower in Peru have also been mentioned already in the case study of this master thesis (chapter 4). These included inter alia the strong economic development of the country and the stable regulatory framework in the electricity sector. As above, they will not be analyzed in detail again. Below, several additional strengths, opportunities and potentials with regard to the development of sHPPs in Peru will be discussed.

Positive investment climate: Peru actively promotes domestic and foreign private investments and the legal system guarantees private property, free competition and free repatriation of profits (E&Y, 2015). "*In addition, the country has one of the lowest import duties for renewable energy equipment out of 55 countries analyzed on Climatescope*" (global-climatescope.org, 2015). A steady tax regime further contributes to the positive investment climate of Peru (ProInversión, 2015).

Incentives for RE technologies: As discussed before, the "*Legislative Decree for the Promotion of Investment in Electricity Generation with Renewable Resources*" from 2008 and its regulations from 2011 promote RE technologies and provide explicit incentives for RE technologies, such as a priority dispatch in the SEIN, the use of RE auctions including guaranteed tariffs denominated in USD and indexed to inflation, etc. Moreover, the accelerated depreciation of up to 20% of investment in equipment and machinery from RE technologies *"can reduce start-up costs and overall taxes, potentially facilitating the entry of businesses into the market"* (ITA, 2014).

Administration and procedures: Even though it was reported that some procedures and the environmental impact assessments for large scale HPPs are a source of delay and frustration, this does not apply to sHPPs*. "Entry into the small-scale hydro market, on the other hand, comes with few barriers. No Environmental Impact Assessment is required for projects that generate less than 20 MW, and only a submitted summary of a project is required when generation is less than 500 KW"* (ITA, 2014).

Development of the electricity market: Due to the expected high electricity demand in the years to come, the security of electricity supply will continue to be a national priority for the government of Peru. This ensures a stable regulatory framework and raises hopes for a continued favorable tariff regime. Moreover, as mentioned previously, the prices for natural gas will increase in the future as Peru just recently became an exporter of LNG. This will again have positive effects on long-term prices for electrical services. Finally, the authorities of Peru have acknowledged the huge potential of the country and are actively trying to take advantage of the locally available energy resources. "*The government has big ambitions to turn the country into a regional energy hub, exporting electricity to Brazil and Chile. Some of these plans are starting to be put in effect*" (IBP, 2015).

Opportunities for first movers: *"Unlike the mining and large-scale hydroelectric industries, renewable energy is still a relatively new industry in Peru, providing both foreign and domestic firms the opportunity to capitalize upon as-of-yet uncaptured market shares"* (Jochamowitz, 2012). *"Moreover, the expected growth rate in energy generation investment over the next two decades indicates that there is room for new entrants in the market […]"* (ITA, 2014).

Data and information: Basic field data and information for projects is available in Peru. ESMAP (2011) mentioned in this regard:

- "*Electronic versions of topographic maps at 1:100,000 scale are immediately available from the Instituto Geográfico Nacional (IGN), and electronic maps at smaller scale (e.g., 1:25,000) can be obtained from IGN upon request.*
- *Similarly, 1:100,000 scale geological maps and several smaller-scale regional and local maps are available from the Instituto Geológico Minero y Metalúrgico (INGEMMET).*
- *Hydrometeorological data are available from the Servicio Nacional de Meteorología e Hidrología (SENAMHI)* […]."

Even though the quality of services from SENAMHI apparently deteriorated during the last years, ESMAP (2011) concluded that "[…] *a reasonable estimate of energy* *production (and possibly even "dependably" dry season output) can usually be obtained*".

Local expertise: There exists sufficient local expertise with regard to project and civil engineering and construction and in carrying out environmental impact assessments. Moreover, various business associations related to renewable energy exist in Peru.

Local attitude towards hydropower: Hydropower is generally considered positive in Peru, as it is an indigenous resource that has reliably provided electricity for a long time. Furthermore, ESMAP (2011) mentioned: "*Hydropower development in Peru has occurred with little social or environmental damage, because it has been mainly run-of-the-river or constructed with small reservoirs*".

Addressing the core question of this master thesis

In the final part of this thesis, the core question of this master thesis will be answered, which is:

- *Is the development of sHPPs in Peru a viable business opportunity for project developers and investors from a risk-return perspective, taking into account the technical potential, the stability of the economic and political situation, the regulatory framework of the electricity sector and economic and financial considerations?*

As described, the technical potential with regard to hydropower is substantial in Peru. The usable technical potential in Peru has been reported at nearly 70,000 MW, of which only a small fraction has been exploited so far. The potential for sHPPs up to 20 MW has been conservatively estimated at 1,600 MW.

The economy has grown rapidly during the last decades in Peru due to political stability and a commitment to comprehensive reforms. As such, the GDP of Peru increased significantly during the last decades, reaching USD 204 billion in 2014. Currently, Peru has an investment grade rating of BBB+ from Standard & Poor's and Fitch Rating and of A3 from Moody's.

With regard to renewable energy technologies, an extensive regulatory framework has been elaborated in the last years. This includes inter alia a priority dispatch in the national grid and the introduction of auctions for renewable energy technologies (including guaranteed tariffs denominated in USD and indexed to inflation). Moreover, an accelerated depreciation of up to 20% of investment in equipment and machinery from renewable energy technologies is granted to project developers.

From an economic and financial point of view it is hardly possible to assess the viability of sHPPs in general, as each plant is exceptional due to the specific conditions of the project site. As analyzed in the course of this thesis, the low price for natural gas was a major obstacle for the development of sHPPs in Peru. In this regard ESMAP (2011) mentioned: "*If the tariff resulting from the Renewable Energy Decree is adequate and predictable, and similar to small hydro preferential prices in other countries (roughly 5 to 7 US cents/kWh), the main barrier to small hydro development would be overcome*". As described in chapter 3 of this thesis, the tariffs offered during the renewable energy auctions conducted so far amounted to roughly 5.3 to 6 US cents/kWh, which are guaranteed for 20 years. This demonstrates that it is nowadays economically and financially viable to operate sHPPs and that the government of Peru has set the correct steps and changes in the regulatory framework in order to exploit the small hydro-electric potential of the country. However, finding financing for sHPPs in Peru is still considered as a serious challenge, except for those companies with strong balance sheets and considerable experience.

Concluding, it thus can be stated that the small hydropower sector in Peru is very interesting and promising for local but also foreign project developers and investors. Even though several risks, challenges and market barriers remain, the development of sHPPs in Peru can be considered as a viable business opportunity for project developers and investors based on the technical potential, the stability of the country, the regulatory framework and economic and financial considerations. As such, also Jochamowitz (2012) mentioned: *"Opportunities for development are widely available, but businesses must be both patient and persistent in attempting to develop renewable energy technology in the country"*.

Even though this thesis analyzed the opportunities, potentials, challenges and risks with regard to the development of sHPPs in Peru, a collective assessment with regard to the economic and financial feasibility of sHPPs in Peru is not possible. On the contrary, a decision to invest in a capital-intensive and long-term project (which both applies when it comes to small hydropower) can only be taken individually, based on the specific site conditions of the project and the experience, risk appetite and available resources of the project developers and investors.

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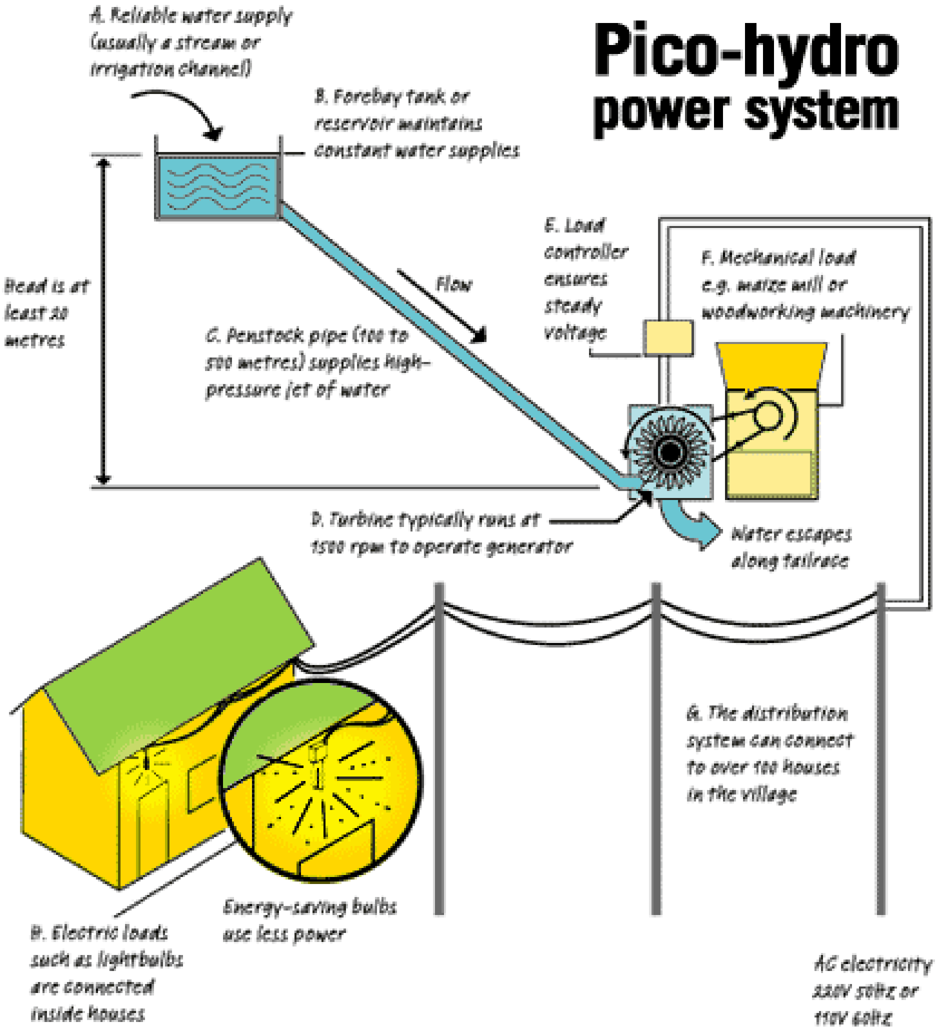
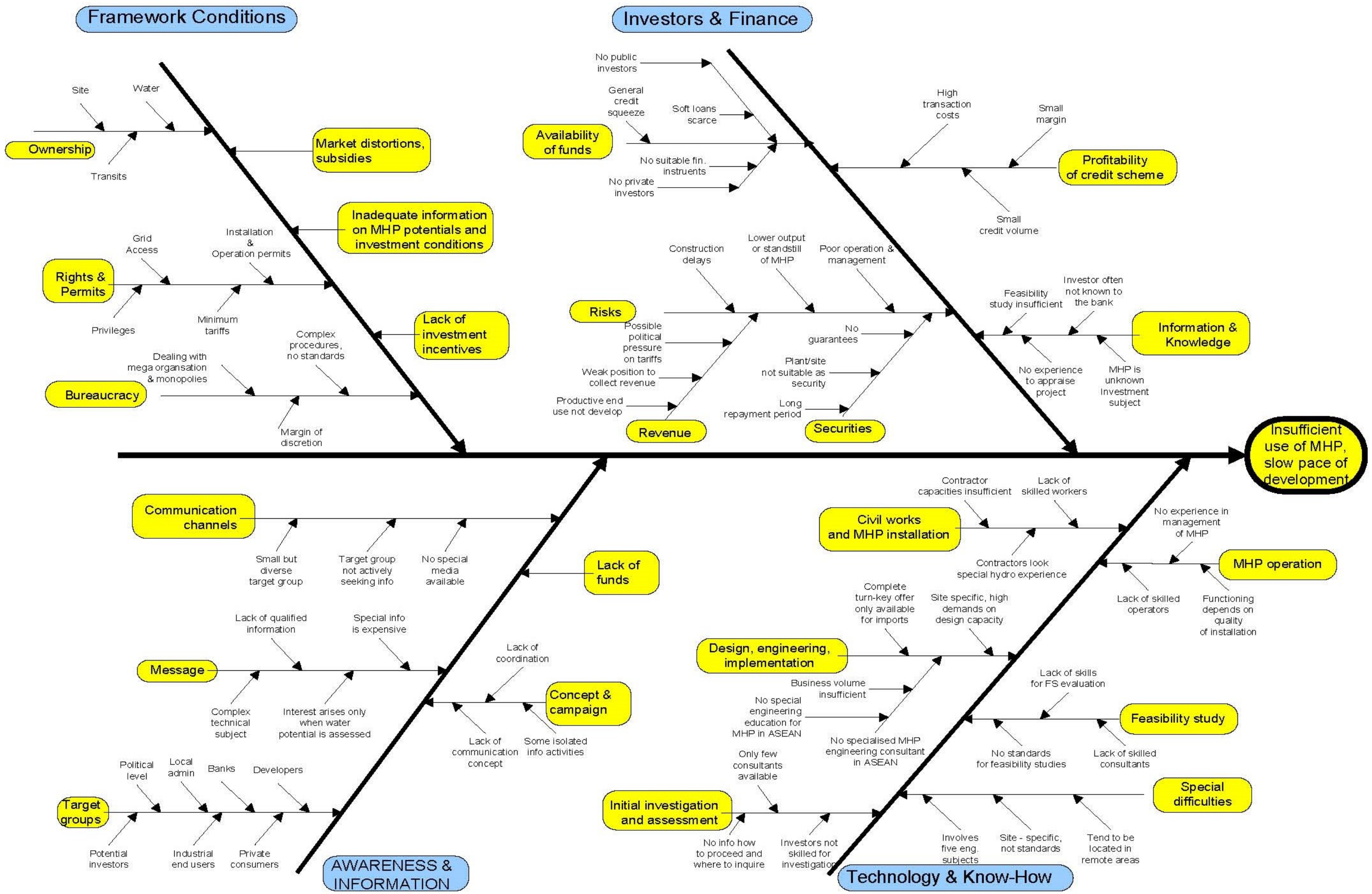
Annexes

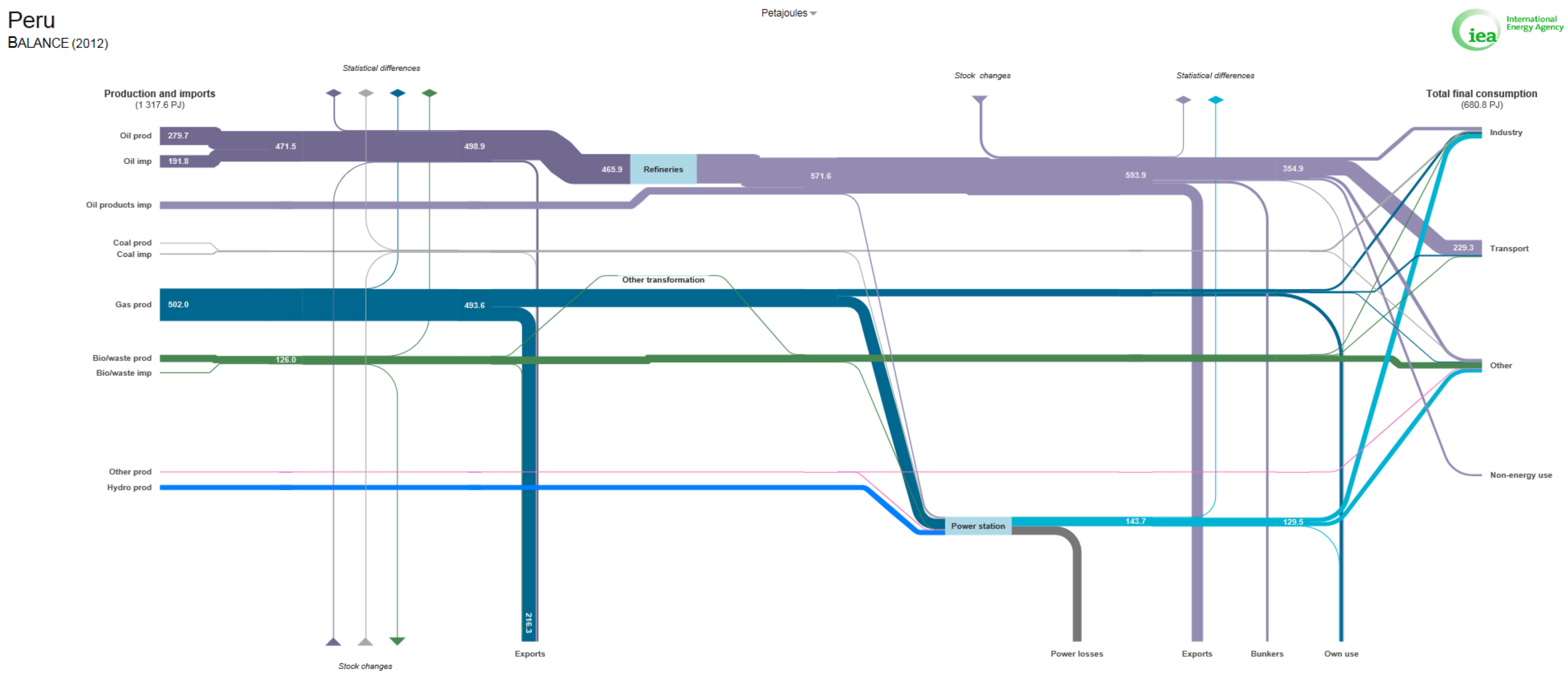
Annex 1. Pico-hydropower system. Source: *http://practicalaction.org/pico-hydro-in-kenya* (2015)



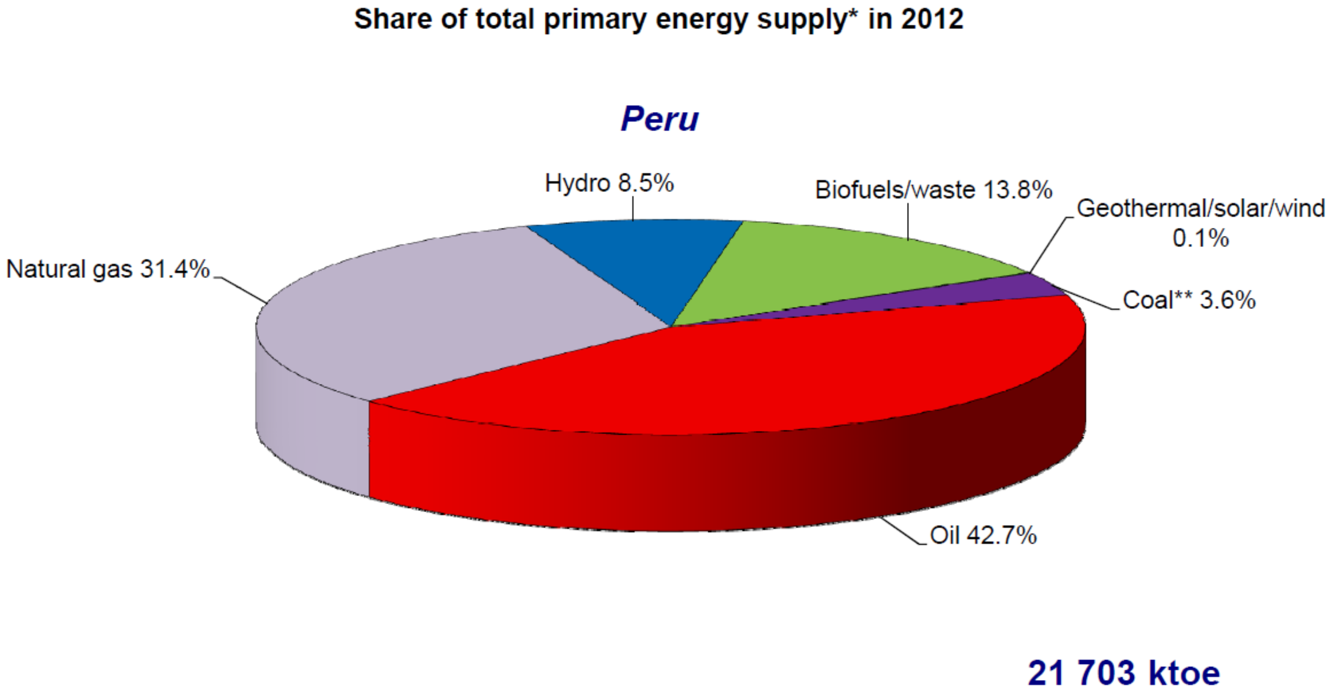
Annex 2. Complexity and barriers of micro-hydropower. Source: *https://energypedia.info/images/b/b7/Complexity_of_MHP.jpg* (2015)



Annex 3. Sankey diagram of Peru in 2012. Source: www.iea.org (2015)



Annex 4. Share of total primary energy supply in Peru in 2012. Source: www.iea.org (2015)

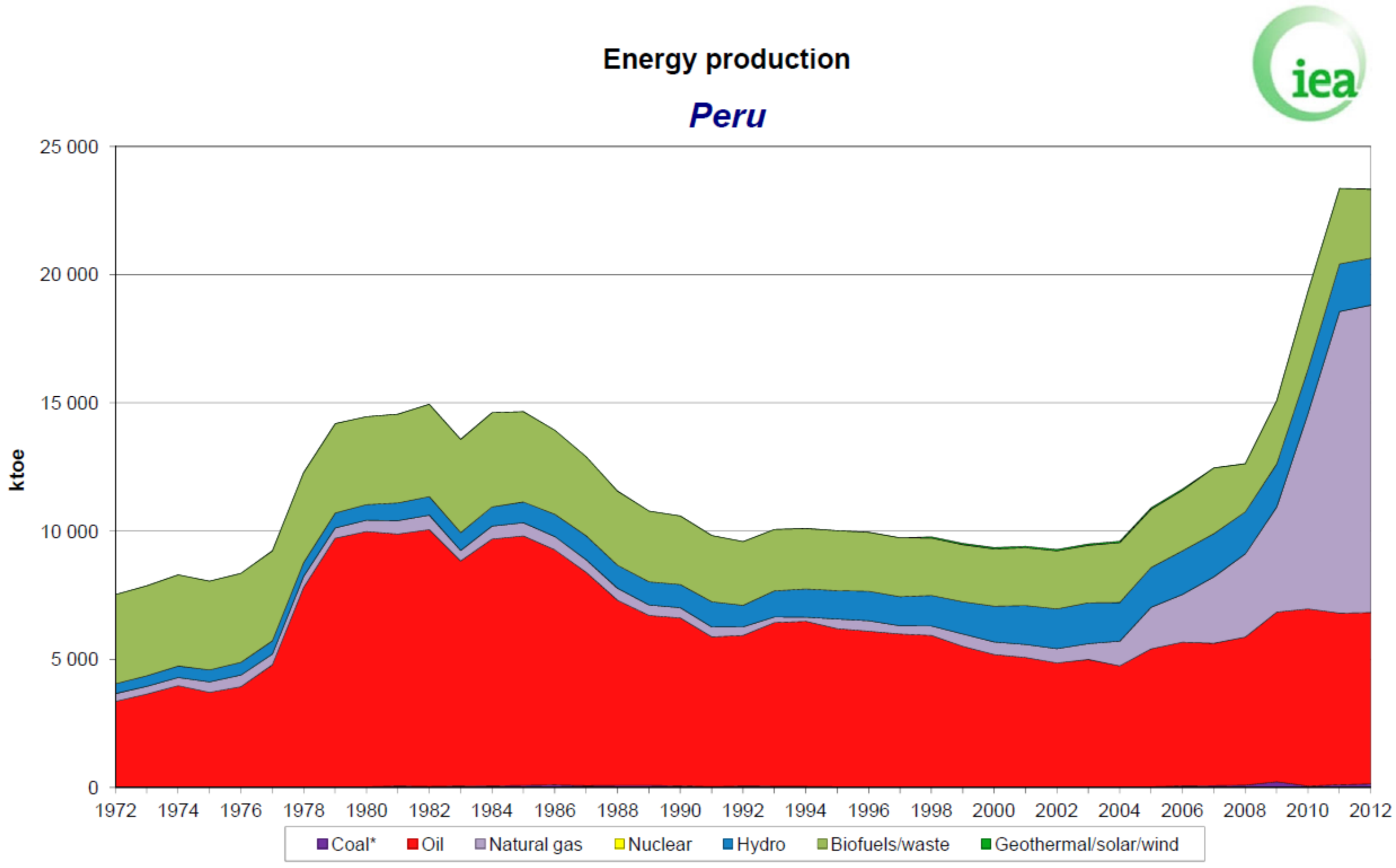


* Share of TPES excludes electricity trade. ** In this graph, peat and oil shale are aggregated with coal, when relevant.

Note: For presentational purposes, shares of under 0.1% are not included and consequently the total may not add up to 100%.

For more detailed data, please consult our on-line data service at http://data.iea.org.

Annex 5. Energy production Peru 2012. Source: www.iea.org (2015)



* In this graph, peat and oil shale are aggregated with coal, when relevant.

For more detailed data, please consult our on-line data service at http://data.iea.org.

Annex 6. Average spot prices in Peru (US$/MWh) from 1999 to May 2015. Source: COES-SINAC (2015), cited by BTG (2015)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	YoY %	MoM %
Jan	17.6	12.9	7.6	20.0	13.1	51.2	22.7	29.4	25.0	17.4	26.7	23.1	17.4	18.5	19.4	21.4	**14.1**	(33.9)%	(6.8)%
Feb	12.8	15.2	13.6	16.9	16.4	36.6	21.8	38.4	35.6	18.4	43.8	24.5	21.5	33.1	31.4	24.0	**16.2**	(32.4)%	14.8%
Mar	7.0	18.1	18.3	15.9	21.6	32.5	29.5	24.1	46.1	20.9	24.9	22.0	21.5	61.0	19.7	34.3	**17.7**	(48.4)%	9.1%
Apr	5.9	7.9	7.3	10.3	11.1	54.5	30.0	38.7	34.6	20.9	25.3	16.6	17.8	32.6	18.8	28.1	**13.1**	(53.3)%	(25.9)%
May	8.6	5.8	9.5	23.3	20.3	108.5	91.2	111.1	36.3	47.9	28.7	18.2	18.6	23.0	27.1	25.4	**15.8**	(37.7)%	20.7%
Jun	13.0	15.6	23.6	31.5	43.2	99.4	74.7	87.9	65.8	154.4	65.7	20.4	25.8	32.2	26.6	31.0			
Jul	14.3	31.8	39.2	33.6	57.4	97.6	47.1	90.7	27.8	235.4	41.2	19.9	20.1	59.1	44.8	24.9			
Aug	21.8	37.1	41.1	51.2	64.6	111.6	92.8	105.9	45.1	157.9	33.9	22.9	31.4	35.0	34.7	27.4			
Sep	20.0	37.0	36.9	51.2	61.3	112.4	85.1	149.8	34.4	185.2	36.2	23.9	33.3	36.4	28.3	23.9			
Oct	19.9	37.4	29.0	35.2	58.1	64.1	91.3	71.9	35.5	63.4	19.8	24.2	27.3	29.0	19.5	18.0			
Nov	33.6	29.3	20.1	18.9	65.9	23.9	98.8	40.6	29.5	60.7	20.4	23.1	27.1	14.8	23.0	21.3			
Dec	16.9	10.7	17.1	18.2	24.0	31.5	75.2	28.9	44.1	81.8	17.2	18.8	21.3	13.8	24.9	15.2			
1Q	12.4	15.4	13.2	17.6	17.1	40.1	24.7	30.6	35.6	18.9	31.8	23.2	20.2	37.5	23.5	26.6	**16.0**	(39.7)%	(11.8)%
2Q	9.2	9.8	13.4	21.7	24.9	87.5	65.3	79.2	45.6	74.4	39.9	18.4	20.8	29.3	24.2	28.2	**14.5**	(48.6)%	(9.7)%
1H	10.8	12.6	13.3	19.7	21.0	63.8	45.0	54.9	40.6	46.6	35.8	20.8	20.5	33.4	23.8	27.4	**15.4**	(43.7)%	
3Q	18.7	35.3	39.1	45.3	61.1	107.2	75.0	115.5	35.8	192.8	37.1	22.2	28.3	43.5	35.9	25.4			
9m	13.4	20.2	21.9	28.2	34.4	78.3	55.0	75.1	39.0	95.4	36.3	21.3	23.1	36.8	27.9	26.7			
4Q	23.5	25.8	22.1	24.1	49.3	39.8	88.4	47.1	36.4	68.6	19.1	22.0	25.2	19.2	22.4	18.2			
Y	15.9	21.6	21.9	27.2	38.1	68.6	63.4	68.1	38.3	88.7	32.0	21.5	23.6	32.4	26.5	24.6			