

A COMPARISON FRAMEWORK BETWEEN TYPES
OF ELECTRIC SYSTEM OPERATORS.
THE UNIQUENESS OF THE BRAZILIAN CASE IN THE CONTEXT
OF HYDRO-DOMINATED SYSTEMS

by

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Abstract

First and foremost, this research project develops a framework for analyzing electric system operators (“ESOs”). A deep literature survey is invoked to inventory the responsibilities of these institutions; then, a graphical model is developed so as any type of operator can be represented. This framework is useful to create comparisons between operators and understand the different nature of the responsibilities they are charged with, in connection with the particularities of their electric sectors. This framework was developed with the precise aim to benchmark the Brazilian operator against similar entities, yet it can be used for any country with an at least functionally unbundled ESO. Canada, Norway and Colombia were chosen due to the high percentage of hydroelectricity in their electricity generation capacity and production matrixes, a characteristic that is similar to the Brazilian case. Nevertheless, the study finds that the Brazilian operator’s particularities owe mainly to the uniqueness of the electricity context, despite a few transaction costs between institutions than can possibly be reduced.

Key-words: *system operator, electricity transmission, hydroelectricity, ISO, TSO.*

Resume

Antes de mais, este projecto de pesquisa desenvolve um quadro de análise para operadores de sistemas eléctricos (“OSEs”). Uma profunda pesquisa bibliográfica é invocada para inventariar as responsabilidades destas instituições; depois, um modelo gráfico é desenvolvido; ele possibilita comparações entre operadores e para entender a natureza distinta das responsabilidades com as quais cada um está encarregado, em função dos sistemas eléctricos onde estão inseridos. Esse modelo foi desenvolvido com a motivação explícita de comparar o operador brasileiro com entidades semelhantes. No entanto, ele pode-se utilizar para qualquer país que tenha pelo menos um operador funcionalmente desverticalizado. Canadá, Noruega e Colômbia foram escolhidas devido à alta participação da hidroelectricidade na capacidade instalada e na produção, uma característica semelhante ao caso brasileiro. A principal conclusão do estudo é que as particularidades do operador de sistema brasileiro devem-se em grande parte à unicidade do contexto do “seu” sector eléctrico, mas que alguns custos de transação entre instituições do sector poder-se-iam reduzir.

Palavras chave: operador de sistema, transmissão de electricidade, hídrica, hidro-eléctrica, ISO, TSO.

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Introduction

“The bulk power system is only as strong as its weakest link.”

Rick Sergel, President of NERC

Since the end of the 1980s, the electricity sector in both developed and developing countries has been subjected to ample reforms. The amplitude of the phenomenon speaks for its global impact: ten years later, most of the then 31 OECD¹ countries and over 70 developing countries had initiated reforms (Bacon, 1999, Steiner, 2001). The general paradigm of these reforms is the passage from a vertically integrated, state-owned monopoly industry to a liberalized, unbundled and competitive way of functioning. This change was a reaction to the post-war electricity sector model, which resulted in economic inefficiencies; these were caused by the use of expensive generation technologies and excess capacities, as well as almost non-existent customer service (Jamashb *et al.*, 2005).

The first country to reform its electricity sector – in the early 1980s - was a South American country: Chile. Despite its weak rule of law and democracy, Chile’s reform is considered a successful model, which shall be explained at key-points during the length of this dissertation.

The consecrated value chain of the electricity sector is composed out of four major lines of business: energy production or generation, transmission over high-voltage lines, across long distances, distribution along low-voltage lines, to final customers and commercialization or retail, which involves selling to and billing customers.

This study focuses on the transmission business. Its pivotal role for wholesale competition in a restructured electricity system is a much debated topic in the specialized international literature. The key requirement that all market participants (i.e.

¹ In July 2010, Slovenia became the 32nd member of the OECD.

generators and distribution companies) have non-discriminatory (or *open*) access to the transmission grid stands at the basis of competition at the wholesale level.

The institutions that oversee transmission are called *electric system operators*. It is these institutions that this study shall examine closely, focusing on hydro-dominated electric systems².

Electric system operators focus on wider areas than traditionally integrated utilities; they contribute to raising the efficiency and economy of serving demand, or *load*. These institutions are essential for insuring grid security and reliability – two words that the international literature not only over-utilizes but also seems to confuse. Maintaining system security or “integrity” means avoiding unplanned load cuts and uncontrolled cascading power outages. “Reliability” is related with security and generally associated with *adequacy of supply*. Both terms refer to avoidance of undesired blackouts (Alvarado and Oren, 2002).

The object of this dissertation is to construct a comprehensive model of functions that electric system operators are charged with, a model which can serve as a comparison framework for different operators. This tool shall be used to examine the particularities of the Brazilian system operator – the National System Operator (ONS³). Due to its continental size (“from Lisbon to Moscow”), vast amount of hydroelectricity – around 80% of consumption - and reform history, Brazil’s electricity market is unique and the way it is configured has no basis for comparison in other countries. The last reform was as recent as 2004, after a harsh rationing period following a major blackout in 2001. Thus, efforts to understand whether the change is being fruitful for the operator’s interaction with the system positively or negatively are justified.

Furthermore, this dissertation seeks to fulfill the following objectives:

- i. A **general objective** of documenting in the most comprehensive possible way the functions and responsibilities of an electric system operator, together with a simple, graphical way to depict these responsibilities; this graphical model

² Countries/regions where hydroelectric penetration in consumption rises above 50% of the total.

³ In Brazilian Portuguese, *Operador Nacional do Sistema*.

should be facile to manipulate and insert into a comparison framework between system operators;

- ii. **Specific objective #1:** making a selection of a few appropriate case studies whose electricity markets resemble that of Brazil sufficiently to be able compare system operators;
- iii. **Specific objective #2:** creating a pertinent comparison for system operating arrangements, using the model created to meet the general objective, between the Brazilian system operator and other, possibly smaller but successful models in order to verify whether the particularities of the base-model justify the institutional arrangement or not.

Methodologically, the approach is the following: after a literature review focused on electric system operation, the main institutional arrangements are been identified as well as the determinants of the latter. Not all system operators fulfil the same responsibilities. Thus, an attempt to put together a comprehensive model with all possible responsibilities shall be made. Furthermore, selected system operators from a number of countries will be examined through this model – which shall provide an indication of their roles in their local electricity systems, including Brazil. Last, a benchmark will be built, on the basis of several criteria in order to better understand the ONS and its insertion in the Brazilian electric system.

The first chapter explains the functions of a system operator thoroughly and includes the comparison framework. The second chapter presents the main types of operating arrangements together with a selected group of criteria for their understanding. Chapter 3 incorporates support-case studies, while Chapter 4 details the situation in Brazil. The last chapter comprises the countries' summary and benchmark comparison and it is followed by a conclusion.

The main conclusion that is reached is that the ONS covers a system too extensive to work on a mercantile basis at this point, a system still in development, which needs centralized planning and operations before it can evolve. All in all, the ONS is organized in a relatively unique way – which is pertinent when taking into account the particularities of the Brazilian electric system.

Chapter 1

Main attributions of an electricity system operator

The transmission system operator is a pivotal institution to any modern electricity market. Arizu *et al.* (2001) define it as the entity whose job is to *ensure the electrical stability of the interconnected system so that bulk power can be transported from generators to distribution networks* in a reliable manner, without incidents.

Briefly, the main activities of the electric value chain are the explained:

- Generation or production of energy; this sector that is considered competitive because electricity production is no longer the lumpy investment it was 15-20 years ago, nor necessarily a very long-term investment, due to technological progress¹. Should generators and distributors have free access to the transmission grid, then any traditional, new gas-fired or renewable etc. producer can compete in the wholesale market;
- Transmission, the high voltage lines² that carry electricity across long distances, from production sites to cities and other consuming localities. Transmission lines are considered a natural monopoly; Such a monopoly usually results from lumpy investment costs that are prohibitively high for new entrant, thus inefficient for the economy;
- Distribution, the lower-voltage lines that connect transmission hubs to the final consumers – also a natural monopoly;
- Commercialization or retail – the act of purchasing electricity from generators and having it delivered and billed to consumers; Retail is also a competitive activity because there is no limit to how many individuals may venture into the activity of buying energy from generators and delivering to customers;

¹ According to the Canadian NEB - National Energy Board (2003) in the late 1980s and early 1990s, in Canada and the U.S. construction of smaller gas-fired power plants began to be achieved much faster, especially with combined-cycle natural gas-fired power plants. Their capital costs are lower. Cogeneration also became profitable for industrial producers in the sense that extra energy could be sold to the grid.

² above 110kV

- A fifth activity, not included in the consecrated model, is *trading* (Kotlowski, 2007). Trading is worth mentioning, as it has come to play an important role in market arbitrage but also with its market-disturbing dimension: speculation. Not all electric sectors have a stock or power exchange that supports electricity trading. As the first energy futures contract was only traded on NYMEX in 1978, with oil, and the activity only grew in proportion at the turn of the century, being a relatively recent addition to the general model.

In Chile, the unbundling of the sub-sectors of the value chain has led to six fold increases in productivity since its 1982 pioneering reform, according to Pollitt (2004). This achievement was made with considerable reductions of workers from the new, foreign entrants who ended up controlling the whole sector. Private property played a key-role in this reform.

1.1 System operator of the electricity market – concept

Stand-alone system operators are quite recent in their present form. The first company exclusively dedicated to electricity transmission and electricity system operation was only created in 1985³, in Spain - Red Eléctrica de España, or “REE”. One year later, an independent system operator was installed in Chile, to manage a number of regional power markets that were formed after the unbundling of the previous incumbents (Pollitt, 2004)

It must not be interpreted though that without a system operator the electricity sector would fail to function. Before these institutions emerged, system operation activities were provided by vertically integrated utilities in their regions of activity. The main gain to having an operator for an entire country or region consists of the efficiency gains from centralized operation and economies made due to reduced redundancy of resources, such as generation reserves. Harris (2006) observes that system operators provide high-value services, from reliability, operational efficiency and grid planning to open access provision and market operation – which are presented in detail in this chapter.

³ See Red Eléctrica de España (2010a)

Furthermore, electricity system operators are found in the international literature under several denominations, although the concept is roughly the same: “system operator”, “network operator”, “grid operator” or “system controller”, to name the most frequent. In Europe, “transmission system operator” (TSO) is the most common term, whereas “independent system operator” (ISO) is used in the Americas. TSOs in Europe own the transmission lines, whereas American ISOs do not, limiting themselves to commanding the way they are used, while their separate owners provide the effective transmission service. Some authors, as Oren et al. (2001), use the term “independent transmission company” (ITC) to refer to European-type TSOs that integrate asset ownership and control and are for profit entities. The same author uses “transmission service provider” (TSP) to name a system operator that generically owns and operates transmission assets. In the United States, the ISO is evolving to a broader concept, that of a “RTO” – a regional transmission organization, whose scope is to control grid operations in vaster, transnational territories. The general term used for RTOs and ISOs, according to the new regulatory mark in the US⁴ is “independent transmission provider” (ITP). EURELECTRIC has devised a European version of a RTO, called “Regional Independent Operator” – RIO – thought to unify the efforts of ISOs in a region of countries and to gradually absorb their network operation-related tasks⁵. To avoid confusion of both concepts and their acronyms along this text, any of these entities shall be referred to as types of electric system operators, or “ESOs”. The table below summarizes names and acronyms.

⁴ The current regulatory mark in the USA, established by the Federal Energy Regulatory Commission (FERC) is called “Standard Market Design”. RTOs are regularized by Order 2000 of the Commission, whereas ISOs are regularized by Orders 888/889.

⁵ See Lundberg (2007) for details.

Table 1 - Denominations for the main types of system operators

Acronym	Name	Essential aspects
ISO	Independent System Operator	Widely implemented in North and South America; Usually a non-profit entity that operates the transmission system without owning any transmission lines.
RTO	Regional Transmission Organization	Emergenced in the USA; Similar in functions to an ISO, yet having a geographically more ample scope.
ITP	Independent Transmission Provider	General term for ISO or RTO.
TSO	Transmission System operator	The European model; A for profit operator that manages and owns assets.
ITC	Independent Transmission Company	Equivalent to TSO.
TSP	Transmission Service Provider	Equivalent to TSO.
RIO	Regional Independent Operator	The European version of "RTO".
ESO	Electric System Operator	A generic term used in this study to name any entity that incorporates system operation without necessarily owning transmission assets.

Source: elaborated by author, based on: Cunha (2005) and Oren *et al.* (2001)

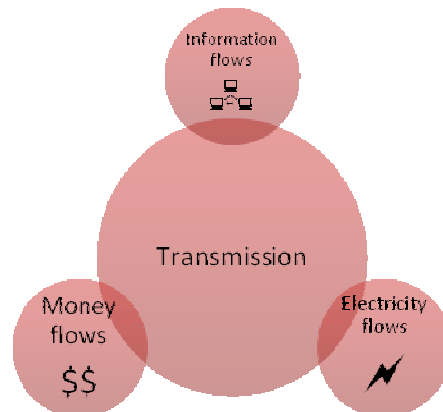
During the next section, the main attributions of ESOs are outlined and discussed. In order to facilitate the understanding of technical terms, definitions have been accordingly provided.

1.2 Attributions – general overview

Transmission grid management can be seen as dealing with three types of flows, as noticed by Harris (2006):

- i. The flow of electricity across power lines – system administration;
- ii. The flow of information about power and the equipment it moves across;
- iii. Financial flows between market actors (producers, transmitters, retailers, buyers and system operators, among others).

Figure 1 - Main flows of the transmission business



Source: elaborated by the author, based on Harris (2006)

These three flows are tackled by the main functions that have been associated to electric system operation provision, in a perspective consistent with that of Oren *et al.* (2002):

- i. (Transmission) system operation;
- ii. Market operation;
- iii. Grid ownership.

The first function, *system operation* essentially refers to the maintaining security and reliability of the electric system, by tasks like: monitoring and control of system operations with a view to securing real time energy balance, congestion⁶ management, generator scheduling⁷, acquisition of ancillary services⁸, planning or approving the maintenance of transmission and/or generation facilities, provision of open access to the transmission system for all market participants, as well as ensuring transparency through making available relevant data for the market participants. Information flows are essential to this function.

Next, *market operation* refers to the administration of spot or/and forward energy market or even bilateral contracts intermediation – usually also providing additional

⁶ Congestion occurs when power flows become large enough to reach or be close to reaching the capacity of a transmission line (or other equipment) – threatening the reliability limits of the facility.

⁷ Generation scheduling is the review and validation of the technical feasibility of schedules submitted by others, as Arizu *et al.* (2001) mentions.

⁸ Ancillary – or auxiliary – services are services that are required for secure grid operation.

services required by the market (metering, accounting, settlement, billing, publicising information). Informational and financial flows are essential for this function.

Third, *ownership of the transmission assets* may involve: effective provision of the transmission service, provision of the service on a non discriminatory basis, maintenance, as well as building the lines. There might exist *various* transmission owners but the system operator is always unique the country/state/region. Electricity and financial flows are most relevant for this case.

Normal, secure transmission system operation, as explained by Alvarado and Oren (2002) and as the Swiss operator's transmission code confines⁹, means that:

- i. System frequency is maintained within limits established according to stability standards;
- ii. Voltage at all locations is maintained within required bounds;
- iii. No component of the network is inappropriately overloaded;
- iv. No load is disconnected involuntarily.

Having explained the general concepts behind electricity system operation and grid security, the next section seeks to establish a general model containing the main functions of an electricity system operator.

1.3 The main functions of an electricity system operator

The three main business functions associated to system operation are reviewed and a graphical synthesis is presented at the end of this section.

A. System operation: securing energy balance

Operation is the main function of an electricity system operator. The objective of operation is to *maintain system security*, which is to effectively balance the supply of electricity to the grid with the demand, taking into account and minimizing the risk imposed by the contingencies of the system¹⁰. Why this is such a demanding task is

⁹ Swissgrid (2010a)

¹⁰ The most widespread security criterion is "N-1" security, which means that the system can sustain the disruption of one arbitrary element, without suffering blackouts. "N-2" or "N-3" security criteria are considered where probabilities of default of more than one arbitrary element is considerable. Nevertheless, in this case operation becomes sensibly more expensive.

explained by the complexity of the electrical system¹¹ together with the fact the electricity cannot be stored¹², so it has to be produced exactly when it is demanded for consumption, an activity which is not precisely predictable. System operation consists of the following sub-functions:

- i. Scheduling coordination. A schedule is a time series of average output values for the delivery or consumption of electricity over a specific period. When the system operator is in charge of scheduling coordination, it verifies that the schedules it receives are equivalent with associated counterpart schedules – between flow generator and flow receiver - for each time unit (Swissgrid, 2010a). Schedules might be submitted by other entities as well, called “schedule coordinators”¹³, but the system operator usually has the task to validate their technical feasibility. It is the system operator that validates the quantity of energy that is produced and transmitted across the system to the distribution lines;
- ii. Congestion management. Congestion management by the system operator means ensuring that secure grid operations can be maintained by means of preventive (e.g. net transfer capacity¹⁴ provisions, transmission capacity auctions etc.) and operational measures (e.g. re-dispatch¹⁵, reductions of flows etc.);
- iii. Deployment of ancillary services. Ancillary – or auxiliary – services are required for secure, reliable grid operation. They comprise, in particular: spinning reserve, system coordination, energy imbalance, primary control, black start and island operation capability of generators, voltage support (including a

¹¹ The electrical system’s complexity is given by the requirement to ensure that all generators, substations, transmission and distribution lines must be functioning at the same time and in a synchronized way. Further, fuel supply must be ensured, which can be a very complicated task depending both weather conditions (hydro) and the economic cycle and market hedging conditions (gas and oil prices can vary sensibly in an interval of a few months). Weather hazard is further problematical. A single tree falling over the 380 kV Lukmanier transmission line in Italy in 2003 resulted in a collapse of entire Italian power grid. See Swissgrid (2010) for more information.

¹² The only large-scale way to store energy is in the reservoirs of hydroelectric power plants.

¹³ See Cunha (2005) for details. A power exchange, for instance, is a regulated scheduling coordinator.

¹⁴ Maximum exchange program between two grid areas, which is compatible with security standards applicable in both areas and takes into account the technical uncertainties of future grid situations. See: Bacon (1999), Cunha (2005), Swissgrid (2010a).

¹⁵ Generation re-dispatch is a traditional tool for maintaining system security – consisting of the fact that system operators submit orders to selected generators to increase/decrease their output according to system security needs.

proportion of reactive energy), operational measurements and the compensation of active power losses (Bacon, 1999, Cunha, 2005, Swissgrid, 2010a). A brief description of the main ancillary services follows.

- **Spinning reserves** are generators that can increase production automatically should frequency tend to decrease (demand signals are outweighing production levels). Sufficient spinning reserves can make up for the default of any element of the system. Reducing demand used to be a form of spinning reserve¹⁶ and nowadays it is increasingly recovering this role through demand-response¹⁷;
- **Supplemental (non-spinning) reserves** are used to re-establish spinning reserve margin after an outage has engaged the latter, so that the system returns to the previous sustainability level;
- **Voltage control/reactive power.** Voltage is the electric force that takes electricity from one point to another, measured in Volts (V) according to the International System of Measurements. The electrical energy required to create electrical or magnetic fields used for maintaining voltage stability during grid operation is called reactive power (Swissgrid, 2010a; Union for the Co-ordination of Transmission of Electricity - UCTE, 2009). The system operator must regulate voltage levels¹⁸;
- **Energy imbalance.** This ancillary service arose from the need to mitigate differences between schedules and actual demand for energy. These differences come both from random changes in load but also from normal time delays in units response, errors in metering or control but also from

¹⁶ As Alvarado and Oren (2002) underscore, traditional induction motor loads automatically reduced consumption as frequency dropped. On the contrary, the new adjustable-speed drives – controls that adjust motor speed independent of frequency – do not have this feature, depriving the transmission grid of a “free” reserve.

¹⁷ Demand-response is a way of turning electricity demand elastic, by providing consumers with price signals so that they reduce their loads during peak hours or install micro-generation and/or storage facilities. PJM Interconnection (2006) provides an illustrative case study, as it opened its synchronized reserves markets to demand response providers. Related to demand response is the concept of demand side management, which means to incentive the consumer to be more energy efficient on a long-term basis, for example by building automation upgrades, variable frequency drives etc.

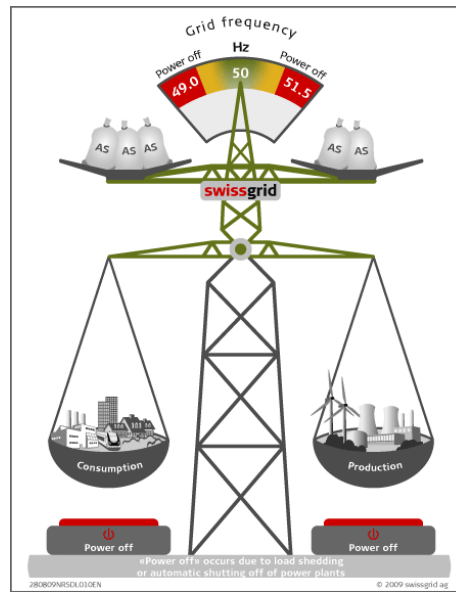
¹⁸ This is usually done by shunt injections, as Alvarado and Oren (2002) briefly outline.

deliberate “price chasing”, of generators who increase their production intentionally when the spot price increases.

Ancillary services can be provided through the power exchange, by the system operator itself – through contracts with providers – or by both, according to the organization of the sector. They can be provided in a bundled fashion or separately. The system operator often procures these services and bills network users. Generators can self-procure some of the ancillary services (reserves and energy imbalance) and may also buy the remainder from the system operator, who procures them by means of competitive auctions (Rahimi and Vojdani, 1999);

iv. Frequency control (or “frequency regulation”). Frequency control has to do directly with balancing generation and load. Measured in Hertz (Hz) in the International System of Measures, alternating current (“AC”) in European households for instance, has a frequency of 50 Hz, or 50 current cycles per second. In Brazil this number is 60 Hz. That is, electrical current is expected to oscillate between a maximum positive value and a maximum negative value around 60 or 50 times per second, in the form of a mathematical sin wave. When the amount of electricity entering the grid is larger than the amount consumed, frequency increases; when demand increases beyond the existent supply, frequency decreases. In both cases cutoffs of power occur if frequency levels fall out of security intervals. See Figure 2.

Figure 2 - Frequency (the case of Switzerland)



Source: Swissgrid (2010b)

Depending on the “depth” of the operator’s “grip” of the market, frequency control may be of two types:

- **Supervisory frequency monitoring**, in order to ensure adequate reserves and ancillary services provision in the control areas that it manages. These are the areas that autonomously do the real-time control;
- **Real-time frequency control**, which means making automatic generation control (“AGC”); using the automatic systems that repose frequency between its established limits in case it fall out of them.

Ancillary services are frequently used to serve this purpose;

- v. Short-run operations planning is the establishment of a short-run operational strategy to tackle the operation of the system;
- vi. Dispatch. The process of dispatch involves sending electrical current physically across the system. General principles are:
 - a. Maintaining quality (voltage);
 - b. Minimizing operational costs;
 - c. Respecting the commercial relations between providers and consumers – schedules.
- vii. Guarantee of third party access rights (“TPA”) to the grid. Previously, vertically integrated companies tended to deny access of other generators to their own

transmission lines, so as to maintain their monopoly status (and revenues). Energy markets restructuring brought forward the concept of TPA, that emerged in the late 1970 – early 1980 in the U.S. In an energy market, the concept of TPA means that an independent market actor – a “third party” – has a legal and enforceable right to use network facilities owned by other market players (Kotlowski, 2007);

- viii. Long-run planning of operations and regulatory gaps identification. As the operating entity, the ESO either effectively draws the rules for system operation, or contributes to their definition, together with the regulatory agency. The ESO frequently identifies regulatory gaps and warns the regulatory agency about them, a function that more often than not is absent from its official statute, but present in its daily activities;
- ix. Ensuring transparency. The system operator insures transparency through making available relevant data for the market participants. The operator acts as a transparency ensuring agent for electricity transmission just as stock exchanges act for financial markets. It makes short, mid and long-term forecasts for the evolution of demand and supply, as well as for other needs of the system. It further meters the relevant variables of the transmission system and archives data on: production, consumption, ancillary services deployed, deviations from schedules etc. Previsions are published in periodical reports, for example, as well as other relevant information (dispatched loads, available transfer capacities¹⁹, reserves, transmission congestion, locational market clearing prices, need for ancillary services etc.) Today, the Internet is the main environment where these reports are available;
- x. International collaboration. Should regional integration be part of the energy policy of the jurisdiction where the operator is inserted, ensuring uniformity or at least a degree of compatibility is part of its responsibilities;

Finally, ensuring economical operation is rather a principle than a responsibility. Under the security criterion in effect, operation must be as economical as possible. In a

¹⁹ Available transfer capacities (ATCs) are volumes of electricity that the network can transfer at a certain moment in time between two grid areas, so that security standards and uncertainties of future situations are considered.

“perfect system”, with no losses or constraints, economical optimality occurs when marginal costs for all producers are equal (Alvarado and Oren, 2002). However, when considering all limitations and losses, marginal production cost is a function of the location of each producer in the system²⁰. The issue reveals itself as even more complex. Thus, the operator does not only need to decide what operation plan is best for the future time, but also how this plan may affect operation at a later stage²¹. Often, the term “economic dispatch” is used to underline this responsibility;

B. Market and commercial operations

Market operation is distinct of system operation in that it relates to settling transactions in electricity markets or “power exchanges” (PX). PXs generally serve as environments where demand and supply of electric power and all additional services are coupled. Moreover, this function entails development of schedules for electricity supplies and loads, based on auctions (Shirmohammadi *et al.*, 1998). PXs can be organized as bilateral contract environments, as energy pools or can be mixed. The inherent market and commercial responsibilities are:

- i. Costs settlement and billing. An ESO’s most basic “market commodities” include: ancillary services, congestion management as well as administrative expenses, which the operator draws from market actors; The operator calculates short run costs and prices for transmission related services and bills the involved parties – consumers, suppliers, ancillary services providers etc. This function may be totally or partly outsourced to so-called “metering agents” (Cunha, 2005);
- ii. Ancillary services procurement is generally done on a competitive basis, either from an organized pool or via bilateral contracts;
- iii. Metering. Metering, accounting, settling, billing and publicising information are thus part of this responsibility.
- iv. Administration of bilateral contracts – intermediation of contracts that are outside any regulated wholesale market;

²⁰ The problem is a non-linear constrained optimization problem – called “optimum power flow” or “OPF”. The idea is that the operator maneuvers electricity production to attain an utmost level of economy of operation, but also considers other restrictions: grid limitations, weather, losses etc.

²¹ Multi-period dynamic optimization

- v. Administration of organized wholesale markets. The market operator conducts energy auctions for the entire scheduling period²² in order to match supply bids from generators and demand bids from retailers. Further, the least cost bids are ranked, scheduled and submitted to the system operator for validation; Support for financial futures markets, capacity markets etc. can be included in this category.

C. Grid Ownership

Grid ownership entails various types of responsibilities that are related to the property or concession right. The term “owner” is used as a general denomination. Thus, ownership responsibilities may include:

- i. Providing the transmission service itself. This is the main and universal function of the transmission owner. All other attributions may belong to the same or to other market actors.
- ii. Planning expansion and investment. Planning is a function frequently attributed to system operator or to a separate planning entity; but it may also be of the responsibility of the grid company. In this case, the company evaluates its expansion needs and proposes them to the sector authority charged with approving these requests. Else, depending on the organization of the system, the system operator may do this activity in conjunction with a planning entity who may or may not have decision authority. Due to its position at the core of transmission operations, the system operator and not the TO is probably the most indicated entity to validate transmission/generation²³ expansion;
- iii. Planning or approving maintenance of transmission facilities;
- iv. Open access. Transmission service provision in the restructured electricity systems implies the obligation of providing non-discriminatory, open access (TPA) to the transmission facilities. This is usually an indirect responsibility of the transmission owner, as in the majority of restructured electricity sectors it is the system operator that guarantees TPA;

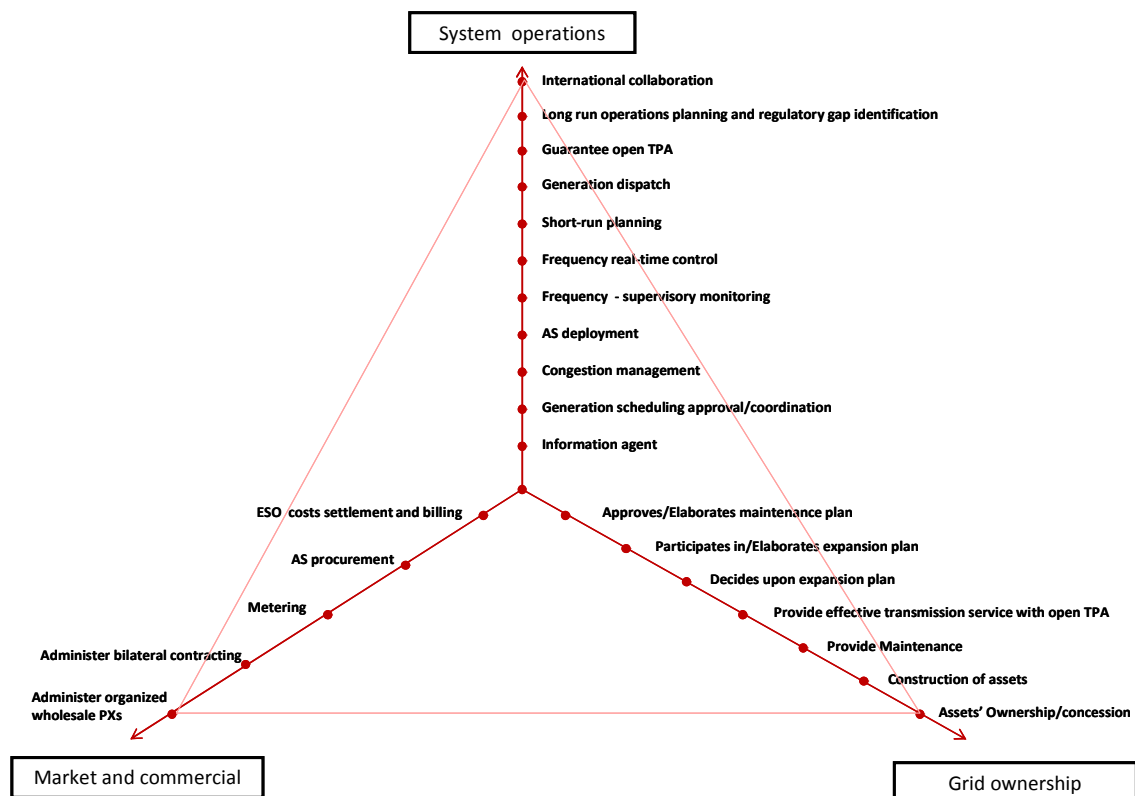
²² The scheduling period is usually divided into discrete time periods, ranging from hours and half hours to periods of 10 minutes, 5 minutes etc.

²³ Further, in Section 2.4, it is argued that transmission and generation expansion are substitutes.

- v. Maintenance. Ensuring that the transmission lines operate, without any defect that may affect functioning outside optimality parameters. Maintenance frequently involves tree-cutting and other provisions that ensure the transmission lines against natural hazard;
- vi. Construction. This refers to the physical expansion of the transmission grid, according to the submission by a transmission trench owner or future owner – currently a developer – of a request to build lines or in a competitive auction for the same purpose. This auction may be organized by a planning authority. Else, constructor may submit projects on a rolling basis to the qualified decision-maker – which can be the ESO.

Thus, we reach the following model of the functions of an ESO. One important observation is necessary at this point. The dots of the axes do *not* represent scales, but simply a way to order actions. More basic actions come at the basis of the axis while more complex responsibilities come thereafter.

Figure 3 - Model of the functions of an electric system operator



Source: elaborated by author Minimalist and maximalist ESO

According to Rahimi and Vojdani (1999), an electricity system operator (“ESO”) can perform the three functions presented above – acting as an electricity market one-stop-shop, but it can also perform only one or two of them, never excluding the first. As far as the responsibilities incorporated in each function are concerned, the situation is the same: all or only some can effectively be delegated to the ESO.

A minimal ESO only ensures real-time system security, publishing sufficient information so that the market can ensure all the other activities, as explained by (Cunha, 2005). An example of such an ESO is the Electric Reliability Council of Texas or ERCOT, who provides real-time reliability service (energy balancing, congestion management and ancillary services provision). European TSOs are examples of “intermediate” ESOs. Returning the Spanish case, REE is a system operator that also owns almost 100% of the transmission grid. Market operation is however not provided by REE, but by two separate organisms, one for spot and another for forward transactions²⁴. The Pennsylvania-New Jersey-Maryland (PJM) Independent System Operator also an intermediate form, providing economic dispatch, unit commitment²⁵ services and operating a day-ahead energy market. PJM owns no transmission assets.

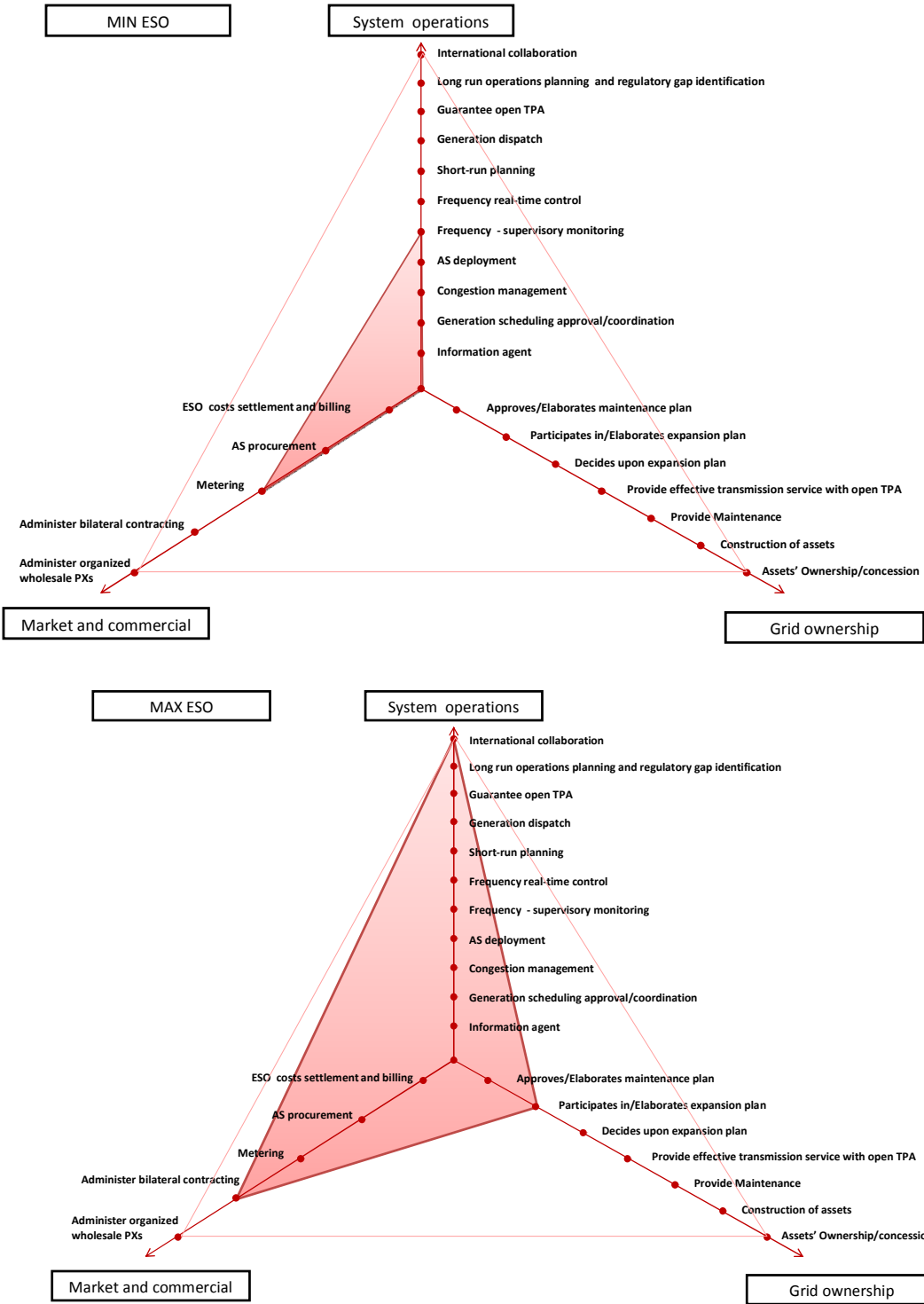
Along the next chapter, the main types of ESOs shall be outlined, according to their level of responsibility, ownership and financial purposes. The objective of this classification is to serve as a basis for examining the differences of behaviour and impact each type of institutional arrangement can have.

In order to better understand how to interpret the following triangles, it does not mean that area equals importance. It is simply a graphical representation. An operator that does not own grid assets for instance can be useful to its economy due to having implemented electricity sector restructuring without divesting and its political costs. It ought not be interpreted as less valuable than one that owns the transmission assets etc.

²⁴ OMIP – Operador do Mercado Ibérico – Polo Português (forward), OMEL – Operador del Mercado Ibérico – Pólo Español (spot).

²⁵ Unit commitment is deciding when and which generating units at each power station to start-up and shut-down. It must not be confused with economic dispatch – the process of deciding on the level of the individual power outputs of the scheduled generating units at each time-point. When the power station starts up a generator, it does not mean that it also “ramps-up”, that is to start working at full capacity. The ramp-up time can vary according to the generation technology.

Figure 4 - Minimalist (shallow) vs. Maximalist (deep) ESO



Source: elaborated by the author

Chapter 2

Main types of electric system operators

The international literature around this topic outlines various criteria for the classification of ESOs. The main criterion is the degree of integration between ownership and control (operation) of the transmission assets (Awerbuch *et al.*, 2000). Oren *et al.* (2001) further classified ESOs according to their ownership structure (public, private), level of dependence (vertically integrated, joint ownership among transmission owners, independent), and profit scope (non-profit, for profit). Alternatively, L  v  que *et al.* (2008) make a simpler classification, based on two criteria: integration between ownership and control and degree of ownership unbundling (degree of *dependence*).

After making a fairly comprehensive review of the main perspectives about classifying ESOs and of the main successful models known, the authors have reached the conclusion that the most relevant classification criteria are: integration between ownership and control and degree of unbundling. This perspective is consistent with that of L  v  que (2008). Further, an important characteristic is the profit scope of the ESO – a non-profit or for profit institution – as the regulatory incentives are different from one case to another. The chosen governance structure is also of utmost relevance, as incentives depend on whether the ESO is stakeholder-governed, State-governed or controlled by a firm independent from the value chain.

2.1 Regulation and its impact on market efficiency

Regulation, as Rioux *et al.* (2008) noticed is a catalyst of market efficiency. Markets are said to be efficient when prices tend towards marginal costs, emitting correct price signals for optimal allocation of production, consumption and location of new investment and load (Oren *et al.*, 2002). Nevertheless, the configuration of how the SOs and TOs (system operators and transmission owners) perform their responsibilities is based on regulation and governance.

The incentive policy that the regulatory agency can provide for transmission consists of the following:

- Market incentives or “light-handed regulation” (support for merchant transmission or building new generation, demand-response, performance-based regulation¹). Light-handed regulation allows discretion for the firm to meet its regulatory targets however it pleases;
- Regulated incentives or “heavy-handed regulation” (rate of return regulation, cost of service regulation²); heavy-handed regulation is less discretionary, being submitted to the “command and control” paradigm.

Four dimensions have been identified regarding the way the regulatory agency defines and organizes the transmission businesses:

- i. Joint or separate ownership and control of transmission assets;
- ii. Level of independence (unbundling) of the SO (system operator) and TO (transmission owner) from utilities³;
- iii. Governance structure and ownership of the SO: stakeholder-governed, State-governed or independent from the two;
- iv. The scope for profit of the ESO.

The dimensions of regulation are outlined in detail in the next section.

2.2 Dimensions of regulation

2.2.1 Degree of integration between assets ownership and control. The transaction costs perspective.

The degree of separation between ownership and control of assets is chiefly important as explained under a transaction costs perspective.

¹ Performance-based regulation is currently seen as the best option of rate-design, as the fixed rate of return permits gains only if the company becomes more efficient, diminishing costs. To further stimulate efficiency, rates of return are diminished rather than augmented.

² Cost-of-service or rate-of-return schemes are frequently implemented rate designs. The first consist of allowing the regulated entity to cover its costs and does not provide incentives for their reduction. The company receives the same rate of return whatever its costs are, as stated by, for example L  v  que *et al.* (2008). The second remunerates the entity with a fixed rate of return relatively to the size of its capital – providing incentive for possibly redundant capital investments, as noted by Averch and Johnson (1973).

³ Especially from generation and retail.

The transaction costs perspective, as most economic approaches to the study of organization, is deeply rooted in the concept of efficiency. Economic literature, organization theory and governance-related contracts law are at the basis of this perspective. The author that pioneered this concept is Roger Commons, who in his 1934 essay, “Institutional Economics”, compares the basic unit of activity for classical economists – the commodity produced by labour – to that of hedonic economists – the commodity enjoyed by the final consumer – and finally to that for institutional economists – the transaction. The dissertation Commons brings forward is that the transaction prevails the other two units, as it relates to the exchanges of rights of property that are to be negotiated before labour can produce and consumers can consume. Further, understanding transaction costs economizing is essential to the study of organizations and crucial for understanding the impact of various types of electric system organization and operation. Kerstenetzky (2000) underscores that the advantage to firms is a substitution of a vast number of contracts by one only.

The main requirement is assigning the different types of transactions to different governance structures, in a discriminatory manner. Williamson (1981) further explains how transaction costs are an implicit measure of rationality and competitiveness. Transaction costs appear to be the solution of an optimization problem with the following limits: limits of information that individuals have the cognitive limits of their minds (including negotiation skills) as well as time limitations. This is due to the fact that the *hyperrationality* of the “economic man” is a theoretical concept that differs from the bounded rationality of the “organization man”, a more realistic model.

The transaction costs approach is, according to Williamson (1981), related to three levels:

- The operating structure internal to the firm: the interaction between its operating divisions;
- The operating divisions’ level: what should be done by the firm and what should be outsourced;
- How human resources are organized: the governance of working groups.

The first two elements are considered relevant to the present analysis, as the particularity of the institution – the ESO – does not primarily reside in the preparation

and governance of its staff but in its role for the economy and the manner in which it performs its functions.

Moreover, transactions are subject to uncertainty, a certain level of frequency and a degree to which transaction-specific investment influences sustaining a least cost supply. In the case of the electricity industry, uncertainty is preset by excellence, taking into account the incomplete predictability of economic cycles, to which energy consumption is strongly tied. Transactions are recurrent, as opposed to frequent and the idiosyncrasy⁴ of the object of transaction underlines the importance of investments in grid and generation capacity expansion and maintenance. The incentives that the governance structure produces in this sense are relevant for the way the ESO maintains least cost system reliability and security. Williamson (1981) further underlines that efficiency is attained only if the governance structure is tailored to the needs of each type of transaction, a point of view shared with Rious *et al.* (2008). The latter state that the way transmission is governed, namely the ownership of the high voltage grid, the choices of regulation for the system operator and the mentioned infrastructure explain the diversity of ESO arrangements.

According to this framework, an integrated owner-operator captures the benefits of scope economies that derive from the ownership of the operated assets (2001). These benefits roughly consist of improved, accurate, complete information. The synergies from their integration generally translate in reduced transaction costs between the system operator and the grid owner (Joskow, 2001).

In this paragraph, coordination costs in the electricity sector are exemplified. In order to maintain the most economical equilibrium between supply and demand, the system operator, uses nowadays advanced automatic algorithms. Despite all the progress, some activities require human intelligence and interaction, such as forecasts – for which the operator needs to communicate with the actors of the sector. Should the operator need to coordinate its forecast with a transmission owner which is integrated in vertically integrated utility, the latter may not act in a trust-worthy manner. The transmission company may secure capacity, invoking reasons such as maintenance requirements. Its

⁴ Electricity as a non-storable commodity that must be produced in order to exactly match a spontaneous demand.

true objective may be to favour one of the mother-company's more expensive generators - which can provide energy through an alternative route (a "loop flow"). This type of behaviour deviates operation from the social optimum because it introduces transaction costs. It is the society that pays these costs in the equivalent of collaboration contracts. Yet, ensuring equilibrium between transaction costs and operations' efficiency tends to be expansive as Benitez (2007) noticed. The complexity of such contracts rises with the number of unbundled entities, an issue that is examined in the next section. Thus, in the case where the ESO and TO are independent and separate entities⁵, neither the ESO nor the regulatory agency have "perfect" information about the situation of the transmission grid, and this triggers trilateral coordination contracts. A synthesis is presented below.

Table 2 - Relevant characteristics of separate and joint owner-operators

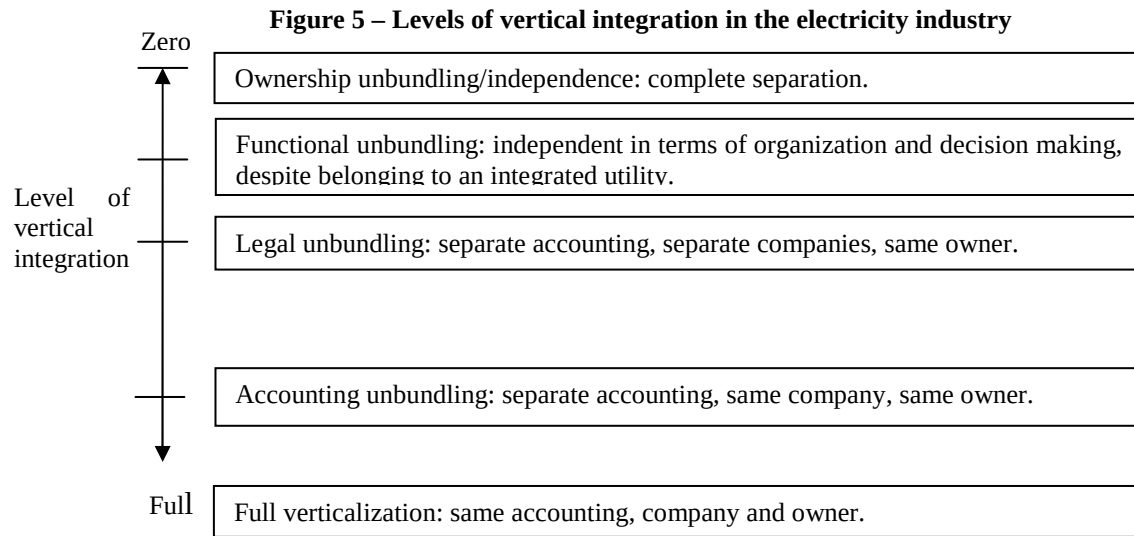
Dimension of regulation		Characteristic
Integration of ownership and control	Joint ownership and control	Reduced transaction costs due to synergies based from perfect information of the operator about transmission assets.
	Separate ownership and control	The SO shall charge society for the cost of coordination contracts between itself and the transmission owner(s) - contracts that are complex and expensive.

Source: elaborated by author, data from: OECD (2001), Lévêque *et al.* (2008), Benitez (2007)

2.2.2 The issue of the independence of system operators from transmission owners. Types of unbundling.

The concept of *independence* has various interpretations. "Independent" means "completely unbundled" from generation activities (Lévêque *et al.*, 2008), i.e. financially (separate accounting), legally (separate company), and from the point of view of ownership (separate owners). The expressions "ownership unbundled" and "independent" refer to the same statute. The main levels of unbundling are graphically illustrated in the following Figure.

⁵ Later referred to as ISO/ITO institutional arrangements.



Source: elaborated by the author

The economics behind vertical integration is relevant in order to understand the gains and losses of unbundling. Whenever prices differ from marginal costs, a welfare loss⁶ arises. As Soares and Sarmento (2009) explained, integration assures that the upstream business sells to the downstream business at marginal cost. But these loss reductions also provide the vertically integrated company with scope and scale economies that translate in market power. So, to reduce this tendency of the energy sector, various sets of measures have been implemented to date. The most widespread tool so far has been network access, as previously stated. In order to ensure it, variations of transmission and distribution unbundling have been undertaken.

The first, basic level of unbundling is legal or juridical. The transmission and/or system operating company must form a separate firm from generation, distribution and/or supply activities. Next, accounting separation also comprises having separate as opposed to consolidated accounts. Further, ownership unbundling additionally requires that the owners be different – so that the business lines cease to belong to a vertically integrated company.

Last, functional unbundling is a concept frequently confused with legal unbundling, yet it is an intermediate step between the latter and ownership unbundling. The difference resides in the fact that the management of the functionally unbundled business (the grid operator, in this case) is separate and there are limits imposed to the flows of

⁶ If prices are higher than marginal costs, the loss is born by the customers, whereas the sellers loose in the opposite situation.

information between it and the other divisions of the parent company. Beyond having separate information systems, the employees of a functionally unbundled company are trained so as to respect so-called “Chinese walls” between business units ...as well as in the company cafeteria. Functional unbundling is intended to serve the purpose of independence without incurring the full unbundling costs that divestments imply and that politics may difficult.

Accounting-unbundled entities will not be considered in this work. There exists empirical evidence that demonstrate that this level of unbundling is insufficient for provision of non-discriminatory treatment – the centerpiece of modern restructured electric sectors. The European Union, for example, has arrived at this conclusion, also noticing that accounting-unbundled transmission businesses create premises for cross-subsidization among the holding’s activities. Soares and Sarmento (2009) underscore the possibility that, in an accounting-unbundled energy holding, costs of other business units may be allocated to the transmission business – especially if cost-of-service regulation is implemented, the author adds. Thus, legal accounting has been pursued through Directive 2003/54/EC⁷. In 2009, the “Third Energy Package” (Directive 2009/72/EC) took a leap forward to promote ownership unbundling. This happened as a consequence of further preferential treatment from the grid company to generators or retailers belonging to the same Group. The cross-subsidization issue of accounting unbundling is especially relevant in the link between generation and transmission. It allows for transparency as far as internal transfer prices are concerned. Price discrimination thus becomes verifiable, but non-price⁸ discrimination remains to be tackled (Soares and Sarmento, 2009).

Baker Jr. (1997), in an official document from the World Bank, goes as far as to state that a system operator is independent if none of the market agents can influence it so that the energy dispatch process and other grid operations can be provided in a non-discriminatory way – which is a more comprehensive definition. In other words, Hogan (1995) states that “the governance structure and incentives ... should be designed to ensure that no subset of the market participants is allowed to control the criteria of

⁷ The “second energy package”

⁸ As questionable maintenance that reduces available transmission capacity of under-investment in grid expansion.

operating procedures.” The conclusion is that independence translates into the ability to act impartially, without privileging any market actor for any reasons outside competitive merit in obtaining access to services, as well as in their pricing. Corredor *et al.* (2008) introduces the concept of conflicts of interest – which is relevant to transaction costs. There ought not exist conflicts of interest that impede the ESO to act according to the rules dictated by the regulatory agency. Legally unbundled transmission system operators (LTSOs) are frequently exposed to conflicts of interests, as they serve the public on the one side and their shareholders on the other. The French Réseau de Transport d’Electricité was functionally unbundled in 2005 and has brought forward sensible welfare effects without particular incentives from the regulator⁹. Even so, the regulatory agency, Commission de Régulation de l’Énergie made an evaluation in 2007 and concluded that it should normalize its communication system relatively to the rest of the firm, which denotes preferential treatment. The European Commission acknowledged the fact, together with some transparency-related issues (European Commission, 2007).

The European Commission periodically reports on the status of its internal energy market. In these reports, special attention is given to the degree of independence of system operators. In one of these reports for instance, the Commission notices that the insufficient degree of achieved independence constitutes a barrier for the entry of new investors, which is necessary for appropriate network expansion. A further example is that the percentage of congestion revenues reinvested in increasing network interconnection has been two times larger in the case of independent transmission system operators or “ITSOs” than in the case of only LTSOs (European Commission, 2008). It can be concluded that the higher the degree of independence, the more the investment has been in network expansion. It must be kept in mind though, that a central factor for undertaking investments in transmission is the expected (and most of the time regulated) rate of return. Third party access to the generation grid, when offered by an independent operator/grid owner should not be discriminatory, as no other actors from the value chain can influence it. Thus, this is a contribution to a higher level of competition. It is precisely because of this feature that the European Union is

⁹ According to Lévêque *et al.* (2008), its losses remained leveled while costs decreased.

privileging independent TSOs as the standard institutional arrangement for system operation (Lévêque *et al.*, 2008). Functional unbundling is regarded as a second-best alternative, despite the arguments against it¹⁰. The synthesis follows.

Table 3 - Essential aspects of unbundling

Dimension of regulation		Characteristic
Level of independence (unbundling)	Vertically integrated undertaking (VIU)	PRO Efficient transfer prices (at marginal cost);
		Integration synergies between the owner and the operator.
	CON	Market power and tendency of abuse, like limiting third-party access;
		Cross-subsidization, especially to the detriment of the transmission division.
	Accounting	PRO Allows for visibility of transfer prices;
		Does not limit non-price discrimination;
	CON	Still, cross-subsidization is possible.
	Legal	PRO Increased focus on social objectives (like service quality, interconnection, grid expansion) as opposed to shareholder-related objectives;
		Information leakage to other divisions still a problem; Possible transparency issues;
	CON	Contradictory signals from shareholders and social objectives.
	Functional	PRO Allows a situation close to that of ownership unbundling without incurring actual divestment and political costs;
		Information leakages are regularized, thus reduced. Nevertheless they continue to exist.
	Ownership	PRO The VIU ceases to have any impact on grid-operations, including third-party access;
		CON Loss of synergies between generation and transmission.

Note: PRO/CON – pro/contra.

Source: elaborated by the author, data from: Corredor et al. (2008), Baker Jr. (1997), Baker Jr. (1997), Soares and Sarmento (2009), Lévêque et al. (2008)

¹⁰ Arizu *et al.* (2001) found that in the US, despite being functionally separated from generators (having autonomous management and a separated juridical form) have affected the good functioning of the system either by questionable maintenance of assets or by information leakage inside the holding. These things are not easy unmask in a Court of Justice.

2.2.3 Governance structure and ownership of the ESO

Oren *et al.* (2002) made a distinction between stakeholder-governance and non-stakeholder-governance of ISOs (independent system operators), dividing the latter in State and independent-governance. Stakeholder governance, that is governance by a board consisting of representatives of consumers, the Government, generators, transmission owners, distributors, retailers, environmentalists etc., may be subject to the formation of coalitions as also noticed by Michaels (2000). It is a natural tendency that these representatives have in order to promote the financial interests as stakeholders of the value chain. Nobel laureate Amartya Sen extended Kenneth Arrow's, "impossibility theorem" to explain that given minimal vote liberty, it is not possible to attain an option that does not affect the position of some voters so that the welfare of others can be maintained (Sen, 1997), or Pareto optimality. Lévêque *et al.* (2008) stated that the independence of the governing board from generation is sufficient to confer a perfectly objective position – a perspective with which this dissertation disagrees. Should the owner be the State, for instance, economically justifiable risk might not be assumed in exchange for a politically motivated over-protection of the system (procuring too many reserves, mostly). It is only in the case where governance is truly independent, with no ties to the industry nor to the State that equilibrated operational and economical decisions are expected (Oren *et al.*, 2002), without forgetting that a non-profit structure is still subject to heterogeneous interests and views. However, assuming that these interests are not connected to fiduciary or political gains, the results of decision-taking are expected to be more socially adequate. A collective synthesis is made at the end of sub-section 2.2.4.

2.2.4 The scope for profit of the ESO

Being profit driven can have different consequences for an ESO, or any other institution for that matter. The governance structure presented in the previous sub-section is also relevant to this discussion. Michaels (2000) made a comparison of systems with ISO/LTO or/and ISO/ITO (ISO systems) to systems with ITSOs. He and other authors such as Joskow (2007) also call the latter *transcos*. These own or lease their lines from owners. He argues that ISOs are a "political solution to an economic problem". ISOs are generally non-profit "arbiters" of electricity transmission and specifically focus on

social welfare, while TOs¹¹ are generally created as for profit entities – with scope for economic efficiency. ISOs are usually non-profit due to their not having any considerable assets, equity or revenues. Nevertheless, as ISOs do not take part in the maintenance of assets nor do they undertake any grid investments directly – which may decrease operational efficiency due to the lack of clear, profit-guided orientation. The alternative of having the transmission system administrated by ITSOs is seen as easier to regulate¹², as there is nothing clearer and more objective before a regulatory agency than financial interests. As Rious *et al.* (2008) noticed, transmission grid ownership is a long-term source of revenue for its owner(s), possibly having a large degree of importance for their finances or/and market value. Furthermore, the security of these revenues is relevant as electricity markets are strongly dependent of economic cycles. Thus to avoid abuse, Governments usually regulate TOs by limiting the scale of their profits. As far as ISOs are concerned, they are usually non-profit entities, where governance effectiveness depends on ownership. The possibility of effectively regulating non-profit ISOs is seen as more reduced, due to being generally stakeholder-governed and thus subjected to the diverse interests of generators, transmission companies, retailers, distributors, consumers etc. The main evaluation principle for non-profit operators is system security. Nevertheless, it is challenging to evaluate aspects as “number of blackouts avoided.” Stakeholders can also form coalitions to defend the interest of some at the costs of the interest of others, further complicating the matter. While Michaels (2000) only refers to stakeholder governed models, the distinction made by Oren *et al.* (2002), between stakeholder ownership, State ownership and independent, non-stakeholder ownership discussed in the previous section are focal points. Not only is the scope for profit of the ESO relevant to the debate, but also that of the TOs. The Brattle Group (2007) examined this issue and drew attention that a non-profit TO, as TenneT in the Netherlands has relatively less incentives to reduce its costs relatively to a for profit TO. State-owned companies do not always have a clear profit strategy, and behave as a mixture of capitalism and welfare. Another example of how incentives policy can impact a for profit ITSO is National Grid; after its privatization,

¹¹ Either ITOs or LTOs

¹² In this context, regulation is in the sense of providing open-access to grid users, as well as fair rates (reducing monopolistic tendencies), as well as providing incentives for proper maintenance of transmission assets.

congestion costs rose consistently and were passed on to customers. The regulatory agency the created an incentive scheme through which NG shared the congestion costs with market participants. Their ulterior fall was no surprise.

In order to grasp the gist of how the scope for profit and the governance structure of SOs and TOs articulate with one another, as well as the challenges and gains this presents to economic efficiency, the following table makes a synthesis.

Table 4 - Essential consequences of different types of governance according to the profit scope for economic efficiency

Profit scope	Argument	Stakeholder governance	Independent from value chain	
			State governance	Privately governed
Non-profit	PRO	"Democratization" of system operation.	Increased level of system security.	Expected to take equilibrated decisions between operation and economic efficiency.
	CON	Subject to coalition.	Might sacrifice economic efficiency for politically motivated security precautions, especially if managed by technical committees.	Subject to personal managerial interests and governed by board members with homogenous views (ex. environmentalists vs. economists)
For profit	PRO	Democratization of system operation; Efficiency gains from previsibility of response to policy, due to being economically driven;	N/A	Economic efficiency is a strong point.
	CON	Might sacrifice quality for economic gain.	N/A	Requires regulation to temper monopolistic tendency.

Note: PRO/CON – pro/contra.

Source: elaborated by the author, data from: Oren et al. (2001), Michaels (2000), Joskow (2007), Sen (1997), Lévêque *et al.* (2008), Rious et al. (2008), The Brattle Group (2007)

After having presented the main dimensions of transmission regulation, the following sections summarizes the main types of system operators that this research covers.

2.3 Types of operators

The four types of institutional arrangements for electricity system operation are classified according to degree of unbundling from other activities from the value chain, especially generation and supply (independent or legally unbundled) and according to

the degree of integration between operation and ownership of transmission assets (joint or separate):

- i. Independent + Joint: ITSO – Independent Transmission System Owner and Operator;
- ii. Legally unbundled + Joint: LTSO – Legally Unbundled Transmission System Owner and Operator;
- iii. Independent + Separate: ISO/ITO – Independent System Operator and Independent Transmission owner;
- iv. Legally unbundled + Separate: ISO/LTO – Independent System operator and Legally Unbundled Transmission Owner;
- v. VIU – The Vertically Integrated Undertaking model.

As specified in the introduction, it must be reminded that in cases iii. and iv. the TO is not necessarily unique. Several TOs can exist, but the OSE is always unique for the territory defined.

Another specification that must be made is that in practice, these models are barely ever well implemented. In ISO/ITO or ITSO models some LTOs usually exist, but in sufficiently minor proportions; equally, in ISO/LTO or LTSO models, the presence of a few ITOs is likely. The Spanish ITSO, for instance went acquiring transmission assets over the years having now attained 99% of them and with the target of reaching 100% until the end¹³ of 2010. In Brazil, the ISO/LTO arrangement coexists with several ITOs¹⁴. The British case is similar: National Grid (or NG) – the ITSO in Britain does not own all the transmission assets it operates. Namely, under the Scottish grid – that NG also operates – the framework is ISO/LTO¹⁵. NG has been the RIO of Great Britain since 2004, when the BETTA – British Electricity Transmission and Trading Agreements – were instituted.

¹³ See Red Eléctrica de España (2010b)

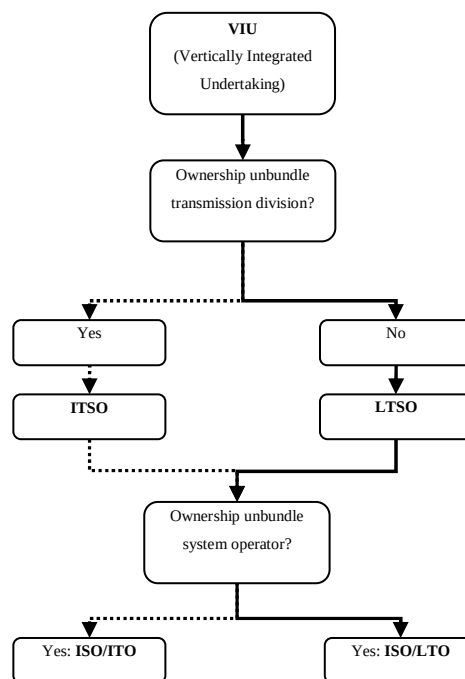
¹⁴ Besides State utilities or privatized, ex-State utilities, there exist two companies that exclusively own and deal with transmission assets – TERN and CTEEP – and two companies that exclusively function as concessionaries of electricity transmission like PLENA and TBE. For details, see Brandão (2008).

¹⁵ Scottish Power and Southern Electric have remained TOs.

The fifth alternative shall not be considered in this dissertation, which is written under the “new” paradigm of restructuring and unbundling of competitive sectors from the ones that represent a natural monopoly.

The models are summarized in the Figure and Table below, together with examples, according to the four criteria defined in Section 2.

Figure 6 – Formation of different institutional arrangements for system operation and ownership



Source: elaborated by the author

Table 5 - Main types of system operation arrangements and examples

Integration of ownership and control	Independence from the value chain	Governance	Profit-scope	Examples
Joint owner-operator	ITSO	State	Mixed-economy	New Zealand, Australia, United Kingdom, Portugal, Norway, Spain
Joint owner-operator	ITSO	Stakeholders	For profit	
Joint owner-operator	ITSO	Independent	For profit	
Joint owner-operator	LTSO	Stakeholders	For profit	France (post-2005), Germany
Separate owner and operator	ISO/LTO	ISO-State / LTO-Stakeholders	ISO- Mixed-econ. / LTO-for profit	Chile (post-2000), Argentina
Separate owner and operator	ISO/LTO	ISO-Stakeholders / LTO-Stakeholders	ISO-non-profit / LTO-for profit	
Separate owner and operator	ISO/LTO	ISO-independent / LTO-Stakeholders	ISO-non-profit / LTO-for profit	
Separate owner and operator	ISO/ITO	ISO-State / ITO-independent	ISO- Mixed-econ / ITO-for profit	USA (PJM, New York, Texas, California), Chile (before 2000), Venezuela, Scotland, Italy
Separate owner and operator	ISO/ITO	ISO-Stakeholders / ITO-independent	ISO-non-profit / ITO-for profit	
Separate owner and operator	ISO/ITO	ISO-independent / ITO-independent	ISO-non-profit / ITO-for profit	

Source: elaborated by the author, data from Oren *et al.* (2001)

Table 6 - Realistic outline of system operation and ownership arrangements

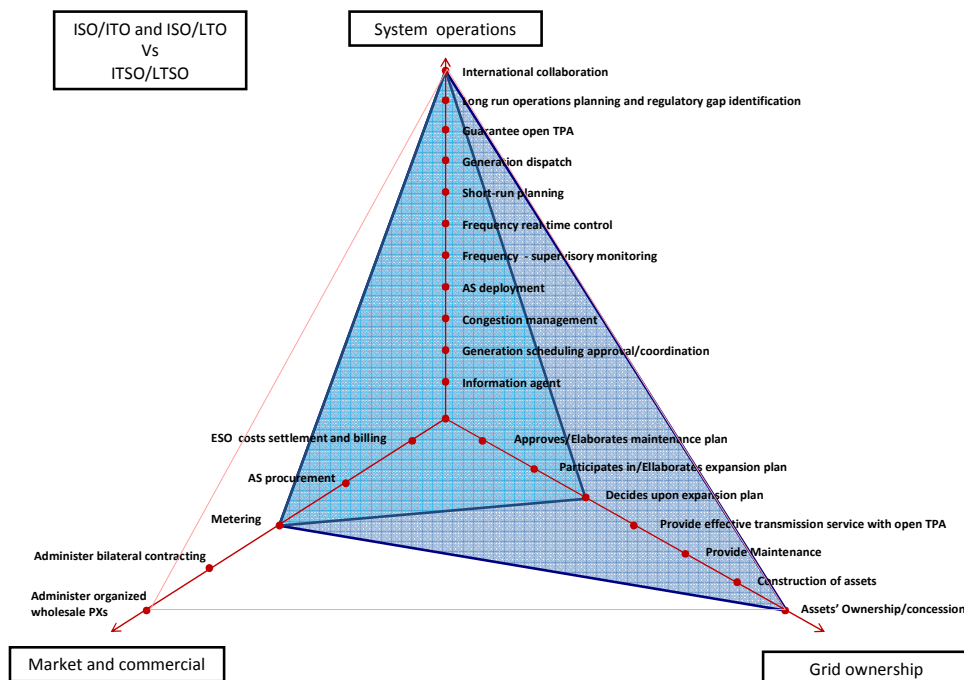
VI	ITSO	LTSO	ISO/LTO	ISO/ITO
<i>ITO*</i>	<i>ITO*</i>	<i>ITO*</i>	<i>ITO*</i>	ITO
TO	ITSO		ISO	ISO
SO		LTSO	LTO	<i>LTO*</i>
Generation and/or Retail	Generation and/or Retail	Generation and/or Retail	Generation and/or Retail	Generation and/or Retail

** are not part of the ideal, theoretical model, but frequently exist in real systems - in a minority proportion;*

Note: dotted lines inside boxes represent integration (total or legal, according to the case).

Source: elaborated by the author

Figure 7 - ITSO and LTSO vs. ISO systems



Source: elaborated by the author

In the two Figures above the comparison framework is used in order to understand the difference of responsibility ranges between the presented models that this dissertation further takes into consideration.

In the next section, the main criteria to evaluate ESOs are presented and discussed. In the end of the section, Table 7 summarizes the conclusions, discriminating by type of institutional arrangement.

2.4 Criteria for ESO evaluation

Several authors examine ESO arrangements. To quote but a few: Pollitt (2008) outlines benefits and costs of ownership unbundling and concludes that it is a key element for a successful market reform while Lévêque *et al.* (2008) take into consideration, apart from transaction costs, conflicts of interest, performance-based regulation implementation, non-discrimination and market integration; The Brattle Group (2008), a consultancy agency, further discuss effects of ISOs on network investments, and Oren *et al.* (2002) take into account: market efficiency, operational efficiency and reliability, the need for regulatory oversight, governance and political feasibility of each model. This study centralized all criteria and a comprehensive filtering has been made. This dissertation views market efficiency as a reflection of the way the SO and TO apply the regulation. Market efficiency is, in the view of the author, translated by the degree to which the following elements are provided:

- i. ESO equilibrium between operational security and economic efficiency;
- ii. Transaction costs within the sector;
- iii. Open TPA provision;
- iv. Incentives for proper transmission expansion;
- v. Regional networks integration;

Further, the relation between either one of these criteria and the four dimensions of regulation are undertaken, “catalyzed” by the type of institutional arrangement.

2.4.1 ESO equilibrium between operational security and economic efficiency

What must be underlined under this criterion is that State-governance of ITSOs or ISOs tends to over-procure reserves and use both transmission lines and generation below economically efficient borders. Thus, the society pays the transaction costs for the

increased security. On the other hand, LTOs may, even if functionally unbundled, privilege the holding they are part of or questionably undertake maintenance, reducing fair competition – all these at the cost of the heavy-handed regulation necessary to temper any monopolistic temptations. Should ownership of operation and control be separate, the ISO may be more objective in its decisions, but it depends on the effectiveness of regulation to what extent the TO serves economic and operational efficiency. Non-profit ESOs operate in a more impartial way, with general economic welfare in mind. A profit-scope can bias the decision of the operator towards own financial gain, affecting security and economic efficiency at the level of the system.

2.4.2 Transaction costs within the sector

Transaction costs are principally higher when there is a need to make contracts and coordinate institutions. For LTOs and LTOs, gains from vertical integration arise, yet in case of the ISO/LTO arrangement coordination costs that might compensate these are to be considered.

2.4.3 Open TPA provision

The ESO generally has the role to ensure open TPA by the TOs. Thus, when these institutions are integrated and independent, it has the best position to do so. Else, regulation is required for the purpose, implying transaction costs that reduce economic efficiency. As an example, the imperfect legal unbundling of the four¹⁶ German TSOs led the European Commission to conclude that they offer preferential TPA to the incumbents, due to historical ties (European Commission, 2007). ISO/ITO and ISO/LTO arrangements are appropriate when reform must be made without the difficult task of unbundling the transmission assets from their (vertically integrated) owners, as has been done on a large scale in the United States.

¹⁶ As of 2005 a new law (“EnWG”) implemented four LTOs in Germany: E.ON Netz GmbH, RWE Transportnetz Strom GmbH, Vattenfall Europe Transmission AG and EnBW Transportnetze AG. In the meanwhile, Vattenfall sold its operator and transmission lines to the Belgian grid operator, Elia and an Australian Infrastructure fund, in March 2010. Earlier in the year, E.ON had done the same with Dutch operator, TenneT as a buyer. See Dow Jones Newswires (2010) for details.

2.4.4 Incentives for transmission expansion

This criterion may be reformulated as “incentives for transmission expansion in the context to its substitutability with generation facilities.” The central point is that should the TO(s) incorporate the transmission planning function or decision¹⁷, they are bound to be biased towards overbuilding transmission lines and sacrificing generation solutions. However, when a certain load cannot be tended to under market conditions, both transmission and generation ought to be considered. Attending a load can either be achieved by building more high voltage lines that link it to an area with available production capacity, or by building generation facilities locally¹⁸. If the SO and TO are integrated and the institution has a say in planning transmission expansion, then the precision of its advice shall be increased relatively to alternatives. The transmission planning function ought to be assigned to a relatively neutral organism, that does not gain financially neither with the expansion of the transmission grid nor with that of generation capacity. As a counterexample to this statement, LTSO’s often face pressure from their shareholders to invest in generation facilities, which theoretically have larger prospective revenues (but also more risk). Transmission assets in turn, present less but more stable revenue, with reduced risk. Furthermore, the integrated generators may feel that building transmission lines from which shareholders may not directly benefit is not worthy. Building generating plants *instead* of building transmission lines actually exposes the producers to less competition – regionally. Thus a LTSO feels this pressure on one side and on the other the need to achieve an optimum transmission expansion in its position of system operator. ISO/LTO situations are similar. In Chile, for instance, the previous integration of transmission and generation in Endesa delayed investments in grid expansion that would have benefited the market as a whole (Pollitt, 2008).

In an ISO/ITO situation, merchant transmission is another relevant subject. Joskow and Tirole (2003) study them and conclude that counting on the investment paradigm of merchant transmission, efficiency in the wholesale market might be underachieved. This is due to the lack of convergence of the incentive for TOs and SOs and the coordination costs involved. Dispatch and planning must be coordinated with

¹⁷ In the case of merchant transmission.

¹⁸ The choice depends on economical, environmental and social concerns (risks incorporated by nuclear plants, for instance).

investment decisions. Soares and Sarmento (2009) further added that investment from new entrants may tend to be deterred should they expect to use the incumbent's grid. Yet there are solutions, as performance-based regulation or the creation of joint owner-operator. The case of Argentina is another illustrative example of a solution to this issue. There, Compañía Administradora del Mercado Mayorista Eléctrico – CAMMESA – is a non-profit system operator, with no transmission assets of its own. The major transmission company, Transener runs a sheer part of the transmission grid. The regulatory agency implemented a nodal pricing scheme that also shares congestion costs with grid users, together with a policy according to which expansions are voted and *paid for* by these users – *the public contest method*. Competitive auctions are made to construct, maintain and run the lines. A fund for part of the congestion revenue (SALEX) contributes to making transmission investments. Intuitively, this situation confirms as appropriate: the more congestion, the more the revenue available to expand the grid; as the users finance new lines, investments shall be well directed, because it is these users who have direct interest in the lines. The Argentine case is considered a successful implementation of the ISO/ITO arrangement in the international literature (Littlechild and Skerk, 2004). An ISO/LTO situation is that of PJM – an ISO present in 13 states and the Federal District. The responsibility for grid investment is with the generators that are also TOs. In this case, investments have been at low levels and increasing congestion has determined the FERC to take measures that stimulate investment: accelerated depreciation and larger returns on capital (Connors, 2005). The lack of independence of TOs was put to question, as well as PJM's relying on expansion plans proposed exclusively by these LTOs. FERC obliged PJM to become involved in planning, so as to reduce congestion.

2.4.5 Regional integration

National interests are usually very strong as far as transmission grids are regarded, which affects the cooperation between ESOs in different countries. A (for profit) ITSO might have incentives to distort the information that it passes on to foreign operators to limit the level of competition, which augments its own revenues¹⁹, also maintaining

¹⁹ Consumers keep using its lines instead of lines from the adjoined (previously isolated) grid.

national transmission costs relatively low²⁰. Keeping these costs as reduced as possible in the territory where it is inserted is part of the ESO's job; the evolution of these costs often serves as a basis for its evaluation. Thus, incentives might exist for the ESO to avoid supporting market integration, so as not to burden the consumer with higher transmission expenses, even if economies from reduced electricity prices may compensate them. Last, institutional arrangements uniformity or at least compatibility is important for a lean integration process. For this purpose, the theoretically best arrangement is one with a non-profit ISO. In this case, there is theoretically more incentive to properly collaborate with international peers. As Baker Jr. *et al.* (1997) noticed, when neighbouring networks are interconnected, operation responsibilities are better shared among equals than among institutions with various degrees of involvement with Governments or private investors. Joint models, which incorporate transmission lines – ITSO and LTSO – might be sceptical to allowing this nationally strategic asset to be controlled directly by an international peer, to the detriment of the process. ISOs however do not have direct interest in the grid; they are non-profit so they incur no potential losses by facilitating cross-border collaboration. When this collaboration is not on the same level, between the same types of institutions, measurements of the collaboration are also harder quantify (Lévêque *et al.*, 2008).

The table on the next page summarizes and creates a crossing between types of operators, regulations variables, and evaluation criteria.

²⁰ After the integration of two previously isolated grids, some consumers start purchasing energy from the new network, which may be more distant than the previously local consumption source; in this case, transmission costs may rise due to the need to wheel energy across larger distances.

Table 7 - Operators, regulation and evaluation criteria

Criteria		Operational security vs. efficiency		Transaction costs	TPA	Incentives for transmission expansion	Regional integration
Integration of ownership and control	Joint ownership and control (ITSO, LTSO)		Generally balanced, with possible bias towards own economic gain, reducing overall efficiency and security if LTSO.	Transaction costs reduced due to better TO-SO coordination.	If independent, TPA is guaranteed more easily than for LTSO.	ESO has better information about the "true" requirements of the system in terms of transmission lines, from an optimal point of view.	Less incentive. The possibility to use transmission assets from other countries might reduce TOs revenue. Also, a the ESO might not be interested in increasing national transmission charges.
	Separate ownership and control (ISO/LTO, ISO/ITO)		If TOs are effectively regulated, the ISO can insure a balance.	Increased transaction costs due to contracts to regulate the SO-TO co-ordination.	Guaranteed at the cost of heavy-handed regulation.	ESO does not have perfect information with respect to transmission expansion.	More incentive due to ISOs' lack of (strategic) transmission assets.
Independence from the value chain + Governance	Ownership unbundled (ITSO, ISO/ITO, ISO/LTO ¹)	State-governed	Biased towards security.	Security might come at a high cost	Guaranteed.	Correct incentives and no transaction costs.	Depending of the energy policy.
		Privately-governed	Generally balanced, with possible bias towards own economic gain at the cost of security and overall efficiency.	Relatively reduced, by a degree dependent of integration between ownership and control.	Guaranteed, but with slight deviation from eventual managerial homogeneity of interests.	Might be biased toward transmission solutions relatively to generation solutions.	Less incentive. The possibility to use transmission assets from other countries might reduce TOs revenue.
	Legally or functionally unbundled (ISO/LTO ¹ , LTSO)	Stakeholder governed	Possible bias of TO towards own economic gain at the cost of security and overall efficiency.	Reduced transaction costs of coordination between generation/ retail and the TO. Eventual need to coordinate with the ISO increase these costs.	Might be affected to the favor of the transmission owning group. Requires heavy regulation.	Might be biased toward transmission solutions relatively to generation solutions.	Less incentive. The possibility to use transmission assets from other countries might reduce TOs revenue.
Profit-scope	Non-profit (ISOs)		Theoretically, no incentive to affect this balance.	N/A	Theoretically, no incentive to affect TPA openness.	Correct incentives and transaction costs depend on the level of integration.	More incentive due to lack of (strategic) transmission assets.
	For profit (ITSO, LTSO, TOs)		If ineffectively regulated, the profit scope can push TOs to serve own economic gains, at the cost of security and overall efficiency.	N/A	If independent, TPA is not affected; else heavy regulation required.	Might be biased toward transmission solutions relatively to generation solutions.	Less incentive. The possibility to use transmission assets from other countries might reduce TOs revenue.

¹ Only the SO is unbundled in this case, while the TO is legally unbundled from a vertically integrated utility.

Source: elaborated by the author, data from all references presented in Section 2.4

Chapter 3

Brazil's electric sector. An overview with a focus on the National System Operator (ONS).

As of 2006 Brazil became the world's 10th largest primary energy consumer. The country emerged on the international energy scene especially during this last decade due to tapping new, off-shore oil reserves as well as for having explored its large hydroelectric potential. Furthermore, its strides in the sugarcane ethanol industry have become a world reference. Considering energy consumption as a proxy for economic growth, the fact that Brazil consumes over seven times more energy in 2009 than thirty years before is more than revealing for the economic expansion the country underwent.

The table below shows Brazil as the third largest energy consumer in the Western hemisphere.

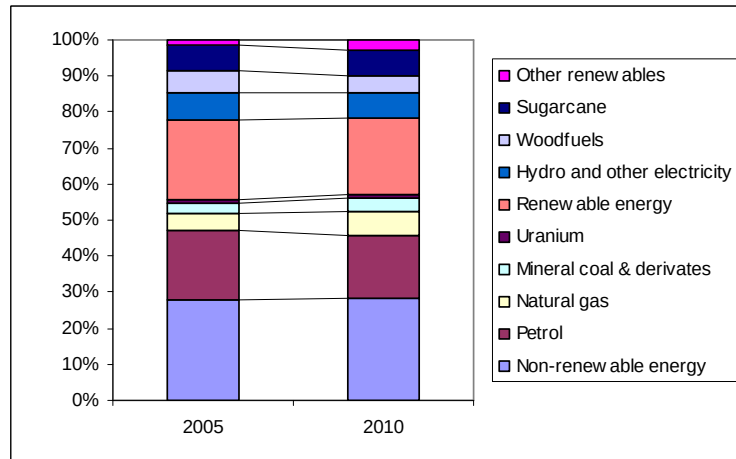
Table 8 - The world's top ten primary energy consumers (in million toe)

Country	2000	2009	Δ%
US	2.309,5	2.182,0	-5,5%
China	967,3	2.177,0	125,1%
Russia	614,3	635,3	3,4%
India	295,1	468,9	58,9%
Japan	510,2	463,9	-9,1%
Canada	300,4	319,2	6,2%
Germany	329,5	289,8	-12,1%
France	253,5	241,9	-4,6%
South Korea	188,8	237,5	25,8%
Brazil	182,9	225,7	23,4%

Source: BP (2010)

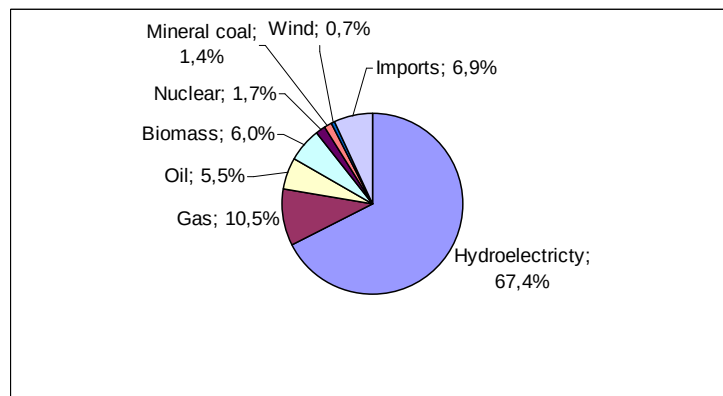
With almost 45% renewable fuels in its energy matrix and the size of a continent, Brazil is a forefront for environmentally friendly energy. About a sixth of the energy matrix consists of electricity and almost 70% of it was produced in hydroelectric power plants in 2009. The following figures further detail the energy and electricity structure of fuel sources of Brazil.

Figure 8 - The Brazilian energy matrix in (2005 and 2010)



Source: Ministério de Minas e Energia (2007)

Figure 9 – Brazilian electricity consumption, by source, 2009



Source: ANEEL (2010)

Due to the complementarity between hydrological conditions in various regions of the country, as well as to its having an interconnected grid that covers almost 97%¹ of the generation capacity, the national hydroelectrical park is like a large virtual reservoir and the optimization of the usage of water versus more expensive, thermal sources is the main determinant of the price of electricity.

3.1 The Brazilian electric sector: brief history

The initial phase of development of the Brazilian electric sector (“BES”) was dominated by two large foreign investors: Amform (American & Foreign Power Co.) and Light

¹ See ONS (2010c).

(Brazilian Traction, Light and Power Company). As Francescutti and Castro (1998) outlined, these companies were regional monopoly concessionaires in Brazil between the 1930s and 1950s. Electricity was mostly produced from hydro power plants. The 1934 Water Act² based investment recovery on the historical cost principle, a fact that determined the two private players to diminish their investments, especially after the post-bellum period; this was when demand started to accelerate relatively to the existing installed capacity. As Francescutti and Castro (1998) discussed, the expected revenue for the (large) investments needed to accompany demand were reduced in comparison to other possible financial applications. The State had to assume the role of investor in new generation capacity.

In the 1960s, an electricity crisis occurred in Brazil, which involved massive-scale rationing. At the core of the debate were the foreign investors, blamed for abusing their monopolies, which gave strength to a nationalist current. From 1952 to 1965, the State invested in generation capacity to the point that it raised its participation in the generation park from 6,8% to over 50% (Electrobrás, 1992). The creation of state-owned holding Electrobrás, today the second largest electric utility in Latin America was the forefront of the interventionist policy of the Brazilian State. The strategy it followed was to build large-scale hydroelectric power plants, whose scale returns would mitigate the large demand attendance deficit. The financing strategy that was chosen comprised: fiscal receipts, revenues from attending the market, internal and international loans (Francescutti and Castro, 1998).

The so-called “Mexican crisis” followed, as a consequence of restrictively high interest rates in the USA – that were part of the firm monetary policy put in place to reduce inflation. This outburst of inflation had been caused by the ever more elevated prices of oil, outcome of the two petrol shocks, of 1973 and 1979. “Recycled” petrodollars had returned too easily to the American financial markets and had provoked this inflation, as Nobel laureate Joseph Stiglitz (2010) noted. The result was that developing countries found themselves not only in a conjuncture of reduced economic growth but also burdened with growing interest rates. Mexico was the most resounding case, having declared itself unable to repay foreign credit in 1982. This sequence of events lead

² “Código de Águas”, in Brazilian Portuguese

expression “Mexican crisis” to refer to the type of effects that developing countries, like Brazil or Argentina, suffered after having borrowed from international financial markets in order to support industrialization processes and infrastructure.

After the “Mexican” crisis, Brazil had found itself confronting with inflation, unemployment, reduced growth and deepening public deficits (Francescutti and Castro, 1998). Electricity consumption followed the soaring demand, prolonging the pay-back periods for the large-scale investments made by the State in the electricity sector with ever mounting interest rates on the background. The public finances’ crisis that followed relied on the electric sector for part of its resources using political pressure. Thus, Eletrobrás became heavily indebted beyond its needs, while confronted with unemployed capacity. The global economy was at the time dominated by neo-liberal views and pressure was created for the Brazilian state to start privatizing its public assets, so that the market economy may play its part in growth restoration and the public finances may be re-equilibrated. Care for generation capacity and distribution companies would now pass from the Government to private initiative.

Since 1990, the electric sector in Brazil undertook two highly consistent institutional reforms, as outlined by Castro and Fernandez (2007).

3.1.1 The 1990 reform: the free electric market and the collapse it created

The root of the first reform, made in 1990, stands as the public finance crisis of the developing countries, which triggered the 1980’s Mexican crisis. The solution that was found for developing countries – lending from the International Monetary Fund (“IMF”) – obliged these countries to accept its neo-liberal policy impositions, namely: large-scale privatization for public finances and monetary balancing. This explains the 1980s-90s large-scale wave of privatizations.

In the Brazilian electric sector (“BES”), the fact that maximizing revenues from privatization was the central point meant that the Government easily permitted consistent advantages³ to the buyers, to the detriment of sector development. Medium-long term planning within the sector was terminated, as the new logic to be implanted

³ These advantages consisted of possibilities to elevate tariffs above the level of inflation and lines of public credit, as Castro (2004) documented.

was market-governed. At the same time, investments in new transmission lines and generation facilities by state-owned companies were ceased, as they were to be sold. In the 1990s' decade, 4 of the 23 generators were privatized, together with 19 distributors (Rosenthal *et al.*, 2006). The new mercantile model further discouraged new investment in extra capacity, as it would be possible to contract from the market to a considerable extent. The investments in new capacity that were made were based on public auctions, as established by the new regulatory agency created in 1996, ANEEL⁴. The auction was won by whoever offered the “largest value for society” through their project (2008).

As it can be noticed in the figure below, Brazilian GDP grew at low rates between 1987 and 1993, so the water left in reservoirs was sufficient to cover the electricity demand. It was in 1993-1994, when growth rates picked up. At this point it is important to say that the reservoirs in Brazil have multi-annual storage possibilities. By then the disequilibrium between supply and demand had become structural, and the perspective of price rises was not compatible to the monetary stability⁵ policy (Castro and Fernandez, 2007).

In the summer of 2001, Brazil's registered rain levels were at a historical low, and the crisis became inevitable, determining an ample rationing program and a wide-scale blackout that severely penalized economic growth; the only exception was the Southern region. Demand was mandatorily downsized by 20% and GDP is estimated to have fallen by 2% (Castro, 2004). Nevertheless, as Araújo (2009) pointed out, hydrology was but one of the causes of the event. The heavy weight resided in the termination of medium and long-term centralized planning in the sector, where distributors became responsible for the job, under market mechanisms; they were to contract their energy from producers via power purchasing agreements (PPAs), thus giving economic signal to the latter to expand capacity. Thus, the distribution sector came to be the catalyst for the physical expansion of the BES. The rationing that followed confirms that in a system the size of Brazil – practically equivalent to Europe – and in its developing economy, with many territories still to be connected to the electric grid, decentralizing planning has a large chance to go default.

⁴ “Agência Nacional de Energia Elétrica”, in Brazilian Portuguese or “National Electricity Agency”.

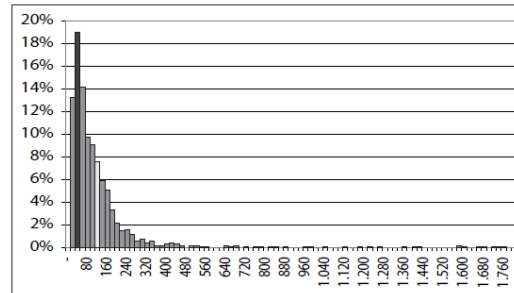
⁵ In this period, Brazil was recuperating from hyper-inflation.

At the methodological level the market mechanism that was implemented was inappropriate. The power purchase agreements that distributors signed with generators comprised prices that included capital costs. Yet on the spot market, prices tended to the marginal operation costs and in Brazil hydroelectricity “dictate” these for long time intervals. This simply means that distributors could buy energy from the spot market at prices lower than those in their long-term contracts! The wholesale market, MAE⁶ was thought so that up to 15% of energy would be contracted spot, a percentage sufficiently elevated to lead to the diminution of bilateral contracts, since the cheaper possibility to contract spot existed. In a system with a hydroelectric base-load like Brazil, around 75%⁷ of the time the spot price was given by hydroelectric plants; this means that during these periods, they are very reduced and even tend to zero for consistent periods of time, as Silva (2006) explained. Note the distribution in Figure 10. Should this kind of prices be used with the same frequency to clear the spot market, the effect is transmitting that there is abundance of water in the reservoirs and eliminating any signal for investors to expand capacity. Araújo (2009) gave a suggestive example: “if the country’s reservoirs were full, and by hazard, all rivers would dry out, we would have enough reserves for six months of consumption, or about 200 TWh.”. But what about the last six months of the year and how about the possibility of low rain levels, that may fail to refill the reservoirs for incoming periods? Clearly, the way the spot market was configured allowed the market to only provide myopic, short term signals, neglecting the medium and long-run. Without the spine of centralized planning, the outcome was inevitable.

⁶ The retail electricity market – or *Mercado atacadista de energia*, in Brazilian Portuguese – had been created in 1998.

⁷ Araújo (2009)

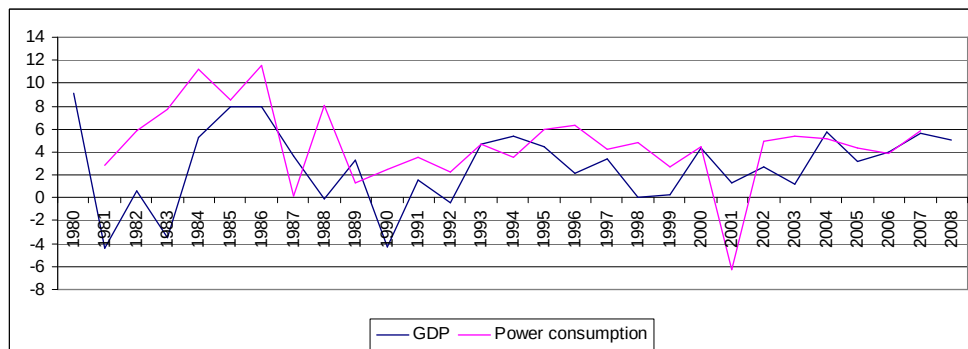
Figure 10 - a typical distribution of the marginal operation cost



Source: Araújo (2009)

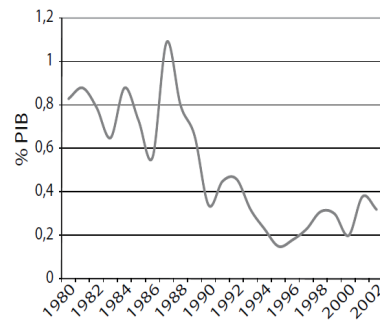
The spot price in the BES is given by the *marginal cost of operation*, a price that results from comparing the cost of satisfying supply in the present and a *future* cost function, of covering supply over the next four years. The present cost is more reduced if hydroelectricity is dispatched today, but this makes water unavailable in the future, and increases the future cost of satisfying supply due to the need to dispatch more expensive, thermal plants. This calculation is made by the system operator with complex software and the spot price should theoretically be aligned with that of providing for the system on a medium-term.

Figure 11 - GDP and power consumption in Brazil, annual % growth rates, 1980-2008



Source: World Bank statistics (2010)

Figure 12 - Investments by Eletrobrás as % of GDP, 1980-2002



Source: Araujo (2009)

3.1.2 The 2004 reform: back to centralized planning and dispatch

After the election of President Lula da Silva in 2002, the system was restructured in about one year and a half, shifting responsibilities from the market back to state-owned companies and deviating from the neo-liberal approach. The principles of the new reform were security of supply, tariffs' moderacy⁸ and democratization of electricity use. Moreover, as Castro and Fernandez (2007) pointed out, the price increases on commodities' markets provided a favorable economic context for the development of emerging economies such as Brazil.

A new institution was created to handle the centralized planning of the system – the Enterprise for Energy Research (“EPE”⁹); the system operator – the ONS – works closely together with the EPE for planning the expansion of the basic grid and encourages public-private partnerships for the process. State-owned companies were no longer used to provide fiscal receipts through privatization, but given autonomy to associate themselves to private entities and contribute to grid expansion; Eletrobrás is pivotal in this respect. Further, their role was to compete in auctions and thus enhance competition (Castro and Fernandez, 2007). The main financing institution, the Brazilian development bank (“BNDES”) pressured companies to adopt corporate governance practices, which, according to authors like Castro, Rosental and Soares¹⁰ have benefits like: boosting investors' confidence, decreasing volatility for publicly negotiated shares, allowing for increased demand for these titles and more affordable access to capital.

⁸ “Tariffs' moderacy” means that the electricity charges ought to be affordable for all consumers.

⁹ Empresa de Pesquisa Energética – EPE – in Brazilian Portuguese

¹⁰ See: Castro *et al.* (2010)

Capacity auctions ceased to have fiscal revenue purposes as well, with the previous paradigm of maximum public benefit being replaced the minimum cost for physically delivering the capacity, in line with desired prices' moderacy

The wholesale market or "MAE" was replaced by the CCEE¹¹ – the Electricity Commercialization Chamber and currently has two trading environments, one for free contracting – ACL¹² – and one for regulated contracting – ACR¹³. The fist one is dedicated to free consumers, who demand more than 3MW yearly¹⁴ and the latter to the other, captive consumers. The novelty was that supply for the regulated market became mandatorily 100% pre-contracted. In 2008, the free market comprised some 30% of electricity demand (2008). The market agents that participate in the ACR are: generators, distributors and captive consumers; in the ACL there are more actors: generators, retailers, importers, exporters and free consumers.

Overall, the revenues in the electricity sector restarted to foment profits as early as 2004, after the heavy losses that stemmed from the 2001 blackout, especially for more "structured" companies, that own all the business lines of the value chain; there are forbidden by law to act as vertically integrated – as self dealing is limited. Nevertheless, it can be inferred that synergies are inevitable as confirmed by the fact that distributors from such groups end up "shielding" their clients from the free market from competitors (Castro and Fernandez, 2007). The same authors noted that debt ratios within the BES have also recorded sensible decreases, and that the stabilization of the regulatory design has furthermore contributed to increased access of sector payers to more competitively priced capital.

Finally, the perspectives of the sector are pointing out towards the increase and diversification of non-hydro fuels for electricity generation, due to the ever higher requirements for obtaining environmental licenses for building power plants, especially

¹¹ "Câmara de Comercialização de Energia Elétrica", in Brazilian Portuguese

¹² "Ambiente de Contratação Livre", in Brazilian Portuguese.

¹³ "Ambiente de Contratação Regulada", in Brazilian Portuguese.

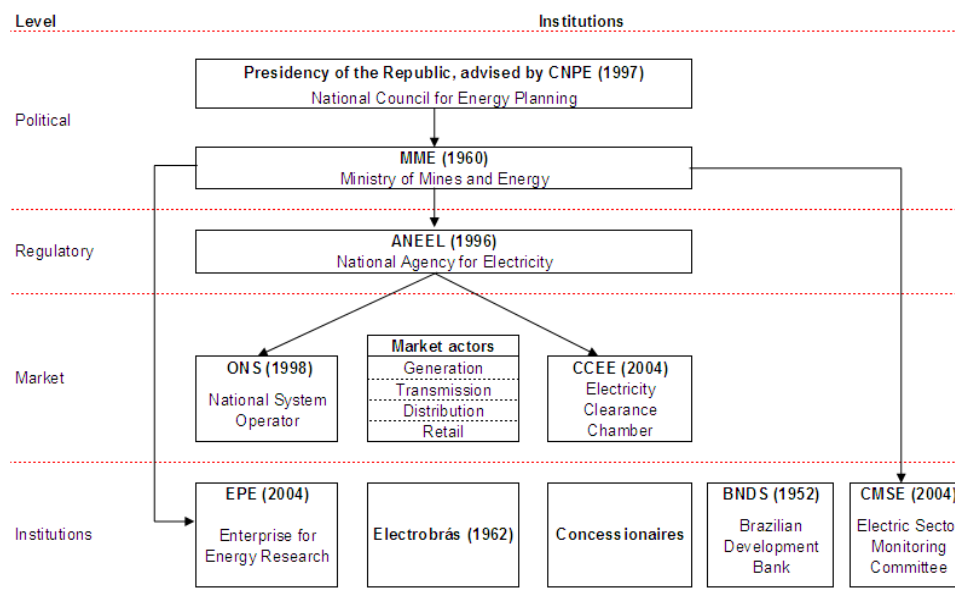
¹⁴ Or 500kW if supplied by renewable sources of electricity: wind, solar, biomass or small hydro, as established by Law N° 9.074, of July 7th, 1995 and Decree 5.163, of July 13th 2004. For easy access to these normative documents, consult the Glossary of www.aneel.gov.br, under "consumidor livre" or "free consumer".

regarding those with large reservoirs. Ever more hydroelectric plants are limited to functioning in a run-of-river regime, that is without using stored water and this augments the so-called “hydrological risk” (Castro and Fernandez, 2007). Increased hydrological risk means increased exposure on (spontaneous) river flows instead of being able to count on predictable levels of water stored in reservoirs. Under these conditions, diversification of non-hydro fuels for electricity generation is the translation of an old saying, very appreciated amongst investors: “don’t put all your eggs in one basket.”

3.2 The Institutional framework of the electricity sector

For a better understanding of the institutional design of the BES, the latter is outlined in a graphical manner.

Figure 13 - Institutional framework of the Brazilian electric sector



Sources: elaborated by the author, information from ANEEL (2008) and Machado (2009)

On the political level, the Ministry of Mines and Energy represents the executive power, commanded by the Presidency. The President of the Republic is advised by the National Council for Energy Planning (“**CMPE**”¹⁵). The latter has the role of monitoring the way supply is attended and giving preventive recommendations for ensuring long-term

¹⁵ “Conselho Nacional para Política Energética”, in Brazilian Portuguese

security. The National Electricity Agency (“**ANEEL**”) disposes **regulation**, organizes public auctions for generation and **transmission expansion**, generally overseeing the process of democratization of supply, tariffs’ establishment as well as the financial health of retail agents. The Electricity Clearance Chamber (“**CCEE**”) runs a complex piece of software called *Newave* weekly in order to establish the clearing price for the free contracting environment (ACL) and subsequently does the financial clearing of the market. It organizes new generation capacity auctions under the guidance of ANEEL. The Enterprise for Energy Research (“**EPE**”) is instrumental for these auctions, as it provides the variables necessary to **optimize system expansion**. Moreover, the perspective of stability the EPE seeks to contribute to via its **planning** function ensure not only investors but also consumers, securing stable revenues and respectively tariffs’ moderacy. The National System Operator (“**ONS**”) is like a counterpart of CCEE, because it dispatches the physical electricity into the SIN for both the ACR and ACL in a centralized fashion, ensuring continuity and security of supply to the maximum possible extent. The National Development Bank (“**BNDES**”¹⁶) played a key role in the 1990s’ privatizations period and continues to finance large infrastructure projects in Brazil.

3.3 Organized and non-organized markets

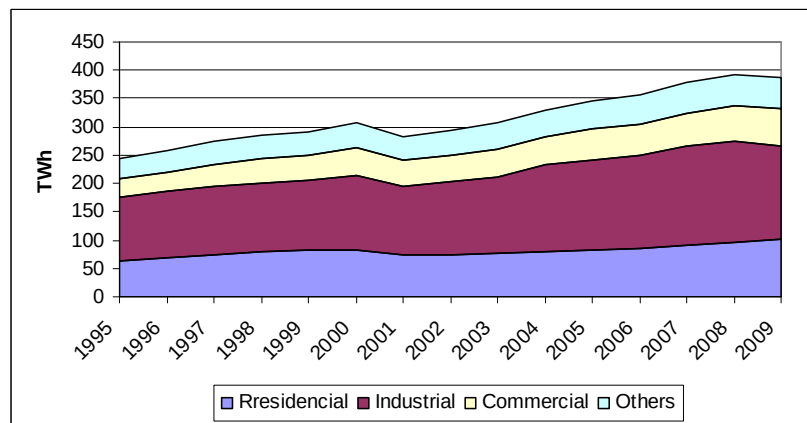
Thus, a long-term bilateral contracting market exists, concentrating roughly 70% of electricity sold in Brazil, while the spot market concentrates the rest. The spot market is where generators sell their excess power and where exports and imports are settled.

3.4 Demand structure

As the figure below demonstrates, in 2009 roughly 43% of demand came from industrial consumers, 26% from residences, 13% from the commercial sector, the latter 15% coming from other consumers. The proportions have remained more or less equal since 1995.

¹⁶ “Banco Nacional de Desenvolvimento Economico e Social”. In Brazilian Portuguese.

Figure 14 - Electricity consumption by consumer class in Brazil, 1995-2009



Source: EPE (2010b)

3.5 Transmission

The Brazilian transmission sub-sector comprises the SIN¹⁷, which is the National Interconnected System covering 96,6%¹⁸ of electricity production facilities in 2008, the rest being isolated systems, mostly present in Amazonia. Covering the Amazonian region is of intense debate currently, especially due to the possibility to tap large unexplored hydroelectric resources that this “lung of the Earth” possesses. The colossal 89.200 km of lines of the SIN were operated by 64 concessionaries in 2008. The concession rights are obtained through public auctions; they are valid for 30 years and can be prolonged for an equivalent period.

3.5.1 System dimensions and expansion

The vision of the ONS in 2007 was that 11.500 km should be added to the SIN until 2010¹⁹, in order to link part of the isolated systems to it. At the end of 2007, the SIN’s transmission lined measured almost 87.300 km in length and by the end of 2008 already 3.100 more were added²⁰. Not only should this expansion bring cheap electricity to these places, but also reduce the Account for Fuel Consumption²¹ that electricity consumer pays in order to cross-subsidize the expensive diesel-oil that these isolated

¹⁷ “Sistema interconetado nacional”, in Brazilian Portuguese

¹⁸ For details, see ANEEL (2008).

¹⁹ See: ONS (2008b).

²⁰ See: ONS (2008a).

²¹ “Conta de consumo de combustíveis” (CCC), in Brazilian Portuguese.

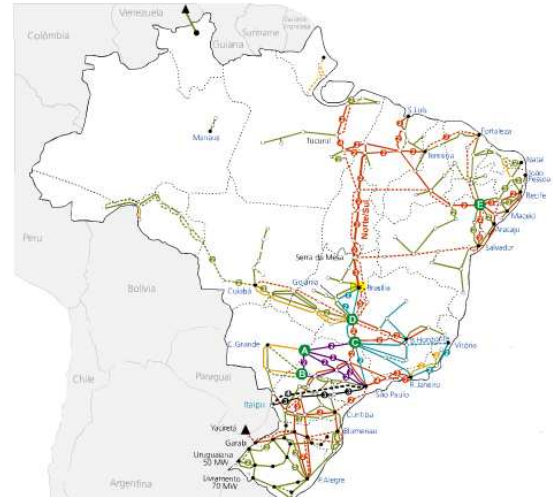
communities rely on, as documented by ANEEL (2008). Maps 1 and 2 denote the insulated and respectively the SIN.

Map 1 - Brazil: the isolated systems (2003)



Source: ANEEL (2008)

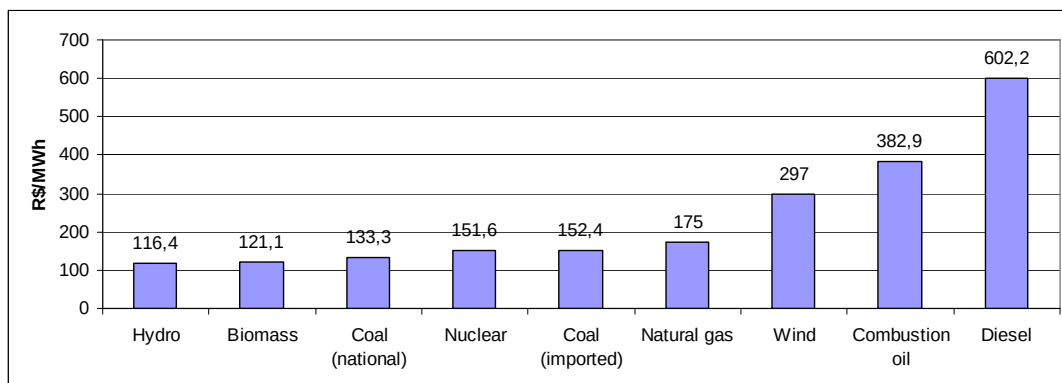
Map 2 - Brazil: the SIN, 2008 view



Source: ONS (2005)

Figure 15 shows the comparative equilibrium tariff of different fuels for electricity generation in Brazil. This tariff permits remuneration of fixed and variable costs. Note that diesel oil is the absolute most expensive one, costing about four times what hydroelectricity costs.

Figure 15 - Equilibrium tariff distribution by electricity fuel type in Brazil, 2009

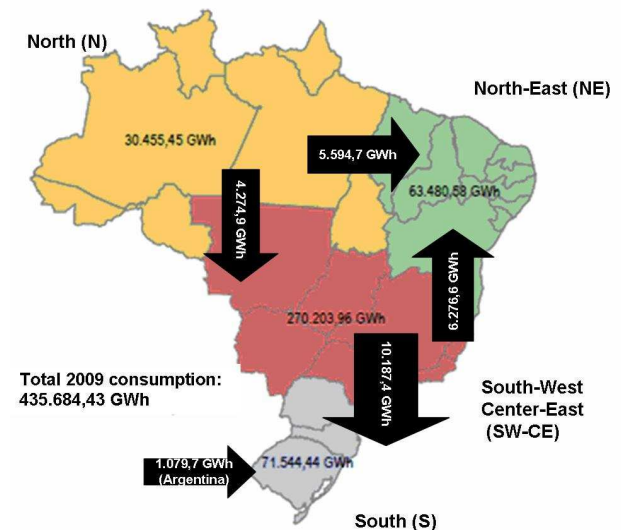


Source: Hubner (2010)

The fact that Brazil chose to explore its potential for hydro power to the extent it did meant assuming a compromise, which resides in the wide physical distances between generation and load. Thus, the transmission interconnections set up between these

points with transmission lines are equivalent to virtual capacity expansions. Instead of making costly investments in capacity expansions, one region can simply import energy from where surpluses exist. The SIN is split up in four such regions or *sub-systems*, as delimited in the following map: North (N), Northeast (NE), Southwest/Center-East (SW-CE) and South (S). The interconnection capacity between these sub-systems is used to carry energy from the areas that experience excess installed capacity relatively to their demand to the areas where the opposite verifies. Overall, the SIN is used to transport electricity from the Northern or Amazonian region to the other sub-systems, especially to the highly energy-intensive Southern region.

Map 3 – Net electricity exports between Brazilian subsystems



Sources: elaborated by the author, information from ANEEL (2008) and ONS (2010b)

The National System Operator – ONS²² - is responsible to coordinate these exchanges, controlling the operation of the SIN. The ONS runs highly complex pieces of software²³ in order to optimize the usage of the water available in reservoirs so that the balance of hydroelectric resources and thermal resources dispatched results in the most reduced price presently; this is ensured in the context of guaranteeing that the most reduced possible prices can be provided in the future, minding security of supply. So, the generators and transmission concessionaires “obey the commands” of the ONS to insert

²² “Operador Nacional do Sistema”, in Brazilian Portuguese

²³ The software used by the ONS are DECOMP and NEWAVE.

energy into the grid and respectively to have the transmission lines up and running at all moments in time, but for agreed maintenance periods.

3.5.2 The National System Operator. Functions and characteristics.

Before 1998, the ONS was part of Electrobrás, a state-owned integrated electric utility and in that period the generation and transmission functions of the BES were conglomerated. Every regional utility operated its own transmission lines and cooperation between them was voluntary; thus “the function of operations of the SIN did not exist.” (Lima, 2004). The fact that operation was voluntary meant that it was not regulated in any way. In 1998, the operator, without any transmission assets was unbundled from Electrobrás and transformed into a private-right, non-profit, non-governmental organization.

The new statute of the ONS (2004) outlines its main functions, and the website of the organization details them in non-legal language (2010a). The operation of the SIN rests on three pillars:

- I. Minimize the cost of ensuring the reliability and security standard stated by ANEEL;
- II. Non-discriminatory open access to the basic grid;
- III. Contribute through its activities so that the expansion of the SIN is made at the lowest possible cost that supports the best possible operational conditions in the future.

The responsibilities of the ONS are subsequently explained.

System operationS

- i. **Real-time operation and centralized dispatch**, guided by security, continuity and economy. The ONS is responsible for planning and programming operation and dispatch both *inside* the SIN and at its international interconnections. It has a central operation center and four regional centers that monitor and act to correct any deviations from normal operations, according to supply and demand conditions, as well as on the state of the system components; follow-up on operations is distributed to market agents via Internet;

- ii. **Elaborating operation procedures.** The operation of the grid is done according to the Network Procedures²⁴ - a set of technical norms the ONS is responsible to elaborate and that are approved by ANEEL. Evidently, the ONS uses data inputs from market actors in order to apply the Procedures;
- iii. **Medium-run evaluation of future operating conditions.** First, the operator uses mathematical algorithms to forecast demand and supply conditions for the following year, with inputs from the market actors for the next five years. This forecast is made to foresee eventualities of deficit with an annual time-frame and is updated on a four-month basis; Second, the operator forecasts appropriateness of operation for the medium-term, taking into account the generation and transmission facilities and possible equipment that can be installed to smoothen system restrictions; a risk-aversion curve is used in this forecast;
- iv. **Short-run evaluation of operation.** The ONS elaborates studies of the SIN's ability to face multiple contingencies, in order to devise automatic algorithms for security increase and faster restart in case of blackouts. Furthermore, studies that support short-run and real-time operation are made using meteorological surveys and multiple water-management scenarios, as well as the demand forecasts the ONS disposes of;
- v. **Analyze system performance and supply indicators.** For this purpose, continuity and quality indicators are measured periodically so as to indicate the performance of the way the ONS acts upon the system as well as that of transmission concessionaires;
- vi. **Operations' historical database.** The ONS keeps this information bank at the disposal of market actors;

Market and commercial operations

- vii. **Administration of transmission services, including ancillary services.** It is the obligation of the ONS to manage the **contracts** for transmission and

²⁴ "Procedimentos da rede", in Brazilian Portuguese.

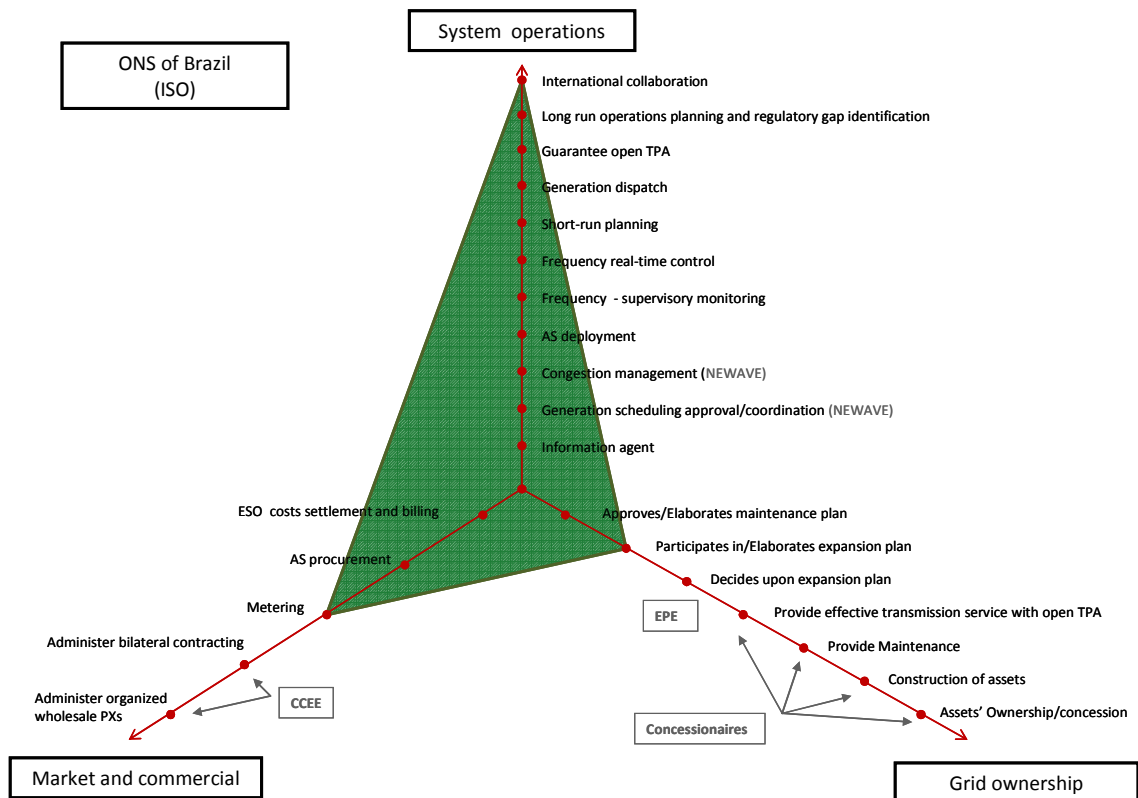
ancillary services. The ONS calculates the monthly revenues for service providers and bills the appropriate parties.

Grid operations

- viii. Elaborating a **plan for expansion and reinforcement of the basic grid**. This plan plays a very important role in the decision process that EPE, which takes it into account when elaborating the expansion strategy for the transmission grid of the SIN. The input of the ONS in this respect is of utmost importance, as it is the entity whose main tool is this exact grid, and consequently knows its requirements best;
- ix. **Integration of new facilities in the SIN**. This responsibility is carried out in an articulated way with ANEEL and CCEE. The ONS elaborates studies that test the effect of the integration of the new facility in the SIN and in case of net benefit award a license that is further approved and published by ANEEL.

To summarize, the following triangle depicts the range of responsibilities of the ONS.

Figure 16 - System operation triangle: Brazil



Source: elaborated by the author

3.5.3 Governance of the operator

The associated parties of the operator, with seats in the **General Assembly** are: generators, transmission, distribution and retail agents, importers, exporters, free consumers, the Ministry of Mines and Energy (MME) and consumers' representatives. All but the latter two have the right to vote and decisions are taken by simple majority, where representatives of all categories named above are present and at least half the votes of associated members are expressed, as described in Article 15 of the Statute of the ONS. Should the quorum not be accomplished, possibilities to take decisions exist with fewer representatives.

The **Administration Council** is nominated by the General Assembly as follows: five councilors of generation agents, four from transmission agents, five from free consumers and one from the MME. The Council proposes Directors to the same institution, together with changes in the Statute and in the internal management directives, approves the annual investments plan, ensuring economical and financial control of the organization as well as the evaluation and remuneration of directors.

The **Fiscal Council** is set up in order to verify that the administration acts according to the established rules, investigating and preventing fraud in the management. They analyze accounting documents, together with financial statements and the budget of the organization in order to verify their health. They assist at the reunions of the General Assembly and the Administration Council depending on the pertinence of the issues to be discussed, being permitted to opine on relevant matters.

The **Directors** of the ONS, proposed by the Administration Council and voted by the Assembly, are responsible for elaborating the Network Procedures and ensuring their application after approval by ANEEL, as well as for presenting the budget of the organization. One General Director is elected, together with four Directors.

In terms of **independence**, the Directors of the ONS:

- Cannot be shareholders of more than 0.3% of the capital of companies from the sector, nor more than 2% of their subsidiaries;
- Must not be part of the Council of Administration, the Fiscal Council or the General Assembly;
- May not be employed in other economical activities;

- May not be part of any syndicate of the employees of the ONS;
- May not be part of any association of electricity consumers.

Chapter 4

Case studies

Three countries have been chosen for operator comparison to Brazil. The main criterion has been the size of their hydroelectric share in their electricity matrix as well as in their effective generation matrix. This criterion was selected due to Brazil's most significant electricity-related issue. Unfortunately, these countries do not have as much relative storage capacity as Brazil, yet they are among the most similar case studies due to relying largely on hydroelectricity. The countries are: Norway, Canada and Colombia. A summary follows, to give an overall perspective and then the individual case studies.

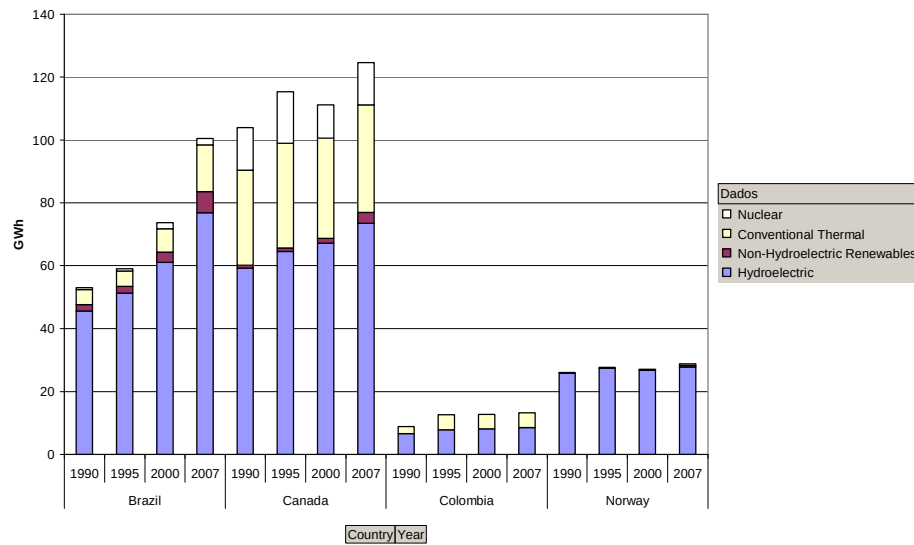
The majority of the data that have been are summarized in the Annexes as follows: Annex 1 comprises general economic and social indicators and Annexes 2 to 5 contains specific country data in the following order: Brazil, Norway, Canada and Colombia.

4.1 Summary of economical, energy and political relevant indicators

Hydro-capacity

Data from the U.S. Energy Information Administration (2010c) show that after China, Canada and Brazil are currently “disputing” the second and third place among the countries with the most generation capacity in the world. If Brazil “overtook” Canada in 2007, it was “overtaken” in 2008. Furthermore, with about twice more installed electric capacity and three times more hydroelectric capacity, Norway has roughly ten times less population. Figure 17 shows details.

Figure 17 - Installed generation capacity summary

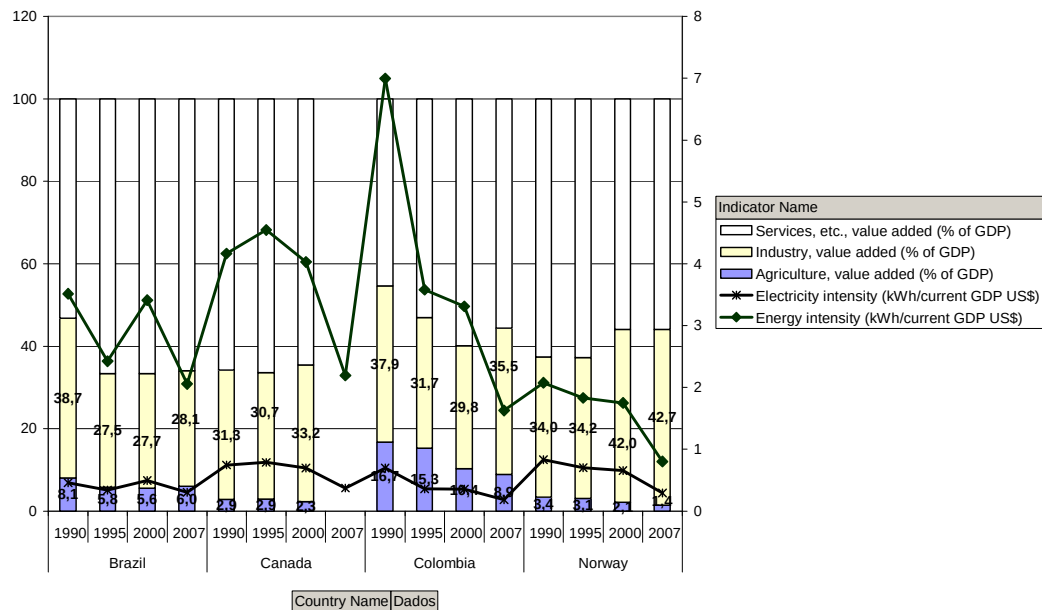


Source: elaborated by the author, data from EIA (2010c)

Economy, demographics and electricity consumption

The next figure outlines the structure of GDP in terms of agriculture, industry and services. This assessment has been thought in order to identify the links between level of industrialization and energy intensity and also to observe the electricity-to-energy ration per current US\$. As the World Bank outlines Brazil and Colombia as developing economies in the upper-middle-income category, it is to be expected that their share of agriculture in GDP is larger, to the detriment of industry and services – when comparing to Norway and Canada, classified as high-income economies. A faint process of de-industrialization is coincident with a process of reduced energy intensity in Brazil, while Canada, traditionally one of the most energy-intense developed countries has been successfully applying energy-efficiency measures. Below, in figure 19, the dimension of GDP has been taken into account to justify the larger or more reduced amounts of energy usage. It is interesting to observe that the most industrialized country, Norway is the least energy and electricity intensive. In Colombia, GDP has risen while energy usage has become constant; authors like Larsen *et al.* (2004) worry about the way political instability may deter foreign investment in the future. Social and political stability proxies are shown in Figure 21.

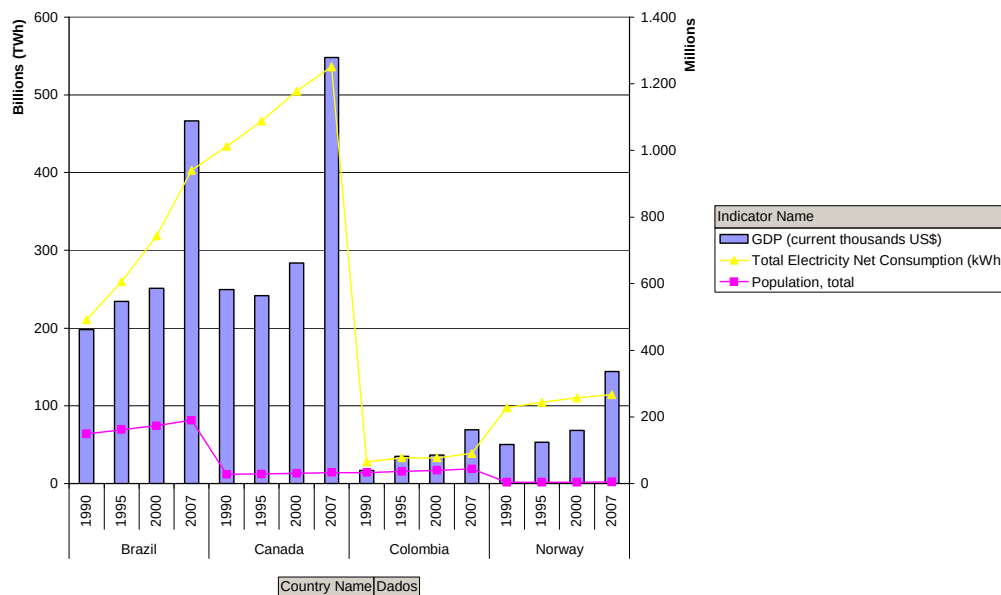
Figure 18 - Summary of GDP structure and energy intensity



Source: elaborated by the author, data from the World Bank (2010)

The next figure compares GDP levels with electricity consumption and population levels. The most abrupt electricity consumption rate is noticeably in Brazil, who, especially since the 2003, is experiencing high economic growth. Similarly, the turn of the century seems to have brought higher-than-average real income increases in Canada, until the 2008 crisis, not depicted here.

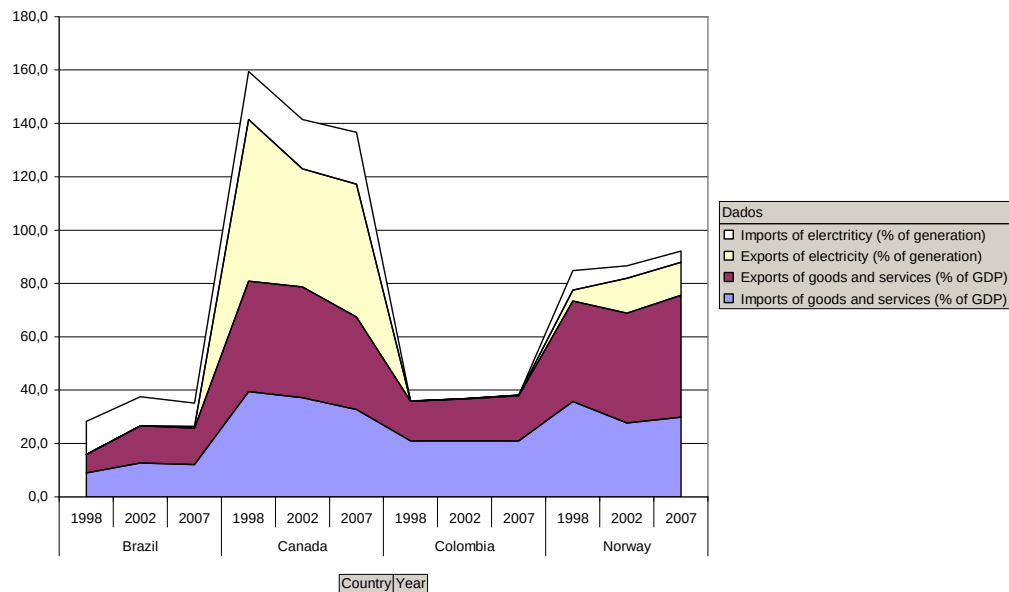
Figure 19 - Summary of GDP, population and net electricity consumption



Source: elaborated by the author, data from the World Bank (2010)

For understanding the lever of regional economic and energetic integration, the following graph has been created. Notice that Canada and Norway are similarly open in terms of global imports and exports, but from the point of view of electricity, it is Canada's integration in the North American grid, with what is the World's largest electricity consuming country according to the EIA (2010c) that makes its electricity exports distinctively large. Norway is also highly integrated, yet it mostly For Canada, the management of this integration is central. As noticeable in figure 25, between 1990-2008, Norway imported an average of 5,2% of its electricity consumption and exported around 8.3%. It mostly imports during the night and exports during the day. Colombia has started to open up its electricity market only in 2003, and its degree of openness remains low. Brazil has three interconnections, two with Argentina and Uruguay in the South and another with Venezuela in the North. Imports of electricity from Venezuela and Uruguay are marginal. Two thirds of imports come from the binational Itaipú power plant that Brazil co-owns with Paraguay, the plant with the largest hydroelectric output in the world. The latter third are imports from Argentina. Markets integration is currently gaining weight in Latin America, yet is only in its infancy.

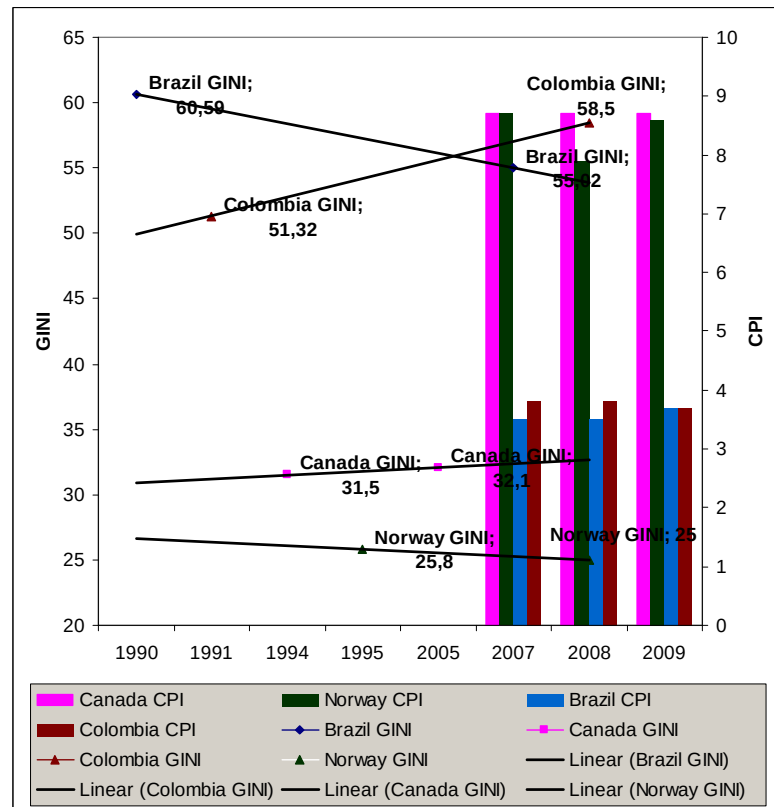
Figure 20 – Summary of degree of imports-exports openness



Source: elaborated by the author, data from EIA (2010c), and the World Bank (2010)

Finally, political stability is of major relevance for such a capital-intensive sector like electricity, characterized by lumpy investments. Investor must be sure that rule of law is enforced, that property is respected, as well that as that fiscal conditions are stable. The Corruption Perceptions Index or “CPI” of Transparency International is a proxy for this the political dimension, yet it ought to be considered with care. The CPI scales from 0 to 10 where 0 means very high corruption perception and 10 means no corruption perception. The methodology for this index is based on measuring the perceptions of individuals with “how corrupt do you believe your political leaders are?”- type of questions, which are exposed to subjectivity. Nevertheless, it is meaningful to observe that Brazil and Colombia have a CPI 2-2,5 times more reduced than Norway and Canada. The responsibility of maintaining stability in the power-system is larger in order to construct a sustainable sector. In Colombia, for instance, non-technical electricity losses and bombing of electricity pylons by guerilla groups are elevated relatively to the regional average, as Larsen *et al.* (2004) evaluated. Next, the GINI index, evaluates inequality income distribution, where 0 means no income distribution inequality and 100 means absolute inequality. This social proxy also counts for political stability.

Figure 21 - Summary of political stability and income distribution



Source: elaborated by the author, data from the World Bank (2010) and Transparency International (2010)

4.2 Norway

Norway is best known of the global energy map for its non-OPEC oil and natural gas reserves, located in the Norwegian Continental shelf. Oil production peaked in 2001 and has been declining since, but natural gas production has been increasing since 1993. Norway is the World's second largest net exporter of natural gas and holds the sixth position as far as net oil exports are concerned¹. Norway is equally recognized on the global map of electricity. It's "specialized" in hydroelectricity, having produced² 98,5% of its electricity from this environmentally-friendly source in 2008.

4.2.1 The Institutional framework of the electricity sector in Norway

The Norwegian electricity market is governed on the basis of the Energy Act of 1990³, stands as the founding document of the restructuring process. It enabled competition in the generation and retail sector, regulated monopoly operations and planning of the sector, among others⁴. It was with this law that liberalization in the Nordic region was initiated (Breidablik *et al.*, 2003) and open access to the transmission lines was prerequisite of the system from the beginning, reflected in market realities.

The Storting – the Norwegian parliament – is the utmost authority in the energy sector, and responsibility is delegated to the Ministry of Petroleum and Energy (MPE), ensuring policy convergence with that of the Storting. On its turn, the MPE delegated administrative responsibility to the Norwegian Water Resources and Energy Directorate (NVE) – its subordinate agency. NVE operated autonomously, as an independent regulator of monopoly network services.

The NVE has four main responsibilities:

- i. Control and regulation of monopoly network operations, including efficient operation, usage and development;

¹ For details, see: IEA - International Energy Agency (2009b) and U.S. Energy Information Administration (2010). The data refers to 2007 for oil and 2008 for natural gas.

² For details, see: NVE (2009). Note that electricity production is generally different from consumption. In dry years, Norway imports and uses more thermal sources, whereas in rainy years, exports occur.

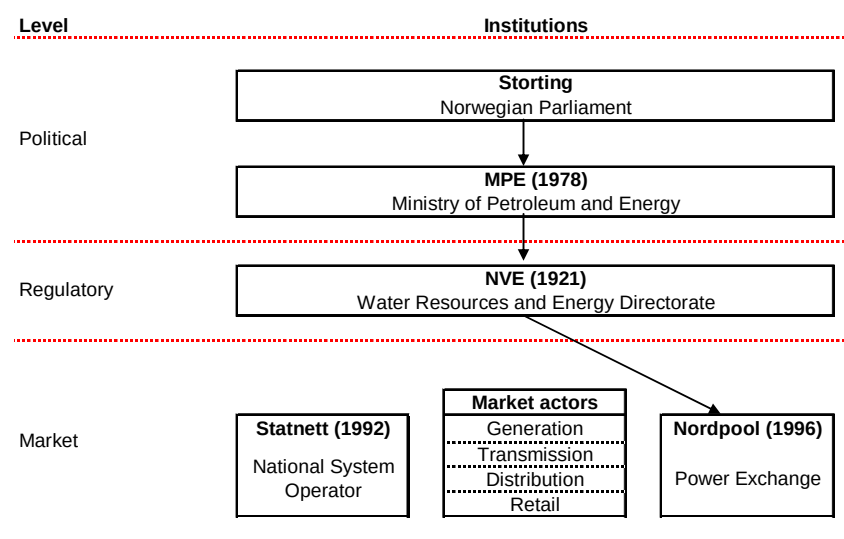
³ The Norwegian Energy Act, Law number 50 of 29/06/1990

⁴ The Energy policy analysis made by the International Energy Agency in 2005 about Norwegian energy policy is particularly clarifying.

- ii. Regulating network access and developing the methodology for transmission tariffs' calculation;
- iii. Licensing new generation and transmission assets' construction;
- iv. Facilitates electricity markets.

The Norwegian competition law⁵ harshly penalizes cartelization or abuse from those with dominating positions. The Norwegian Competition Authority regulates the electricity generation and retail sectors.

Figure 22 - The institutional framework of the electricity sector in Norway



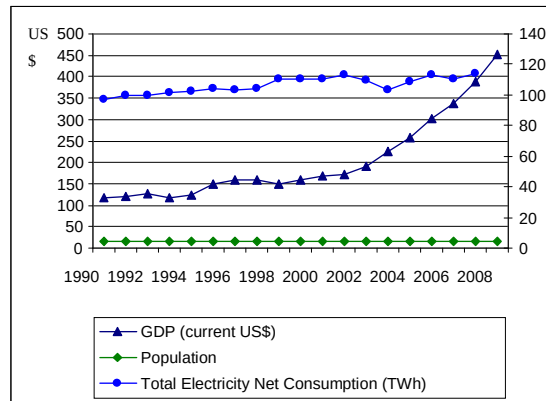
Source: elaborated by the author

4.2.2 Brief of the economy

From 2003-2004, economic growth has been steady, yet unaccompanied by the net electricity consumption. Norway is said to have made heavy investments in energy efficiency.

⁵ The Competition Act

Figure 23 - GDP, population and net electricity consumption in Norway, 1990-2008



Source: elaborated by the author, data from The World Bank (2010)

4.2.3 Electricity markets organization

Unbundling

Norway is part of the Nordic power market, called NordPool, together with Sweden, Finland and Eastern Denmark. NordPool started operations in 1993, as a Norwegian initiative. Until 2010, it was owned by the Norwegian and Swedish TSOs, each in a proportion of 50%⁶. The Financial Supervisory Authority of Norway and Sweden as well the Norwegian Ministry of Finance license and supervise NordPool ASA.

The Energy Act established necessary accounting unbundling of competitive and non-competitive divisions of the energy sector. Legal unbundling as well as some functional unbundling provisions are required for vertically integrated companies with more than 100 000 connected customers⁷.

The wholesale market

NordPool's operations are comprised of four business lines:

- i. Elspot is a market for physical power trading that functions in coordination with the TSOs;

⁶ In 2010, the financial interests in Nordpool ASA were sold to Nasdaq OMX

⁷ See NordREG (2009)

- ii. Eltermin is a financial futures market, also providing support for forward contracts and a number of other risk management tools;
- iii. Clearing: for the contracts made through the power exchange and for financial bilateral contracts;
- iv. Information provision for the market.

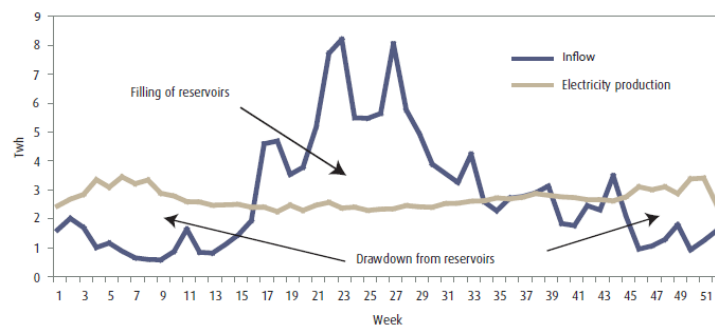
Around 75% of electricity traded in Scandinavia is traded via Elspot, the physical spot market, whereas the remaining 25% is traded bilaterally⁸.

Hydrology

In Norway, water inflows usually start to occur during spring, around March-April, when the snow melts and fills the reservoirs. This water is consumed later in the year, during the autumn and winter, when precipitations fall in the form of snow, thus when rainfall is unavailable. This is called *seasonal regulation*, as opposed to *multi-annual regulation*, when energy from a “wet” year can be stored for consumption in a different “dry” year, or from *short-term regulation*.

According to the Norwegian Ministry of Petroleum and Energy (2008), at the beginning of 2008, reservoir storage capacity in Norway was of about 84,3 TWh, of about two thirds of the annual electricity consumption of the country. It is not the case for multi-annual storage.

Figure 24 - Hydrology and electricity demand in Norway. weekly, 2007

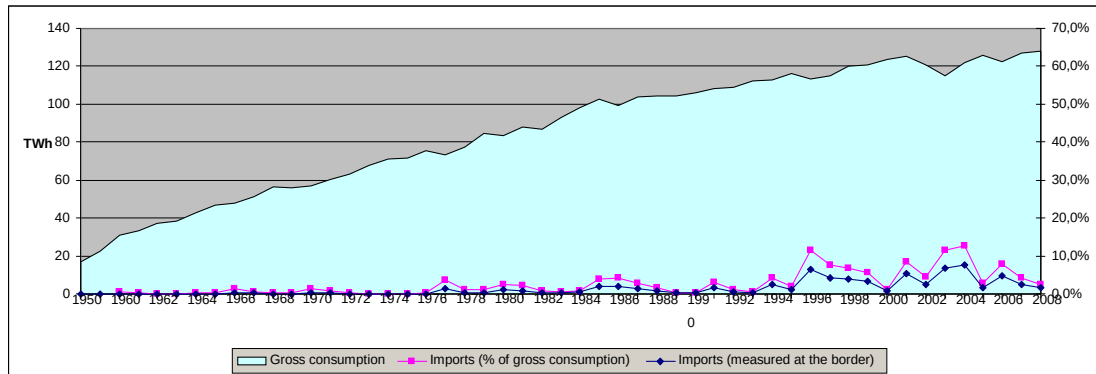


Source: of Petroleum and Energy (2008)

⁸ See Ibid..

Yearly hydrology varies in Norway and despite long-term net exports amounting roughly to zero. The conditions can be such that imports amount to 15,3 GWh in a “dry” year as 2004 or to 1,3 GWh in a “wet” years, as was 2000. The figure below shows details.

Figure 25 – Gross consumption and imports in Norway, 1950-2008

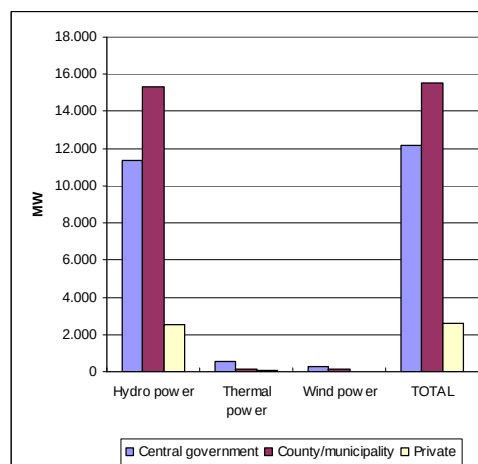


Source: Norwegian Statistics Bureau

4.2.4 Installed capacity for electricity production and supply concentration

The chart below demonstrates not only the dominance of hydroelectricity in Norway, but also the fact that generation capacity in this country is public, by excellence. 91% of generation capacity belonged to the central Government, to Counties or Municipalities at the end of 2008.

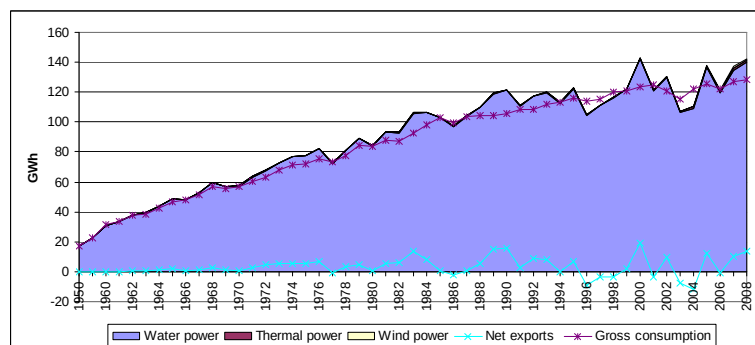
Figure 26 - Installed capacity in Norway (2008) , by type and owner



Source: Statistics Norway (2010)

The next chart depicts the Norwegian production of electricity in parallel with its net imports of the commodity.

Figure 27 - Electricity production in Norway by source and net imports, 1950-2008



Source: Statistics Norway (2010)

4.2.5 Transmission

System dimension and expansion planning

The Norwegian transmission sub-sector has a length of about 10 000 km, of which around 90%⁹ is owned by Statnett. The TSO intends to become the sole owner of the “electricity highways”, as the transmission lines are also called. The rest of the transmission grid was owned by around 20 other entities at the time Oren *et al.* (2001) studied the matter. The author did not encounter more recent data. Nevertheless, in the cases where energy holdings are involved in both competitive and non-competitive activities, they are required to keep separate accounts for the different divisions, as the Electricity Act incorporated the Directive 96/92/EC, regarding accounting unbundling. This is to avoid cross-subsidization. These accounts are thoroughly checked by NVE, as part of its tariff supervision function.

Regional overview

Beyond Finland, Sweden and Denmark, Norway’s transmission grid is also connected to Russia, Germany, The Netherlands and The United Kingdom. After Norway liberalized its electricity market, a similar process occurred in Finland (1995), Sweden (1996) and Denmark (1998). The centerpiece of the process was the formation of NordPool in Sweden, which gradually integrated the latter countries by the year 2000.

⁹ See Statnett (2008).

The TSO. Functions and characteristics.

Regulated by NVE, Statnett is a state-owned TSO organized as a public enterprise. Statnett does not issue regulation.

The **system operation** function consists of real-time balancing of generation and supply, as well as evaluating and proposing better tools for the job. The balancing market for Norway is called the “regulatory” market. Contracts for power reserves are thus an inherent part of Statnett’s attributions and all ancillary services are purchased from the market on a competitive basis. All those market actors who attend the regulatory power market have balancing responsibilities, be they producers or consumers, so that about 140¹⁰ entities are involved in power balancing. In the other Scandinavian countries, this number amounts to less than a third. The international collaboration between the Nordic TSO was formalized through Nordel, an association formed as of 1999. Ten years passed, in 2009 ENTSOE, the European peer of Nordel took over its attributions, as part of the integration in the internal energy market of the European Union. Nordel’s main attribution included: achievement of a common Nordic regulating power market and reserves’ pooling as well as conjoint transmission system planning and forecasting.

Statnett has three local control centers monitoring its transmission grid.

As far as the grid ownership function is concerned, Statnett is in charge of planning and development of the national grid, having NVE as a licensing entity. To ensure optimum grid planning, Statnett has a 10-year plan that is annually updated, according to various scenarios, environmental concerns and to the European context. Furthermore, Statnett has an important role in development and operation of international interconnectors. When domestic or foreign transmission lines are congested, market splitting “breaks” Norway into two, three or even five separate pricing zones.

Statnett has few **market and commercial** responsibilities beyond procuring ancillary services, metering relevant data and billing for its services. It is NordPool that sets the marginal price in every zone, according to local supply availability and the demand situation. The difference from the regional system price makes up the congestion rent that only exists at the boarder. Statnett thus contributed to lowering congestion levels

¹⁰ See NordREG (2009).

through counter-trading (using reserves). It bears the congestion levies, which provide an incentive for transmission grid expansion and development. Even though the market system is in place in Norway, reservoirs do not cease to have *some* seasonal storage capacity and instead of the operator or market administrator, individual generators use different techniques to plan long-term reservoir usage. As mentioned by Wolfgang *et al.* (2009), the EFI's Multi-area Power-market Simulator ("EMPS") that many generators use in this sense. Similarly, a dynamic optimization model called "PoMo", with a time horizon of three years is used by the Swedish National Energy Administration (Amundsen and Bergman, 2007).

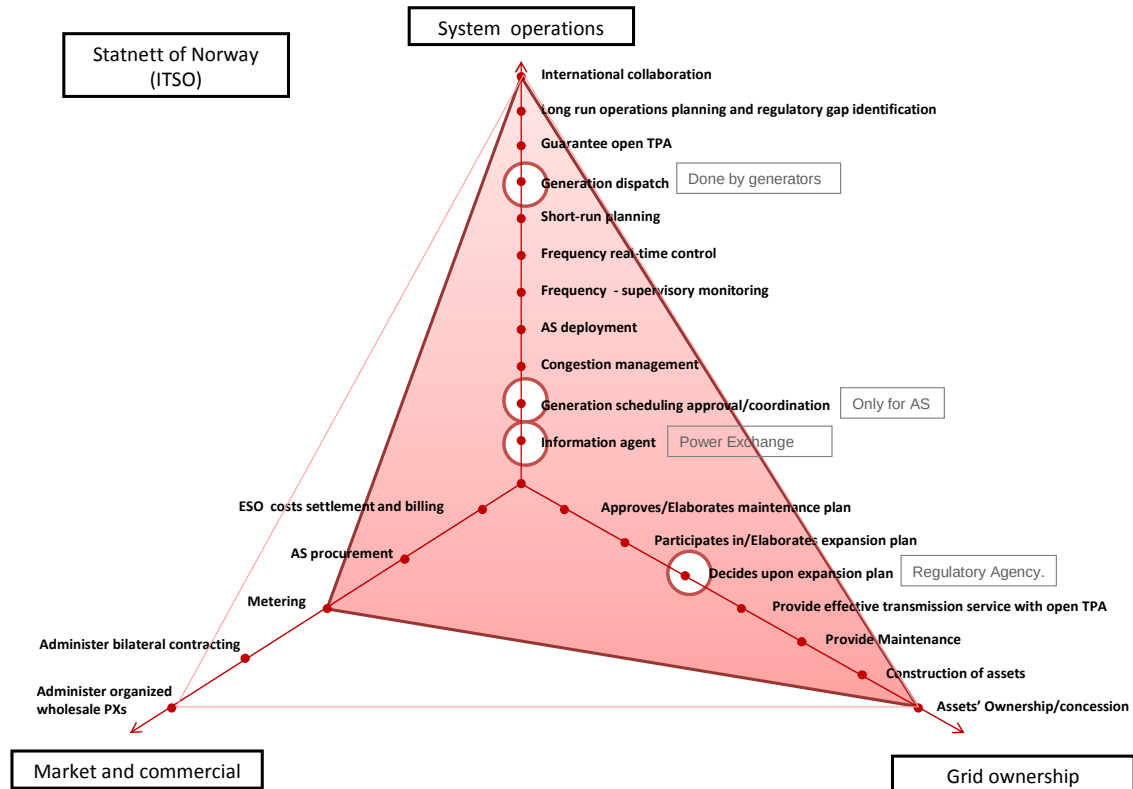
Remuneration for Statnett and other grid companies is capped by the NVE, according to local conditions: costs, climate or settlement patterns (Ministry of Petroleum and Energy, 2008). This method is called "data envelopment analysis" or "DEA" – and consists of taking into account geographic and climate related conditions between companies. A pre-defined return is included in the cap, beyond covering costs and depreciation. A Cost for Energy Not Supplied ("CENS") scheme is used to reduce revenues should energy in case of delivery interruptions. The **point tariffs** the transmission companies charge are such that inside the country, the customer pays the same tariff no matter where he buys from or sells to. Remuneration of transmission services is regulated by NVE and articulated with income caps. These are based on empirical data, and reduced yearly according to general efficiency plans, accompanied by individual efficiency requirements of 0-5,2%¹¹ for less efficient companies. Statnett sets its own transmission tariffs, in accordance with its revenue cap. Tariffs must be cost-reflective. Apart from these performance-based regulatory methods, NVE's heavy penalties for supply interruption are another motivating factor for keeping transmission services at good quality levels. As far as grid access is concerned, NVE continually verifies Statnett and administers complaints.

Statnett is **governed** by a board formed of seven to nine members; one must be from the generation sector; with the particularity that two to three members must be elected by all employees. A User Council, formed out of six members from all categories of basic

¹¹ See IEA (2005). The income caps are annually adjusted for general inflation and interest rates.

grid users, is annually appointed to assist the Board in its decisions. Statnett is **owned** by the state and administered by the Ministry of Petroleum and Energy.

Table 9 - ESO triangle: Norway



Source: elaborated by the author

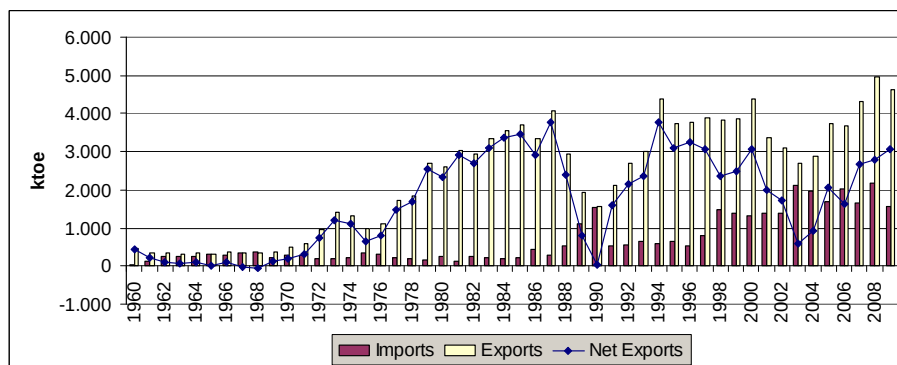
4.3 Canada

As Brazil, Canada is a federation. It comprises ten provinces and three territories. By area Canada is the second largest country on Earth, spanning a territory with around 17% more land than Brazil. However, its population was equivalent to only 17% of the Brazilian population in 2009, around 34 million inhabitants.

Rich in energy resources, Canada has been the world's fifth energy producer, after Saudi Arabia, Russia, China and the largest producer that is the U.S. (2010d). Moreover, Canada is also a net electricity exporter and has been ever since the International Energy Agency has documented data, which is the year 1960¹², as the next Figure exhibits.

Around 6,8%¹³ of the Canadian GDP owes to the energy sector. The country is rich in resources and has a fairly diversified base, including: hydropower, wind and ocean resources, biomass, solar, geothermal, oil and coal. The country is among the top-providers of natural gas and electricity for the US.

Figure 28 – Electricity trade in Canada, 1998-2008

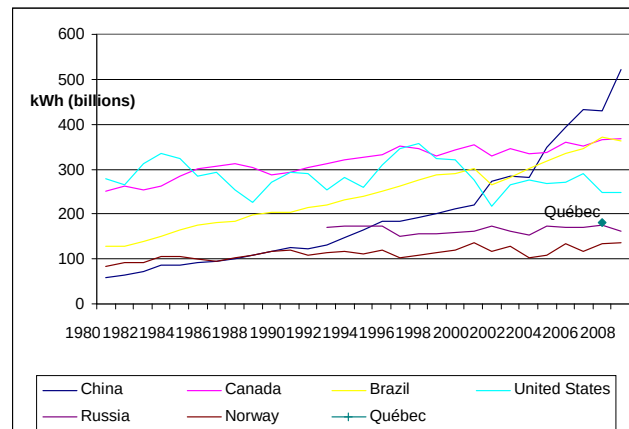


Source: elaborated by the author, data from IEA (2010)

¹² See the comprehensive database accessible from SourceOECD (2010). 1968-69 are years when Canada was exceptionally a net importer, yet the relative quantities are minute.

¹³ See the IEA's Canada 2009 Energy Policy Review for a comprehensive description of the energy sector.

Figure 29 - Top-5 net producers of hydroelectric power in 2008 (evolution as of 1980)



Source: elaborated by the author, data from EIA (2010c)

As far as hydroelectricity is concerned, Canada was the World's first hydroelectric power producer as recently as 2003, but China's exponential growth has turned into an undisputed leader. During the last three-four, another emerging country is taking a leap: Brazil. Canada is now "disputing" the second position in the world ranking with Brazil, whose steady evolution can be observed in Figure 28. Yet Canada remains a traditional hydroelectric powerhouse with the province of Québec as its engine. If Québec were a separate country instead of Canada, it would be the World's fourth¹⁴ largest producer of hydroelectricity. Other provinces that concentrate large hydroelectric installed capacity are Ontario and British Columbia, with Manitoba and Newfoundland and Labrador concentrating minor amounts. Refer to Figures 34-35 for details. Overall, 59% of Canadian power is generated in hydroelectric power plants.

As far as the dimension of the economy and inhabiting population, the more meaningful provinces are: Ontario, Québec, British Columbia and Alberta (see Figure 34). As far as hydroelectric capacity is concerned, Québec and British Columbia are relevant – not only do they have high hydroelectric penetration ratios (around 94% and respectively 90% of generation in 2007), but also the absolute amount of installed capacity is relatively high. This last proposition is particularly true for Québec. British Columbia

¹⁴ By comparing data from the International Energy agency with that of Statistics Canada, it can be noticed that in 2007, Russia – the fourth largest hydroelectric power producer – generated approximately 175,3 TWh of electricity, whereas Québec generated 181,1 TWh.

has roughly three times less hydroelectric installed capacity – see Figure 33. The largest Canadian provincial economy is that of Ontario, where generation is preponderantly thermal.

4.3.1 The Institutional framework of the electricity sector

In Canada, provinces and territories individually own any natural resource found on their territory. Thus, they have autonomy in organizing their electricity sectors. Inter-provincial and international trade is regulated at a federal level, by the Natural Energy Board (“NEB”). The NEB is in charge of regulating international power lines’ construction and export permits. It is an independent federal agency, established in 1959. The NEB responds to the Parliament through the Minister of Natural Resources Canada (NRCan), a department with a history tracing back 125 years. The regulatory institutions in every province are specified in Annex 4. They are generally independent boards or commissions with quasi-judicial attributions that respond to provincial legislative assemblies through their responsible ministers. Members of these boards or commissions are appointed and removed by Provincial Cabinets, which are provincial executive councils. The commissions’ or boards’ actions can be challenged through provincial Courts of Appeal (2009a). Saskatchewan and Nunavut are exceptions, where the Executive sets energy rates and oversees the functioning of the sector.

The transmission grid in Alberta and Ontario is managed by Alberta Electric System Operator (AESO) and respectively by the Independent Electricity System Operator (IESO). These were the only independent system operators in Canada until the creation of the New Brunswick System Operator¹⁵ (NBSO) in 2004. Where they exist, system operators of the other provinces are vertically integrated in the afferent Crown utilities.

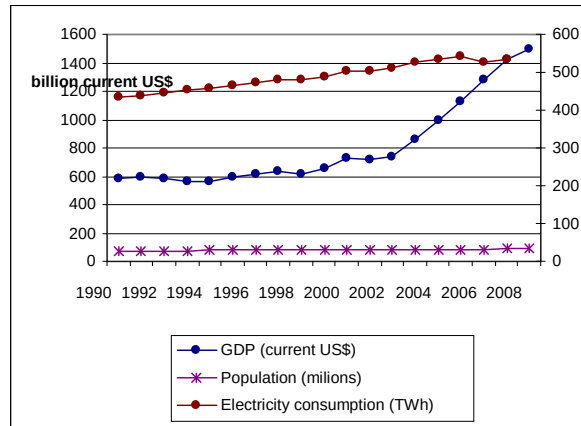
4.3.2 Brief of the Economy

The phenomenon observed in Norway confirms itself in Canada: raising GDP levels since around 2003 and relatively stable electricity consumption. It is not to the purpose

¹⁵ NBSO is a reliability coordinator for the Maritimes area (New Brunswick, Nova Scotia, Prince Edward Island and part of northeastern Maine). It is a balancing authority and transmission operator for New Brunswick, Prince Edward Island and northeastern Maine, yet the latter two do not have high-voltage transmission systems.

of this dissertation to explore efficiency measures taken by the Governments, yet they are possible determining factors of the event.

Figure 30 - GDP, population and net electricity consumption in Canada, 1990-2008



Source: elaborated by the author, data from The World Bank (2010)

4.3.3 Electricity markets organization

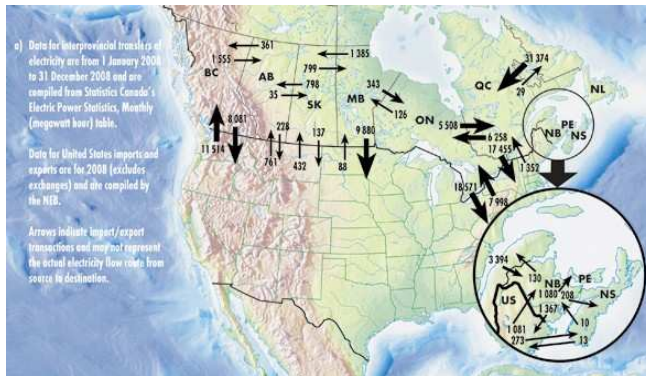
Due to the former perception of the electricity provision with its entire value chain as a natural monopoly, the public ownership of vertically integrated energy utilities was established in Canada, the so-called Crown corporations. Most provinces created regulatory bodies to oversee these monopolies or quasi-monopolies. Nevertheless, restructuring also occurred in Canada in the late 1990s.

Unbundling

Not all provinces liberalized their markets and those who did took different paths. Most provinces still maintain vertically integrated structures and own them in the form of Crown corporations. Figure 31 shows the ownership structure of utilities across provinces and for the entire country. In 2007, almost 75% of installed capacity was publicly owned in Canada. These Crown corporations are generally of large comparative dimensions and do not directly compete with eventual private generators. Functional separation is a timid trend, yet completely unbundled companies also exist. In Newfoundland and Labrador generation is separate from transmission and distribution is separate from retail. Ontario and Alberta are the provinces where restructuring is the most advanced, as they implemented full retail competition. These two markets are mostly unbundled.

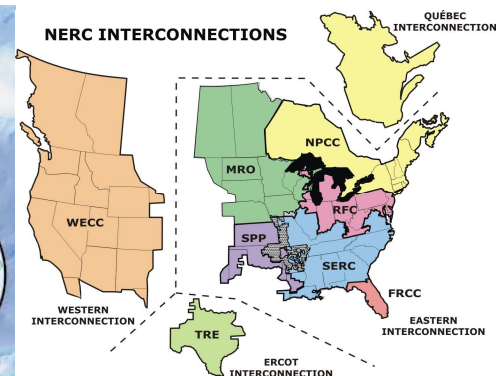
The southern and Southeastern Canadian provinces are integrated into the North American Grid.

Map 4 - Canada Electricity Trade in 2008 (GWh)



Source: NEB (2010)

Map 5 – Regional interconnections and reliability councils in the North American grid



Source: NERC (2010)

The North American Electric Reliability Corporation (NERC) was created in 1968, following a large blackout that occurred in the Northeast region in 1965 – to improve reliability and security of the bulk power system in the USA and Canada. As Map 5 shows, the NERC works with eight regional reliability councils, of which the first three are of interest to this case study:

- Northeast Power Coordinating Council – NPCC – the first council that was created, out of all eight;
- Western Electricity Coordinating Council – WECC;
- Midwest Reliability Organization – MRO;
- Reliability First Corporation – RFC;
- SERC Reliability Corporation – SERC;
- Southwest Power Pool Regional Entity - SPP RE;
- Texas Regional Entity – TRE;
- Florida Reliability Coordinating Council – FRCC;

A detailed map with balancing authorities in North America is shown in Annex 4 and a resume of the relevant regional arrangements for Canada is shown below:

Table 10 - Northern reliability councils' geographic composition

Regional council	Country	Areas covered	Access
NPCC	US	New York, 6 New England states	N/A
	CA	Ontario, Québec, New Brunswick, Nova Scotia	
WECC	US	North and South Dakota, Minnesota, Wisconsin, Iowa, part of Montana	N/A
	CA	Manitoba, Saskatchewan	
	US	14 Western States	Open, non-discriminatory access among all members
	CA	Alberta, British Colombia	
	MX	Northern Baja California	

Note: N/A information not available

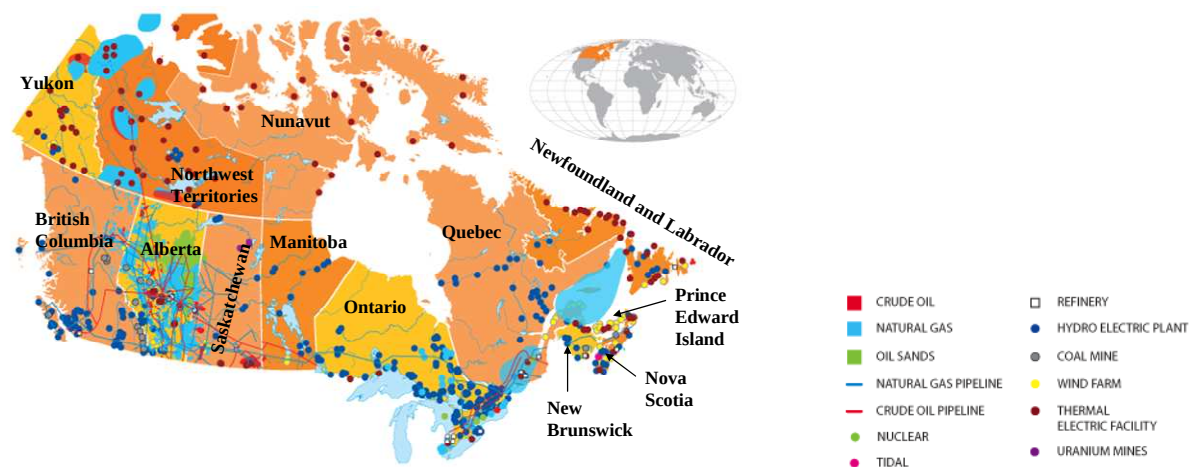
Source: elaborated by the author, based on NERC (2010) and WECC (2010)

Manitoba is the only Canadian province that also integrates an American RTO, namely the Midwest ISO (MISO).

The Map 6 is particularly useful to understand the energy sources distribution in Canada, yet the apparent abundance of hydroelectricity in Ontario is to be evaluated with care. The number of sources is not relevant for the overall quantity, as according to Figure 35. Ontario only generates a relatively reduced share of energy based on water.

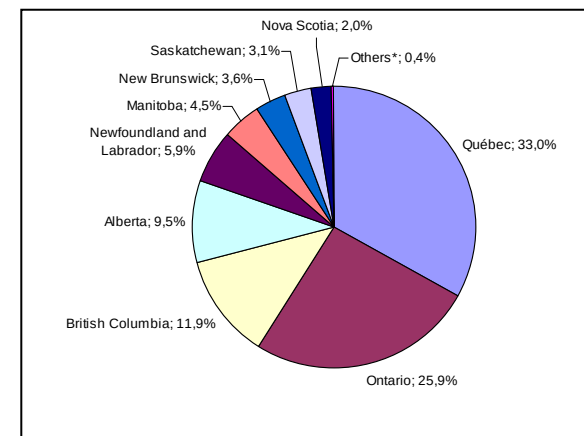
The Yukon, the Northwest Territories and Nunavut have no interconnections with the North American grid and almost no transmission grids, due to the scarce weather conditions. They function mostly as isolated and dispersed communities.

Map 6 - Energy map of Canada, 2010



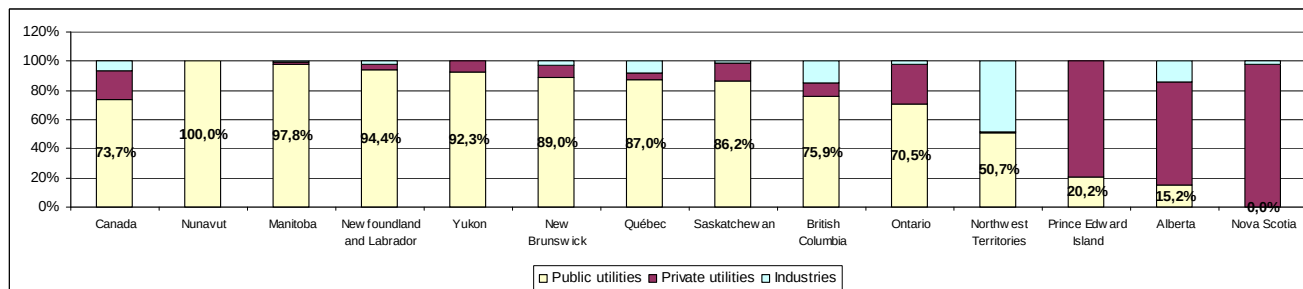
Source: adapted from Centre for Energy (2010)

Figure 32 - Installed electric capacity per province in Canada, 2007



Source: Statistics Canada (2009a)

Figure 31 - Ownership structure of the installed electric capacity in Canada by province, 2007



Source: Statistics Canada (2009a)

Figure 33 - Installed generation nameplate capacity by province and by fuel type, 2007

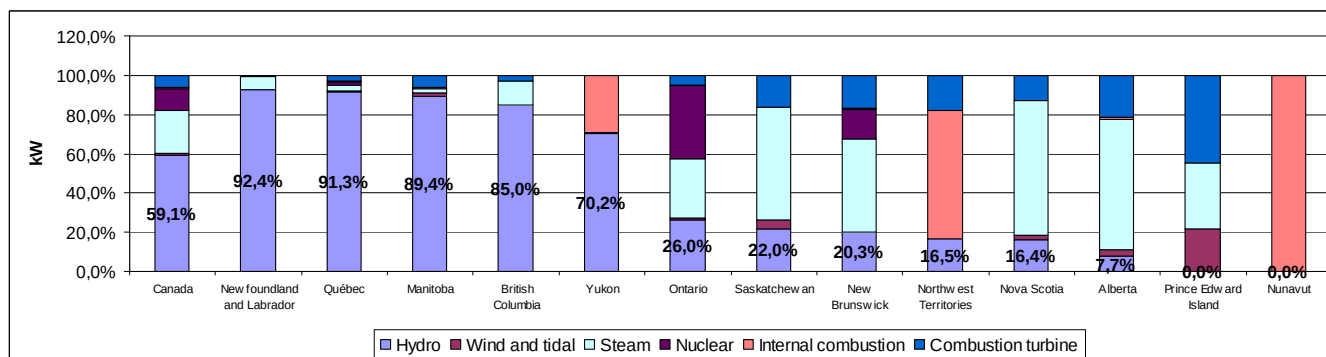


Figure 34 – Effective electricity generation in Canada by province and fuel type, 2007

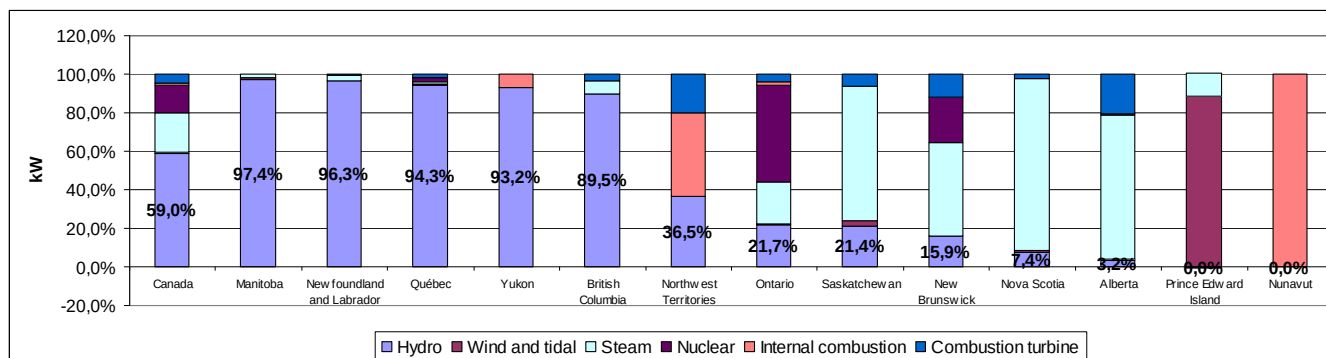
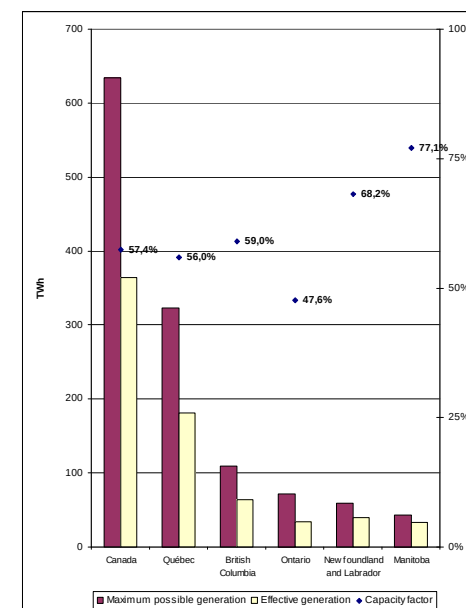
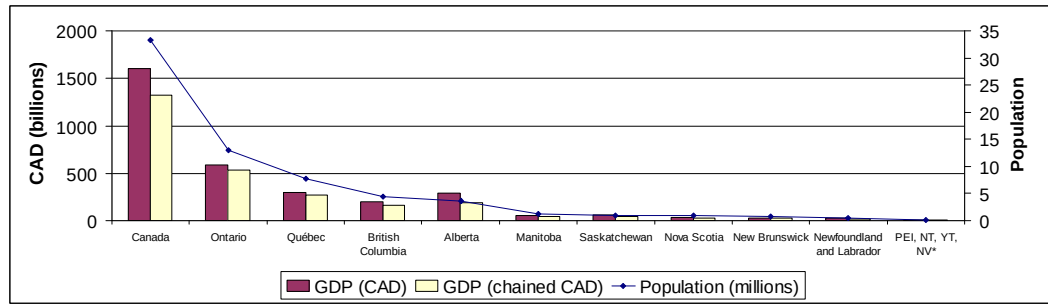


Figure 35 - Effective hydroelectric generation and capacity factors for relevant provinces, 2007



Source: Statistics Canada (2009a)

Figure 36 - Wealth and population distribution by province in Canada, 2008



* Prince Edward Island, Northwest Territories, Yukon and Nunavut

Source: Statistics Canada (Statistics Canada, 2009b, c, d)

4.3.4 Transmission

The ESOs. Functions and characteristics.

British Columbia

With a massive 95% of hydroelectric installed production capacity in 2007, British Columbia has an independent ESO between 2003 and 2010: the British Columbia Transmission Corporation (“BCTC”). It was reintegrated into vertically integrated, Crown Corporation BC Hydro in July 2010, after its unbundling seven years before.

BC Hydro was created in 1961, and it currently serves 94% of British Columbians. It reports to the British Columbia Ministry of Energy, Mines and Petroleum Resources.

BCTC was unbundled in 2003 mainly to ensure fair open access to transmission lines, which remained in the possession of BC Hydro and the other, residual owners. Cost duplication issues and failure to add value are evoked as the cause of the insuccess of the unbundling.

Further, the former BCTC is described, only with the title of example, as the institutional arrangement only was in place during seven years.

The **system operation function** that the BCTC performed included: generation scheduling, real-time dispatch, as well as load balancing, regulating voltage and frequency. Open TPA was also enforced. Congestion management for imports and exports was performed by Powerex, a subsidiary of BC Hyro. Operations long-term planning were also a responsibility of the operator, which forecasts different load

scenarios in order to make the best dispatch choices, i.e. more economical on both short and long term.

Market and commercial operations were limited to the necessary billing and settlement, together with ancillary services procurement.

The **grid operations function** included: long term expansion planning and maintenance planning. Asset ownership implies service provision and assets maintenance, as the vertically integrated model in British Columbia dictates.

Governance is assured by the board members who are appointed by the British Columbia Government. The author has not found any documentation requiring that the board directors of BC Hydro should be **independent**. The British Columbia Utilities Commission (“BCUC”). The BCUC also sets all **electricity rates**, which must be cost-reflective.

A particular observation about the market power in BC is the inter-dependence between it and Alberta. The latter buys power from BC during the day, at peak hours, and the former buys Albertan electricity during the night. BC thus recharges its hydroelectric reservoirs (Meritt, 2008). The fact that the markets have different designs does not interfere in this symbiotic relationship, caused by different physical conditions.

Québec

Québec has the largest transmission system in North America, with 33.244 km in 2009, according to the website of Hydro Quebec TransÉnergie, the local system operator. Hydro-Québec is the dominant Crown Corporation in the province, functionally divided in 1997 into: HQProduction, HQTransÉnergie, HQDistribution and HQ Equipment.

As part of the NPCC interconnection, HQ TransÉnergie maintains the required reliability standard in what is the most extensive transmission grid in North America.

HQ TransÉnergie is a LTSO. Its **operation function** includes the following responsibilities: planning the control process, open TPA enforcement for all wholesale customers, generation/load scheduling, frequency and voltage control. System operation is done in a department called “the System Control Centre” (“SCC”). The SCC acts as an information agent for its available transfer capacities’ level.

The **market and commercial operations** of HQ TransÉnergie reside in the provision of ancillary services and drawing revenue for its services. Ancillary services are not purchased via competitive tender. HQ TransÉnergie buys them from HQ Production, as it assesses that no other provider in Québec fulfills the requisites for the job.

Grid operations include: transmission expansion and maintenance planning, provision of the service and the effective maintenance. HQ TransÉnergie is the owner of the transmission grid in the province.

The market for electricity in Québec is also a hybrid. Every year, up to 165 TWh¹ is mandatorily sold by HQ Production to HQ Distribution at a fixed price – an called “the heritage pool”. Even if regulated, it is still a matter of *self dealing*. Beyond the level of the “heritage pool”, energy is subject to auctions by HQ Distribution, which are open or not, depending on particularities of the generation and location requirements. The fixed price protects hydroelectric generators, as it guarantees investment recovery. The final contracts are approved by the Régie de l’énergie. Transmission and distribution are in fact regulated by the Régie de l’énergie: it approves capital investment and sets rates based on cost of service.

According to the Hydro-Québec Act², the **governing** board of Hydro-Québec is appointed directly by the Government of the province and at least two thirds of directors and the Chair are mandatorily **independent**. Quoting from the law:

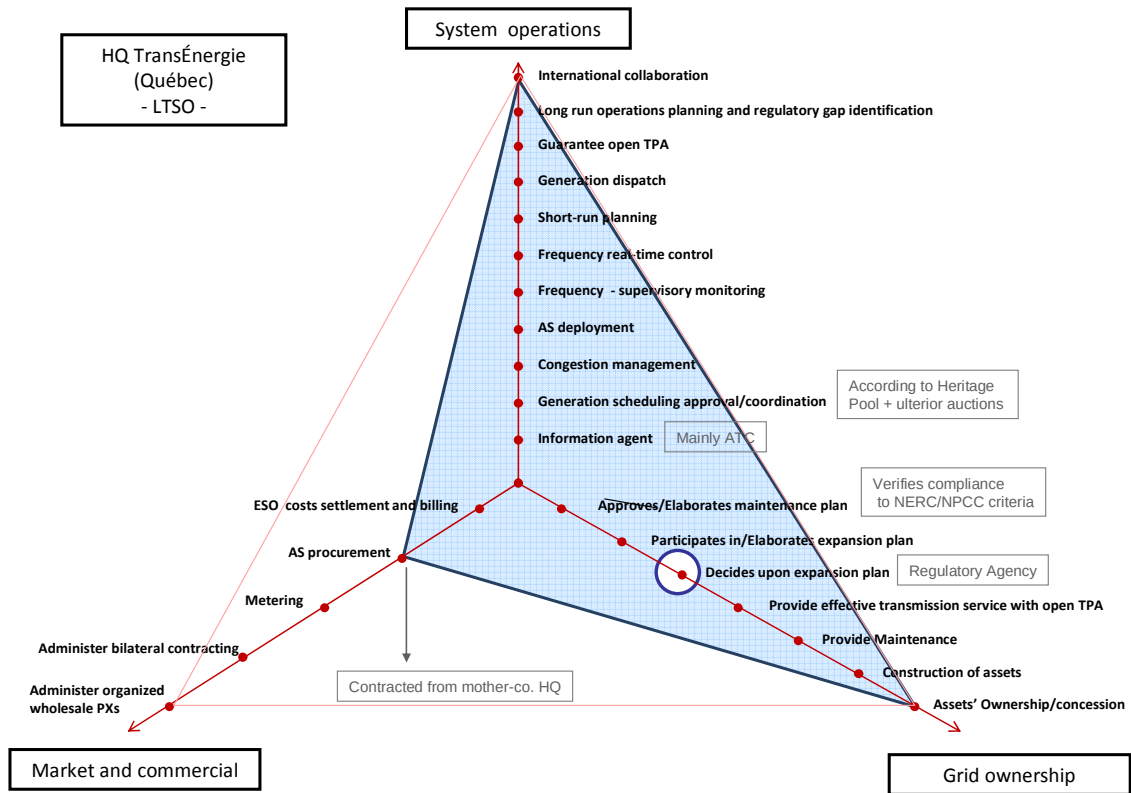
“Board members qualify as independent directors if they have no direct or indirect relationships or interests, for example of a financial, commercial, professional or philanthropic nature, likely to interfere with the quality of their decisions in relation to the interests of the Company.”

¹ Equivalent to 85% of the 2009 total generation in Québec.

² Québec (2010)

Summarizing, this is the ESO triangle for Québec:

Figure 37 - ESO triangle: Québec



Source: elaborated by the author

The ESOs in Alberta and Ontario are described barely for informative reasons, as the share of hydroelectricity in their generation matrix is too reduced for them to be worthy of comparison.

Ontario

In Ontario, the Independent Transmission System Operator (IESO) initiated its activities as of 1999. It is a system operator for Ontario, maintaining reliability in the integrated regional power grid, and develops and administers the wholesale market of electricity. It is accountable to NPCC for compliance with NPCC and NERC reliability standards. Its “footprint” was comprised of 44 generators, 4 TOs in 2006. Yet Ontario Power Generation Inc. (OPG) produces 70% of the province’s electricity, with a hydro-nuclear base (2006).

The IESO administers the **wholesale market**, officially opened in 2002. It **dispatches** generation to meet demand under security-constrained economic dispatch principles.

Furthermore, it conceives and applies rules for market and grid government, being overseen by the Ontario Energy Board (“OEB”). Bilateral contracting has a very low penetration in the Ontario wholesale market and are not part of the scheduling and dispatch done by the IESO (Zareipour *et al.*, 2004). IESO documentation is available on its website, including daily forecasts – it acts as a market rules and data information agent.

Generation, physical switching of transmission lines and equipment maintenance are not performed by the IESO. It owns no transmission, generation or distribution assets. Long-term planning is done together with the OPA with inputs from market participants.

The transmission lines these belong to a transmission, distribution and retailing company – Hydro One Inc. From the point of view of monetary value, Hydro One owns 96% of the transmission assets in Ontario³. As far as maintenance is concerned, the NPCC and NERC standards are maintained by the IESO by continual compliance verification. Transmission grid expansion proposals are formulated by Hydro One and regulatory approval is contingent on the IESO’s approval. The Ontario Power Authority (“OPA”) is in charge of general system long-term forecast and independent planning.

Ontario has implemented both wholesale and retail access in its electricity markets. However, the system is not purely market-based, having a rather hybrid organization. The market prices are formed in the wholesale market, yet they are “tempered” by contractual conditions, that involve guarantees and fixed prices (2009a).

The IESO procures ancillary services through market principles.

The IESO is a **non-profit** entity, **governed** an independent Board, appointed by the Government of Ontario. Its fees and licenses to operate are set by the OEB. The authority also approves transmission and distribution tariffs as well as the annual budget of the IESO.

³ The rest is owned by: Great Lakes Power, Canadian Niagara Power, Five Nations Energy and Cat Lake Power Utility Limited.

Alberta

The Alberta System Operator (AESO) has been in place since 2003. It is an ISO. Just as in Ontario, the Albertan electricity market is deregulated – as of 1998 – and generation, transmission, distribution and retail are functionally unbundled.

In what regards **system operation**, the AESO guarantees open TPA – unlike the Ontario case, acts as a balancing authority, regulating frequency and voltage and settling load, acquires transmission services, elaborates forecasts and acts as an information agent. It ensures that the NERC and WECC reliability standards are implemented.

As far as **market and commercial operations** are concerned, the AESO procures ancillary services, administers transmission tariffs – which is particular for an ISO, settles supply and demand in an hourly wholesale market, which it administers. This includes financial settling. All electricity in Alberta is sold through the wholesale pool (2009a), so no bilateral contracts are in question. **Electricity rates** result from the wholesale market, yet regulated rates are in place for residential and other small consumers. These are approved monthly by the Alberta Utilities Commission (“AUC”) and are contingent on the spot market price.

Regarding **grid operations**, the AESO owns no transmission assets. It is in charge of elaborating forecasts and **planning** transmission expansion though, under the approval of the AUC. AltaLink owns sufficient transmission lines to serve 85% of Albertan consumption.

The IESO is a **non-profit** entity, whose governance is assured by an independent board, appointed by the Minister of Energy of Alberta.

4.4 Colombia

Colombia is Brazil's north-eastern neighbour, a country of about 45 million inhabitants⁴, but of a size equivalent to 13% of Brazil's. Colombia is a much more densely populated country than Brazil or Canada. For instance, although it is more populated than Canada by a third, its territory is roughly equivalent to a tenth.

Map 7 - The National Transmission System of Colombia (2006)



Source: UPME and XM (2006)

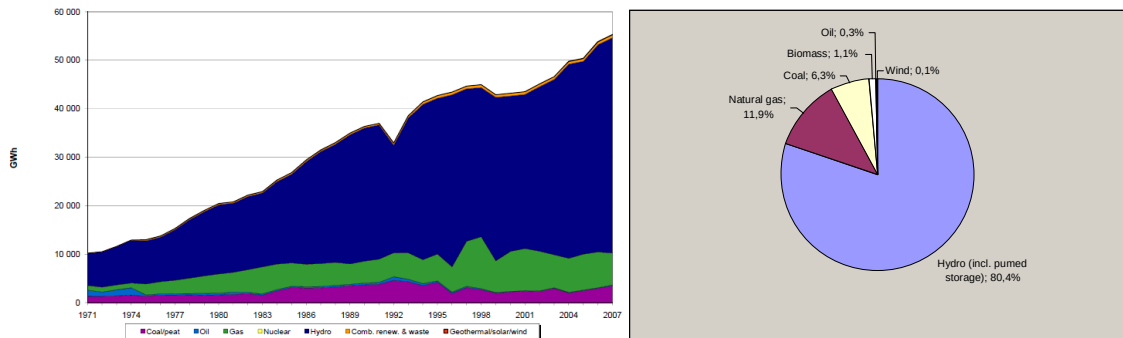
Moreover, 96% of the population is concentrated in one third of the territory, which is covered by the National Transmission System (“STN⁵”). The remaining two thirds are designated as “non-interconnected zones” (“ZNI⁶”), comprising roughly 4% of the population. Note the similarity of proportion to the Brazilian SIN and isolated systems. Hydrographical and hydrological conditions have been similarly generous to Colombia, so that it around 80% of its electricity generation is water-based. In the ZNI, diesel-based generation is the main fuel for electricity, together with some small-hydroelectric power plants and solar panels. Below, the electricity generation structure in Colombia is shown.

⁴ XM (2010a)

⁵ In Spanish: “Sistema de Transmisión Nacional”.

⁶ In Spanish: “Zonas No Interconectadas”

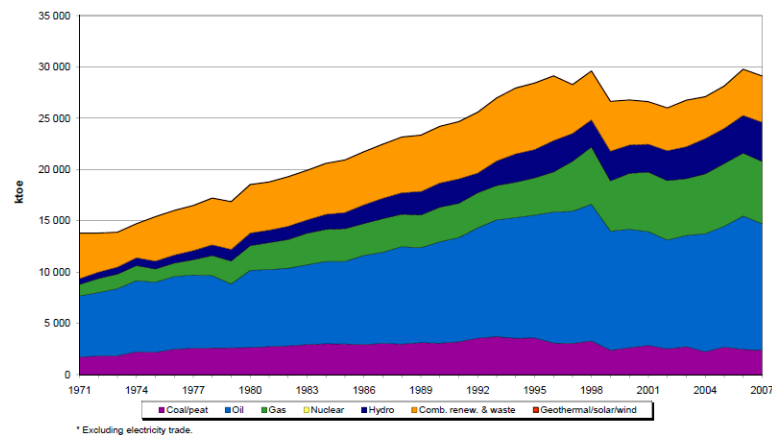
Figure 38 - Electricity generation structure in Colombia, by fuel, 1971-2007 (left) and proportions for 2007 (right)



Source: EIA (2010a)

Colombia is an important coal and gas producer. The bulk of its energy consumption is oil-based (42% in 2007), yet the fact that most of its electricity is produced by hydroelectric plant enables the country to be able to export large parts of its coal production (2010b). The figure below outlines the evolution of the country's primary energy supply.

Figure 39 -Total primary energy supply in Colombia, by source, 1971-2007



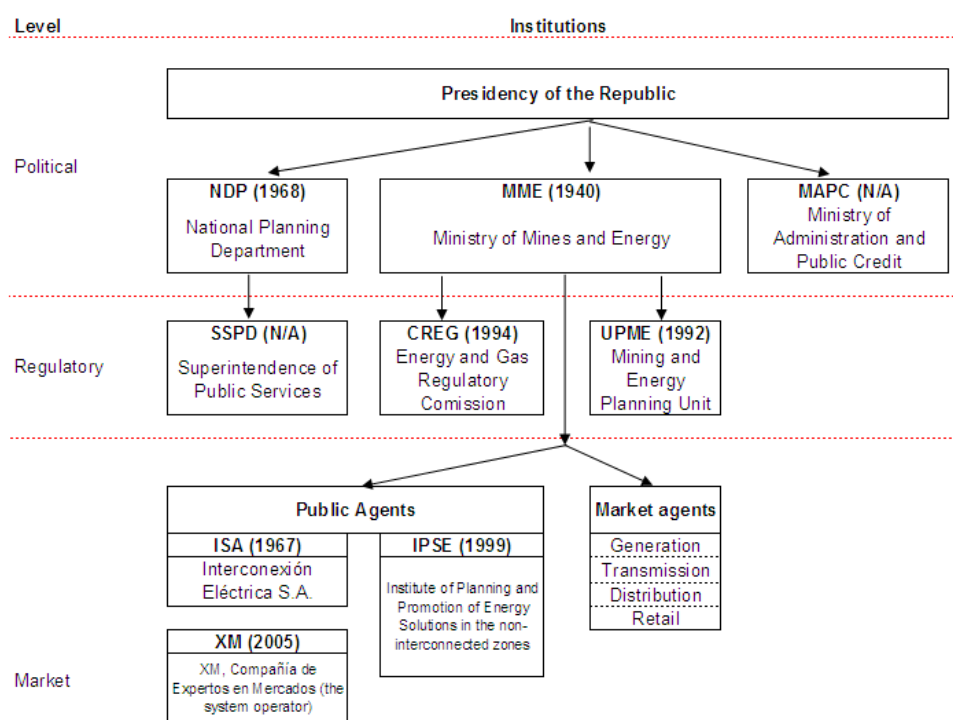
Source: EIA (2010a)

4.4.1 Institutional Framework of the Electric Sector

In Colombia, **policy** is of the responsibility of the Ministry of Mines and Energy (“MME”), who regulates the way all energy sources are exploited. The Mining and Energy Planning Unit (“UPME”) formulated indicative investment **plans**, including the National Energy Plan and the Expansion Plan. It holds auctions for expanding the transmission grid in an organized way. **Regulation** is the responsibility of the “CREG”

– the Energy and Gas Regulatory Commission, which answers to the MME. CREG is an independent agency, whose costs are covered by the market agents in the electric sector. The President of the Republic, through the Superintendence of Public Services (“SSPD”) oversees and controls the electric sector. **System operation** is ensured by the National Dispatch Centre (“CND”), a department inside XM – Los Expertos en Mercados – a subsidiary of state-owned ISA. The CND operates the market according to the operation rules disposed by the CREG and the technical norms dictated by the National Operation Council or “CNO”; the CNO who is in place to ensure a *safe, reliable* and *economic* operation. The CND ensures *coordination, supervision* and *control*, as well as elaborating *indicative operational planning*. There exists a power exchange administered by XM, which involves billing and settling all transactions.

Figure 40 - Institutional framework of the Colombian electric sector

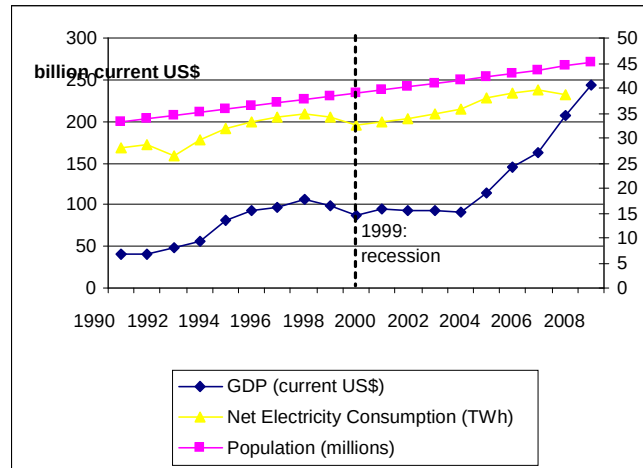


Source: UPME (2010c)

4.4.2 Brief of the economy

After a deep recession in 1999, Colombia started to recuperate ten years later and GDP is steadily growing. Nevertheless, as its electric sector is also a developing one, the issue is put differently here. The relatively reduced pace of electricity consumption growth may signal problems in satisfying demand.

Figure 41 – GDP, population and net electricity consumption in Colombia, 1990-2008



Source: elaborated by the author, data from The World Bank (2010)

4.4.3 Electricity markets organization

1995 is the year when the Colombian electric sector was restructured. This is when the National Energy Commission was dissolved in order to create the CREG, and the UPME, together with the restructuring of the MME. The market model set up in Colombia was articulated with the British one, but adapted to Colombian reality: mixed ownership structure, allowance for cross-subsidization of low-income consumers and the creation of the planning unit, UPME, as Larsen *et al.* (2004) noted.

The sequence of events that led to this restructuring is strikingly similar to that of Brazil, both being developing countries that had to confront the “Mexican” crisis. In the late 19th century, private initiative founded the electricity sector in Colombia. Insufficient private investment led to the State having to buy all these companies in the mean time. Yet the international conditions of the 1970s-80s – the global recession, skyrocketing oil prices and the debt crisis – slowly came to reveal the weakness of public administration in the country’s electricity sector. In 1991-1992 a large-scale rationing period occurred, which brought forward a neo-liberal ideology: a free market would be created so that any interested agent could enter. A good part of the assets in the possession of the State were sold, while its role would be rather supervisory and regulatory than administrative (2010).

Unbundling

The Colombian electricity sector has been functionally unbundled into the four traditionally consecrated activities, as of 1995. Three vertically integrated companies persist, as well as twelve generator-retailers and nine generators-distributors-retailers (XM, 2010b).

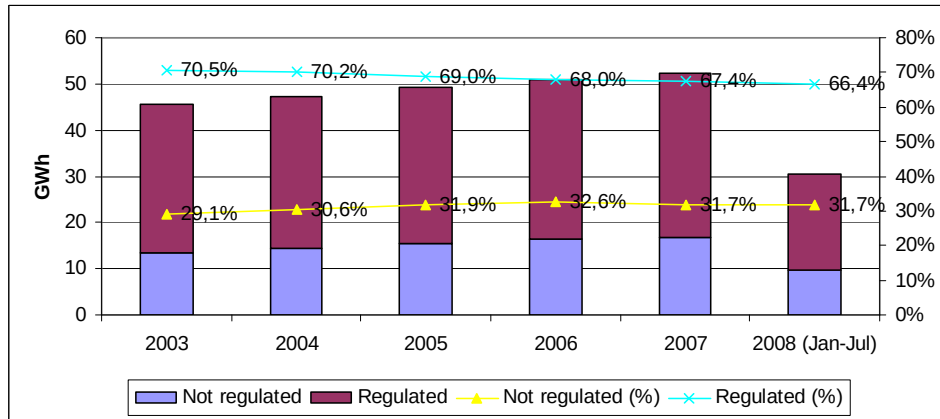
The wholesale market

Part of the reform was the **Wholesale Energy Market** – organized for transactions as an internal department of the XM. It comprises a spot market (a power exchange or “bolsa de energía”) and a long term market. All generators with an installed capacity of at least 20 MW are obliged to submit price bids to the system operator for spot transactions. Generators with less installed production capacity may also trade in the spot market, but are not obliged to. Their other option, the **long-term energy market**, is an environment for bilateral contracting with retailers. This activity did not exist before 1995.

Part of the **customers** is regulated and another part is not. Regulated customers buy energy from retailers at rates fixed by CREG, while others buy from retailers that draw energy from the wholesale market via spot transactions or bilateral contracts with retailers of generators. The non-regulated customers must fulfill one of two conditions: having an average demand for potency of at least 100 kW during the last six months or an average monthly consumption of at least 55 MWh in the same period (XM, 2010d).

The proportion of regulated and non-regulated customers in the market is of roughly two thirds to one, as the figure above demonstrates.

Figure 42 - Structure of the Colombian electricity demand, 2003-2007



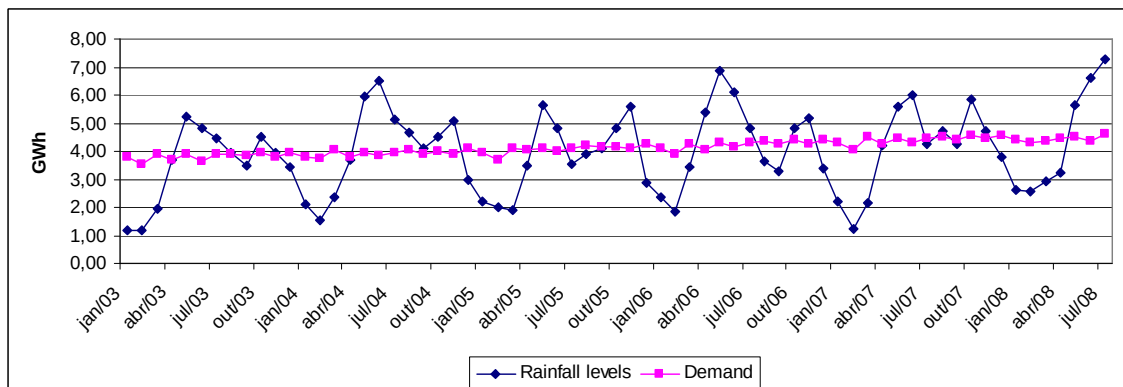
Source: elaborated by the author with UPME (2008) data.

Hydrology

In Columbia, one reservoir (Peñol) is apt for multi-annual storage, while the rest are manageable for weeks or months (Garcia and Arbeláez, 2002). With an installed capacity of 560 MW, the Peñol power plant only represents about 6,6% of 8.525 MW of installed hydroelectric capacity at the end of 2009.

A salient particularity of the Colombian territory with pronounced impact on its electricity market is the periodical presence of two meteorological events: “El Niño” is brings strong draughts in Colombia on an average every 3 or 4 years and “La Niña” brings very heavy rains. Their impacts are complementary: higher electricity spot prices in the first case and water abundance and relatively reduced prices in the second (Larsen *et al.*, 2004).

Figure 43 – Accumulated rain levels and demand evolution in Colombia, 2003- 2007



Source: elaborated by the author with UPME (2008) data.

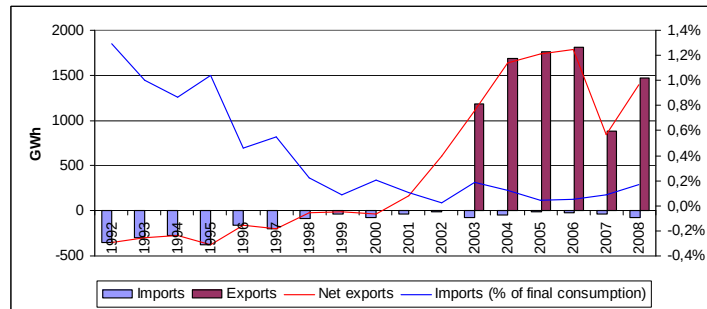
As the only reservoir with multi-annual storage capacity has a relatively reduced proportion of the overall installed hydroelectric capacity, alternative sources are essential for securing supply during the dry period. Before 2007, a capacity payments scheme was in place yet this was substituted with a reliability charge as of 2007. The capacity scheme only required capacity to exist, without any other compromise (2006). It actually happened that thermal power plants ended up not being dispatched for periods as large as two years. The novelty consists of “firm energy” auctions, created in December 2006 – thought to ensure energy in case of low hydrology. This time, there is a compromise. Thermal power plants assume the obligation to deliver energy whenever the spot price surpasses a level called *scarcity price*. Their rates are pre-fixed with the idea to guarantee enough revenue to ensure long-term investments for security of supply.

Larsen *et al.* (2004) had foreseen this issue: “the instability of the system at the present time is not giving a clear signal for the short- or long-term technology mix. It is not quite clear if the current market mechanism will be able to provide this signal. Given the market-based investment strategies that companies necessarily will take, it is not possible to predict what an equilibrium technology mix might look like and when it will be reached.” The system could go wrong in two ways: either investors would choose finish their existing projects, but to delay them, either existing power plants could marginally expand capacity; the latter solution, according to Larsen, would not have brought forward sufficient capacity to ensure long-term equilibrium.

Regional integration

Since 2003, Ecuador and Colombia have integrated their markets for electricity and bids are made on an hourly basis at border nodes and the direction of current is from the system with a more reduced to the system with a relatively higher price (Amador *et al.*, 2004). This kind of transactions are mandatorily enforced by the Andean Community, a supranational body, formed by Colombia, Peru, Ecuador, Venezuela and Bolivia. It is clearly noticeable in the Figure below that the presence of sudden exports as of 2003 is not arbitrary. Colombia exports to Equator fairly larger amounts that it imports.

Figure 44 - Exports and imports of electricity in Colombia, 1992-2008



Source: UPME (2010a)

Furthermore, there exists a *Puebla-Panama Plan*, which is to allow the interconnection between Colombia and Mexico, through Central America through a 300 MW transmission line, commissioned by the ISA and ETESA, the Panamanian transmission company. Despite having 2010 as the foreseen year of operation, delays have led to a new time target: 2013 (Secretaria de Prensa de la Presidencia de Colombia, 2010).

4.4.4 Transmission

The transmission sub-sector is regulated so that TOs must provide open TPA to their assets for all generators and distributors. Revenues are regulated for both transmitters and distributors. After the reform, state-owned ISA, the TO, had to divest its generation assets. The 38.551 km of lines it owned at the end of 2009 constitute the lion's share of the Colombian transmission grid.

XM is considered the electric system operator. It has a dispatch centre (CND), while acting also as wholesale market operator, commercial exchange administrator⁷ ("ASIC") and agent for accounts' administration and clearing for grid usage ("LAC")⁸.

The **system operation** function is performed by the CND and consists of: planning operations on a short and long term, ensuring open TPA, controlling frequency and voltage. The **CND** programs dispatch according to the bids received through the power exchange and the foreseen demand, independent of generation and transmission constraints (*ideal predispach*). Next, the *predispach* phase takes into account the latter

⁷ In Spanish: "Administrador del Sistema de Intercambios Comerciales".

⁸ In Spanish: "Liquidador y Administrador de Cuentas".

restrictions. Further on, the *preliminary dispatch* also considers probabilities of failure of system elements. Finally, *dispatch* is done taking into account all constraints and possible failure as well as economic restrictions. Ancillary services are deployed by the CND as well. XM also administers the international interconnections established as of 2003 with Ecuador in terms of spot transactions and coordinates market integration with Venezuela. In its operations, the rules laid down by CREG and the technical agreements established by the CMO must be respected.

The **market and commercial operations** that XM fulfills are consistent: it administers the wholesale market (“Mercado Mayorista”) according to CREGS’s standards. As the designated ASIC, XM registers all contracts, clearing all financial obligations and billing all the parts involved. Firm energy auctions are also of the responsibility of XM, as well as the maintenance of information systems. It also ensures clearing and administration of charges for the usage of the STN (LAC).

XM is a **private right, for-profit, independent** company, and its owner is the Colombian State. Its yearly evaluation is done according to a balanced scorecard, where financial performance, compliance with CREG and productivity are weighted with these proportions: 35%-35%-30%. **Remuneration of ISA** is regulated as a postage-stamp tariff per MWh consumed. This criterion insures that the transmission company, although for profit, does not have incentives to modify energy flows in the network. **Remunerations of XM** is regulated so as to cover operations cost, investments costs and a certain return, which it draws 50% from generators and 50% from retailers.

State-owned ISA owns 99,73% of XM and its **governance** is ensured by an Administration Board made up of five members, three of which are in fact independent (XM, 2010c). Decisions are taken with at least four members, two of which must be independent, at least, in order to guarantee a balanced output. The fact that ISA had to divest its generation assets means that its role is passive, just having to keep the grid working; ISA does not buy energy, nor does it sell energy.

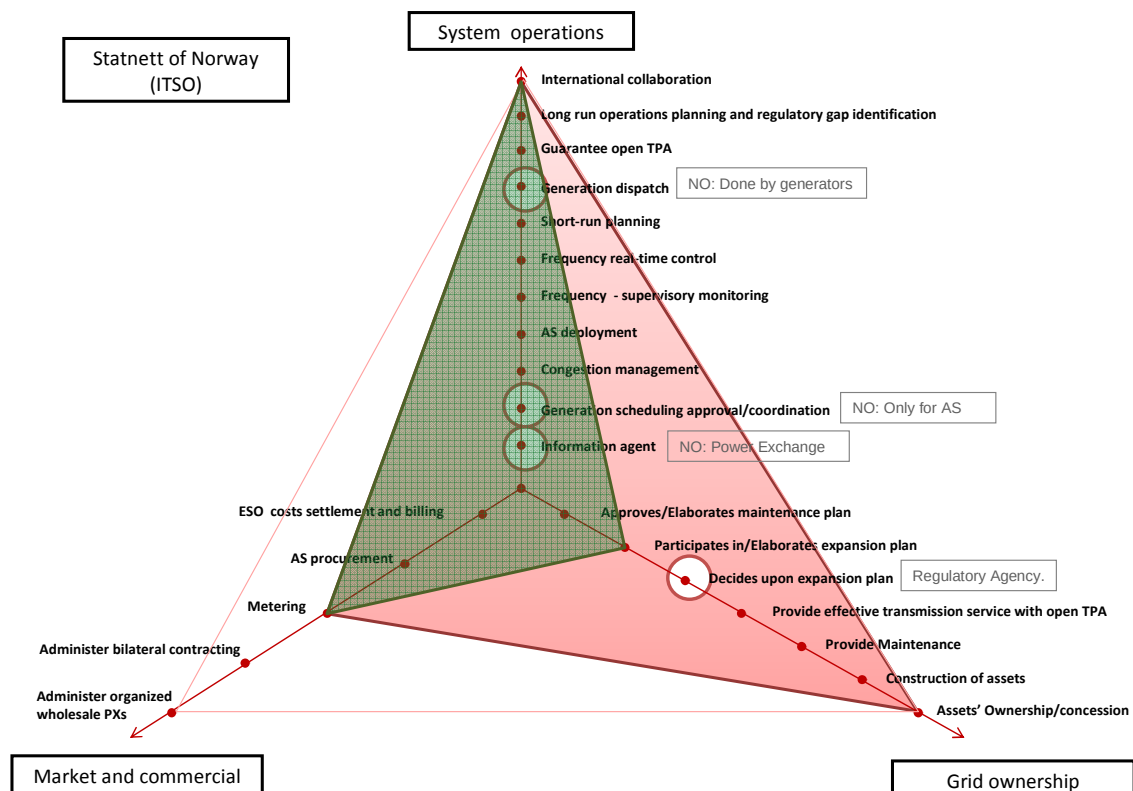
Chapter 5

Comparison

In this chapter, the triangles that graphically show system operators' responsibilities in Norway, Canada and Colombia shall be compared to that of Brazil. The three axes shall serve as comparison criteria, together with the scope for profit, level of integration and governance of the operator. The benchmark shall be done by identifying the diverging points and the market logic that led to the differences. The order of analysis is such that the countries with more divergences shall be examined first, to facilitate the understanding of differences in the latter cases, and also to avoid duplicating explanations.

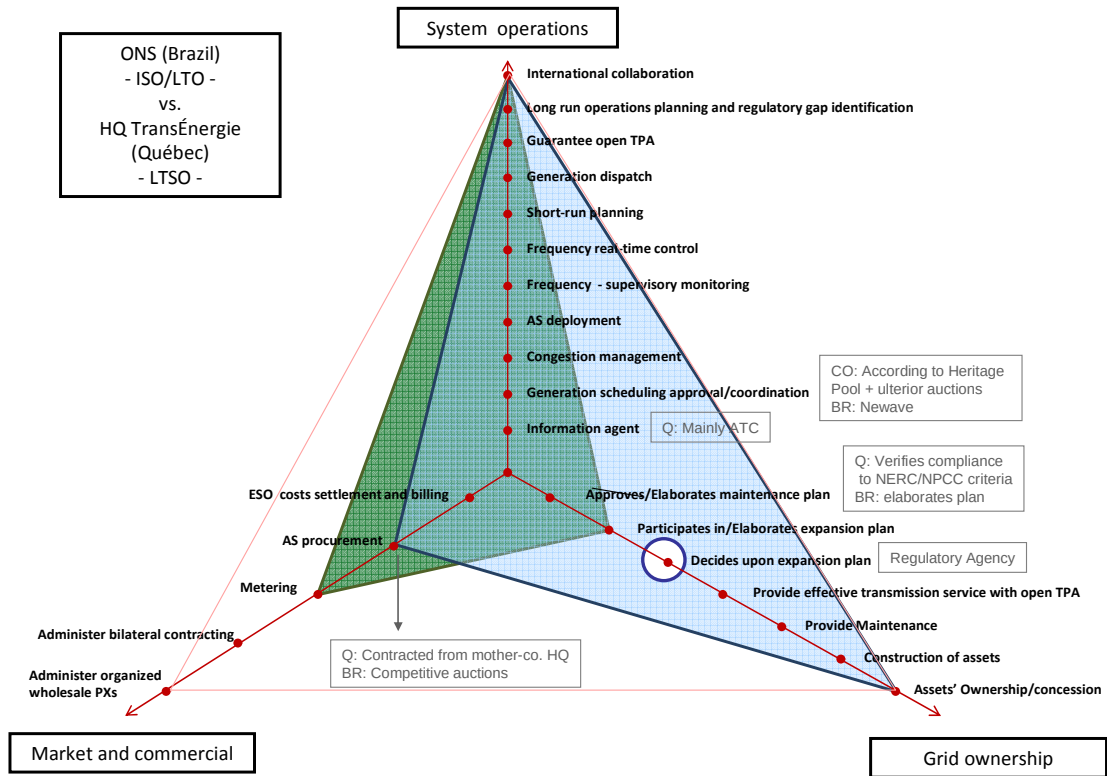
The following figures denote the superposing of triangles.

Figure 45 - ESO benchmark: Brazil - Norway



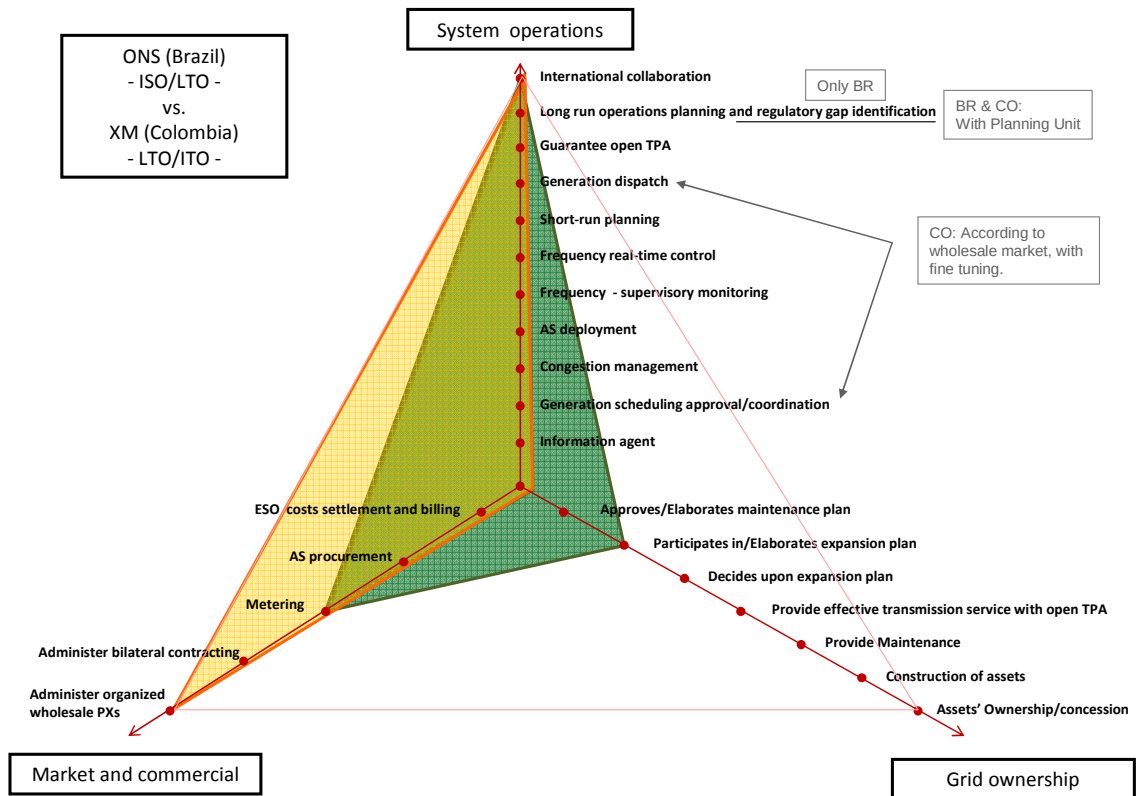
Source: elaborated by the author

Figure 46 - ESO benchmark: Brazil - Québec



Source: elaborated by the author

Figure 47 - ESO benchmark: Brazil - Colombia



Source: elaborated by the author

5.1 Brief comparison between market paradigms

Colombia and **Norway** share two distinctive characteristics:

- i. the existence of a functioning electricity exchange;
- ii. a lack of multi-annual storage capacity in reservoirs.

These two features are intuitively coupled. As run-of-river hydroelectric power plants either sell their spontaneous production or they lose it, no planning for the administration of these energy sources is necessary. In **Brazil**, the lack of a planning unit culminated with a rationing of 20% of energy consumption, because reservoirs are such that energy can be stored as water for several years. The role of a market is to optimize resource allocation on the short as well as long run. But in Brazil this role is incompatible with a short-time market and an (unplanned) long term market, due to the weak price signals zero-cost hydroelectricity incorporates. Planning dispatch in Norway and Colombia is not a missing variable, though. In Colombia, the operator takes all bids and only dispatches after clearing all restrictions, respecting the merit order. In Norway, the EMPS model is used by many generators to plan long-term reservoir usage, as well as PoMo in Norway, to plan ahead as far as three years.

Canada is a patchwork of systems and cannot be compared as a single market. **Ontario** and **Alberta**, the liberalization pioneers share the system of Norway and Colombia. Nevertheless, their electricity generation sources are by thermal by excellence so the nature of the markets is only interesting for the market integration section. Still, the comparison of operators is considered by the author illustrative and shall be briefed. **British Columbia, Québec, Manitoba and Newfoundland and Labrador**, have hydro-dominated electricity matrixes, yet none of them has an independent system operator at present. British Columbia has one between 2003 and 2010, yet inefficiencies resulted in its reintegration in Crown “BC Hydro” Corporation. The fact that the model in Québec is functionally unbundled lead to its’ being chosen for comparison. Yet a large difference between the market in Québec and that of Brazil is its large degree of openness and exchange of electricity with its neighbouring provinces and the U.S. Even if hydro-dominated in its electricity generation matrix, Québec has multiple imports and exports options.

5.2 System operations

Brazil-Colombia

The only consistent difference in the vertical axis of the triangle is the way generation scheduling is done. As Colombia has a market system in place, appropriate for its run-of-river-dominated electricity matrix, dispatch is “easier” to organise. The market “does the bulk of the work”. Nevertheless, the operator steps in to fine-tune the schedule the market transmits, clearing it of all technical limitations, with three pre-dispatch phases. The dimension and inherent complexity of the Brazilian market, with 4,5 more inhabitants and 7,5 times more territory, together with the multi-annual capacity of its reservoirs make centralized dispatch a better option of this country. The conclusion is that both systems reduce congestion and balance load in ways that are fit for their size and endowments.

Brazil-Québec

In this case, the essential difference resides in the Heritage Pool system. In Québec, the heritage pool was equivalent to 85% of electricity generation for 2009; the remainder of the energy is contracted under regulatory supervision. These mean that the bulk of the market is mostly pre-scheduled and the ESO has only to ensure the necessary ancillary services. No free market mechanism is in place within the Quebecer electric sector, and local academics like Clark and Leach (2007) or more recently, Migué and Bélanger (2009) signal the fact that HQ acts as a money-losing Government instrument, selling one of North America’s cheapest electricity to its internal market. It can hardly be argued that Québec is relevant for comparison, after taking note of these facts. The limitations of the study when choosing hydro-dominance as the main criterion for country selection are evident in this case. Some similarities exist though: in Québec, one firm owns all hydroelectric power plants endowed with reservoirs, as equivalent to the virtual reservoir the ONS simulates. ONS is actually doing the best possible alternative, behaving as the monopoly manager of water stored in reservoirs.

Brazil-Norway

The most important difference between the electricity contexts between Norway and Brazil is the insertion of the first in a functional, integrated market – NordPool, who plays the role of an information agent. Based on this information, generators bid into the market and dispatch according to the resulting schedules. The operator has thus

outsourced the generation dispatch function and only kept this responsibility for ancillary services. Furthermore, it has outsourced the operations planning function. In the Norwegian system, reservoirs only have seasonal water planning capabilities, so a short-term market is reasonably appropriate, also. Nonetheless, even a seasonal water storage capacity requires planning ahead, and efforts are duplicated in this respect; generators use optimization software (EMPS, PoMo etc.) on their own. Nevertheless, results have for a long time confirmed the success of NordPool as a market. However, this framework is not applicable in Brazil mainly due to its multi-year water storage reservoir profile. The regulatory design of the market optimized reservoir coordination, towards to the mathematical optimum – with the exception of out-of-merit-order dispatch, which is the “insurance fee” the system pays for needing to survive in a relatively secluded grid. Norway, with as a highly interconnected grid, enjoys the privilege of not having to pay “insurance”. In “dry” years, it pays higher prices to import from its “thermal” neighbours, an opportunity that Brazil is currently exploring. Norway would be a more similar case to Brazil should its electrical borders be isolated.

5.3 Market and commercial operations

Brazil-Colombia

There are no essential differences in the responsibilities that CND-XM and the ONS hold on the market and commercial operations axis. However, XM is system operator and wholesale market administrator altogether. This latter job is done in Brazil by the CCEE, which also hosts auctions for capacity and transmission expansion for the following years – attribution which is associated to ANEEL. For the moment, the author believes that ONS could successfully perform the function of market administration, since it uses the same pieces of software as CCEE and auctions could be retrieved to ANEEL or confined to EPE – the planning unit. The gain would be the simplification of the system.

Brazil-Québec

In the case of Québec, the divergence with Brazil is resides in the lack of an effective market and the vertically integrated structure of HydroQuébec, who dominates the 80% of the generation sector and is practically a monopoly of transmission. Purchasing

ancillary services from HQ Production is an apparently rational option, especially since the operator acknowledged that no other player is sufficiently qualified. In Brazil, there are sufficient different generators that can supply the auxiliary services, thus buying them based on competitive tender is the natural way to proceed. TransÉnergie needs not act as a metering agent beyond available transfer capacities' publication, as its main market is "internal". In the extensive Brazilian territory, one of the most important functions of the ONS is provision of information.

Brazil-Norway

There are no essential differences in the responsibilities that Statnett and the ONS hold on the market and commercial operations axis. A comment that can be made however is the insertion of Norway in a voluntary pool arrangement while Brazil is only initiating collaboration, on a politically less stable but economically emerging continent. The challenges ahead are different.

5.4 Grid operations

Brazil-Norway

The dissonance of superposing these triangles results from the possession by Statnett of a vast part of the transmission grid. In Brazil, on the other hand, the transmission sub-sector is said to be well-organized, due to the following points: no divestiture had to be done by the owning groups while lines' maintenance is ensured by concessionaries under a strict penalty regime in case of failure. Despite a growing number of disturbances of the basic grid that the ONS measured between 2005 and 2007, in 2008 a drop became visible, while the network is in continual expansion⁹. Indicators for continuity of supply have bettered steadily since 2004. The robustness indicator, which shows the percentage of load cutoffs has remained constant. The existence of a **planning** unit is also helping to develop a robust transmission system in Brazil and there seems to be no need for the ONS to be its owner in order to ensure either better expansion or better maintenance, like in the Norwegian model. The ONS gives all necessary inputs to the Planning unit (EPE), which elaborates the overall system expansion plan in order to minimize the number of subsystems¹⁰. In Scandinavia,

⁹ ONS (2008a)

¹⁰ ONS (2010d)

comparatively, the system relies on market mechanisms to accurately show dimension of congestion under a unique system operator, just as the ONS and its four sub-systems. Yet the market-system put in place is appropriate to “inspire” system (including grid) planning in Scandinavia, just as organized planning is necessary in Brazil at the current stage of development.

Brazil-Colombia

Colombia has an Independent TO, which is XM. Conversely, it is the main TO that owns the SO in a quasi-functionally unbundled regime, and not conversely. On the grid operation’s axis the major difference is that the ONS elaborates the maintenance plan for the basic grid, while also participating in expansion planning. XM nonetheless is not involved with grid assets. **Planning** is officially the responsibility of UPME in Colombia, as well as auctioning new projects for transmission/generation expansion. In the view of the authors, Brazil gains an important advantage at this point: as the operators is a global transmission flow manager, its input for the planning unit, EPE, has all requisites to considerably increase efficiency and efficacy.

Brazil-Québec

Last, just as Statnett, HQ TransÉnergie owns the transmission assets in Québec, in this case exclusively, and unlike XM e involved in transmission expansion in its region. Yet this is not a surprise in Québec, as the region is still dominated by Crown corporation HQ, who owns approximately 79% of generation capacity and the majority of downstream businesses. The issue of weather the Brazilian ONS would be better off owning the transmission assets was addressed in the first part of this section.

5.5 Scope for profit and governance

The four operators in question find themselves in the following situation:

Table 11 - Scope for profit and governance summary

ESO	Origin	Profit scope	Ownership	Unbundling	Governance
ONS	Brazil	Non-profit NGO	Stakeholders	ISO/LTO	Independent
Statnett	Norway	For profit (mixed-economy)	State	ITSO	Stakeholders
CND-XM	Colombia	For profit (mixed-economy)	State	LSO/ITO	Partly independent
HQ TransÉnergie	Québec	Mixed-economy (for profit)	State	LTSO	Partly independent

Sources: elaborated by the author (Hydro-Québec, 2010, ONS - Operador Nacional do Sistema, 2010e, Statnett, 2010, XM, 2010e)

In Table 11 the operators are classified according to their profit scope, ownership and governance situation. An argument that this dissertation brings forward is the influence that these elements have on the way the ESO acts, as explained in the first chapter. In the profit scope item, the most relevant position is put first, followed by the less relevant in brackets. Thus Statnett is primarily perceived as a for-profit organization, inserted in the NordPool competitive logic, despite being State-owned – which implies a mixed-economy regime. This fact may translate in a combination of capitalist and welfare logic, where the first is dominant. HQ TransÉnergie is in the opposite case, firstly a welfare promoter and secondly a profits-seeking division; the “heritage pool” is the key argument in this case. As the author is more familiar and has worked closely to the Brazilian electric sector institutions, she is confident in the independence of the ONS. Academic literature states that the ESO of Québec acts in a more partial manner as it is influenced by the political forces. More research is needed in order to understand the situation in Colombia.

ONS is the only case with a separate owner-operator and by superposing triangles no conclusion can be drawn for now about efficiency differentials relatively to the other cases.

Chapter 6

Conclusion

Generally, the dissertation focused on the high voltage electricity transmission system and its management in the context of restructuring that emerged in the last two decades.

This research work has three objectives: a general and two specific ones.

The general objective was to construct a comparison framework for electric system operators that would be as comprehensive as possible, visually easy to capture the gist of and at the same time as simple as possible. This challenging task included an extensive study of system operators and institutional arrangements for electric system operations around the World – since 1985 when the first system operator emerged in Spain to the present situation where most developed and developing countries have created one.

The model that was developed and further used is considered a fairly dynamic and modular solution. It consists of three axes disposed as a three cornered star, one incorporating system operations tasks, another incorporating market and commercial operations tasks and the third one incorporating grid management tasks. Triangles are formed by uniting the points that mark extent of tasks that the operator covers on each one of the three axes.

Furthermore, relevant criteria for assessing operators are discussed: independence, the level of unbundling, the unification between owner and operator responsibilities, and the governance structure and the scope for profit. Where relevant, these elements are pointed out as distinctive factors with their effects. In principle, an independent operator ought to act impartially than their alternatives; legally or functionally unbundled ones might provide the mother-companies with some efficiency gains, possibly to the detriment of social welfare. Also, synergies may arise when system operator are also grid owners. Non-profit operators are exposed to subjective motivations of their board members and managers but are also neutral to financial interests these could lead to reduced-quality operations. For-profit operators may act more efficiently, though, and might be easier to regulate due to their clear objectives. Last, governance may be

independent, stakeholder or state-lead. State-lead governance can transform an operator into a “mixed-economy” type entity instead of a clearly for-profit or non-profit organization. Political interests might use system operation as their tool, possibly overburdening the system with costly reserves instead of assuming economically justifiable risk. Stakeholder-governed operators might be subject to coalitions, but at least all interested parties have a say; nevertheless, voting-schemes are questionable and most of the times not all interests can be satisfied. Independently-governed operators are expected to take decisions that are relatively closer to the social optimum. Yet all these conclusions are merely indicative and the particularities of every system can change them. The bottom line is that, through a transaction-costs approach, the best operator is the one that delivers the maximum social welfare, minimising the transaction costs in the electric sector, between *all* its actors.

The first specific objective was to select a few electric system operators pertinent for comparison with the Brazilian National System Operator. The particularities of geographical size, electric capacity and load configuration make the Brazilian ONS hard to benchmark against. A feature for comparison however was found: a high degree of hydroelectric capacity used for electricity generation. Norway, Colombia and Canada were then selected for comparison.

The second specific objective of the dissertation was to effectively use the operator comparison framework developed according to the general objective and make the comparison of the ONS with the operators in the selected case studies (Statnett – Norway, HQ TransÉnergie – Québec/Canada and XM – Colombia). In the end, the particularities that stood at the creation of such a different system operation model in Brazil would justify themselves or not. The conclusion that was reached is that the system operator in Brazil is “adequately particular.”

As far as **system operation** is concerned, the fact that Brazil is an extended, developing country, with many territories not yet having access to electricity, and given its uniquely large dimension of multi-annual storage capacity, short term market signals are insufficient to provide efficient signals to system expansion in a sustainable way. Where hydroelectric capacity is more run-of-river than with large reservoirs, like is the case in Colombia and Norway, real-time markets are useful and even considered as far as

investment signals for expansion are concerned. The monopolistic behaviour the ONS assumes for water management is best compared to the situation of Québec but in relation to a less developed electric system like that of Brazil. Long-term planning is still necessary in more evolved situations like that of NordPool, but the ONS does it in an orderly, centralized way, compared to Norway.

Secondly, in terms of **market and commercial operations**, the authors do not find particular reasons why market administration might not have more synergies if integrated with the Brazilian operator, according to the Colombian model. It is the ONS that dispatches all generation in Brazil, anyway, for the moment. Possibly, the system may be simplified in this way. Neither the LTSO in Québec, nor the Norwegian ITSO make a good comparison base comparable for the ONS on this axis, as their market models are based on different fundamentals, even if the generation of electricity shares hydro-dominance.

Last, from the point of view of **grid operations**, ONS does not own the transmission assets, like Statnett or TransÉnergie, but the market scheme where it is inserted resolves the problem of assts' reliability with the potential heavy penalties in case of cut-offs. The assets are completely controlled by the ONS, and their physical maintenance and financial administration are "outsourced" co concessionaires. In Colombia, the transmission owner is State-owned but unbundled from other sector activities, but integrated into the TO as the heritage of vertically unbundling. Brazil took a leap forward and separated the two activities in a pertinent way for its context of a large system, with a great number of transmission concessionaires.

Overall, the conclusion it that the Brazilian system is:

- **System operations:** still insufficiently interconnected and covered by transmission lines for the system operator to leave the organization of dispatch at the fate of the market game; as far as planning operations is concerned, the situation is equivalent;
- **Market and commercial operations:** sufficiently developed for the system operator to procure ancillary services from the market and possibly to integrate market administration;

- **Grid operations:** too large for the operator to have any facility in owning the whole transmission grid;

Limitations

The limitations of this work are numerous, and the more salient shall be pointed out with a view to further research:

- Other case studies with relevant hydroelectric penetration ratios in the generation matrixes: Switzerland, Peru, a more advanced study of NordPool in its whole dimension, New Zealand, British Colombia (especially to investigate why unbundling of BCTC in 95% hydroelectric system went default) and Manitoba are but a few;
- Brazil is gradually increasing its run-of-river power plants presence. An ulterior, more “mature” step is studying countries with large non-hydro renewables’ penetration in general, like wind generation – plants whose marginal costs tend to zero and whose capital investments are lumpy; nuclear energy has a similar behaviour;
- More updated 2008 and 2009 data can be retrieved. The object of this work however is to try to explain the issue in general lines, with qualitative rather than quantitative data. Nevertheless, an updated picture may improve data quality.
- Updating this study ten years from now, in 2020 shall probably find Brazil in an exciting new context: a more integrated Latin-American electricity grid, a more developed economy and certainly a generation matrix where reservoirs take a step backwards, so that run-of-river, thermal and wind energy may step forward.

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Annex 1

Economic and social indicators for all countries studied

Table 1 – Economic and social indicators for Brazil, Colombia, Norway and Canada, 1990, 1995, 2000 and 2007

Country	Year	Agriculture, value added (% of GDP)	Electricity intensity (GWh/kUS\$)	Energy intensity (GWh/GDP current kUS\$)	Energy use (ton of oil equivalent)	Exports of goods and services (% of GDP)	GDP (current thousands US\$)
Brazil	1990	8,1	0,456766893	0,686341801	139505000	8,199990015	461951782
	1995	5,771251402	0,475735426	0,666444242	160175000	7,256807333	546233380,3
	2000	5,602810361	0,54302961	0,732585173	189168000	9,978193817	586863191,4
	2007	5,98222907	0,370069909	0,49157438	235556000	13,68176374	1089061121
Canada	1990	2,862509582	0,744146988	0,813890758	208680000	25,81373424	582722831,7
	1995	2,90607832	0,826246043	0,929694244	230915000	37,32358044	564493995,3
	2000	2,276159331	0,763384923	0,863235634	251164000	45,5785327	661264723,7
	2007		0,419237682	0,478791483	269369000	34,65108495	1278640691
Colombia	1990	16,74809279	0,698287112	1,366934272	24223000	20,56542915	40274264,73
	1995	15,28357035	0,713234622	0,791579725	28459000	14,53374289	81709451,91
	2000	10,35903522	0,713234622	0,705324887	26783000	17,38642789	86301299,82
	2007	8,916323845	0,713234622	0,406649701	29048000	16,87413456	162346564,5
Norway	1990	3,423276874	0,828892033	0,405759668	21000000	40,14578416	117624486,8
	1995	3,051810142	0,838003015	0,427498734	23422000	37,95907941	124519241,7
	2000	2,096535991	0,692717793	0,362246738	25350000	46,53638402	159045286,7
	2007	1,391922248	0,339891925	0,181280391	26859000	45,77089127	336733506,9

Source: elaborated by the author, data from the World Bank (2010)

Country	Year	GDP per capita, PPP (current international \$)	GINI index	Imports of goods and services (% of GDP)	Industry, value added (% of GDP)	Population, total	Services, etc., value added (% of GDP)	Total Electricity Net Consumption (GWh)
Brazil	1990	5181,748026	60,59	6,961765546	38,69	149570485	53,21	211004280
	1995	6291,7064	59,24	8,775001661	27,52572832	161691994	66,70302028	259862570
	2000	7006,094098		11,74167982	27,73186068	174174447	66,66532896	318684090
	2007	9693,543388	55,02	12,14050141	28,05103082	190119995	65,96674011	403028750
Canada	1990	19499,10954		25,68298376	31,30658026	27791000	65,83091016	433631440
	1995	22696,57908		34,13241925	30,72876425	29354000	66,36515743	466410930
	2000	28407,24262	32,562	39,82566969	33,20622444	30769700	64,51761623	504799520
	2007	38515,89901		32,70643104		32976000		536054360
Colombia	1990	4341,088629		14,82095023	37,88955007	33203846	45,36235714	28123000
	1995	5462,673138	57,22	20,96348743	31,69267989	36459011	53,02374977	33370000
	2000	5691,442171	57,5	18,86789397	29,78387535	39772905	59,85708943	33333000
	2007	8522,766111		21,04279864	35,46901019	44359445	55,61466597	38592990
Norway	1990	17885,32903		33,78120696	33,95307373	4241500	62,62364939	97498000
	1995	23586,04595		31,7932199	34,19160384	4360000	62,75658601	104347500
	2000	36130,12221	25,79	29,42768935	41,95083085	4491000	55,95263316	110173500
	2007	53765,97446		29,81962671	42,68130994	4709153	55,92676782	114453000

Source: elaborated by the author, data from the World Bank (2010)

Table 2 - Geographic size of the selected countries

Country	Area (km2)
Canada	16.068.769
Brazil	13.703.366
Norway	521.109
Colombia	1.832.904

Source: CIA (2010)

Table 3 – Installed electricity generation capacity and effective power generation for Brazil, Colombia, Norway and Canada, 1990, 1995, 2000 and 2007

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Brazil	Generation (GWh)	1990	1,936	204,641	3,39936	208,04036	8,33592	0	218,31228
Brazil	Generation (GWh)	1991	1,37	215,604	3,48294	219,08694	9,2073	0	229,66424
Brazil	Generation (GWh)	1992	1,663	221,11	4,42187	225,53187	9,90008	0	237,09495
Brazil	Generation (GWh)	1993	0,41968	232,714	4,33164	237,04564	9,6303	0	247,09562
Brazil	Generation (GWh)	1994	0,05221	240,278	4,88823	245,16623	9,9828	0	255,20124
Brazil	Generation (GWh)	1995	2,39465	251,366	5,14426	256,51026	11,64566	0	270,55057
Brazil	Generation (GWh)	1996	2,30755	263,111	6,21021	269,32121	14,1987	0	285,82746
Brazil	Generation (GWh)	1997	3,01055	276,182	6,76403	282,94603	15,95556	0	301,91214
Brazil	Generation (GWh)	1998	3,135	288,55431	6,84047	295,39478	16,79498	0	315,32476
Brazil	Generation (GWh)	1999	3,778	290,07	7,564	297,634	25,86974	0	327,28174
Brazil	Generation (GWh)	2000	4,94	301,359	7,05181	308,41081	25,90828	0	339,25909
Brazil	Generation (GWh)	2001	14,268	265,197	7,96645	273,16345	31,99948	0	319,43093
Brazil	Generation (GWh)	2002	13,84	283,231	9,1324	292,3634	30,02924	0	336,23264
Brazil	Generation (GWh)	2003	13,4	302,56	10,7949	313,3549	28,0543	0	354,8092
Brazil	Generation (GWh)	2004	11,6	317,589	11,3118	328,9008	36,31972	0	376,82052
Brazil	Generation (GWh)	2005	9,9	334,082	12,21077	346,29277	35,11088	0	391,30365
Brazil	Generation (GWh)	2006	13,754	345,317	13,93423	359,25123	35,58276	0	408,58799
Brazil	Generation (GWh)	2007	12,307	370,275	17,19875	387,47375	37,735	0	437,51575
Brazil	Generation (GWh)	2008	13,97	361,411	19,02175	380,43275	54,511	0	448,91375

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Brazil	Capacity (GW)	1990	0,657	45,558	2,051	47,609	4,784	0	53,05
Brazil	Capacity (GW)	1991	0,657	46,616	2,06	48,676	4,808	0	54,141
Brazil	Capacity (GW)	1992	0,657	47,709	2,029	49,738	4,734	0	55,129
Brazil	Capacity (GW)	1993	0,657	48,6	2,093	50,693	4,882	0	56,232
Brazil	Capacity (GW)	1994	0,657	49,928	2,118	52,046	4,939	0	57,642
Brazil	Capacity (GW)	1995	0,657	51,311	2,121	53,432	4,948	0	59,037
Brazil	Capacity (GW)	1996	0,657	53,428	2,236	55,664	5,209	0	61,53
Brazil	Capacity (GW)	1997	0,657	54,97	2,232	57,202	5,198	0	63,057
Brazil	Capacity (GW)	1998	0,657	56,759	2,342	59,101	5,455	0	65,213
Brazil	Capacity (GW)	1999	0,657	58,997	2,579	61,576	5,968	0	68,201
Brazil	Capacity (GW)	2000	1,966	61,063	3,214	64,277	7,449	0	73,692
Brazil	Capacity (GW)	2001	1,966	62,523	3,538	66,061	8,208	0	76,235
Brazil	Capacity (GW)	2002	2,007	65,311	4,564	69,875	10,598	0	82,48
Brazil	Capacity (GW)	2003	2,007	67,793	5,039	72,832	11,693	0	86,532
Brazil	Capacity (GW)	2004	2,007	68,99865	5,945	74,94365	13,809	0	90,75965
Brazil	Capacity (GW)	2005	2,007	70,858	6,106	76,964	14,185	0	93,156
Brazil	Capacity (GW)	2006	2,007	73,434	6,524	79,958	14,67	0	96,635
Brazil	Capacity (GW)	2007	2,007	76,871	6,644	83,515	14,927	0	100,449
Brazil	Capacity (GW)	2008	NA	NA	NA	NA	NA	0	NA

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Canada	Capacity (GW)	1990	13,538	59,195	0,944	60,139	30,278	0,186	104,141
Canada	Capacity (GW)	1991	13,052	60,052	0,721	60,773	30,624	0,183	104,632
Canada	Capacity (GW)	1992	13,987	61,485	0,723	62,208	31,723	0,183	108,101
Canada	Capacity (GW)	1993	15,465	61,23	0,965	62,195	30,625	0,183	108,468
Canada	Capacity (GW)	1994	16,393	62,941	1,014	63,955	33,207	0,183	113,738
Canada	Capacity (GW)	1995	16,393	64,573	1,049	65,622	33,264	0,177	115,456
Canada	Capacity (GW)	1996	16,393	65,481	1,106	66,587	33,783	0,177	116,94
Canada	Capacity (GW)	1997	13,39	66,646	1,288	67,934	31,152	0,177	112,653
Canada	Capacity (GW)	1998	10,615	66,778	1,297	68,075	31,082	0,177	109,949
Canada	Capacity (GW)	1999	10,615	66,944	1,35	68,294	31,888	0,177	110,974
Canada	Capacity (GW)	2000	10,615	67,23	1,454	68,684	31,848	0,177	111,324
Canada	Capacity (GW)	2001	10,615	66,882	1,82	68,702	33,043	0,177	112,537
Canada	Capacity (GW)	2002	10,615	69,029	1,951	70,98	33,207	0,177	114,979
Canada	Capacity (GW)	2003	10,615	70,197	2,419	72,616	34,863	0,177	118,271
Canada	Capacity (GW)	2004	12,805	70,68	2,481	73,161	34,316	0,177	120,459
Canada	Capacity (GW)	2005	13,345	71,801	2,41	74,211	35,105	0,177	122,838
Canada	Capacity (GW)	2006	13,345	72,661	3,176	75,837	34,588	0,177	123,947
Canada	Capacity (GW)	2007	13,345	73,439	3,476	76,915	34,263	0,177	124,7
Canada	Capacity (GW)	2008	NA	NA	NA	NA	NA	NA	NA

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Colombia	Generation (GWh)	1990	0	27,248	0,226	27,474	8,129	0	35,603
Colombia	Generation (GWh)	1991	0	27,21	0,212	27,422	8,895	0	36,317
Colombia	Generation (GWh)	1992	0	22,217	0,282	22,499	10,214	0	32,713
Colombia	Generation (GWh)	1993	0	27,724	0,272	27,996	9,471	0	37,467
Colombia	Generation (GWh)	1994	0	31,972	0,297	32,269	8,448	0	40,717
Colombia	Generation (GWh)	1995	0	31,838	0,386	32,224	10,387	0	42,611
Colombia	Generation (GWh)	1996	0	35,136	0,495	35,631	8,077	0	43,708
Colombia	Generation (GWh)	1997	0	31,369	0,501	31,87	13,068	0	44,938
Colombia	Generation (GWh)	1998	0	30,474	0,56	31,034	13,706	0	44,74
Colombia	Generation (GWh)	1999	0	33,404	0,489	33,893	9,298	0	43,191
Colombia	Generation (GWh)	2000	0	31,753	0,523	32,276	10,648	0	42,924
Colombia	Generation (GWh)	2001	0	31,48	0,523	32,003	10,448	0	42,451
Colombia	Generation (GWh)	2002	0	33,628	0,517	34,145	10,082	0	44,227
Colombia	Generation (GWh)	2003	0	35,812	0,52	36,332	9,739	0	46,071
Colombia	Generation (GWh)	2004	0	39,676	0,542	40,218	9,037	0	49,255
Colombia	Generation (GWh)	2005	0	39,405	0,574	39,979	10,537	0	50,516
Colombia	Generation (GWh)	2006	0	39,9	0,615	40,515	11,316	0	51,831
Colombia	Generation (GWh)	2007	0	41,408	0,603	42,011	8,56728	0	50,57828
Colombia	Generation (GWh)	2008	0	43,085	NA	NA	7,31797	0	NA

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Norway	Generation (GWh)	1990	0	119,933	0,292	120,225	0,211	-0,102	120,334
Norway	Generation (GWh)	1991	0	109,032	0,265	109,297	0,18	-0,191	109,286
Norway	Generation (GWh)	1992	0	115,505	0,27885	115,78385	0,181	-0,168	115,79685
Norway	Generation (GWh)	1993	0	118,024	0,31685	118,34085	0,192	-0,17	118,36285
Norway	Generation (GWh)	1994	0	110,398	0,34355	110,74155	0,351	-0,456	110,63655
Norway	Generation (GWh)	1995	0	120,13	0,3495	120,4795	0,366	-0,411	120,4345
Norway	Generation (GWh)	1996	0	102,55509	0,36855	102,92364	0,466	-0,123	103,26664
Norway	Generation (GWh)	1997	0	108,931	0,305	109,236	0,415	-0,754	108,897
Norway	Generation (GWh)	1998	0	114,24	0,34345	114,58345	0,396	-0,38	114,59945
Norway	Generation (GWh)	1999	0	120,239	0,365	120,604	0,478	-0,182	120,9
Norway	Generation (GWh)	2000	0	137,526	0,3195	137,8455	0,353	-0,192	138,0065
Norway	Generation (GWh)	2001	0	117,116	0,405	117,521	0,322	-0,241	117,602
Norway	Generation (GWh)	2002	0	128,121	0,40425	128,52525	0,332	-0,243	128,61425
Norway	Generation (GWh)	2003	0	104,556	0,648	105,204	0,432	-0,259	105,377
Norway	Generation (GWh)	2004	0	107,774	0,703	108,477	0,478	-0,218	108,737
Norway	Generation (GWh)	2005	0	134,308	0,891	135,199	0,498	-0,315	135,382
Norway	Generation (GWh)	2006	0	118,157	1,074	119,231	0,599	-0,146	119,684
Norway	Generation (GWh)	2007	0	132,595	1,325	133,92	0,847	-0,479	134,288
Norway	Generation (GWh)	2008	0	137,965	1,25	139,215	0,664	-0,629	139,25

Country	Indicator	Year	Nuclear	Hydroelectric	Total Non-Hydroelectric Renewables	Total Renewables	Total Conventional Thermal	Hydroelectric Pumped Storage	TOTAL
Norway	Capacity (GW)	1990	0	25,817	0,067	25,884	0,183	1,067	27,134
Norway	Capacity (GW)	1991	0	25,823	0,068	25,891	0,183	1,067	27,141
Norway	Capacity (GW)	1992	0	25,963	0,072	26,035	0,183	1,067	27,285
Norway	Capacity (GW)	1993	0	25,983	0,072	26,055	0,218	1,067	27,34
Norway	Capacity (GW)	1994	0	26,215	0,072	26,287	0,218	1,067	27,572
Norway	Capacity (GW)	1995	0	27,379	0,131	27,51	0,138	0,673	28,321
Norway	Capacity (GW)	1996	0	27,494	0,137	27,631	0,139	0,672	28,442
Norway	Capacity (GW)	1997	0	27,327	0,137	27,464	0,139	0,672	28,275
Norway	Capacity (GW)	1998	0	26,982	0,135	27,117	0,137	0,663	27,917
Norway	Capacity (GW)	1999	0	27,54	0,161	27,701	0,129	0,663	28,493
Norway	Capacity (GW)	2000	0	26,766	0,16	26,926	0,129	1,36	28,415
Norway	Capacity (GW)	2001	0	26,319	0,186	26,505	0,101	1,36	27,966
Norway	Capacity (GW)	2002	0	26,262	0,253	26,515	0,116	1,652	28,283
Norway	Capacity (GW)	2003	0	26,758	0,27	27,028	0,11	1,318	28,456
Norway	Capacity (GW)	2004	0	26,088	0,313	26,401	0,134	1,424	27,959
Norway	Capacity (GW)	2005	0	26,41	0,415	26,825	0,163	1,44	28,428
Norway	Capacity (GW)	2006	0	27,545	0,435	27,98	0,146	1,396	29,522
Norway	Capacity (GW)	2007	0	27,832	0,475	28,307	0,543	1,465	30,315
Norway	Capacity (GW)	2008	0	NA	NA	NA	NA	NA	NA

Annex 2

Country-specific data: Brazil

Table 1 - Electricity consumption and its growth in Brazil per type of consumer, 1995-2009, GWh

Consumption (GWh)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Brazil	243.074	257.330	273.280	284.522	292.188	307.529	283.257	293.226	306.987	330.598	345.512	357.514	378.359	392.688	388.204
Rresidencial	63.576	68.581	74.089	79.340	81.291	83.613	73.622	72.718	76.162	78.470	82.644	85.784	89.885	94.746	100.638
Industrial	111.626	117.128	121.717	121.979	123.893	131.278	122.539	130.927	136.221	155.054	159.838	164.565	175.701	180.049	165.632
Commercial	32.276	34.388	38.198	41.544	43.588	47.626	44.434	45.222	47.531	49.686	53.035	55.369	58.647	61.813	65.567
Others	35.596	37.234	39.276	41.659	43.416	45.011	42.663	44.359	47.073	47.389	49.995	51.796	54.125	56.079	56.368
Growth (%)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Brazil	7,8	5,9	6,2	4,1	2,7	5,3	-7,9	3,5	4,7	7,7	4,5	3,5	5,8	3,8	-1,1
Rresidencial	13,6	7,9	8	7,1	2,5	2,9	-11,9	-1,2	4,7	3	5,3	3,8	4,8	5,4	6,2
Industrial	4	4,9	3,9	0,2	1,6	6	-6,7	6,8	4	13,8	3,1	3	6,8	2,5	-8
Commercial	11,9	6,5	11,1	8,8	4,9	9,3	-6,7	1,8	5,1	4,5	6,7	4,4	5,9	5,4	6,1
Others	6,7	4,6	5,5	6,1	4,2	3,7	-5,2	4	6,1	0,7	5,5	3,6	4,5	3,6	0,5

Source: EPE (2010a)

Table 2 – Electricity costs by fuel in Brazil, 2008

	Unit.	Hydro	Biomass	Coal (national)	Nuclear	Coal (imported)	Natural gas	Wind	Combustion oil	Diesel
Disp.	MW	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Average variable cost	R\$/Mwh	1,5	14,7	37,5	25,2	54,3	108,6	4,5	300	500
Fixed cost	R\$/kW ano	11,3	46	57,8	138	57,8	57,5	46	28	25
Investment cost	US\$/KW	1.250	1.100	1.500	2.000	1.500	900	2.000	800	600
Equilibrium tariff	R\$/MWh	116,4	121,1	133,3	151,6	152,4	175	297	382,9	602,2

Source: Hubner (Hubner, 2010)

Table 3 – The electricity matrix of Brazil

Undertakings in operation							
Type		Installed capacity		%	Total		%
		No. of plants	(kW)		No. of plants	(kW)	
Hydro			79.414.693	67,36	857	79.414.693	67,36
Gas	Natural	94	11.055.618	9,38	127	12.331.101	10,46
	Processed	33	1.275.483	1,08			
Oil	Diesel	816	4.008.322	3,4	845	6.532.125	5,54
	Residual	29	2.523.803	2,14			
Biomass	Bagass	302	5.403.421	4,58	370	7.048.066	5,98
	Black gas	14	1.240.798	1,05			
	Wood	38	327.767	0,28			
	Biogás		44.672	0,04			
	Rice crust	7	31.408	0,03			
Nuclear		2	2.007.000	1,7	2	2.007.000	1,7
Mineral Coal	Mineral coal	9	1.594.054	1,35	9	1.594.054	1,35
Wind		45	794.334	0,67	45	794.334	0,67
Imports	Paraguay		5.650.000	5,46		8.170.000	6,93
	Argentina		2.250.000	2,17			
	Venezuela		200.000	0,19			
	Uruguay		70.000	0,07			
Total		2.255	117.891.373	100	2.255	117.891.373	100

Source: ANEEL (2010, ONS - Operador Nacional do Sistema, 2010b)

Table 4 – Electricity exchanges between regions, Brazil, 2009

2009 (GWh)	S/SW-CE	N/SW-CE	N/NE	SW-CE/NE	International/S
Jan	-595,8	0,0	1.049,8	852,5	6,8
Feb	-2.064,2	566,1	1.082,1	290,5	135,0
Mar	-2.948,5	1.168,1	1.232,0	309,0	326,3
Apr	-3.627,4	820,6	982,6	253,3	113,7
May	-3.884,5	1.836,6	194,2	3,4	107,6
Jun	-3.863,5	1.725,6	323,9	58,0	197,8
Jul	-1.782,6	410,0	297,1	12,1	239,5
Aug	1.898,2	0,0	53,8	832,4	174,6
Sep	2.364,1	-539,7	0,0	1.095,8	-82,5
Oct	2.454,8	-930,4	0,0	864,2	-135,3
Nov	1.287,8	-781,9	0,0	836,0	-1,8
Dec	574,2	0,0	379,4	869,5	-1,9
TOTAL	-10.187,4	4.274,9	5.594,7	6.276,6	1.079,7

Source: ONS (2010b)

Annex 3

Country-specific data: Norway

Table 1 – Electricity balance of Norway, 1950-2008

Year	Water power	Thermal power	Wind power	Total Production	Imports (measured at the border)	Export (measured at the border)	Net exports	Gross consumption	Consumption in power stations	Consumption in pumping plants	Losses and statistical differences	Final net consumption
1950	16924	.	.	16924	.	.		16924	.	2175	.	14749
1955	22600	.	.	22600	.	.		22600	.	2885	.	19715
1960	30915	206	.	31121	210	78	-132	31253	.	3744	.	27509
1961	33386	208	.	33594	140	231	91	33503	.	3514	.	29989
1962	37625	119	.	37744	34	325	291	37453	.	3664	.	33789
1963	39263	196	.	39459	54	898	844	38615	.	3662	.	34953
1964	43778	164	.	43942	116	1421	1305	42637	.	4150	.	38487
1965	48858	92	.	48950	117	2176	2059	46891	.	4929	.	41962
1966	48188	160	.	48348	631	907	276	48072	.	5088	.	42984
1967	52773	93	.	52866	344	1859	1515	51351	.	5548	.	45803
1968	59609	92	.	59701	179	3174	2995	56706	.	5853	.	50853
1969	56803	219	.	57022	221	1569	1348	55674	.	5407	.	50267
1970	57261	345	.	57606	808	1644	836	56770	.	5311	.	51459
1971	63281	282	.	63563	458	3373	2915	60648	.	5766	.	54882
1972	67440	175	.	67615	120	4767	4647	62968	.	6067	.	56901
1973	72893	143	.	73036	66	5259	5193	67843	495	37	6299	61013
1974	76644	56	.	76700	63	5607	5544	71156	549	67	6247	64292
1975	77415	71	.	77486	83	5703	5620	71866	560	122	6491	64693
1976	82037	96	.	82133	240	6877	6637	75496	581	148	7400	67367
1977	72203	229	.	72432	2653	1570	-1083	73515	668	258	6740	65849

Year	Water power	Thermal power	Wind power	Total Production	Imports (measured at the border)	Export (measured at the border)	Net exports	Gross consumption	Consumption in power stations	Consumption in pumping plants	Losses and statistical differences	Final net consumption
1978	80864	133	.	80997	845	4250	3405	77592	766	225	7316	69285
1979	88977	146	.	89123	842	5493	4651	84472	864	398	7656	75554
1980	83962	137	.	84099	2039	2501	462	83637	903	498	7129	75105
1981	93270	127	.	93397	1925	7154	5229	88168	967	623	8505	78072
1982	92888	268	.	93156	642	6704	6062	87094	1001	556	7441	78096
1983	106048	321	.	106369	431	13847	13416	92953	995	516	8331	83111
1984	106339	327	.	106666	860	9130	8270	98396	1019	623	7565	89191
1985	102946	346	.	103292	4083	4627	544	102748	942	804	9071	91931
1986	96819	465	.	97284	4212	2180	-2032	99316	910	883	6997	90526
1987	103753	530	.	104283	2983	3320	337	103946	958	686	8521	93781
1988	109544	475	.	110019	1727	7355	5628	104391	964	982	7659	94787
1989	118698	499	.	119197	314	15166	14852	104345	1066	426	7658	95194
1990	121382	466	.	121848	334	16241	15907	105941	1019	339	6874	97709
1991	110580	429	.	111009	3274	6049	2775	108234	932	637	6703	99964
1992	117062	441	.	117503	1380	10109	8729	108774	963	558	6814	100442
1993	119622	467	7	120096	587	8486	7899	112197	840	556	8851	101949
1994	112676	528	9	113213	4836	4968	132	113082	753	1476	7927	102926
1995	122487	514	10	123011	2300	8962	6662	116349	592	1367	9426	104964
1996	104148	555	9	104712	13212	4236	-8976	113688	604	408	8529	104147
1997	110938	471	11	111420	8692	4874	-3818	115238	611	1661	8074	104893
1998	116280	496	11	116787	8046	4412	-3634	120421	688	824	8460	110448
1999	121882	538	25	122445	6857	8776	1919	120526	996	615	8395	110520

Year	Water power	Thermal power	Wind power	Total Production	Imports (measured at the border)	Export (measured at the border)	Net exports	Gross consumption	Consumption in power stations	Consumption in pumping plants	Losses and statistical differences	Final net consumption
2000	142289	496	31	142816	1474	20529	19055	123761	682	673	10051	112355
2001	121026	555	27	121608	10760	7162	-3598	125206	673	805	9967	113761
2002	129837	561	75	130473	5329	15002	9673	120800	602	665	9338	110195
2003	106084	943	218	107245	13472	5587	-7885	115130	488	863	7950	105829
2004	109291	929	252	110472	15334	3842	-11492	121964	569	728	9335	111332
2005	136452	860	499	137811	3653	15695	12042	125769	635	1091	9995	114048
2006	119729	1035	636	121400	9802	8947	-855	122255	567	515	10073	111100
2007	134736	1536	892	137164	5284	15320	10036	127128	558	1543	10079	114948
2008	139981	1214	913	142108	3414	17291	13877	128231	637	1338	9677	116579

Source: Statistics Norway (2010)

Table 2 – Installed generation capacity by type and owner in Norway, 2008

Owner	Hydro power		Thermal power		Wind power		Maximum output from the stations, total	TOTAL
	No.	MW	No.	MW	No.	MW	MWA	MW
Total	1181	29229	44	726	186	389	30 766	30344
Central government	216	11380	14	522	125	284	12 195	12186
County/municipality	796	15312	24	140	60	104	15 768	15556
Private	169	2538	6	64	1	2	2 803	2604

Source: Statistics Norway (2010)

Annex 4

Country-specific data: Canada

Table 1 – Value of transmission assets across provinces and territories in Canada, 2007

	Canada	Québec	Ontario	Alberta	Manitoba	British Columbia	New Brunswick
All utilities	46.185.009	20.888.103	12.932.008	3.130.143	3.066.961	3.009.340	845.114
Public utilities	42.042.045	20.888.103	12.637.902	52.313	3.066.961	2.615.317	845.114
Private utilities	4.142.964	0	294.106	2.607.013	0	394.023	0
	Newfoundland and Labrador	Saskatchewan	Nova Scotia	Prince Edward Island	Yukon	Northwest Territories	Nunavut
All utilities	789.758	779.992	592.453	57.608	54.547	38.982	0
Public utilities	596.195	779.992	0	0	54.547	34.784	0
Private utilities	193.563	0	592.453	57.608	0	4.198	0

Source: Statistics Canada (2009a)

Table 2 – Electricity regulatory bodies across Canada

Province/Territory	Electricity regulatory body
British Columbia	Public Utilities Commission
Alberta	Alberta Utilities Commission
Saskatchewan	Province of Saskatchewan
Manitoba	Province of Manitoba and Public Utilities Board
Ontario	Ontario Energy Board
Québec	Régie de l'énergie
New Brunswick	Provincial government
Prince Edward Island	Regulatory and Appeals Commission of PEI
Nova Scotia	Utility Review Board
Newfoundland and Labrador	Commissioners of Public Utilities
Yukon	Yukon Utilities Board
Northwest Territories	Public Utilities Board
Nunavut	Government of Nunavut

Source: IEA (2009a)

Table 3 – Population by year, province and territory in Canada

	2005	2006	2007	2008	2009
	persons (thousands)				
Canada	32245	32576,1	32932	33327,3	33739,9
Ontario	12528,0	12665,3	12794,7	12936,3	13069,2
Québec	7581,0	7631,6	7687,1	7753,5	7828,9
British Columbia	4196,8	4243,6	4309,5	4383,8	4455,2
Alberta	3322,2	3421,3	3513,1	3595,9	3687,7
Manitoba	1178,3	1184,0	1193,9	1206,1	1222,0
Saskatchewan	993,6	992,1	1000,1	1013,6	1030,1
Nova Scotia	937,0	938,0	935,9	936,6	938,2
New Brunswick	748,0	745,7	745,6	747,1	749,5
Newfoundland and Labrador	514,0	510,3	506,5	506,4	508,9
Prince Edward Island	138,0	137,9	138,1	139,5	141,0
Northwest Territories	43,4	43,2	43,5	43,7	43,4
Yukon	31,9	32,3	32,6	33,2	33,7
Nunavut	30,3	30,8	31,3	31,6	32,2

Source: Statistics Canada (2009c)

Table 4 – Nominal and real GDP per province and territory in Canada, 2004-2008

	Gross domestic product, expenditure-based					Real gross domestic product, expenditure-based				
	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
	\$ millions					millions of chained (2002) dollars				
Canada	1290906	1373845	1449215	1532944	1600081	1211239	1247807	1283419	1315907	1321360
Ontario	516.106	537.383	560.286	585.723	587.827	49.678	510.509	522.845	53.488	532.209
Quebec	262.761	272.049	28.222	297.384	302.225	251.028	255.559	259.853	267.033	269.665
British Columbia	157.675	169.664	18.231	191.598	197.931	146.541	153.489	159.916	164.519	164.520
Alberta	189.743	21.981	23.841	256.915	291.256	163.564	170.872	181.418	18.587	185.780
Manitoba	39.748	41.681	45.029	48.718	50.834	37.861	3.886	40.158	41.593	42.407
Saskatchewan	40.796	43.996	45.498	50.811	63.509	37.741	38.904	3.852	39.896	41.583
Nova Scotia	29.853	31.199	31.743	32.933	34.188	2.771	28.016	28.254	28.598	29.215
New Brunswick	23.672	24.716	25.884	26.993	27.372	22.366	22.638	23.254	23.356	23.351
Newfoundland and Labrador	19.407	2.196	26.052	29.226	31.277	17.209	17.593	18.201	19.856	19.953
Prince Edward Island	3.983	4.096	4.249	449	4.624	3.877	3.921	4.026	4.126	4.148
Northwest Territories	432	4.267	4.281	4.578	5.103	3.543	3.517	354	39	3.589
Yukon	1.394	1.497	1.629	1.735	1.903	1.293	1.329	1.403	1.436	1.500
Nunavut	1.074	1.137	1.226	1.431	1.602	989	996	1.027	1.129	1.233

Source: Statistics Canada (2009d, 2009b)

Table 5 – Installed generating nameplate capacity, by province or territory and type of organization, 2007

<u>Utilities and industries</u>	Canada	Québec	British Columbia	Ontario	Newfoundland and Labrador	Manitoba	New Brunswick
Hydro	73435687,0	37459391,0	12608898,0	8349602,0	6795500,0	5029288,0	922670,0
Wind and tidal	1600399,0	375750,0	0	413529,0	0	103950,0	0
Thermal	49204221,0	3182679,0	2223104,0	23403061,0	557035,0	494185,0	3611838,0
Steam	27211548,0	1126253,0	1768750,0	9747630,0	490000,0	119250,0	2148800,0
Nuclear	13345000,0	675000,0	0	11990000,0	0	0	680000,0
Internal combustion	593480,0	129179,0	60974,0	66150,0	24035,0	9515,0	14338,0
Combustion turbine	8054193,0	1252247,0	393380,0	1599281,0	43000,0	365420,0	768700,0
Total installed capacity	124240307,0	41017820,0	14832002,0	32166192,0	7352535,0	5627423,0	4534508,0
Percentage of total for Canada	100	33,01	11,94	25,89	5,92	4,53	3,65
Total installed capacity, 2006	123579274,0	40068551,0	14827701,0	32520892,0	7494133,0	5629007,0	4485608,0
Percentage change from 2006	0,53	2,37	0,03	-1,09	-1,89	-0,03	1,09
<u>Public utilities</u>							
Hydro	63964169,0	33344764,0	10159000,0	7105407,0	6426220,0	5029288,0	891030,0
Wind and tidal	206880,0	2250,0	0	2400,0	0		0
Thermal	27346309,0	2339579,0	1091474,0	15574625,0	514035,0	472185,0	3144538,0
Steam	16219250,0	660000,0	950000,0	8472000,0	490000,0	97250,0	1921500,0
Nuclear	8335000,0	675000,0	0	6980000,0	0	0	680000,0
Internal combustion	387139,0	123579,0	48474,0	38625,0	24035,0	9515,0	14338,0
Combustion turbine	2404920,0	881000,0	93000,0	84000,0	0	365420,0	528700,0
Total installed capacity	91517358,0	35686593,0	11250474,0	22682432,0	6940255,0	5501473,0	4035568,0
Percentage of total for Canada	100	38,99	12,29	24,78	7,58	6,01	4,41
Total installed capacity, 2006	91155312,0	35235201,0	11248503,0	22667577,0	7081453,0	5503057,0	4035868,0
Percentage change from 2006	000	1,28	0,02	0,07	-1,99	-0,03	-0,01
<u>Private utilities</u>							
Hydro	4428248,0	980527,0	921988,0	984985,0	252230,0	0	31640,0
Wind and tidal	1392919,0	373500,0	0	410529,0	0	103950,0	0
Thermal	18511657,0	686050,0	419600,0	7368466,0	0	0	340000,0
Steam	9129393,0	309203,0	229500,0	1006000,0	0	0	100000,0
Nuclear	5010000,0	0	0	5010000,0	0	0	0
Internal combustion	131051,0	5600,0	7100,0	26185,0	0	0	0
Combustion turbine	4241213,0	371247,0	183000,0	1326281,0	0	0	240000,0
Total installed capacity	24332824,0	2040077,0	1341588,0	8763980,0	252230,0	103950,0	371640,0
Percentage of total for Canada	100	8,38	5,51	36,02	1,04	0,43	1,53
Total installed capacity, 2007	24465877,0	1985900,0	1270988,0	9095510,0	252630,0	103950,0	371640,0
Percentage change from 2006	-0,54	2,73	5,55	-3,64	-0,16	000	000
<u>Industries</u>							
Hydro	5043270,0	3134100,0	1527910,0	259210,0	117050,0	0	0
Wind and tidal	600	0	0	600	0	0	0
Thermal	3346255,0	157050,0	712030,0	459970,0	43000,0	22000,0	127300,0
Steam	1862905,0	157050,0	589250,0	269630,0	0	22000,0	127300,0
Nuclear	0	0	0	0	0	0	0
Internal combustion	75290,0	0	5400,0	1340,0	0	0	0
Combustion turbine	1408060,0	0	117380,0	189000,0	43000,0	0	0
Total installed capacity	8390125,0	3291150,0	2239940,0	719780,0	160050,0	22000,0	127300,0
Percentage of total for	100	39,23	027	8,58	1,91	0,26	1,52

Canada							
Total installed capacity, 2007	7958085,0	2847450,0	2308210,0	757805,0	160050,0	22000,0	78100,0
Percentage change from 2006	5,43	15,58	-2,96	-5,02	000	000	063

<u>Utilities and industries</u>	Alberta	Saskatchewan	Nova Scotia	Yukon	Northwest Territories	Prince Edward Island	Nunavut
Hydro	909028,0	854660,0	403750,0	77900,0	25000,0	0	0
Wind and tidal	438860,0	171180,0	52760,0	810	0	43560,0	0
Thermal	10502791,0	2852950,0	2006425,0	32250,0	126078,0	157550,0	54275,0
Steam	7844690,0	2212950,0	1686125,0	0	0	67100,0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	103886,0		0	32250,0	98878,0	0	54275,0
Combustion turbine	2554215,0	640000,0	320300,0	0	27200,0	90450,0	0
Total installed capacity	11850679,0	3878790,0	2462935,0	110960,0	151078,0	201110,0	54275,0
Percentage of total for Canada	9,54	3,12	1,98	0,09	0,12	0,16	0,04
Total installed capacity, 2006	11735969,0	3878790,0	2463135,0	107960,0	142143,0	171110,0	54275,0
Percentage change from 2006	0,98	000	-0,01	2,78	6,29	17,53	000
<u>Public utilities</u>							
Hydro	52200,0	854660,0	0	76600,0	25000,0	0	0
Wind and tidal	900	159960,0	0	810	0	40560,0	0
Thermal	1749500,0	2329500,0	0	25000,0	51598,0	0	54275,0
Steam	1602000,0	2026500,0	0	0	0	0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	5400,0	0	0	25000,0	43898,0	0	54275,0
Combustion turbine	142100,0	303000,0	0	0	7700,0	0	0
Total installed capacity	1802600,0	3344120,0	0	102410,0	76598,0	40560,0	54275,0
Percentage of total for Canada	1,97	3,65	000	0,11	0,08	0,04	0,06
Total installed capacity, 2006	1808325,0	3344120,0	0	98610,0	67763,0	10560,0	54275,0
Percentage change from 2006	-0,32	000	000	3,85	13,04	284,09	000
<u>Private utilities</u>							
Hydro	856828,0	0	398750,0	1300,0	0	0	0
Wind and tidal	437960,0	11220,0	52760,0	0	0	3000,0	0
Thermal	7086496,0	482000,0	1962665,0	7250,0	1580,0	157550,0	0
Steam	5630225,0	145000,0	1642365,0	0	0	67100,0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	83336,0	0	0	7250,0	1580,0	0	0
Combustion turbine	1372935,0	337000,0	320300,0	0	0	90450,0	0
Total installed capacity	8381284,0	493220,0	2414175,0	8550,0	1580,0	160550,0	0
Percentage of total for Canada	34,44	2,03	9,92	0,04	0,01	0,66	000
Total installed capacity, 2007	8306284,0	493220,0	2414375,0	9350,0	1480,0	160550,0	0
Percentage change from 2006	001	000	-0,01	-8,56	6,76	000	000
<u>Industries</u>							
Hydro	0	0	5000,0	0	0	0	0
Wind and tidal	0	0	0	0	0	0	0
Thermal	1666795,0	41450,0	43760,0	0	72900,0	0	0
Steam	612465,0	41450,0	43760,0	0	0	0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	15150,0	0	0	0	53400,0	0	0
Combustion turbine	1039180,0	0	0	0	19500,0	0	0
Total installed capacity	1666795,0	41450,0	48760,0	0	72900,0	0	0
Percentage of total for Canada	19,87	0,49	0,58	000	0,87	000	000
Total installed capacity, 2007	1621360,0	41450,0	48760,0	0	72900,0	0	0
Percentage change from 2006	003	000	000	000	000	000	000

Source: Statistics Canada (2009a)

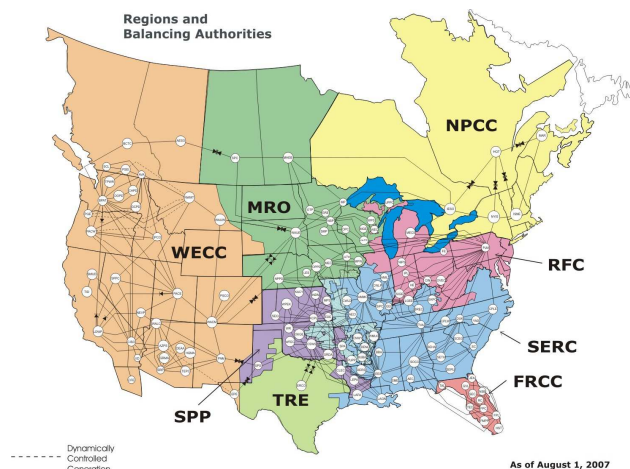
Table 6 - Generation of electric energy by province and territory in Canada, 2007

<u>Utilities and industries</u>	Canada	Québec	British Columbia	Ontario	Newfoundla nd and Labrador	Manitoba	New Brunswic k
Hydro	364128200,0	181099757,0	64288157,0	34336031,0	40048491,0	33513217,0	2802981,0
Wind and tidal	2947582,0	617379,0	0	492947,0	0	325115,0	0
Thermal	250393809,0	10244962,0	7544855,0	123405432,0	1534822,0	564170,0	14835866,0
Steam	127952921,0	2562433,0	5008592,0	34343191,0	1255915,0	511502,0	8595138,0
Nuclear	88190431,0	4321577,0	0	79750154,0	0	0	4118700,0
Internal combustion	4259828,0	271988,0	82664,0	2878664,0	43426,0	12934,0	6088,0
Combustion turbine	29990629,0	3088964,0	2453599,0	6433423,0	235481,0	39734,0	2115940,0
Total energy generated	617469591,0	191962098,0	71833012,0	158234410,0	41583313,0	34402502,0	17638847,0
Percentage of total for Canada	100	031	012	026	007	006	003
<u>Electric utilities</u>							
Hydro	334251275,0	163301462,0	54706270,0	33404214,0	38525161,0	33513217,0	2793761,0
Wind and tidal	2946466,0	617379,0	0	492947,0	0	325115,0	0
Thermal	232462561,0	9763621,0	3005243,0	121234683,0	1287323,0	479021,0	13490207,0
Steam	117958123,0	2081092,0	1341144,0	33081450,0	1255915,0	426353,0	7941891,0
Nuclear	88190431,0	4321577,0	0	79750154,0	0	0	4118700,0
Internal combustion	3883277,0	271988,0	58489,0	2769301,0	43426,0	12934,0	6088,0
Combustion turbine	22430730,0	3088964,0	1605610,0	5633778,0	-12018,0	39734,0	1423528,0
Total energy generated	569660302,0	173682462,0	57711513,0	155131844,0	39812484,0	34317353,0	16283968,0
Percentage of total for Canada	100	031	010	027	007	006	003
<u>Industry</u>							
Hydro	29876925,0	17798295,0	9581887,0	931817,0	1523330,0	0	9220,0
Wind and tidal	1116,0	0	0	0	0	0	0
Thermal	17931248,0	481341,0	4539612,0	2170749,0	247499,0	85149,0	1345659,0
Steam	9994798,0	481341,0	3667448,0	1261741,0	0	85149,0	653247,0
Nuclear	0	0	0	0	0	0	0
Internal combustion	376551,0	0	24175,0	109363,0	0	0	0
Combustion turbine	7559899,0	0	847989,0	799645,0	247499,0	0	692412,0
Total energy generated	47809289,0	18279636,0	14121499,0	3102566,0	1770829,0	85149,0	1354879,0
Percentage of total for Canada	100	038	030	007	004	000	003

<u>Utilities and industries</u>	Alberta	Saskatchewan	Nova Scotia	Yukon	Northwest Territories	Prince Edward Island	Nunavut
Hydro	2141189,0	4392985,0	924514,0	330632,0	250246,0	0	0
Wind and tidal	715553,0	579488,0	177060,0	407	0	39633,0	0
Thermal	64575617,0	15601976,0	11472468,0	23655,0	436006,0	5099,0	148881,0
Steam	50180443,0	14271754,0	11218593,0	0	0	5360,0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	492488,0	1395,0	0	23655,0	297529,0	116	148881,0
Combustion turbine	13902686,0	1328827,0	253875,0	0	138477,0	-377	0
Total energy generated	67432359,0	20574449,0	12574042,0	354694,0	686252,0	44732,0	148881,0
Percentage of total for Canada	011	003	002	000	000	000	000
<u>Electric utilities</u>							
Hydro	2141189,0	4392985,0	892138,0	330632,0	250246,0	0	0
Wind and tidal	714437,0	579488,0	177060,0	407	0	39633,0	0
Thermal	56368247,0	15305777,0	11267885,0	23655,0	82919,0	5099,0	148881,0
Steam	46834467,0	13976441,0	11014010,0	0	0	5360,0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	492024,0	509	0	23655,0	55866,0	116	148881,0
Combustion turbine	9041756,0	1328827,0	253875,0	0	27053,0	-377	0
Total energy generated	59223873,0	20278250,0	12337083,0	354694,0	333165,0	44732,0	148881,0
Percentage of total for Canada	010	004	002	000	000	000	000
<u>Industry</u>							
Hydro	0	0	32376,0	0	0	0	0
Wind and tidal	1116,0	0	0	0	0	0	0
Thermal	8207370,0	296199,0	204583,0	0	353087,0	0	0
Steam	3345976,0	295313,0	204583,0	0	0	0	0
Nuclear	0	0	0	0	0	0	0
Internal combustion	464	886	0	0	241663,0	0	0
Combustion turbine	4860930,0	0	0	0	111424,0	0	0
Total energy generated	8208486,0	296199,0	236959,0	0	353087,0	0	0
Percentage of total for Canada	017	001	001	000	001	000	000

Source: Statistics Canada (2009a)

Map 1 - Regions and balancing authorities in the North American grid



Source: NERC (2010)

Annex 5

Country-specific data: Colombia

Table 1 – Net installed electricity capacity by type in Colombia, 1998-2009

Net installed capacity (MW)	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Biomass	0	0	0	0	0	0	0	0	3	3	3	42
Coal	687	716	720	720	690	692	692	694	700	700	700	700
Fuel oil	13	13	13	13	13	19	22	20	23	23	23	14
Natural gas	3395	2945	3522	3704	3679	3656	3766	3682	3585	3675	3739	3759
Hydro	8032	7738	8224	8645	8997	8833	8917	8942	8950	8991	8996	9010
Wind	0	0	0	0	0	0	20	10	18	18	18	18

Source: Source: UPME (2010b)

Table 2 – Number of agents from the electricity sub-sectors, by ownership

	Public	Private	Mixed	Total
Generation	6	28	10	44
Transmission	5	1	3	9
Distribution	26	3	2	31
Retail	14	41	18	73

Source: XM (2010b)

Table 3 – Electricity matrix of Colombia, 1992-2008

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE	EE
	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh	GWh
.Centrales Hidroeléctricas	22039	27639	31841	31942	35272	31254	30559	33520	31853	31577	33747	35953	39856	39576	42523	44214	46161
.Centrales Térmicas	9200	8988	7649	9757	7366	12364	13379	8666	10119	10494	9938	9401	8663	9519	9753	9307	8128
.Central Eolica													52	49	63	49	54
.Autoprodutores	2205	1592	1869	1917	1967	2001	2014	1962	1980	1792	1556	2389	1720	1520	2416	980	2490
.Centros Tratamiento de Gas																	
.Refinerías																	
.Coquerías																	
.Altos Hornos																	
.Carboneras																	
1.1_Producción	33445	38219	41359	43616	44605	45619	45952	44148	43952	43863	45241	47743	50291	50665	54755	54550	56833
1.2_Importaciones	348	303	280	370	164	199	85	33	77	40	8	69	48	16	21	39	77
1.3_Exportaciones					3		64	27	37	210	618	1182	1682	1758	1813	877	1473
1.4_Variación de Inventarios																	
1.5_No Aprovechado																	
1.6_Pérdidas	6487	8234	9138	9561	9743	10183	10610	10547	9654	8414	8737	9071	9704	9819	10455	9819	10798
1_OFERTA INTERNA	27305	30288	32501	34425	35024	35635	35363	33608	34339	35279	35893	37559	38954	39104	42508	43894	44639
A JUSTE	312	-4	20	-1263	-836	-501	-2355	-2097	-3108	-762	-603	-11	-595	-817	839	423	-185
2_DEMANDA INTERNA	26993	30292	32481	35688	35859	36136	37718	35706	37447	36040	36496	37571	39549	39921	41670	43470	44823
2.1_Consumo Propio	837	798		848	703	768	879	740	751	841	874	793	970	982	1046	1234	1708
2.2_Transf/Reciclo/Perd.Transf	210										210						
.Centrales Hidroeléctricas																	

.Centrales Térmicas																	
.Autoprodutores	210										210						
.Centros Tratamiento de gas																	

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
.Refinerías																	
.Coquerías																	
.Altos Hornos																	
.Carboneras																	
2.3_Consumo Final	25946	29494	32481	34840	35156	35368	36838	34966	36696	35199	35413	36778	38579	38939	40624	42236	43116
.Residencial	11664	13192	14064	14610	14682	14658	14450	14504	14487	14470	14403	15162	15792	16254	16904	17618	18146
.Comercial y Público	5385	5743	6208	6369	6600	6795	7793	7514	9102	7794	8188	8422	9073	9179	9592	9880	10028
.Industrial	7652	8910	9792	10150	10362	11285	11873	9807	11362	11188	11412	11903	12301	12508	13133	13724	13930
.Transporte	6	8	10	12	15	47	48	48	50	51	55	52	55	55	57	57	58
.Agropecuario y Minero	1087	1140	1168	1194	1290	1220	1960	1010	1290	1290	1303	935	1299	879	886	905	896
.Construcciones	43	46	53	55	56	59	95	93	56	56	53	52	59	64	52	53	58
.No Identificado	109	456	1187	2449	2152	1304	620	1990	350	350		250					
2.3.1_Consumo Util	20622	23455	20556	21419	22093	28136	29164	27794	29231	28030	28221	29402	30771	31167	32536		34534
.Residencial	9331	10554	9109	9455	9531	11726	11560	11603	11589	11576	11522	12130	12634	13003	13524		14517
.Comercial y Público	4308	4594	2607	2675	2772	5436	6234	6011	7282	6235	6550	6738	7258	7343	7673		8022
.Industrial	6275	7306	7383	7654	7813	9254	9736	8042	9317	9174	9358	9761	10087	10256	10769		11423
.Transporte	5	6				39	39	39	41	42	45	43	45	45	47		47
.Agropecuario y Minero	598	627	551	563	609	671	1078	556	709	709	716	514	714	483	487		493
.Construcciones	24	25	42	43	44	32	52	51	31	31	29	29	33	35	36		32
.No Identificado	82	342	863	1029	1324	978	465	1493	263	263		188					
2.3.2_Pérdidas Consumo	5324	6040	11925	13420	13063	7232	7674	7171	7465	7169	7192		7808	7772	8088	42236	8582
1_CONSUMO INDUSTRIAL	7652	8910	9792	10150	10362	11285	11873	9807	11362	11188	11412	11903	12301	12508	13133		

.Alimentos Bebidas y Tabaco	1428	1662	1827	1894	1933	2105	2215	1830	2120	2087	2129	2221	2295	2333	2450		
.Textil y Confecciones	1073	1249	1373	1423	1453	1583	1665	1375	1593	1569	1600	1669	1725	1754	1842		
.Calzado y Cueros	96	112	123	128	130	142	149	123	143	141	143	150	155	157	165		
.Maderas y Muebles	111	129	142	147	150	164	172	142	165	162	166	173	179	182	191		

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
.Papel e Imprenta	646	752	826	857	874	952	1002	828	959	944	963	1005	1038	1056	1108		
.Químicos	1215	1415	1555	1612	1645	1792	1885	1557	1804	1776	1812	1890	1953	1986	2085		
.Cemento	721	840	923	957	977	1064	1119	924	1071	1054	1076	1122	1159	1179	1238		
.Piedras Vidrio y Cerámicas	323	376	414	429	438	477	502	414	480	473	482	503	520	528	555		
.Hierro Acero y No Ferrosos	1408	1639	1802	1868	1907	2077	2185	1804	2091	2059	2100	2190	2263	2301	2417		
.Maquinaria y Equipos	342	399	438	454	463	505	531	439	508	500	510	532	550	559	587		
.Otros	289	336	370	383	391	426	448	370	429	422	431	449	464	472	496		
2_CONSUMO TRANSPORTE	6	8	10	12	15	47	48	48	50	51	55	52	55	55	57		
..Pasajeros Privado Interurbano																	
..Pasajeros Privado Urbano																	
..Pasajeros Público Interurbano																	
..Pasajeros Público Urbano																	
..Carga Urbana																	
..Carga Interurbana																	
.Total Carretero																	
.Aéreo																	
.Fluvial																	
.Marítimo																	
.Ferroviario	6	8	10	12	15	47	48	48	50	51	55	52	55	55	57		

3_CONSUMO AGRICOLA Y MINERO	1087	1140	1168	1194	1290	1220	1960	1010	1290	1290	1303	935	1299	879	886		
..Tractores																	
..Secado de Granos	18	18	21	22	23	22	36	18	23	23	24	17	24	16	16		
..Procesamiento Agrícola	3	4	3	3	4	4	6	3	4	4	4	3	4	3	3		
..Riego	17	17	20	21	22	21	34	18	22	22	23	16	23	15	15		

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
..Fumigación																	
..Otros	295	305	296	302	327	309	496	256	327	327	330	237	329	223	224		
.Total Agrícola	333	345	341	348	376	356	572	295	376	376	380	273	379	256	258		
..Iluminación	151	163	169	173	187	177	284	146	187	187	189	135	188	127	128		
..Fuerza Motriz	452	470	489	500	540	510	820	423	540	540	545	391	543	368	371		
..Otros Usos	151	163	170	173	187	177	284	147	187	187	189	136	188	128	129		
.Total Minero	754	796	828	846	914	864	1388	715	914	914	923	662	920	623	628		
4_CONSUMO RESIDENCIAL	11664	13192	14064	14610	14682	14658	14450	14504	14487	14470	14403	15162	15792	16254	16905		
..Cocción	3575	4043	4310	4478	4500	4492	4429	4445	4440	4435	4414	4647	4840	4982	5181		
..Iluminación	1883	2129	2270	2358	2370	2366	2332	2341	2338	2336	2325	2447	2549	2624	2729		
..Agua Caliente	1830	2070	2207	2293	2304	2300	2268	2276	2273	2271	2260	2379	2478	2551	2653		
..Nevera	2274	2571	2741	2848	2862	2857	2817	2827	2824	2821	2807	2956	3078	3168	3295		
..Aire Acondicionado	303	343	365	380	382	381	375	377	376	376	374	394	410	422	439		
..Otros	494	558	595	618	621	620	611	614	613	612	609	642	668	688	715		
.Total Urbano	10358	11715	12489	12974	13038	13017	12832	12880	12865	12850	12790	13465	14024	14435	15012		
.Total Rural	1306	1477	1575	1636	1644	1641	1618	1624	1622	1620	1612	1697	1768	1820	1894		

Source: UPME (2010b)

Table 4 - Rainfall in Colombia, 2003-2008 (July), expressed in GWh

	2003	2004	2005	2006	2007	2008
Jan	1.172,90	2.093,60	2.225,70	2.363,80	2.209,90	2.623,50
Feb	1.185,20	1.563,20	2.005,30	1.828,30	1.222,60	2.551,30
Mar	1.953,10	2.355,90	1.904,90	3.460,10	2.178,30	2.914,20
Apr	3.696,20	3.688,00	3.488,90	5.387,10	4.208,90	3.236,40
May	5.255,40	5.936,80	5.618,00	6.873,40	5.602,00	5.651,70
Jun	4.816,60	6.496,20	4.844,50	6.119,20	6.025,20	6.640,70
Jul	4.457,70	5.138,80	3.540,10	4.811,20	4.254,20	7.292,20
Aug	3.926,40	4.685,30	3.909,70	3.640,50	4.740,80	
Sep	3.511,70	4.100,30	4.112,10	3.258,70	4.256,60	
Oct	4.520,50	4.526,10	4.801,00	4.834,90	5.849,90	
Nov	3.958,30	5.062,10	5.613,90	5.159,40	4.741,00	
Dec	3.455,40	2.967,30	2.870,00	3.387,70	3.803,70	
Total	41.909,40	48.613,50	44.934,10	51.124,30	49.093,10	30.910,00

Source: UPME (2008)

Table 5 - Electricity demand in Colombia, 2003-2008 (july), GWh

	2003	2004	2005	2006	2007	2008
Jan	3.774,30	3.810,40	3.946,80	4.096,60	4.309,50	4.418,50
Feb	3.539,00	3.743,70	3.708,70	3.880,90	4.067,00	4.314,80
Mar	3.891,00	4.027,50	4.089,00	4.268,50	4.511,30	4.363,50
Apr	3.693,80	3.790,60	4.056,00	4.039,60	4.242,70	4.470,30
May	3.887,20	3.931,10	4.110,80	4.287,50	4.474,80	4.513,10
Jun	3.642,10	3.835,60	4.003,60	4.152,40	4.314,80	4.377,90
Jul	3.902,60	3.937,50	4.090,50	4.324,50	4.468,60	4.595,40
Aug	3.886,80	4.027,20	4.195,70	4.369,10	4.507,80	
Sep	3.836,00	3.903,60	4.136,00	4.281,90	4.414,70	
Oct	3.941,70	4.000,40	4.167,10	4.428,20	4.541,90	
Nov	3.809,50	3.921,70	4.083,90	4.272,20	4.453,60	
Dec	3.964,00	4.088,10	4.240,80	4.413,20	4.547,00	
Total	45.767,90	47.017,30	48.828,90	50.814,60	52.853,40	31.053,50

Source: UPME (2008)

Table 6 – Number of agents from the electricity sub-sectors, by ownership

	2003	2004	2005	2006	2007
Generators*	42	43	45	40	44
Retailers*	60	62	67	71	75
Distributors	32	31	32	32	32
Transmitters	11	11	11	11	11

*agents that have transacted in the wholesale market;

Source: XM (2010b)