Comparative analysis of the regulatory and commercial frameworks for Combined Heat and Power systems in Latin America and the Caribbean

Within the project

Mechanisms and technology transfer networks related to climate change in Latin America and the Caribbean

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Introduction

This study is part of the project "*Mechanisms and technology transfer networks related to climate change in Latin America and the Caribbean*" (in Spanish: "*Mecanismos y redes de transferencia de tecnología relacionada con el cambio climático en América Latina y el Caribe*"), prepared by the Inter-American Development Bank (IDB), approved by the Council of the Global Environment Facility (GEF), and managed by the Bariloche Foundation. It focuses on a comparative analysis of the regulatory and commercial frameworks for the implementation of Combined Heat and Power (CHP) projects in Latin America and the Caribbean, paying special attention to particularities on six countries: Brazil, Colombia, Guatemala, Mexico, Nicaragua and Uruguay.

CHP projects are considered an alternative that contributes to the mitigation of the environmental impact by reducing the emissions generated in the energy sector. They are also known to increase adaptability and reduce vulnerability toward grid disconnection events, while contributing to the development of Distributed Generation (DG) and the making of more efficient electrical systems.

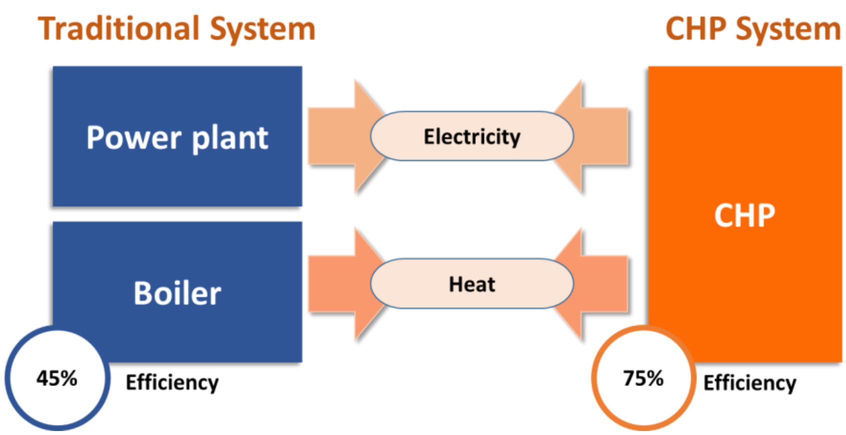
1 Combined Heat and Power systems: general context

1.1 Overview

Combined Heat and Power (CHP, also known as Cogeneration), is the joint and sequential production of **electricity** and **useful thermal energy** (heat or cold), from a unique fuel source and **at the same place of consumption**.

Conventional thermoelectric generation systems usually operate at efficiencies on the 38-45% range, dissipating most of the primary fuel energy in the form of waste heat. CHP systems allow the recovery of such heat, using it in other processes and increasing the total efficiency of the generation system, as shown in Figure 1.

Figure 1. Primary energy conversion into electricity and thermal energy

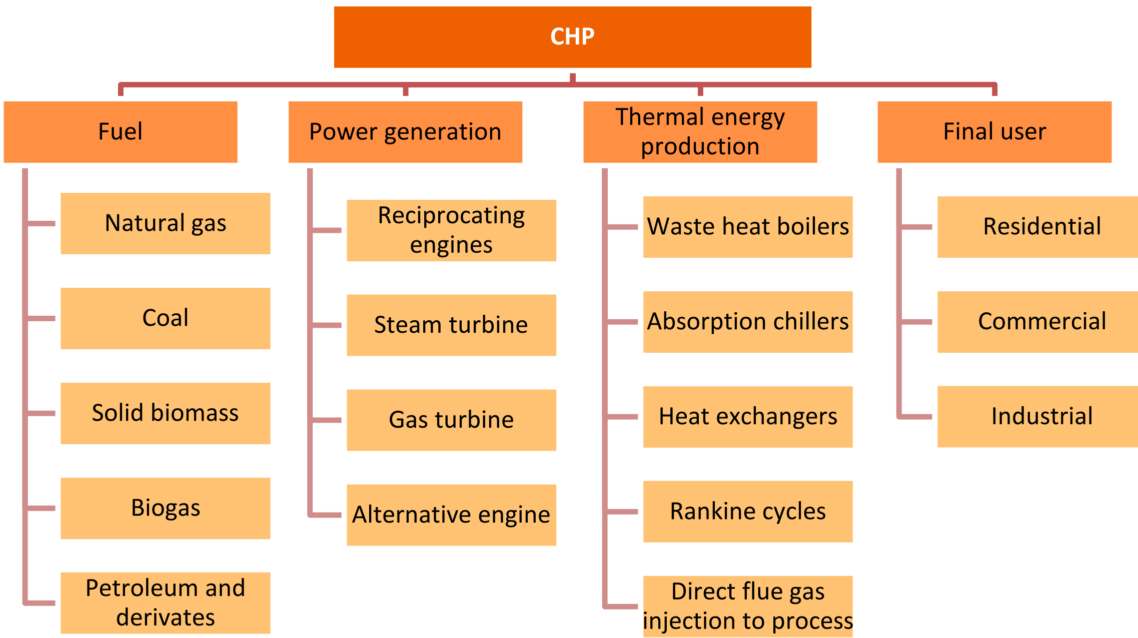


As thermal energy is more difficult to transport than electricity, CHP systems are usually installed close to the thermal demand location, which makes CHP a Distributed Generation (DG) technology (on-site generation). That is why most CHP users belong to the industrial sector, even when it is also common to find this type of system in commercial facilities such as university campuses, hospitals, military bases, power generation plants, and even residential complexes. In some cases, it is possible to produce more electricity than required and sell the surplus power to the grid in order to obtain additional income.

Associated with cogeneration there are some other systems such as **Trigeneration** systems, which simultaneously produce electricity, heat, and cold; **Combined Cycles**, where waste heat from power generation is used to produce additional power; and **Self-Generation** systems, where electricity is generated for self-consumption but there is no thermal energy exploitation.

In general terms, CHP systems can be differentiated according to the fuel employed, the type of user, and the technology for electricity and thermal energy production, as shown in Figure 2:

Figure 2. CHP systems classification



According to the World Energy Council, by 2014 CHP represented approximately 7.3% of the total installed capacity for electricity generation worldwide. In absolute terms CHP generation went from 437.4 GW in 2006 to 733.7 GW in 2015, which corresponds to an annual growth rate of 5.9%. By regions, CHP participation in the Commonwealth of Independent States (CIS) is around 45%; in the European Union about 14.5%; in North America approximately 6.2%; in Asia-Pacific 4.9%; and in Latin America just around 3%.

1.2 Technology

The main components of a CHP system are the equipment for power generation and heat recovery, which are presented in Tables 1 and 2. These equipment can be combined in multiple ways (Figure 3) depending on the specific site conditions, electrical and thermal demands, available fuel, environmental restrictions, and several other aspects.

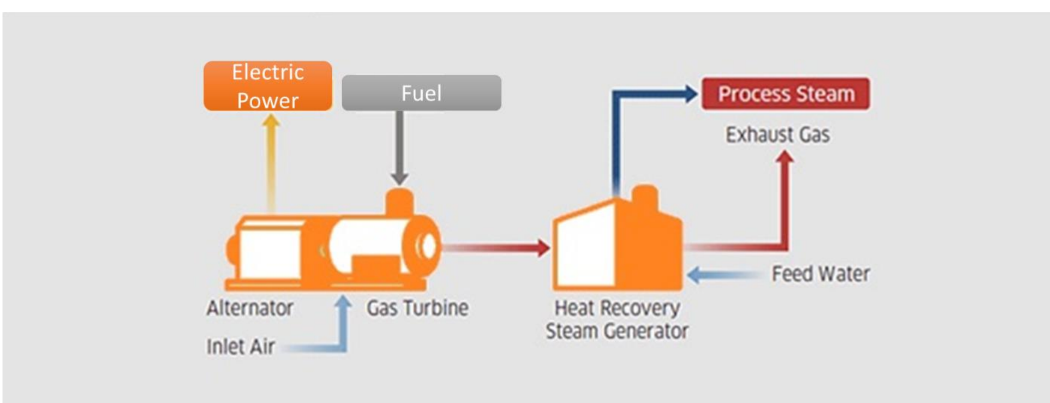
Table 1. Power generation equipment

Technology	Reciprocating engines	Gas turbines	Steam cycles
Fuel	Liquid and gas	Liquid and gas	Liquid, solid, and gas
Power range	100 kW - 10MW	30kW - 300MW	100kW - 250MW
Electric efficiency	35-45%	25-35%	5-30%
Heat-to-power ratio	0,65 – 1,40	1,15-2,4	0,5-15
Cogeneration efficiency	60-85%	65-85%	40-85%
Capex (USD/kW)	400 - 700	600 – 900	1200 - 1600
Opex (USD/kWh)	0,009-0,024	0,009-0,015	0,008-0,02

Table 2. Heat recovery equipment

Technology	Waste heat boilers	Absorption chillers	Heat exchangers	Organic Rankine cycles
Product	Steam, hot water or thermal oil	Chilled water	Hot water, hot air or hot fluid	Electricity
Heat source	Hot flue gas	Hot flue gas or hot water	Hot water from an engine	Hot flue gas or hot water
Power generation technology	Engine, gas turbine	Engine, turbine, steam cycle	Engine	Engine, turbine, steam cycle
Product Temp.	Max. 250°C	Min. 5°C	Max. 90°C	---
Size range	With equipment 100kWe -200MWe	10 TR - 1.500 TR	Any size	5kWe - 5MWe
Efficiency	---	COP up to 1,45	---	5-20%

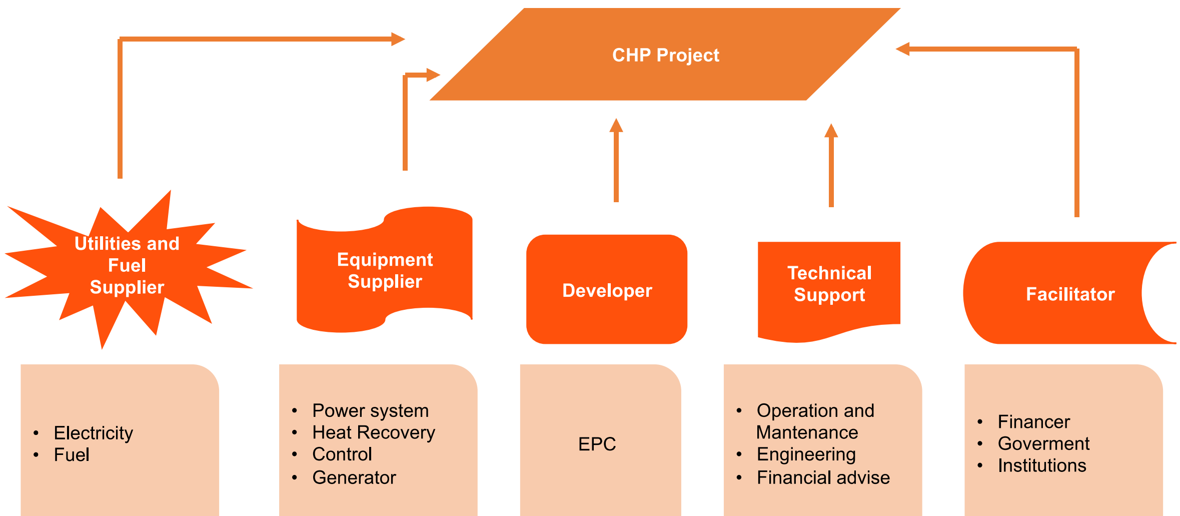
Figure 3. CHP system configuration example – Gas Turbine coupled to a Heat Recovery Steam Generator



1.3 Market

Besides the end user, there are different stakeholders around a CHP project. Each of them have different interests and can bring advantages to a project, depending on their position and particular qualifications. In general, they can be classified in groups as shown in Figure 4.

Figure 4. CHP project supply chain



To coordinate the action of the mentioned stakeholders, different business models have been developed and the contractual agreements are adapted to each particular case. In order to manage the risks, the responsibilities are usually assigned to the best-qualified parties. In general, business models can be distinguished depending on who exercises the ownership of the assets, where the resources come from, and what tariff structure is proposed.

In general, a CHP project is feasible when some of the following conditions are met:

- Temporal correspondence between electric and thermal demands.
- Wide gap between electricity and fuel prices.
- Favoring regulatory framework.
- High number of annual operation hours.
- Highly desired reliability in the power supply.

1.4 Benefits

As shown in Table 3, the Cogeneration brings some important benefits to different stakeholders. Such benefits constitute the main factors driving the growth of the Cogeneration as an alternative for power production.

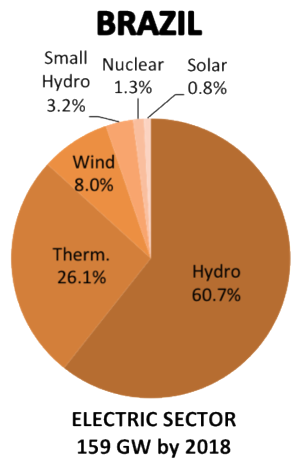
Table 3. CHP benefits for different stakeholders

Final users	The main benefits obtained by final users of CHP projects are: • Decrease in operational costs due to increased efficiency and savings in energy transmission and distribution. • Resilience and reliability before the probability of power supply interruption. • Improvement on the ability to predict energy costs.
Governments	Some governments have been creating conditions to increase the competitive advantage of CHP since it addresses a series of national priorities, including: • Operational costs reduction. • Reduction on investments for power generation, transmission, and distribution. • Electric generation efficiency increase. • Transmission losses reduction. • Progress in environmental and climate change objectives by reducing GHG emissions. • Improvement of the national energy infrastructure. • Diversification of energy sources and the possibility to integrate distributed energy resources to the grid. • Increase in energy security and resilience in the event of power supply interruption from the grid. • National economy growth, given by the improvement of business competitiveness.
Utility companies	Utility companies have started to show interest for including CHP solutions in their portfolios as they represent benefits like: • Transmission losses reduction. • Infrastructure operation optimization by reducing congestion and future investment, and increasing response capacity. • Power supply reliability increase. • Electric generation efficiency increase. • Broadening of solutions portfolio for their customers.

2 Comparative analysis of the institutional, regulatory and comercial framework for CHP

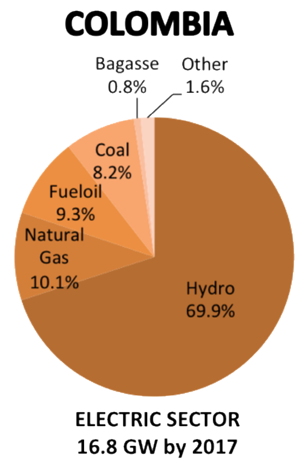
2.1 Current status

Figure 5. Current status of cogeneration in the six countries studied



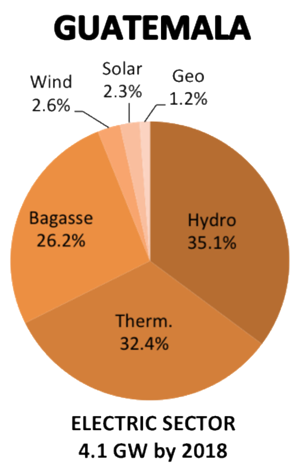
COGENERATION

- 18,2 GW installed by 2017
- Fast growth from 9,3 GW in 2010
- 62% in sugar cane sector
- 15% in industries using natural gas as fuel
- 14% en paper industry using black liquor as fuel
- Other projects use wood residues, biogas, and other fuels



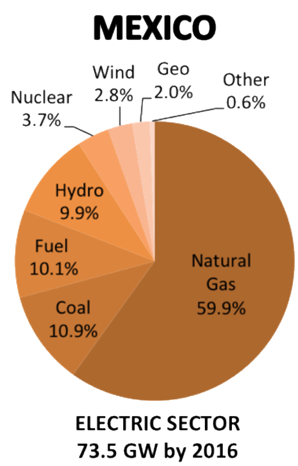
COGENERATION

- 748 MW installed by 2014
- 80% industrial sector – 20% oil sector
- 47% in industries using natural gas natural
- 39% biomass (mainly sugar cane industry)
- 14% in industries using coal
- Most part (55%) is installed in a single departament (Valle del Cauca)



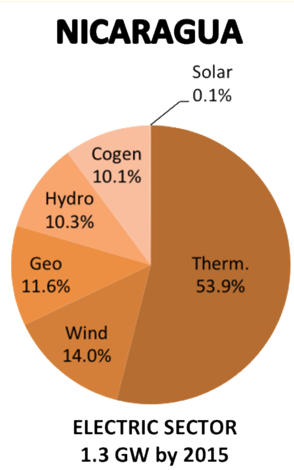
COGENERATION

- 1020 MW installed by 2018
- Almost all installed in sugar cane industry
- Sugar cane is the most common fuel, specially in zafra time
- When required, sugar cane is completed with bunker, coal or other type of biomass
- There are a few experiences with biogas



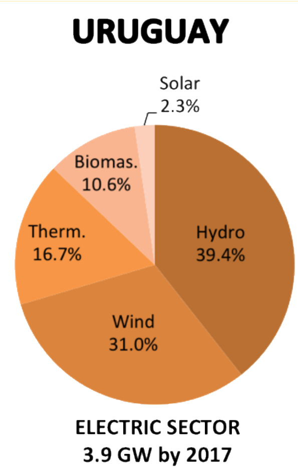
COGENERATION

- 3574 MW installed by 2012
- Most power in oil (48%) and petrochemical sector (23%)
- Other industrial sectors (chemical, paper, sugar, textile) are significant
- Tertiary sector has a low participation (turism represents 3%)
- Mainly use of natural gas. In a lower scale coal, fuel oil y biomass



COGENERATION

- 134 MW installed by 2015
- 49% in sugar cane sector
- Sugar cane is the most common fuel, specially in zafra time
- When required, sugar cane is completed with other type of biomass (wood or eucaliptus) and bunker

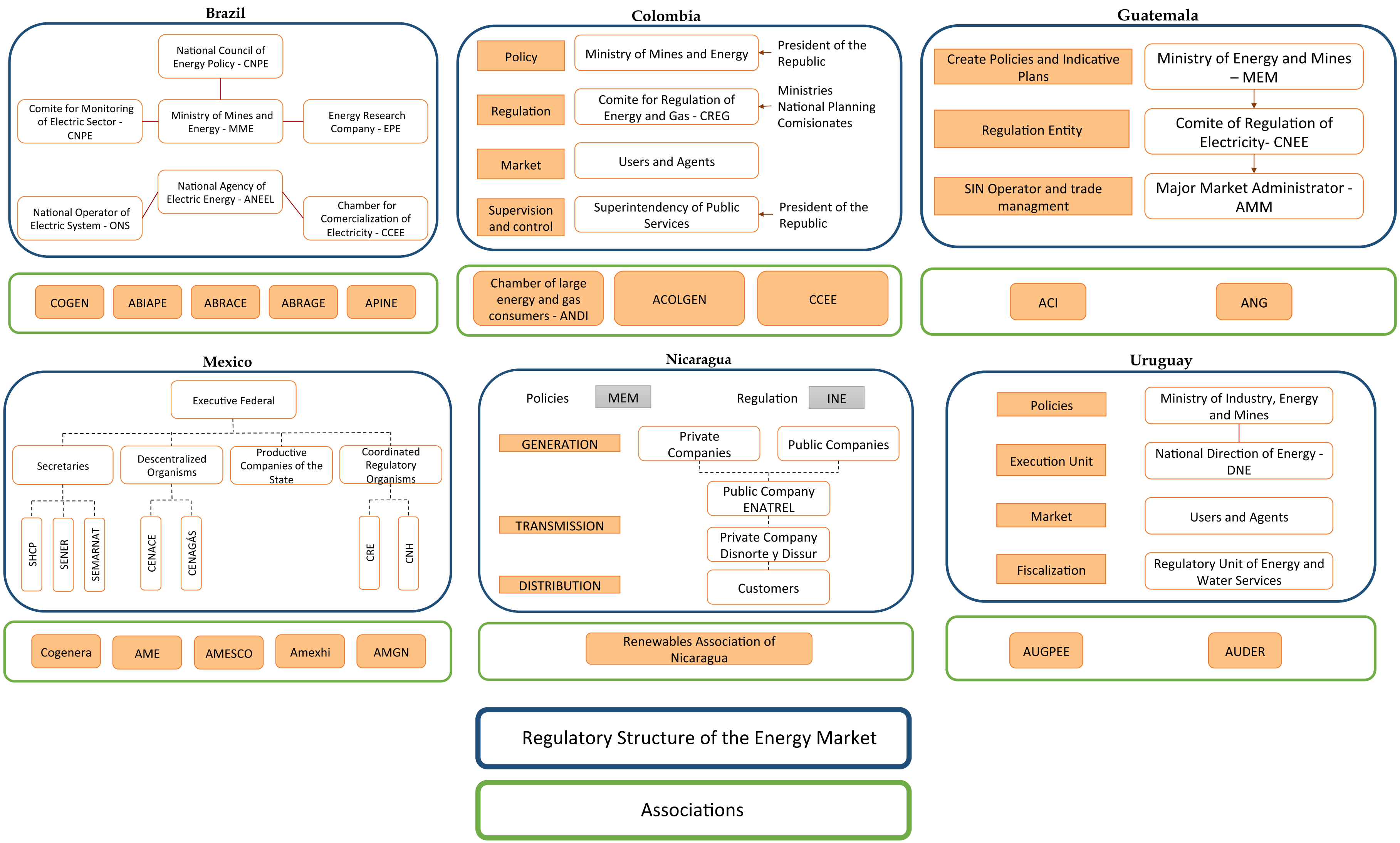


COGENERATION

- 396 MW installed by 2017
- Mostly in agroindustrial sector
- Mainly biomass (sugar cane, eucaliptus, forestal waste, rice husk, black liquor)
- Potential with natural gas or other fossil fuels is very restricted

2.2 Institutional framework

Figure 6. Institutional structure of the energy market in the studied countries



* The names of some institutions have been translated for clarity but their acronyms have been kept in their original language (Spanish or Portuguese).

2.3 Comparative analysis of regulatory and commercial framework

Table 4 summarizes the most important regulatory and commercial framework aspects by country. The information has been organized so that each aspect follows a similar structure for all countries, however, some regulation particularities can not be presented in a corresponding way to some of them.

Table 4. Comparative matrix for the regulatory and commercial framework in the studied countries

Aspect	Brazil	Colombia	Guatemala	Mexico	Nicaragua	Uruguay
Permits/ Licenses	Cogeneration permits - ANEEL. Simplified paperwork < 5MW. Environmental permits.	Connection permits – CREG. Environmental authorization – ANLA; CARs (if < 100 MW).	Environmental License - Ministry of Environment and Natural Resources.	Authorization from CRE to be generator. Unique Environmental License - SEMARNAT.	Environmental License -MARENA. Additional permits - INE for > 1MW.	Environmental authorization - DINAMA. Simplified paperwork for plants < 10MW.
Efficiency	Existing regulation for efficiency calculation. Minimum values to classify as "qualified cogeneration"	Existing methodology for efficiency calculation. Minimum EEE to classify as “cogenerator”.	No minimum efficiency requirement.	Existing regulation for efficiency calculation. Minimum values to classify as "efficient cogeneration".	No minimum efficiency requirement or regulation.	No minimum efficiency requirement or regulation.
Surplus power sale	Possibility to sale through different ways. Both eventual and permanent commercialization is allowed.	Conditions change depending on the size and the ability to provide power guarantee. There are different channels for commercialization.	Resulting surplus from contracts can be traded in the major market, at no different price. Special treatment to biomass plants.	Open and non-discriminatory access to the grid: freedom for production and sale. Several contract models exist.	The surplus power sale is not regulated, but CHP plants use to deliver power to the grid.	There is no specific regulation. Direct commercialization with UTE at freely agreed prices.

Aspect	Brazil	Colombia	Guatemala	Mexico	Nicaragua	Uruguay
Connection to the grid	Requirements - National System Operator (ONS). Costs according to ANEEL.	Conditions - CREG. Broad number of paperwork and requirements.	Regulation - MEM y CNEE. Requirements, studies, contracts and design conditions.	Equality of conditions for any power producer, which implies higher costs for small and medium-size plants.	Charges for usage of the transmission network – calculated by ENATREL and approved by INE	Exemption of charges and fees for connection to the grid. There is a void in the regulation about the technical requirements.
Emissions / Carbon market	There are previous experiences with CHP systems included in the CDM.	CHP systems don't usually participate in this market.	CHP plants don't usually classify for CDM benefits.	Plants classified as "Clean Energy" can access the CELs market.	Just a few experiences of CHP plants accessing CDM benefits.	Experiences of biomass-based CHP having CDM benefits.
Electricity price scheme	Competition with non-CHP power producers in equality of conditions at the different markets.	Competition with non-CHP power producers in equality of conditions at the different markets.	Regulation-established formulas to calculate charges. No differentiation for CHP.	Same cost structure for all producers. Competition with non-CHP power producers in equality of conditions at the different markets.	No differentiation for CHP. Usually sale through long-term contracts.	Price to consumers fixed by distributors. Contract prices fixed through free negotiation.
Incentives	CHP-specific incentives: PIS and CONFIS exemption, and special prices for surplus power.	CHP-specific incentives limited to some sectors and/or renewables. There are VAT exemptions available.	Incentives only for biomass-based CHP: VAT exemption, income, IEMA, and emission reduction certificates.	No CHP-specific incentives. Benefits for "Clean Energy" plants.	No CHP-specific incentives. Import tariffs, VAT, and income tax exemption if renewable energy.	Income tax exemption for cogeneration. Patrimony tax, VAT, import tariffs, and income tax for renewables.

2.4 Financing schemes

There are no special financing lines for CHP in the six countries studied. However, there are some Multilateral Organizations (see Figure 7) and some commercial banks or public funds at each country (see Table 5), which designate capital resources for renewable energy or energy efficiency projects. Furthermore, there are ESCO companies and private investment funds all around the region that are interested in this type of projects.

Figure 7. Multilateral Organizations that have previously funded CHP projects in the region

CAF; IDB; WB – World Bank; CABEI – Central American Bank for Economic de Integration;
EC – European Comission; CIFI – Interamerican Corporation for Infrastructure Financing

Table 5. Commercial banks, special programs, institutions and funds at the national level

Country	Commercial bank (*Fund or financing line*)	Institution/Special fund
Brazil	- BNDES (*Renewable energy and energy efficiency; Finem Energy; Amazônia; Clima*) - Banco do Brasil (*Proger Urban Business*) - Banco Santander (*CDC Energy Efficiency for Equipment*) - Caixa Econômica (*BCD – Durable Consumer Goods*) - BRDE (*Energy efficiency and renewable energy for companies*) - Bandes (*Green Economy*)	- Joint Action Plan Inova Energia - PROINFA – Program of Incentives to Alternative Electricity Sources - Programs of the National Bank for Economic and Social Development BNDES: PROESCO, PRORENOVA
Colombia	- Grupo Bancolombia (*Verde*) - Bancoldex (*Energy efficiency and renewable energy; Energy efficiency for hotels, clinics, and hospitals*) - Banco ProCredit (*ProEco PYME*)	- Fund for Non-conventional Energy and Energy Efficiency Management - FENOGE - Fund for Financial Support of Energy at Non-interconnected Zones - FAZNI
Guatemala	- Banco Proamerica (*Green credits*)	- Fund Rural Electrification Plan
Mexico	- Citibanamex (*Green financing*) - Bancomext (*Renewable energy and energy efficiency projects*) - NAFIN - Nacional Financiera (*Investment Bank – Sustainable Projects*)	- Fund for the sustainable electricity use - Fund for sustainability of energy - Mexican oil fund
Nicaragua	- BANPRO/Grupo Promerica (*Energy efficiency)* - Banco LAFISE BANCENTRO - (*Energy efficiency and sustainability in small and middle-size enterprises*)	- Fund for the development of the electric industry - FODIEN
Uruguay	- BBVA (*Financing of efficient equipment*) - BROU (*Cleaner production; Investment projects*) - Banco Bandes (*Energy efficiency projects*)	- Energy Efficiency Trust - Uruguayan Trust for Development of Energy Efficiency - FUDAEE

* Names of some financing lines or funds have been translated for clarity. In general the names of institutions and acronyms have been kept in their original language (Spanish or Portuguese).

3 Comparative analysis through a typical project

3.1 Considered process plant

A comparative analysis is performed to a hypothetical industrial plant, which could be installed at any of the studied countries (see Figure 8 and Table 6). The plant is located at sea level and has an average ambient temperature of 25ºC. The fuel considered is natural gas (bunker in the cases of Guatemala and Nicaragua, where natural gas is not available), which is used to produce steam in a system of boilers. The choosing of a fossil fuel for the analysis (i) allows studying the effects of the regulation for cogeneration without interference of the regulation for renewable energy, and (ii) makes the problem more universal in the sense that biomass or biogas would limit the analysis to certain productive sectors.

Figure 8. Electricity consumption for the considered process plant

Variable	Value
Average Demand (kWe)	2,133
Maximun Demand (kWe)	2,924
Annual Consumption (kWh/yr)	18,683,361
Average Consumption (kWh/month)	1,556,947

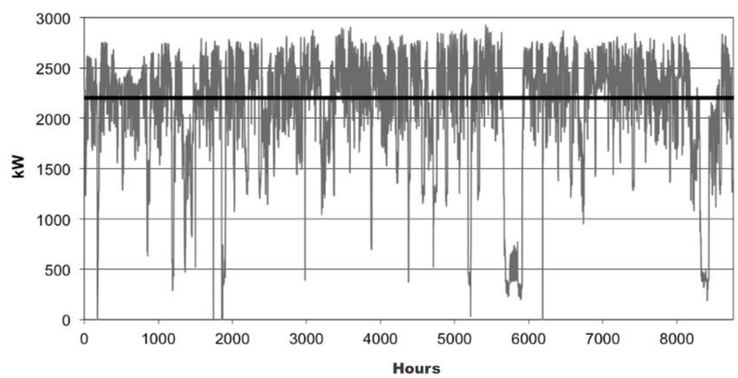


Table 6. Steam consumption for the considered process plant

Variable	Value
Boiler system capacity (lb/h)	12.000
Steam pressure/temperature (psig / °C)	125 / 178,2
Feedwater temperature (°C)	80
Boiler system efficiency based on LHV (%)	85
Average fuel consumption (MMBtu/mes / MMBtu/h)	8.100 / 11,25
Average steam production (lb/h)	8.200

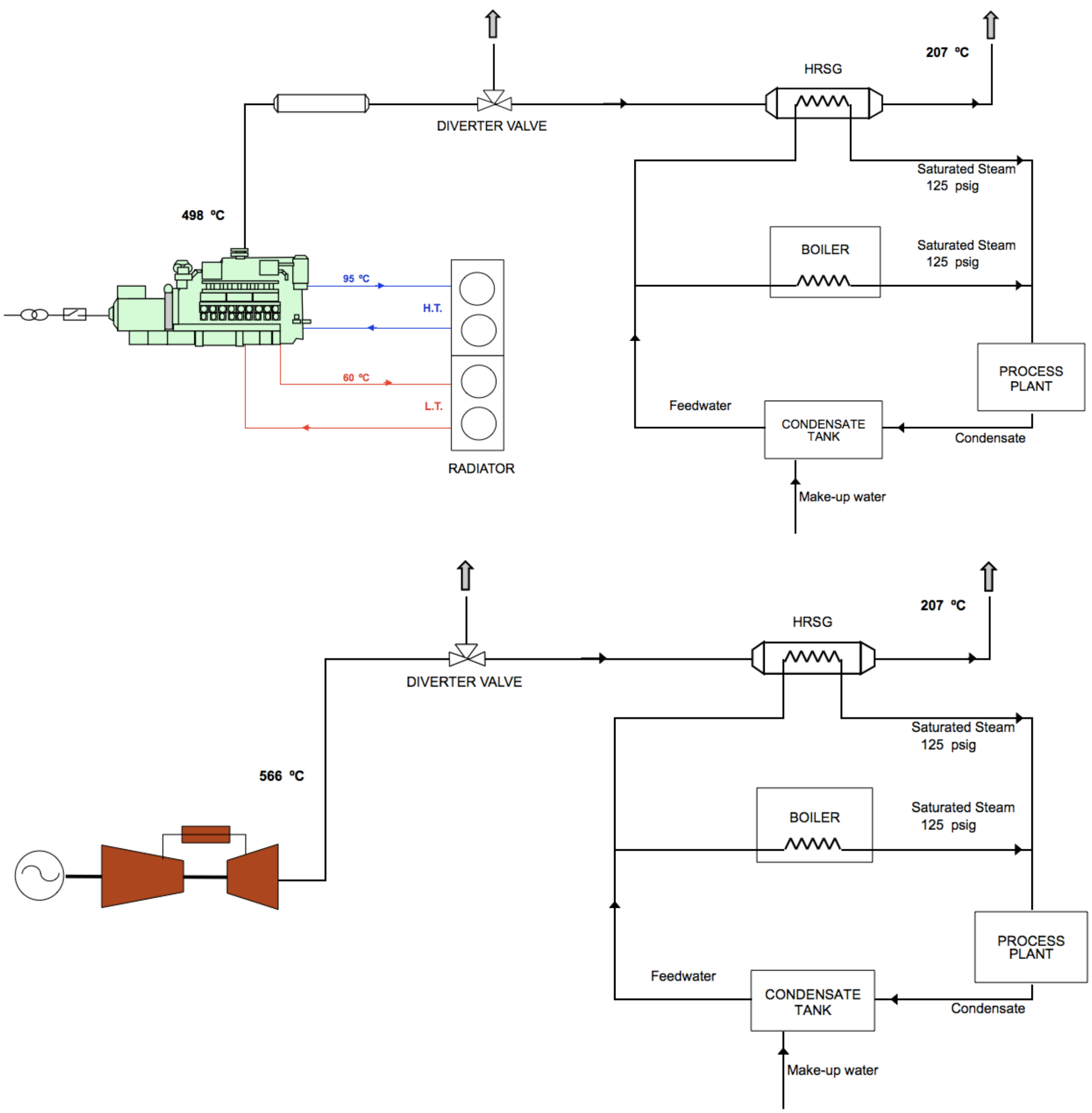
Regarding the possible scenarios for electricity generation and energy exchange to/from the grid, two options have been considered:

- ✓ **Electricity production for self-consumption.** All the electricity produced is consumed at the process plant. There is no surplus power sale. If the electricity demand surpasses the production, the difference is taken from the public grid.
- ✓ **Electricity production with surplus power sale.** In this case the production and sale of electricity in excess is allowed.

3.2 CHP plant selection

The choosing of natural gas or bunker limits the power generation technologies to the use of internal combustion engines or gas turbines. Process plant thermal needs limit the cogeneration possibilities to the addition of a HRSG for steam production from the exhaust gases of the power generation equipment. Figure 9 shows the two resulting possibilities.

Figure 9. CHP plant configurations



For the particular power generation equipment, four different models available in the market have been considered, which cover the spectrum of possible alternatives (see Table 7). Effective power of the equipment and the electricity consumption curve determine the production, required energy to be bought from the grid, and surplus power availability. Process variables for each option are obtained from mass/energy balances at average operation conditions.

Table 7. Selected equipment, operation characteristics, and energy flows

Parameter		Model 1 Engine (self-consum.)	Model 2 Engine (surplus)	Model 3 Turbine (self-consum.)	Model 4 Turbine (surplus)
Power (kWe)	ISO	2.200	5.200	2.000	5.670
	Effective	2.200	5.200	1.900	5.100
	Average	1.767	4.680	1.666	4.845
Heat Recovery Steam Generator (HRSG), average values	Flue gas flow (kg/s)	2,86	7,43	10,83	18,6
	Flue gas temperature (ºC)	412	395	280	510
	Recovered heat (kWt)	837	2.008	1.290	2.395
	Produced steam (lb/h)	2.721	6.530	4.196	7.790
Efficiency, based on LHV	Electric efficiency	41,10%	45,60%	32%	30,50%
	Cogeneration efficiency	60,60%	65,20%	56,80%	45,60%
	Effective Electric Eff., EEE	52,40%	58,30%	44,20%	36,60%
Electricity (kWh/mes)	Generation	1´290.191	3´416.400	1´216.336	3´536.850
	Surplus (for sale)	---	2´015.148	---	2´057.751
	Missing (to be bought)	266.756	155.695	340.611	77.847
	Used in process	1´556.947	1´556.947	1´556.947	1´556.947
	Saved in process	1´290.191	1´401.252	1´216.336	1´479.100
Thermal energy, based on HHV (MMBtu/mes)	Cogeneration savings	2.690	6.450	4.143	7.693
	Process fuel (to be bought)	5.410	1.650	3.957	407
	Generation fuel (to be bought)	11.736	28.008	14.184	43.344

* 90% and 95% availability assumed for engines and turbines respectively.

The fuel consumption savings in the process boilers caused by the recovered heat, together with the electricity production, represents an economical benefit from the CHP project. To quantify and compare the economical benefit relative to its energy cost, some indicators such as the cogeneration efficiency and the Effective Electric Efficiency (EEE) can be used (see Table 7). For the considered situation and the two analyzed scenarios (self-consumption and surplus power sale), both indicators suggest that internal combustion engines are more convenient than gas turbines. This, however, would not be true for a situation where the amount of steam required is much larger, as the gas turbines could be a better solution.

3.3 Comparative analysis for the studied countries

The comparative analysis studies the feasibility of the project by country (a function of the corresponding regulatory and commercial framework) for the *self-consumption* and *surplus power sale* scenarios, and the *internal combustion engine* option. The parameters used in the analysis are presented in Table 8.

Table 8. Parameters for the comparative analysis

Variable	Brazil	Colombia	Guatemala	Mexico	Nicaragua	Uruguay
Electricity cost (USD/MWh)	92,7	122,9	98,2	90,1	156,4	128,2
Surplus power price (USD/MWh)	63	57	58	56	98	61
Fuel cost (USD/MMBtu)	7,97	9,6	11,5	5,5	11,6	15,4
Inflation (% anual)	6,33%	3,87%	4,36%	3,77%	5,03%	7,99%
Income taxes (%)	25%	33%	25%	30%	30%	25%
VAT (%)	19%	19%	12%	16%	15%	22%
Import tariffs (%)	25,7%	0,0%	0,0%	5,0%	0,0%	14,0%
General incentives	PIS-CONFIS exemption	VAT exclusion	No incentives	No incentives	No incentives	Exemp. inc. tax (IRAE)
Surplus power sale incentives	Preferential price	No incentives	No incentives	No incentives	No incentives	No incentives
Electr. emission factor ($kgCO_2/kWh$)	0,0817	0,374	0,650	0,499	0,750	0,300
Fuel emission factor ($kgCO_2/MMBtu$)	59,19	59,19	81,66	59,19	81,66	59,19

Project costs include fuel, operation and maintenance, and capital costs. Income includes fuel and electricity savings, as well as surplus power sales. Savings related to reliability or quality of electricity supply, and income due to demand response mechanisms are excluded from the analysis. The evaluation performed takes into account the following criteria:

- ✓ CAPEX: USD 2'150.000 for self-consumption (56% Imported engine, 7% Imported HRSG, 37% Local Balance of Plant). USD 4'550.000 for surplus power sale (68% Imported engine, 6% Imported HRSG, 26% Local Balance of Plant).
- ✓ OPEX: 17 and 12 USD/MWh for self-consumption and surplus power sale respectively.
- ✓ For IRR calculation: 20 years evaluation period, 30% equity in dollars, 70% credit in dollars at a 10% annual rate (exchange rate effects not required).
- ✓ Electricity, fuel, and O&M prices indexed with inflation.
- ✓ Depreciation: 10 years with a zero final cost assumed for the equipment.

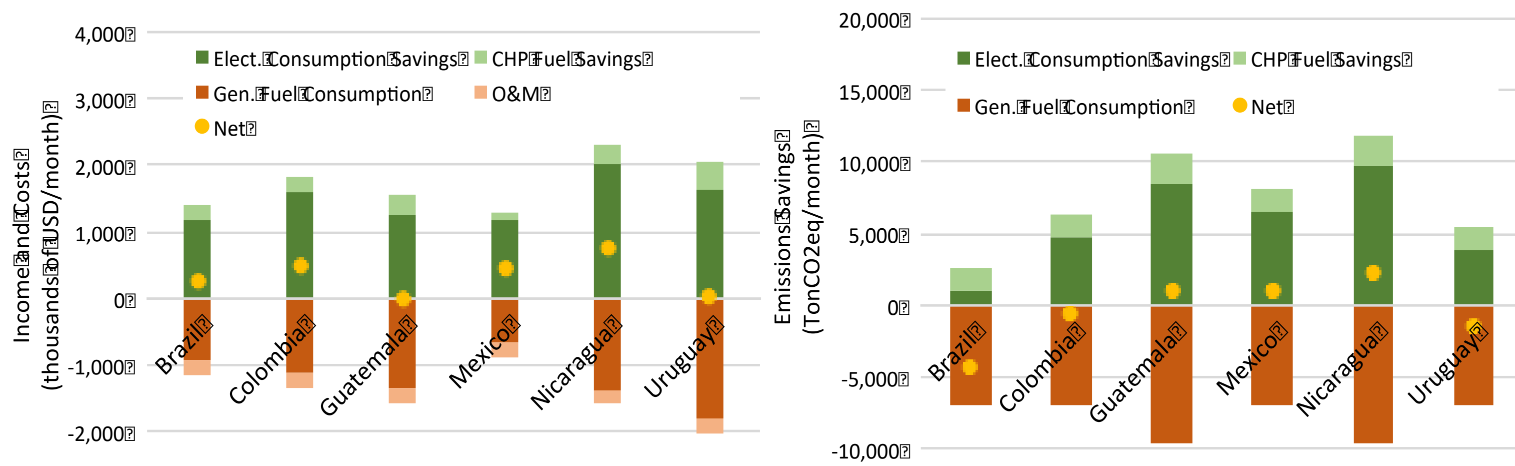
CHP incentives are evaluated for each country under the following three scenarios:

- ✓ **No Incentives:** project assumes full VAT, import tariffs, and income tax.
- ✓ **Current Incentives:** as indicated for each country in Table 8.
- ✓ **Maximum Incentives:** project exempt of VAT and import tariffs (for CAPEX calculation), and exempt of income tax for the first 5 years. Surplus power has a preferential price by 50% reduction in the transmission and distribution charges.

3.3.1 Scenario 1 - Electricity production for self-consumption

As shown in Figure 10, countries with expensive electricity and a high electricity-to-fuel price ratio have an advantage in terms of energy income and costs for the project. At the other side emissions savings depend on the emission factors both of public grid and fuel, and may even be negative in some countries.

Figure 10. Economical and environmental analysis results – self-consumption scenario



Financial evaluation for each of the incentives scenarios and countries (see Table 9) shows that, under the assumed conditions, the project is feasible for Brazil, Colombia, Mexico and Nicaragua. For Guatemala and Uruguay, project revenues are very low to make it viable.

Tabla 9. Financial evaluation for the project

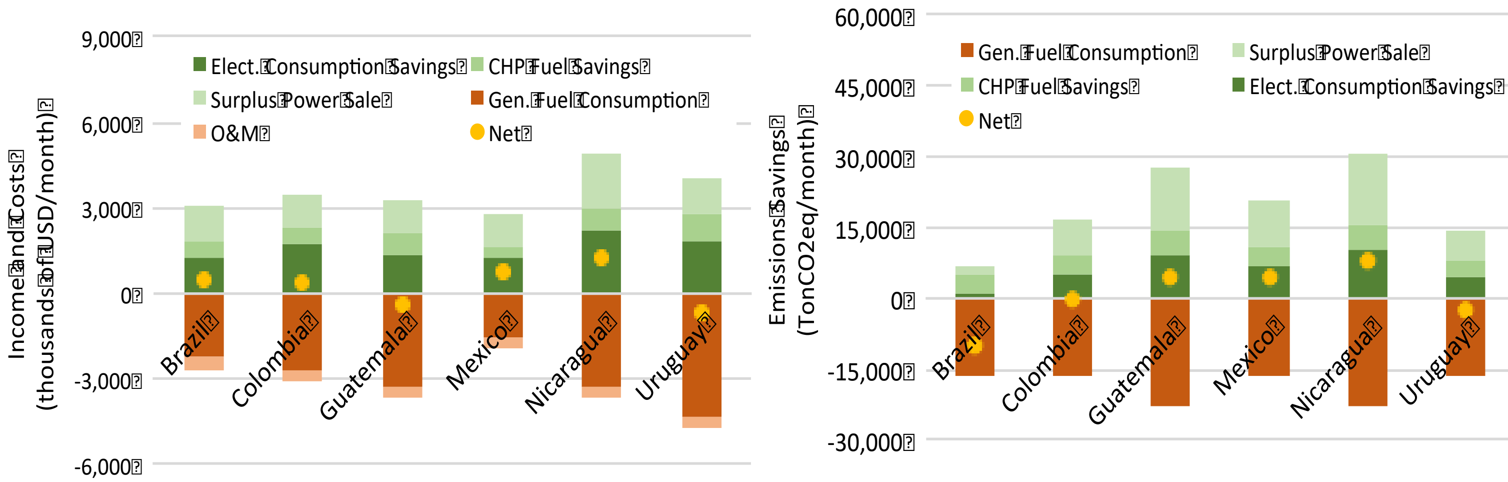
Scenario	Concept	Brazil	Colombia	Guatemala	Mexico	Nicaragua	Uruguay
No Incentives	Total CAPEX (USD)	2.972.700	2.558.500	2.408.000	2.572.500	2.472.500	2.854.300
	Simple Payback (Years)	9,69	4,28	273,20	4,81	2,75	57,17
	IRR (10% credit rate)	16,1%	43,6%	---	39,0%	77,2%	---
Maximum Incentives	Total CAPEX (USD)	2.150.000	2.150.000	2.150.000	2.150.000	2.150.000	2.150.000
	Simple Payback (Years)	7,01	3,60	243,93	4,02	2,39	43,06
	IRR (10% credit rate)	27,0%	61,3%	---	54,0%	100,0%	-14,2%
Current Incentives	Total CAPEX (USD)	2.784.100	2.150.000	2.408.000	2.572.500	2.472.500	2.854.300
	Simple Payback (Years)	9,07	3,60	273,20	4,81	2,75	57,17
	IRR (10% credit rate)	18,1%	54,6%	---	39,0%	77,2%	---
	IRR (7% credit rate)	21,6%	58,1%	---	42,4%	81,0%	-13,8%
	IRR (4% credit rate)	24,6%	61,2%	---	45,5%	84,5%	-9,1%

The difference between the results without incentives and maximum incentives is significant, with a simple payback that is reduced between 15% and 40%, and an IRR that increases between 30% and 70%. Mexico, Nicaragua and Guatemala don't have applicable incentives, so the scenario without incentives is the same as the current one. Additionally, for the current incentives scenario, IRR was modeled with interest rates of 7% and 4% for the credited portion of the CAPEX, in order to see the effect of a subsidized loan rate.

3.3.2 Scenario 2 - Electricity production with surplus power sale

Similar to the latter case, the net income of the project for the surplus power sale scenario depends on the electricity and fuel prices, and the emissions savings depend on the corresponding emission factors (see Figure 11).

Figure 11. Economical and environmental analysis results – surplus power sale scenario



In this case, a preferential price was assumed for the surplus power under the maximum incentives scenario. This is calculated by assuming a 50% discount in the transmission and distribution charges, after taking into account a 5% for commercialization. Among the studied countries, only Brazil has current incentives to the sale of surplus power (see results Table 10).

Table 10. Financial evaluation for the project

Scenario	Concept	Brazil	Colombia	Guatemala	Mexico	Nicaragua	Uruguay
No Incentives	Total CAPEX (USD)	6.291.200	5.414.500	5.096.000	5.444.200	5.232.500	6.040.600
	Income (1000s USD/month)	44,0	39,1	-34,4	79,5	125,6	-70,4
	Simple Payback (Years)	11,91	11,53	---	5,70	3,47	---
	IRR (10% credit rate)	10,0%	4,0%	---	31,1%	58,1%	---
Maximum Incentives	Total CAPEX (USD)	4.550.000	4.550.000	4.550.000	4.550.000	4.550.000	4.550.000
	Income (1000s USD/month)	69,3	99,3	1,1	109,4	176,5	-9,2
	Simple Payback (Years)	5,47	3,82	337,03	3,47	2,15	---
	IRR (10% credit rate)	35,1%	48,9%	---	65,2%	110,4%	---
Current Incentives	Total CAPEX (USD)	5.892.000	4.550.000	5.096.000	5.444.200	5.232.500	6.040.600
	Income (1000s USD/month)	69,3	39,1	-34,4	79,5	125,6	-70,4
	Simple Payback (Years)	7,09	9,69	---	5,70	3,47	---
	IRR (10% credit rate)	26,7%	10,1%	---	31,1%	58,1%	---
	IRR (7% credit rate)	30,2%	14,6%	---	34,4%	61,6%	---
	IRR (4% credit rate)	33,3%	18,5%	---	37,4%	64,8%	---

Project is financially viable in Brazil, Colombia, Mexico and Nicaragua, with simple payback reduced between 40%-70% for the maximum incentives scenario when compared to the current incentives one. Additionally, for the current incentives, IRR was modeled with interest rates of 7% and 4% for the credited portion of the CAPEX, to see the effect of a subsidized loan.

4 Opportunities, barriers, and challenges for CHP in the region

Several types of barriers exist in almost all countries studied. They are expressed to a greater or lesser extent depending on each case and even some of them have been already identified and addressed through public strategies. In general, they have a very diverse nature and can be roughly classified as follows:

- ✓ Policy, legal, and regulatory
- ✓ Financial, economic, and market
- ✓ Information
- ✓ Technical skills and human resources
- ✓ Sociocultural

The challenges and opportunities for CHP are mainly focused in the creation of strategies to promote its diffusion and the development of technology in the markets with greater potential. It is worth mentioning the following:

- ✓ Increase of technical capacities through training programs and experiences exchange.
- ✓ Generation of specific regulation dedicated to CHP and addressing market imperfections related to electricity and fuel prices.
- ✓ Promotion of cogeneration through public purchases.
- ✓ Implementation of regulation for the requirement of CHP feasibility studies.
- ✓ Granting benefits to the efficient use of energy resources.
- ✓ Creation and access to innovative financing instruments.
- ✓ Development of industrial complexes on which thermal and electrical energy can be commercialized with nearby consumers.

4.1 Barriers and opportunities by country

For this section, several interviews were conducted to representative entities at each country, which was supplemented with secondary sources. It is pointed out that the data collection performed was not intended to be exhaustive, so that the national landscapes presented in Table 11 are by no means complete and only include aspects that appeared during the exercise.

Table 11. Barriers and opportunities by country

Barriers	Opportunities
Brazil	
✓ Lack of adaptation to regulatory strategies and recent incentives. ✓ High-risk perception due to past legal	✓ Most opportunities associated to sugar sector. ✓ Development potential for natural gas, black liquor, and biomass from agro-industries like

Barriers	Opportunities
instability in the electricity sector. ✓ Complex price structure. ✓ Fuel prices very dependent on project location. ✓ Uncertainties in long-term fuel supply. ✓ Insufficient awareness of CHP technology and business by some stakeholders. ✓ Low priority for energy efficiency investment.	palm oil, rice husk and cashew nuts. ✓ High knowledge of CHP technology with biomass. ✓ Long-term policies for renewable sources. ✓ Incentives specially directed to CHP, recognizing its particularities. ✓ Existence of an association dedicated specifically to CHP.
Colombia	
✓ Lack of recognition of CHP in the regulatory framework. ✓ Electricity tariffs very influential in viability of projects. Uncertainty about long-term stability. ✓ Natural gas tariffs very dependent on geographical location. ✓ CHP with biomass is focused on the sugar sector and is subject to its dynamics. ✓ Insufficient knowledge at different levels. ✓ Difficulty finding new projects. ✓ Lack of CHP-specific engineering knowledge. ✓ Low priority for energy efficiency investment. ✓ Resistance to the entry of third parties for project execution.	✓ Development potential in the sugar, palm oil, and industrial sectors. ✓ Incentives for projects using renewable energy sources and CHP in industries.
Guatemala	
✓ There is no specialized regulation for CHP or intermittent/seasonal generation technologies. ✓ Difficulties for obtaining licenses and meeting regulatory requirements. ✓ The current electric oversupply creates low tariffs and makes surplus power sale difficult. ✓ There are no incentives or tariff structures that internalize the benefits of CHP. ✓ CHP using fuels other than biomass not viable ✓ There is need for development and technification of plants in the sugar sector. ✓ Influence of ethnic communities on the granting of licenses.	✓ Strength of the sugar cane sector, which uses CHP extensively ✓ Existence of an association dedicated specifically to CHP. ✓ Possibilities for the incorporation of other fuels different to cane bagasse. ✓ Possibilities for optimization of existing plants and implementation of some complementary processes. ✓ Coal-based cogeneration in out of zafra times. ✓ Surplus power sale is representative for sugar sector ✓ Important contribution of cogeneration to the national electricity mix.
México	
✓ Lack of independence for investment decisions in the public sector. ✓ Resistance of companies to invest in CHP and energy efficiency.	✓ Recognition of the strategic importance of CHP in national policies. ✓ Existence of instruments that recognize CHP particularities.

Barriers	Opportunities
✓ Lack of technological renovation in existing CHP plants. ✓ Lack of recognition to the importance of CHP. ✓ Dependence on government will for the application of strategies and benefits ✓ Complexity of procedures for licenses, benefits and incentives. ✓ Limited access to fuels due to insufficient natural gas infrastructure and high dependence on subsectors for the biomass. ✓ Necessity of greater diffusion of CHP with a more specific emphasis.	✓ Development of national strategies such as NAMAs in cogeneration. ✓ Existence of an association dedicated specifically to CHP. ✓ Potential for the development of CHP projects using biomass. ✓ Possibilities of additional income for the CHP plants by participating in complementary markets such as energy markets, power balance, alternative services, and Clean Energy certificates. ✓ Good instruments and high number of opportunities for access to financing.
Nicaragua	
✓ Unstable political context. ✓ Most CHP systems associated to sugar cane sector, which show no expansion trend. ✓ It is difficult to obtain new projects and qualified personnel. ✓ Limited information divulgation. ✓ Low development level for supply chain. ✓ Difficulties for accessing to financing. ✓ CHP is not specifically considered in the regulatory framework.	✓ Most CHP systems associated to sugar cane sector, which have good performance for biomass production. ✓ Policies to encourage investment and generation with renewable sources. ✓ CHP is an important contributor to the electricity mix.
Uruguay	
✓ Necessity to have a specific regulatory framework for CHP. ✓ The negotiation of electricity tariffs must be done freely, letting market conditions affect prices. ✓ Investor uncertainties about the solidity of the projects in the long term. ✓ Limited fuel availability due to lack of natural gas infrastructure. ✓ Availability of personnel with engineering knowledge, but not specialized in CHP. ✓ It is difficult to find new project or markets opportunities. ✓ Prioritization of investments needs other than energy efficiency. ✓ Users are not always willing to implement system changes to their process plants.	✓ Planned improvements are projected to the regulatory framework in order to include CHP specifics. ✓ Existence of incentives applicable to CHP. ✓ Connection charges and fees exemption for nodes with dual offer/demand features. ✓ Potential of new project development in the cement, dairy, pulp and paper, refrigeration, hotels, and health subsectors. ✓ Posibility to sale thermal energy from CHP systems, given the proximity of certain potential users.

4.2 Political landscape related to COP21 commitments

Most of the six countries examined under this study, considered the energy sector as a priority (see Table 12) and defined measures for the promotion of renewable energy, energy efficiency, and the reduction of contaminating gases in power generation processes. In general, the outlook is favorable for the cases where biomass is used as fuel. In particular, two countries (Mexico and Colombia) have included specific commitments related to CHP on their NDCs.

Table 12. COP21 energy-related commitments for the studied countries

Brazil	Mexico
Worth mentioning is the goal of reaching 45% renewable energy in the energy mix by 2030, including: ✓ The expansion in the use of renewable energy sources different from hydroelectricity. ✓ The expansion in the use of non-fossil fuel energy and the increase of biomass. ✓ Reaching improvements of 10% in the efficiency of the electric sector by 2030.	Importantly, the industrial and energy sectors are involved in the commitments through: ✓ 35% Electricity production from clean energy by 2024 and 43% by 2030. ✓ Substitution of heavy fuels for natural gas, clean energy and biomass in the industry. ✓ Control of particulate material in industrial equipment and installations.
Colombia	**Nicaragua**
For the fulfilling of the country goal a plan was created for the electric sector (in Spanish "Plan de Acción Sectorial – Energía Eléctrica"). One of the driving policies of such a plan is *the promotion and active participation of the demand side (self-generation, cogeneration) in the National Electric System*, which considers the creation of special legislation for such objective.	Establish the goal of increasing up to 60% the percentage of electric generation from alternative renewable sources like solar, wind, an biomass by 2030, which also includes the increase on coverage.
Guatemala	**Uruguay**
To reach the country goal, the following mechanisms oriented to the energy sector have been proposed: ✓ The increase on the participation of renewable sources to the electricity production. ✓ Energy efficiency. ✓ Incentives for the development of renewable energy projects. ✓ Technical standard for the connection, operation, control, and commercialization of energy from renewable sources and surplus power.	The following strategies, oriented to the energy sector, are important: ✓ The increase by 2025 of the electricity production from biomass, both to deliver to the grid (160 MW) and for self-consumption (250 MW). ✓ Changes to the high voltage transmission lines to hold the decentralized electricity production from renewable sources.

4.3 Development instruments

Development instruments for CHP can have different objectives and be oriented in various directions (see Figure 12). The specific design of an instrument depends on them.

Figure 12. Design considerations for development instruments

Diversity of objectives:	Different ways:
✓ To facilitate the creation of technical skills ✓ To reach higher divulgation levels ✓ Incentivize the development of a market niche or a business model ✓ To increase profitability of projects	✓ *Support to the investment*: the most indicated when difficulties for capital access are present or there is no atractive investment return. ✓ *Support to the operational stage*: can be used to internalize the benefits of a CHP project or to address market imperfections. ✓ *R+D investment*: can support the industry to develop solutions for sustainability of energy systems.

Furthermore, development instruments can take different particular forms, including:

1. *Fiscal incentives*: aimed at reducing both the operation and implementation costs of CHP projects. They can be applied as:

- ✓ Exemption to importing tariffs
- ✓ Exemption to VAT
- ✓ Accelerated depreciation to CHP investments
- ✓ Income tax benefits
- ✓ Other tax benefits, depending on the fiscal system of each country

2. *Subsidies*: facilitate the implementation of CHP systems when investment barriers or capital restrictions are present, or when new technologies are entering the market. For this type of instrument to be successful, there must be a good mechanism to find the users really needing the subsidy.

3. *Special tariffs*: they directly affect the operating costs of projects, acting on electricity or fuel prices. Some of its most common forms are:

- ✓ Feed-in Tariffs – FiT: which considers a special price for the electricity injected to the grid that was produced by non-conventional energy sources.
- ✓ Backup power price: it helps to reduce operational costs, if lowered to CHP projects.
- ✓ Net metering: favors electricity consumers that are also producers, by charging them only the difference between the consumed and the injected power.

- ✓ Natural gas price: it is possible to reduce the natural gas cost for CHP plants by lowering fuel taxes.

4. *Certificates*: can be designed to serve as (i) image incentives on which companies are recognized as efficient or greener, (ii) generation of additional income through the negotiation of certificates or (iii) allowing the access to benefits according to a certain classification system.

5. Facilities to exchange electricity with the public grid: there are three main measures to make the exchange of energy with the grid easier:

- ✓ ***Clear connection standards,*** defined respect to the technical requirements and paperwork.
- ✓ ***Preferred access,*** for CHP plants to have priority when dispatching electricity to the grid.
- ✓ ***Incentives to grid operators***, so that they don't experience economic losses when connecting CHP plants.

For this type of instruments to be successful, it is necessary to work hand in hand with the main actors, so that the designed schemes are beneficial to them. Furthermore, it is important to develop standards considering all elements of the interconnection process, make sure that the processes and associated costs are the right ones for the size of the generators, and constantly monitor the effectiveness of the instruments.

Conclusions

Cogeneration projects can be classified in two types according to the fuel they use: fossil fuel-based and biomass-based. The latter can easily access to incentives designed for renewable energy projects, the former, instead, need incentives specifically directed to cogeneration. For the six countries studied in this project, there is a significant potential for cogeneration, however, most experience is focused on biomass systems, which constraints in some way the development of cogeneration projects based in fossil fuels.

For all countries the cogeneration is regulated by dispositions designed to the traditional energy sector. There is specific regulation for cogeneration, with various levels of complexity, in Brazil, Colombia, Mexico, and Uruguay. However, countries like Guatemala and Nicaragua have a very incipient specific regulation in that matter.

Given that any cogeneration project is subject to the particular national macroeconomic conditions as well as to the availability and applicability of technologies, some countries are naturally more beneficial to them. To modify this, and make projects feasible even under disadvantageous circumstances, incentives are the type of instrument that are more often successful. The six countries analyzed have incentives directed to promote renewable energy, where biomass-based cogeneration projects can find an opportunity. However, there is a lack of a broader type of promotion instruments, covering other systems and helping its development, as well as contributing to the countries' environmental goals. It is worth noting that Brazil is the only country with an incentives system specifically directed to the cogeneration, which particularly favors the sale of surplus power while recognizes the importance of cogeneration as a distributed generation strategy.

In general terms the incentives found in the region are very standard and similar respect to the lowering of import, VAT, and income taxes. They are designed to motivate capital investment instead of trying to encourage the power production itself, and for that, do not address the specific features of CHP systems. To this respect, it would be important to extend this study to evaluate the incentives applied in other countries around the world and consider them for Latin America.

Even when there are particular barriers on each considered country, almost all of them present common factors like the instability in the supply and price of fuels, which creates long-term uncertainty and modifies the viability of projects. At the same time, there is a common need to have specific regulatory frameworks favoring the sale of surplus power and promoting the internalization of the environmental benefits of cogeneration. Additionally there are deficiencies with information divulgation that are translated into lack of knowledge about the technology and the difficulty to execute new projects. Finally, there are in general sociocultural conditions related to the lack of trust, which block the necessary association with third parties.

Generally speaking, there is an interesting cogeneration potential through the region, which could be developed in the future, as the market has not been completely exploited. Furthermore, it is important that the studied countries have all considered the energy sector within their strategies to comply with emission reduction plans, where cogeneration can play an important role. It is expected that countries create new policy instruments to reach their goals, which could advance the regulatory framework for cogeneration.