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The potential of natural gas use including cogeneration in large-sized industry and commercial sector in Peru

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HIGHLIGHTS

- ▸ This paper presents future scenarios for the use of natural gas in the large-sized industrial and commercial sectors of Peru.
- ▸ The potential use of natural gas is calculated through nine different scenarios.
- ▸ The scenarios were based on different hypotheses on developments in the natural gas industry, national economic growth, energy prices, technological changes and investment decisions.
- ▸ We estimated the market potential and characterized the energy consumption, and made a selection of technological alternatives for the use of natural gas.

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ABSTRACT

In recent years there have been several discussions on a greater use of natural gas nationwide. Moreover, there have been several announcements by the private and public sectors regarding the construction of new pipelines to supply natural gas to the Peruvian southern and central-north markets. This paper presents future scenarios for the use of natural gas in the large-sized industrial and commercial sectors of the country based on different hypotheses on developments in the natural gas industry, national economic growth, energy prices, technological changes and investment decisions. First, the paper estimates the market potential and characterizes the energy consumption. Then it makes a selection of technological alternatives for the use of natural gas, and it makes an energetic and economic analysis and economic feasibility. Finally, the potential use of natural gas is calculated through nine different scenarios. The natural gas use in cogeneration systems is presented as an alternative to contribute to the installed power capacity of the country. Considering the introduction of the cogeneration in the optimistic–advanced scenario and assuming that all of their conditions would be put into practice, in 2020, the share of the cogeneration in electricity production in Peru would be 9.9%.

1. Introduction

In the past few years, the widespread use of natural gas as a source of energy has been a hot topic of discussion in Peru; this was part of the agenda during the presidential debates in early 2011. During these debates, the importance of developing a domestic demand for natural gas rather than gas exports was the central theme of discussion. Since 2010, specially, with the new government there have been signs to set the energy policy guidelines aimed at prioritizing the domestic market for natural gas: the formation of a committee devoted to earmarking part of the gas reserves committed to export for use in the domestic market, pipeline construction projects in the south and north of the country, and commitments to expand gas distribution networks, among others (Gestión, 2011a).

The final energy consumption in Peru has been increasing since 1993, over the past 5 years the average annual growth rate was 4.2%. In 2009, final energy consumption was 605,075 TJ (MEM, 2009). The transportation, residential, and industrial–commercial sectors are the largest consumers of energy which represent 37.8%, 24.4% and 21%, respectively. In 2009, the highest final energy consumption was diesel (28.4%), followed by electricity (17.7%), firewood (12.4%), gasoline (8.6%), LPG (7.8%), natural gas (5.3%), residual oil (5.1%), kerosene (4.6%), coal (4.1%) and others (6%).

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According to MEM (2009), the energy reserves were 26,471,441 TJ. Natural gas being the largest reserve (45.12%), followed by hydropower (22.54%), natural gas liquids (13.16%), petroleum (11.65%), coal (4.21%) and uranium (3.32%). Although natural gas is the largest reserve, the country has a dependency on energy imports. In recent years, the imports represent on average 30% of the energy supply. In 2009, the largest energy imports were petroleum (73.9%) and diesel (13.3%).

According to the DGE (2010), the peak demand in the Peruvian electricity market was 4322 MW. In the past seven years the demand has increased by 5.9% per year and the power generation has increased by 4.5% per year as well. The greatest growth of power generation has come through thermoelectric plants; mainly because of the great supply of natural gas from Camisea and because investors prioritized this type of technology due its lower initial investment and shorter return on capital. Currently, the power generation in Peru is 43% hydraulic and 57% thermal (DGE, 2010). Regarding the production of electrical energy, in 2000, the participation of the hydraulic generation was 85% and, in 2009 it was 60%.

The residential sector is highly dependent on energy such as firewood, electricity and LPG; in 2009 these accounted for 45.49%, 28.39% and 17.06% of the total consumption, respectively.

In the industrial and commercial sector, the sources of energy used are electricity (32.3%), diesel and residual oil (28%), coal (15.9%), natural gas (15.3%), LPG (8%) and others (0.5%). The use of natural gas in this sector has potential for a wider use, especially as a replacement for fuels such as residual oil, diesel and LPG. Moreover, together with fuel switching projects there is an opportunity to put in place more efficient technologies such as cogeneration, which represents an alternative to lower production costs and still have the ability to selling electricity.

In the literature review there are papers related to the estimate of the potential use of natural gas in industry and commerce. Lemar (2001) estimated the impact of public policies and incentive programs for use of cogeneration in the US industry. Basically the study considers two types of fuel, natural gas and biomass. It also takes reference from penetration factors obtained during the introduction of this technology in the US with Public Utility Regulatory Policies Act (PURPA). Soares et al. (2004) estimated the technical and economic potential of cogeneration in Brazil's chemical industry using natural gas as fuel. Also, it analyzes the impacts of incentive policies on the economic viability of this potential. Szklo et al. (2004) estimated the technical potential for gas fired cogeneration in Brazilian hospitals: an initial work to characterize the energy consumption in hospitals according to their size and level of comfort was carried out. Schwob et al. (2009) estimated the technical potential of natural gas use in the Brazilian ceramic industry focusing on replacing fuel wood for natural gas, including cogeneration.

This paper presents future scenarios for the use of natural gas in large-sized industry and commercial sectors in Peru, based on different hypotheses on developments in the natural gas industry, political policies and national economic growth, energy prices, technological changes and investment decisions.

Section 2 of this paper is an introduction to the natural gas industry in Peru and future pipelines. Section 3 presents the methodology used in this study, including the scenarios analyzed. Section 4 presents the results of the study. Section 5 presents the conclusions.

2. Natural gas in Peru

The natural gas industry in Peru is relatively new. By 2004, production was just in Talara (Noth west) and Pucallpa (Amazonian), and the natural gas was mainly used as fuel for electricity generation. Between 1983 and 1987 in Camisea, north of Cuzco, the largest natural gas reserves in the country were discovered. In 1988, Peru signed the first agreements to develop the natural gas found in Camisea. However, in 1998, the consortium Shell/Mobil announced its decision to discontinue the Camisea project. In 1999, the Peruvian government opened an international bidding for production of the Camisea project, and concessions of transportation and distribution of natural gas in Lima and Callao. In 2000, were awarded the stages of production, transportation and distribution of Camisea (Gonzales and Nebra, 2004a).

In 2004, the operation of the Camisea Project was initiated. In 2009, the share of natural gas in final energy consumption was 5.3% (32,198 TJ). However, according to DGH (2010) the audited production of natural gas was 129,304 TJ in the same year. The natural gas was used mainly for electricity generation (70.7%) and in the industrial sector (21.6%).

Fig. 1 shows the existing and future gas pipelines routes in Peru. The Camisea gas pipeline is 729 km long and an initial capacity of 8.5 Mm^3/day, which was extended to 12.8 Mm^3/day (GFGN, 2009) at the end of 2009. In addition to the natural gas of Camisea, natural gas liquids are being transported through a pipeline of 548 km from Camisea to Pisco. In 2010, for the natural gas export project, the operation of a gas pipeline of 408 km long and a capacity of 17.6 Mm^3/day was started (GFGN, 2010). Currently, the construction of a pipeline and a distribution network in Ica are being planned-approximately a 260 km long high pressure gas pipeline with branches that amount 74 km of distance. On the other hand, there is the proposed Kuntur gas pipeline project that will supply natural gas in the regions of Cuzco, Puno, Arequipa, Moquegua and Tacna; the project will involve building a pipeline of 1071 km. Finally, there is a proposed Centro–Norte gas pipeline project that would supply natural gas in the regions of Ayacucho, Junin, Ancash and La Libertad.

3. Methodology and scenarios

To estimate the use of natural gas in large-size industrial and commercial sectors requires a calculation methodology that considers the alternative technologies, regulations, efficiency and economic feasibility of converting the current energy generation process into one that has natural gas as fuel.

In the first part, the model internalizes economic growth and geographical location for future investment in the Peruvian natural gas industry (in this paper, this variable will be internalized by the activity level-AL). In the second part, the model internalizes the patterns of consumption and end use of energy, substitution of current fuel to natural gas with different technological alternatives and penetration factors (in this paper, this variable will be internalized by energy intensity-EI). The final equation for calculating energy consumption will be:

$$\text{Energy Consumption} = \sum_{i=1}^{i=n} \text{AL}_i \times \text{EI}_i$$

Fig. 2 shows an overview of the methodology used in this study.

3.1. Estimating market potential

The number of potential applications using natural gas in large-sized industry and commercial sectors depends on the natural gas supply, number of firms, size and energy consumption.

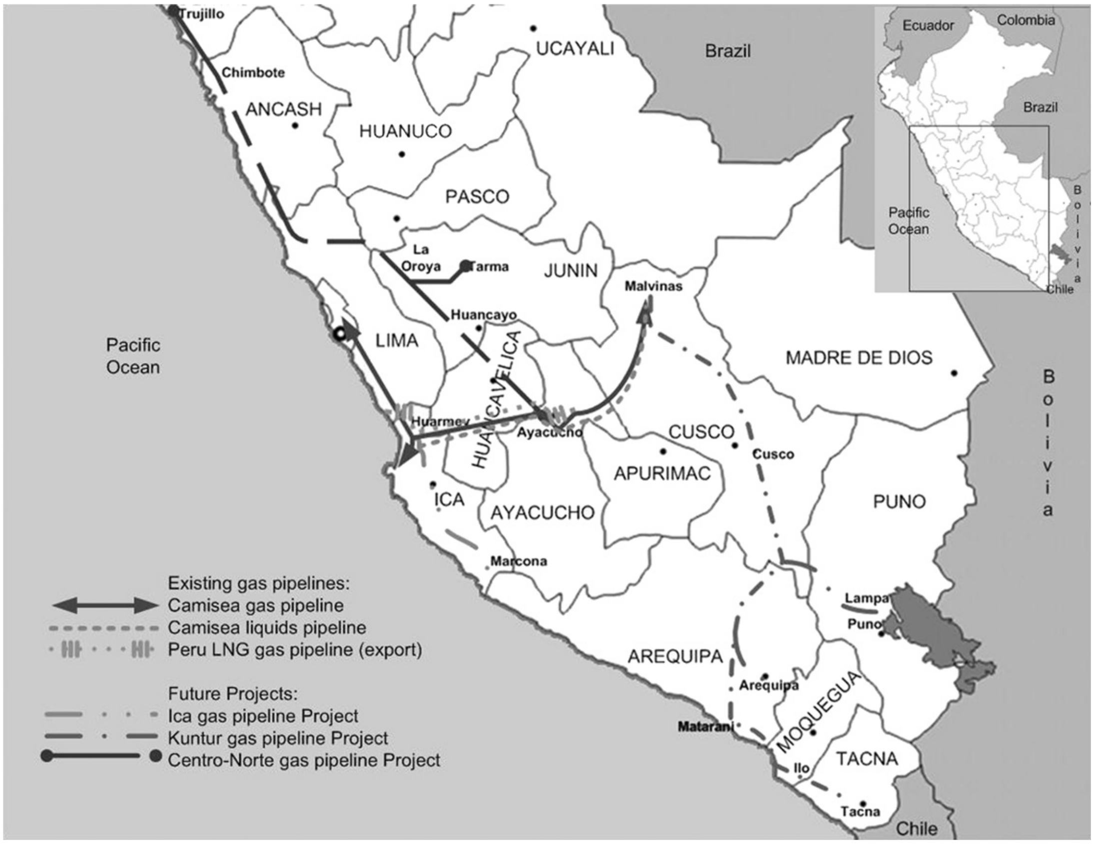

Fig. 1. Existing and future gas pipelines route in Peru.

To estimate the supply of natural gas in 2011–2020, current and future projects of gas pipelines and natural gas distribution networks are considered. Basically, four geographic areas of natural gas supply will be taken into consideration: (a) Lima and Callao region, (b) Ica region, (c) Kuntur: regions of Cuzco, Puno, Arequipa, Moquegua and Tacna, (d) Centro–Norte: regions of Ayacucho, Junín, Ancash and La Libertad.

In this paper the following industrial sectors are considered to be the most important ones for the potential use of natural gas: food, beverages, cement and ceramics, paper, textile, glass and plastics, chemical–pharmaceutical and fishing processing. On the other hand, the following are considered to be among the most important ones in the commercial sector: Hospitals, shopping centers, supermarkets and hotels.

The field research consisted mainly in collecting data on the total number of public and private companies or institutions and their size. To classify the industries, it was necessary to use data of type, size and production of various industrial facilities, which were obtained from the SNI (2009) and supplemented with information from their websites. In some industries, however, due to the limited information available, their electricity consumption data were used as a standard for comparison; this information was published by the Osinergmin (2010). In the case of the food and beverage industry, the classification was made based on their size and number of products produced. In the cement, ceramics, paper and fishing industries, their size and annual production were used as parameters. The chemical–pharmaceutical industry was classified by their size. Finally the electricity consumption was used to classify the textile, glass and plastic industries.

To classify Hotels, only 4 and 5 stars hotels were considered. These were classified primarily by the number of rooms, which is given by the SHP (2010). In order to classify the shopping centers, data gathered by the ACCEP (2010) were used; considering the number of visits and sales per year. The supermarkets classification was made according to their size and number of existing stores. Data from the publication of DIA 1 (2011) were used. Data from the ESSALUD (2010) and the ACP (2010) were used to classify hospitals according to their size, number of existing doctors and specialties.

The characterization of energy consumption was done based on the industrial and commercial classification, and fuels and electricity consumption data published by Cenergia (2006), MEM (2008) and Osinergmin (2008–2010). Table 1 shows the quantity, classification and characterization of large-sized industrial and commercial sectors.

3.2. Selection of technological alternatives

Energy consumption in the large-sized industrial and commercial sectors is designed to meet the electrical and thermal demands. Then, the natural gas potential consumption depends on the chosen alternative technology available for use. This alternative could be either meeting the thermal demand or meeting the electricity and thermal demand.

In order to meet the thermal demand, the conversion of boilers or heaters that use diesel, residual oil or LPG into boilers that use natural gas (CBCNGU) is considered. In this alternative, in the case of supermarkets and shopping centers, it has been considered to change their electric chillers for double-effect absorption refrigeration system to natural gas for the cooling production.

To meet both electrical and thermal demand, the use of cogeneration systems has been considered. Depending on energy needs, the cogeneration system may consist of a prime motor for power generation, a heat recovery steam generator (HRSG) for heat production, and an absorption refrigeration system (ARS) for

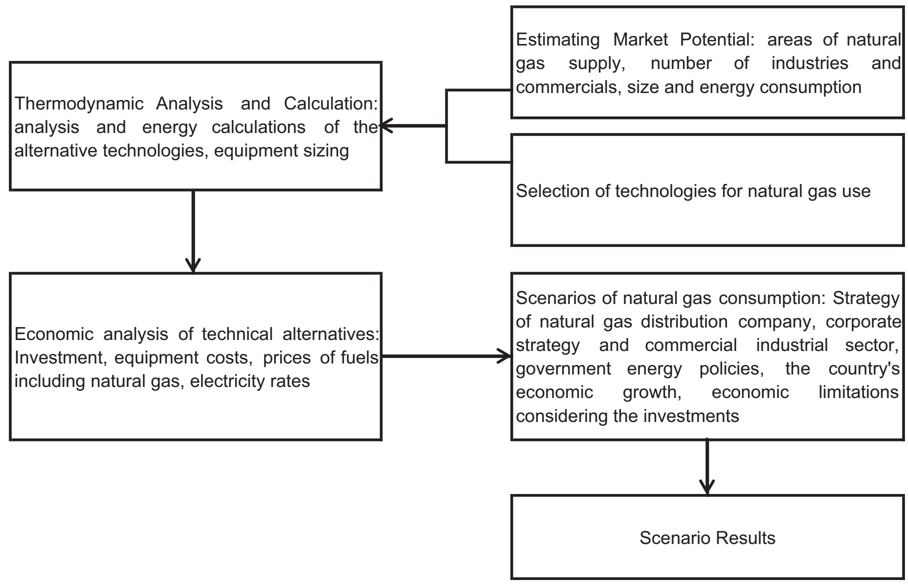

Fig. 2. Overview of the methodology used in this study.

cooling production. The prime motor may be a reciprocating engine (RE), a gas turbine (GT) or a steam turbine (ST). In order to choose a type of prime motor, we can either use the power-to-heat ratio (Soares et al., 2004) or the heat-to-power ratio (Conae, 1999). Here, we use the heat-to-power ratio to define the type of prime motor we need. If the ratios are 2–30 a ST is used, if the ratios are 1.2–4 a GT is used and finally if the ratios are 0.8–2 a RE is used. The overlapping of ranges of various types of technologies is due to the fact that the power-to-heat ratio is important, but not decisive in the choice of prime motor. The choice of the cogeneration system will also depend on factors such as quality of thermal energy needed, load patterns, fuels availability, system reliability, grid dependent system versus independent system, retrofit versus new installation, electricity buy-back, and local environmental regulation. The final decision, however, may vary depending on the economical evaluation results.

3.3. Thermodynamic analysis and calculation

The energetic analysis uses the power and heat consumption data presented in Table 1. The technical solutions considered three alternatives for the investor to decide:

Alternative 1: Supply the demand for heat or cooling by switching the current fuel to natural gas;
Alternative 2: Use of a cogeneration system designed on base power load. If a bigger heat production is needed, supplemental natural gas burning shall be used;
Alternative 3: Use of a cogeneration system designed on base heat load with the possibility of sell surplus electricity.

Cogeneration reduces losses in the transmission and distribution grid. It can also provide important services such as the distribution of extra electricity when it is needed, improving the quality of energy supply (Hinnells, 2008).

For the calculation of the technological solutions, the energetic analysis will be used to evaluate the best technical alternative and the size of the equipment. To accomplish this, a model based on the first law of thermodynamics was made for each of the different alternatives; these models were similar to those presented by Gonzales and Nebra (2004b) and Gonzales and Nebra (2005), which considers RE and GT with combinations of other equipment such as HRSG and ARS. The model was developed in EES software (EES, 2011). The performance of RE and GT was introduced by the load percentage for each proposed solution. For RE, manuals from manufacturers such as (Cummins, 2010) and (Waukesha-Dresser, 1999) were used. For GT, manuals from manufacturers such as (Siemens, 2009) and (Solar Turbines, 2009) were used. The efficiency gained by converting the existing boilers that use residual oil or diesel (75%) to boilers that are adapted for natural gas (84%) has been taken into consideration. In the case of electric chillers it is considered a COP of 3.42, for double-effect ARS it is considered a COP of 1, and for the simple-effect ARS that was proposed in the cogeneration alternatives, it is considered a COP of 0.69. Moreover, the calculations of the indicators that define the qualifying cogeneration facilities stipulated in the DS-064-2005-EM (MEM, 2005) are considered. These indicators which are defined as the effective electrical performance (REE) and the power-to-heat ratio (C) are different depending on the prime motor. If it is qualified it will have access to lower natural gas wellhead price which is similar to that of electrical generators.

3.4. Economic analysis

In the analysis of economic feasibility, in general, the current operating costs are compared to the alternatives of natural gas use proposed in Section 3.3. The lower operational cost of the technical alternatives should amortize the investment made for the equipment conversion or installation of the cogeneration system. Here it is assumed a lifetime of 20 years at a discount rate of 10%. In terms of income and expenses, the following are considered:

Income:

- Current fuel consumption costs: LPG (2.41 $/gal), diesel (3.87 $/gal), residual oil-R500 (1.85 $/gal) and residual oil-R600 (1.93 $/gal);
- Current electricity consumption prices—MT3 price will be considered: 49.6 $/MWh and 9.53 $/kW–month;
- In case of sell surplus electricity, the selling prices are assumed to be at a 90% level of those of MT3.

Table 1
Quantity, classification and characterization of large-sized industrial and commerce sectors.

Number of large-sized industries and shops					Energy comsuption				
	Lima and Callao	Ica	Kuntur	Centro–Norte	Electricity G(W h/yr)	LPG (m^3/yr)	Diesel (m^3/yr)	R-500 (m^3/yr)	R-600 (m^3/yr)
Food- I	2		3	1	31.97		1677	12,501	
Food-II	4		1	1	12.52		1338		
Food-III	4		6	1	4.37		195		692
Food-IV	3				10.87		12		571
Food-V	2				4.13		13		502
Food-VI	4	2	3	1	2.18	832			
Beverage-I	4		2	1	46.73		76	6,741	
Beverage-II	3	1		1	8.22			1,350	
Beverage-III	2		1	1	11.52		14		444
Beverage-IV	2		1	1	5.92		11	405	668
Beverage-V	2				2.69		27	521	
Cement-I	1		2	2	172.89		11		33,368
Ceramic-I	3				22.29		3160		
Ceramic-II	2		1	1	6.42		3054		603
Ceramic-III	2				3.30			2,498	
Paper-I	2				41.61			11,355	
Paper-II	3		1	1	24.39			5,905	
Paper-III	3	1		1	14.35			4,542	
Paper-IV	3				6.05			1,225	
Textile-I	2		1		40.56		4905	11,602	
Textile-II	1		2		24.28		7528	6,120	
Textile-III	4	1	1	1	17.92		5377	4,372	
Textile-IV	2				15.84		946		6,007
Textile-V	2				9.59	594	639	3,326	
Textile-VI	7				7.59		704	2,277	
Textile-VII	6				6.21				878
Chem-Pharma-I	3				6.85		14		899
Chem-Pharma-II	9				3.10	361	375		
Chem-Pharma-III	6				1.72		84	309	
Chem-Pharma-IV	9				4.74		136		
Glass and plastic-I	4				22.75				9,947
Glass and plastic-II	12		2	3	14.79				7,460
Fish processing-I	1	1	1	7	2.61			14,380	
Fish processing-II	4	3	2	7	1.56			8,628	
Hospital-I	2		2	2	9.45		24		1,108
Hospital-II	4	1	6	4	5.17			745	
Hospital-III	8	3	7	4	2.53		984		
Hospital-IV	31	3	13	10	1.30			353	
Shopping Centers-I	6		2		31.11				
Shopping Centers-II	19	1	16	4	15.97				
Supermarket–I	5		2	3	13.85				
Supermarket–II	13	2	1	4	7.99				
Supermarket-III	25	2	5	4	5.33				
Supermarket-IV	19		4	2	1.96				
Supermarket-V	38	7	13	11	0.82				
Hotels-I	12	2	3	1	1.80	204			
Hotels-II	16	6	17	9	1.20	136			

Expenses:

- Investment for the boilers conversion or the installation of cogeneration system. Prices for RE and GT were obtained from manufacturers Cummins and Solar Turbine, respectively;
- Natural gas consumption costs, natural gas prices is a function of the monthly demand and is classified by type A (up to 300 m^3/month – 0.34 \$/m^3), B (between 300 and 17,500 m^3/month – 0.24 \$/m^3), C (between 17,500 and 300,000 m^3/month – 0.19 \$/m^3) and D (greater than 300,000 m^3/month – 0.18 \$/m3). For the qualifying cogeneration facilities the natural gas price type C and D are 0.15 \$/m^3 and 0.14 \$/m^3, respectively;
- Maintenance costs of RE or GT;
- The current maintenance cost of boilers and electric chillers are similar to the maintenance costs of boilers conversion or HRSG and ARS.

Table A1–A3 (Appendix A) shows the results of energetic and economic analysis for technical solutions.

3.5. Scenarios of natural gas consumption

The natural gas consumption in the large-sized industrial and commercial sectors depends on many factors: market strategy of the natural gas distribution company, corporate strategy of industrial and commercial sectors, government energy policies, national economic growth, technological alternatives, average energy consumption and economic constraints considering the investments. These variables will be internalized through different scenarios. According to Lemar (2001), the scenarios are not predictions or recommendations, these are simply alternatives for future development and they are useful in organizing potential policies in terms of theirs cost and potential impacts on energy use and carbon emissions.

Table 2
Scenarios summary considerate in this paper.

Reference		Pessimist	Trend	Optimistic
1. *Lima and Callao*:The expansion of distribution networks for natural gas continues 2. *Ica*: In May 2015, started operating the natural gas distribution networks 3. *Kuntur*: In November 2016, started operating the natural gas distribution networks 4. *Centro-Norte*: In November 2020, started operating the natural gas distribution networks	**Natural gas prices and grid access:**	IPRP.1: Neither company qualifies as CHP plant according to the regulations DS-064–2005-EM, then one has no natural gas rate differential IPRP.2: By not qualify as CHP plant does not have regulations for grid access and prices for standby electricity IPRP.3: The electricity distribution companies have no interest in cogeneration	ITRP.1: IPRP.1 ITRP.2: IPRP.2 ITRP.3: IPRP.3	IORP.1: ITRP.1 IORP.2: ITRP.2 IORP.3: ITRP.3
	Policy costs, efficiency and reliability of companies:	IPRC.1: Companies have increased interest in investing in projects to expand production, not energy efficiency projects IPRC.2: Companies are only interested in changing the current fuel by natural gas IPRC.3: The security of natural gas supply is considered as a risk	ITRC.1: IPRC.1 ITRC.2: IPRC.2 ITRC.3: IPRC.3	IORC.1: ITRC.1 IORC.2: ITRC.2 IORC.3: ITRC.3
	Project finance:	IPRF.1: There is no preferential rate loans for energy efficiency projects IPRF.2: In the country there is not companies interested in BOT or similar type projects IPRF.3: Companies only make the investment when the payback is less than 2 years, and only on projects for fuel switching to natural gas	ITRF.1: IPRF.1 ITRF.2: IPRF.2 ITRF.3: Companies only make the investment when the payback is less than 3 years, and only on projects for fuel switching to natural gas	IORF.1: ITRF.1 IORF.2: ITRF.2 IORF.3: Companies only make the investment when the payback is less than 4 years, and only on projects for fuel switching to natural gas
	Expansion of natural gas distribution networks:	IPRE.1: The government has directed energy policies for a major natural gas use IPRE.2: The expansion of distribution networks for natural gas continues, getting penetration factors related to the city of Bogota	ITRE.1: IPRE.1 ITRE.2: IPRE.2	IORE.1: ITRE.1 IORE.2: ITRE.2
Moderate				
1. Lima and Callao: The expansion of distribution networks for natural gas continues 2. Ica: In November 2014, started operating the natural gas distribution networks 3. Kuntur: In February 2016, started operating the natural gas distribution networks 4. Centro-Norte: In May 2020, started operating the natural gas distribution networks	**Natural gas prices and grid access:**	IPMP.1: IPRP.1 IPMP.2: IPRP.2, then, the companies that make investment in CHP projects need to contract electrical power network to stand by IPMP.3: IPRP.3	ITMP.1: ITRP.1 ITMP.2: IPMP.2 ITMP.3: ITRP.3	IOMP.1:ITMP.1 IOMP.2: ITMP.2 IOMP.3: ITMP.3
	Policy costs, efficiency and reliability of companies:	IPMC.1: Companies have increased interest in investing in projects to expand production and energy efficiency projects IPMC.2:Companies are interested in changing the current fuel by natural gas and also in CHP projects IPMC.3:The security of natural gas supply is not considered as a risk	ITMC.1: IPMC.1 ITMC.2: IPMC.2 ITMC.3: IPMC.3	IOMC.1: ITMC.1 IOMC.2: ITMC.2 IOMC.3: ITMC.3
	Project finance:	IPMF.1: IPRF.1 IPMF.2: In the country has few companies interested in BOT or similar type projects IPMF.3: Companies only make the investment when the payback is less than 2 years, and only on projects for fuel switching to natural gas and CHP designed on the base electric load	ITMF.1: IPMF.1 ITMF.2: IPMF.2 ITMF.3: Companies only make the investment when the payback is less than 3 years, and only on projects for fuel switching to natural gas and CHP designed on the base electric load	IOMF.1: ITMF.1 IOMF.2: ITMF.2 IOMF.3: Companies only make the investment when the payback is less than 4 years, and only on projects for fuel switching to natural gas and CHP designed on the base electric load

Table 2 (*continued*)

Expansion of natural gas distribution networks:	IPME.1: IPRE.1 IPME.2: IPRE.2	ITME.1: IPME.1 ITME.2: IPME.2	IOME.1:ITME.1 IOME.2: ITME.2
Policy costs, efficiency and reliability of companies:	IPAC.1: IPMC.1: IPAC.2: IPMC.2 IPAC.3: IPMC.3	ITAC.1: IPAC.1 ITAC.2: IPAC.2: ITAC.3: IPAC.3	IOAC.1: ITAC.1 IOAC.2: ITAC.2: IOAC.3: ITAC.3
Project finance:	IPAF.1: IPMF.1 IPAF.2: In the country has companies interested in BOT or similar type projects IPAF.3: Companies only make the investment when the payback is less than 2 years, and only on projects for fuel switching to natural gas and CHP designed on the base heat load	ITAF.1:IPAF.1 ITAF.2: IPAF.2 ITAF.3: Companies only make the investment when the payback is less than 3 years, and only on projects for fuel switching to natural gas and CHP designed on the base heat load	IOAF.1:ITAF.1 IOAF.2: ITAF.2 IOAF.3: Companies only make the investment when the payback is less than 4 years, and only on projects for fuel switching to natural gas and CHP designed on the base heat load
Expansion of natural gas distribution networks:	IPAE.1: IPME.1 IPAE.2: IPME.2	ITAE.1: IPAE.1 ITAE.2: IPAE.2	IOAE.1: ITAE.1IOAE.2: ITAE.2

The potential use of natural gas is calculated through 9 scenarios. Then to calculate the activity level, three hypothesis of macroeconomic growth will be used: pessimistic, trend, and optimistic-GDP growth of 3.8%, 6% and 8.4%, respectively (IEDEP/CCL, 2010). To calculate the energy intensity, Three hypotheses of natural gas penetration are used: reference, moderate and advanced. In the latter hypothesis, the following variables are considered: Natural gas prices and grid access; Policy costs, efficiency and reliability of companies, Project Finance, and Expansion of natural gas distribution networks. In the proposed scenarios, future natural gas supplies in other regions are considered, in addition to the existing ones in the Lima and Callao regions. The potential natural gas use is calculated as a function of any combination of macroeconomic growth and natural gas penetration scenarios, shown in Table 2. This table is supplemented with the results from the energetic and economic analysis for technical solutions, shown in Table A1–A3.

4. Scenario results

In this part the introduction of natural gas consumption in the large-sized industrial and commercial sectors are shown. 2010 has been chosen as the base year since the projections are for the 2011–2020 period. The benefits gained by reducing the use and import of residual oil and diesel, also by introducing a new capacity and sell surplus electricity in the electrical system are shown.

4.1. Pessimistic scenario: Reference, moderate and advanced

The projections and results of economic analysis (Table A1–A3) show that the greatest potential use of natural gas is in the industrial sector, being some economic difficulties for their use in shopping centers and supermarkets.

In this study, the worst-case scenario for the use of natural gas and development of cogeneration projects is shown in the pessimistic-reference scenario because the lower macroeconomic growth, compared with the GDP growth obtained in recent years, has been considered. Barriers were also considered to the use of cogeneration and business decisions to prioritize energy projects of lower investment (see Table 2).

Thus, in the pessimistic-reference scenario, natural gas consumption is expected to be 563.7 Mm^3 in 2011 and 1193.7 Mm^3 in 2020 (Fig. 3). The introduction of natural gas would reduce the use and import of residual oil by 381.9 thousand m^3 and that of diesel by 75.1 thousand m^3 in 2011, and in 2020 the use of residual oil will be reduced by 900.1 thousand m^3 and that of diesel will be reduced by 167.8 thousand m^3. In addition, only by introducing cogeneration with natural gas, the installed capacity would be of 43.7 MW and sell surplus electricity of 219 GWh/yr in 2011 and until 2020, there would not be more cogeneration development projects (Fig. 4).

4.2. Trend scenario: Reference, moderate and advanced

The most likely scenario for the use of natural gas and penetration of cogeneration, in the period 2011–2020, analyzed in this study is the trend-moderate scenario because it considers a macroeconomic growth projection shown by different international institutions, such as the World Bank (RPP, 2011), the International Monetary Fund (Gestión, 2011b) and HSBC (La republica, 2012). It also considers the introduction of cogeneration projects by business decisions that seek lower production costs, while having regulatory barriers to access electricity grid, and lower natural gas wellhead price (see Table 2).

Therefore, in the trend-moderate scenario, natural gas consumption is expected to be 648.2 Mm^3 in 2011 and 1729.1 Mm^3 in 2020 (Fig. 5). The introduction of natural gas would reduce the use and import of residual oil by 388.6 thousand m^3 and that of diesel by 76.4 thousand m^3 in 2011, and in 2020 the use of residual oil will decline by 1162.8 thousand m^3 and that of diesel by 210.2 thousand m^3. In addition, only by introducing cogeneration with natural gas, the installed capacity would be of 112.5 MW and sell surplus electricity of 219 GWh/yr in 2011. In 2020 the installed power capacity will be 250 MW, but there would not be new projects that are capable of sell surplus electricity (Fig. 6).

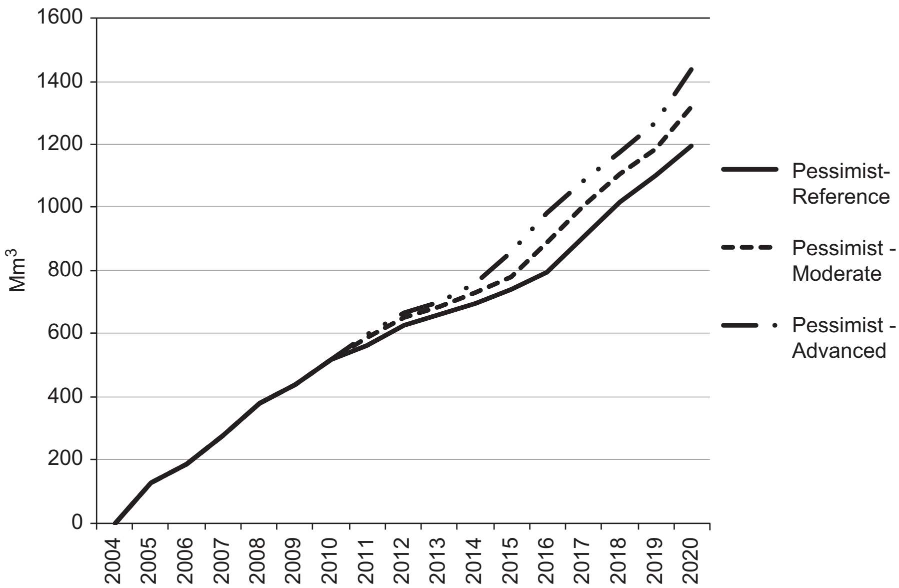

Fig. 3. Natural gas consumption–Pessimistic scenario: reference, moderate and advanced.

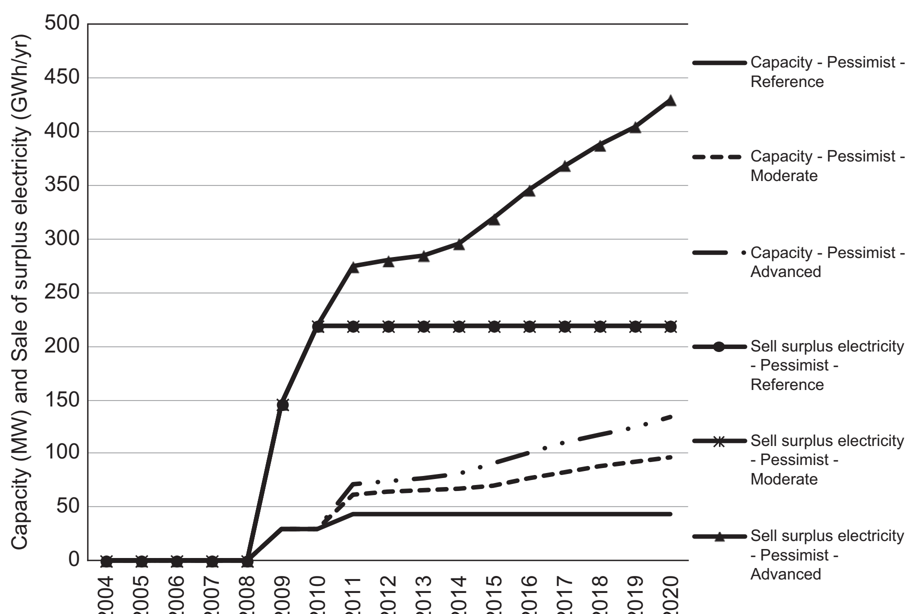

Fig. 4. Installed capacity and sell surplus electricity by cogeneration–Pessimistic scenario: reference, moderate and advanced.

4.3. Optimistic scenario: Reference, moderate and advanced

The most favorable scenario for the use of natural gas and development of cogeneration projects in this study is the optimistic–advanced scenario. This scenario considers a higher macroeconomic growth when compared with the GDP growth obtained in recent years. It also considers incentives for the cogeneration projects through regulation for the access to electricity grid and natural gas wellhead price similar to electricity generators (see Table 2).

Thus, in the optimistic–advanced scenario, natural gas consumption is expected to be 871 Mm^3 in 2011 and 3127 Mm^3 in 2020 (Fig. 7). The introduction of natural gas would reduce the use and import of residual oil by 395.9 thousand m^3 and that of diesel by 77.8 thousand m^3 in 2011. In 2020 the use of residual oil will decline by 1518.4 thousand m^3 and that of diesel by 266.2 thousand m^3. In addition, only by introducing cogeneration with natural gas, the installed capacity would be of 298.3 MW and sell surplus electricity of 1018.7 GWh/yr in 2011. In the 2020 the installed capacity will be 1085.9 MW with a sell surplus electricity of 3152.3 GWh/yr in 2020 (Fig. 8).

5. Conclusions

The economic analysis shows that in most of the segments analyzed, the use of natural gas has considerable economic advantages. Only in the case of shopping centers and supermarkets, this has been proven not to be viable, because the savings from electricity consumption would not be sufficient to cover the investment of ARS. However, this analysis also shows that efforts to switch current fuel into natural gas requires little

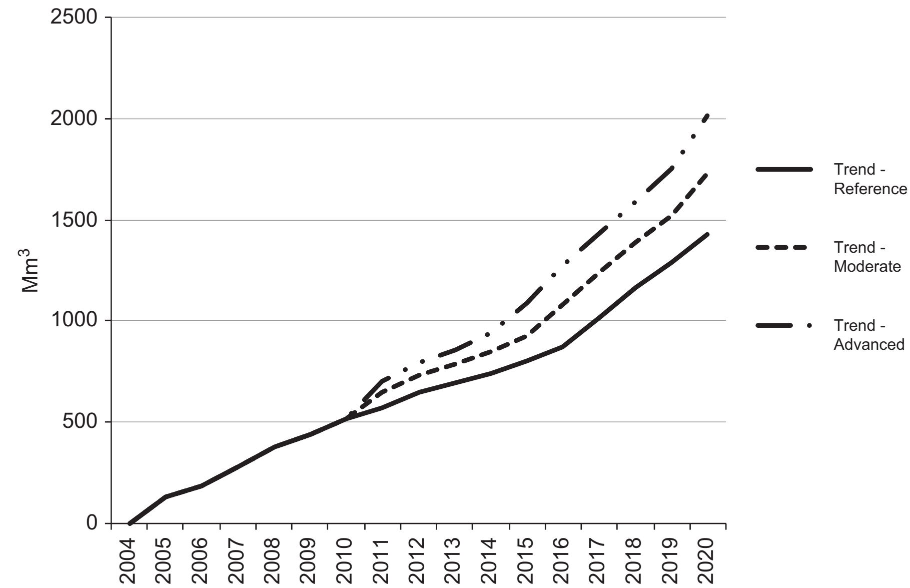

Fig. 5. Natural gas consumption–Trend scenario: reference, moderate and advanced.

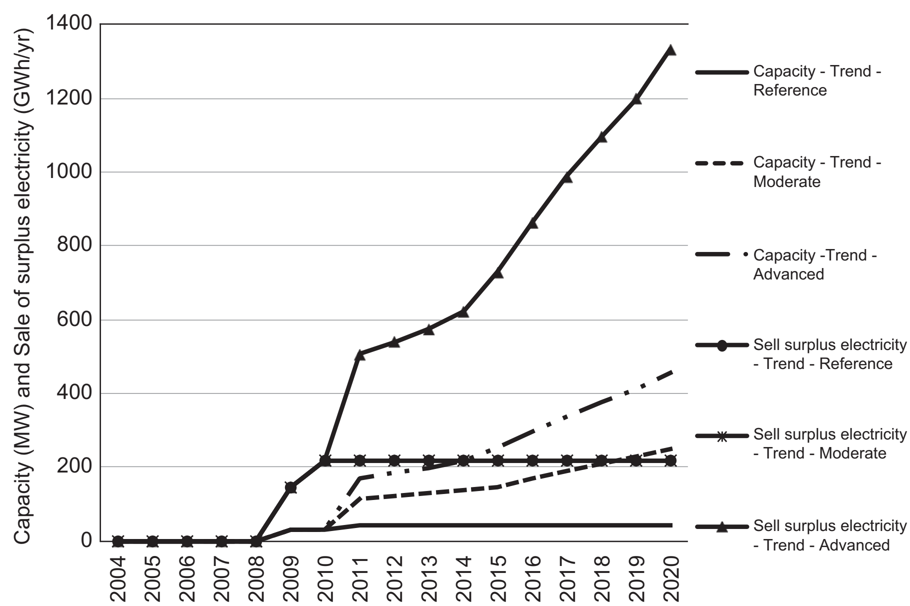

Fig. 6. Installed capacity and sell surplus electricity by cogeneration–Trend scenario: reference, moderate and advanced.

investment, compared to those required for cogeneration, and are very profitable. Other factors contribute also to this tendency: lack of companies interested in BOT[1] projects, business decisions based on preference for projects that are part of the "core business" of the company and prioritization of investments to increase production. Similarly, Jiang et al. (2008) concludes that switching from coal to natural gas in the industrial sector would be more attractive than in power plants because replacing an inefficient coal boiler requires lower capital than converting a power plant from coal to natural gas.

[1] BOT (Build-Operate-Transfer) is a form of project financing, wherein a private entity receives a concession from the private or public sector to finance, design, construct, and operate a facility stated in the concession contract. This enables the project proponent to recover its investment, operating and maintenance expenses in the project.

The use of natural gas is presented as a source of energy that can be used to replace part of the residual oil and diesel consumption in the industrial and commercial sector. According to the results, the share of residual oil and diesel consumption in the industrial and commercial sector would be 12.6% (pessimistic), 11.2% (Moderate) and 9.9% (Advanced) in 2020. However, these values could be lower if the penetration of natural gas in small-sized industries and stores is considered. Moreover, this substitution of petroleum fuels to natural gas would bring environmental benefits; primarily in reducing CO_2 emissions. According to IPCC (1996), the carbon emissions factor of the natural gas would be lower compared that of diesel and residual oil. Similarly, Frota et al. (2010), shows that natural gas located in the state of Amazonas (Brazil) is the best alternative to replace current consumption of petroleum derived liquid fuels in this state, especially in the electricity production. Jiang et al. (2008),

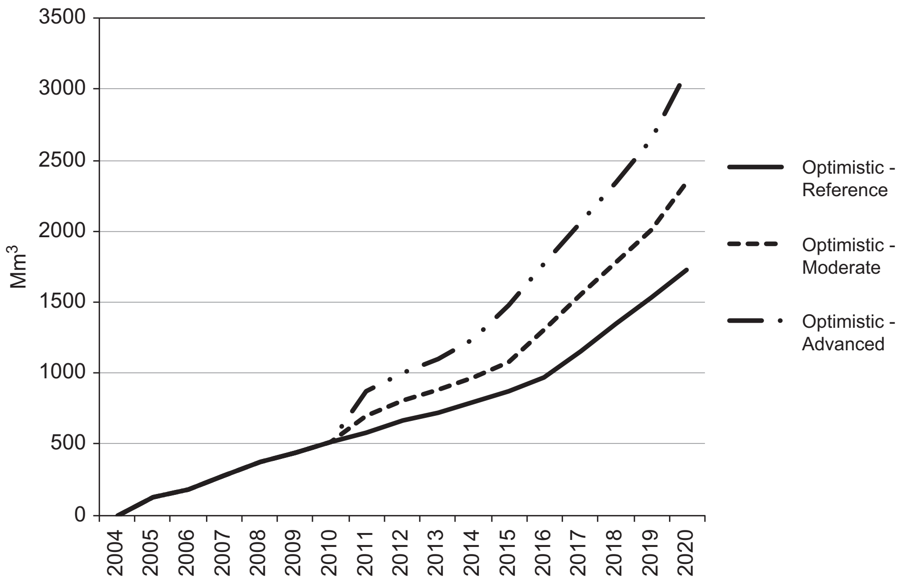

Fig. 7. Natural gas consumption–Optimistic scenario: reference, moderate and advanced.

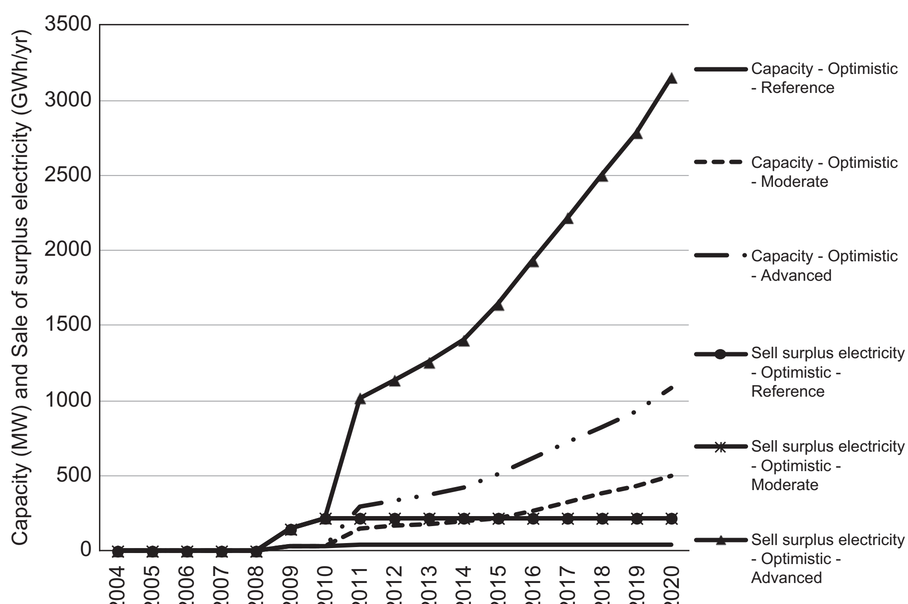

Fig. 8. Installed capacity and sell surplus electricity by cogeneration–Optimistic scenario: reference, moderate and advanced.

shows that policies for greater penetration of natural gas in the cities of Beijing, Guangdong and Shanghai should be coupled with environmental policies of restricting emissions of SO_2. On the other hand, Amiri et al. (2009) shows that natural gas can replace fuels that are currently used for heat production and that it could generate electricity using cogeneration systems. In addition, this will come with the benefit of reducing CO_2 emissions (490 kt/year) in three municipalities of the county of Östergötland (Sweden).

The use of cogeneration is presented as an alternative to increase the use of natural gas which will enhance a more efficient way to use the natural resources. According to the estimates, these projects become more viable when they are designed based on heat load and natural gas wellhead price similar to electricity generators. However, most of the analyzed companies would not participate to the qualifying cogeneration facilities indicators (REE and *C*), which is necessary to have access to natural gas wellhead price similar to electricity generators. Similarly, Amiri et al. (2009) shows that an increasing price of electricity and increasing district heating demand improve the profitability of natural gas conversion using cogeneration plant. However, Campos Celador et al. (2011), with his study on feasibility of small-scale gas engine-based residential cogeneration plants, showed that a rise in the natural gas price would increase the current feasibility of a cogeneration plant. This distortion is due to Spanish regulations, which anticipate increases in electricity rates, as the gas price rises. In this case, these projects would be having a better return because of the greater efficiency of cogeneration systems. Andersen et al. (2011), shows that an output contraction due to demand shocks will generally have larger negative effects on gas demand, than increases in natural gas prices in the industrial sector of OECD countries in Europe.

As discussed in Section 4.2, the more likely option is trend-moderate scenario. However, to achieve this level of natural

Table A1
Results of energetic and economic analysis for technical solutions.

	Without Cogeneration			Cogeneration designed on the electric load base				Cogeneration designed on the heat load base			
	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis
Food-I	14,375	CBCNGU	Payback:1.1; NPV: 44.191 IRR:1503%; Inv: 1.220	5.05	18,972	GT, HRSG	Payback:2.5; NPV: 38.557 IRR:67%; Inv: 9.080	9.98	23,450	GT, HRSG REE=0.65; C=0.54	Payback:2.6; NPV: 55.439 IRR:64%; Inv: 13.895
Food-II	1,251	CBCNGU	Payback:0.8; NPV: 9.682 IRR:5750%; Inv: 0.114	1.68	4,596	RE, HRSG, ARS	Payback:2.5; NPV: 6.666 IRR:67%; Inv: 1.586	2.39	5,102	RE, HRSG, ARS REE=0.55; C=0.78	Payback:2.2; NPV: 10.749 IRR:82%; Inv: 2.034
Food-III	0.891	CBCNGU	Payback:1.0; NPV: 3.235 IRR:2206%; Inv: 0.081	0.59	2,056	RE, HRSG, ARS	Payback:3.8; NPV: 1.601 IRR:36%; Inv: 0.822	1.71	3,639	RE, HRSG, ARS REE=0.46; C=1.03	Payback:3.7; NPV: 3.096 IRR:37%; Inv: 1.524
Food-IV	0.595	CBCNGU	Payback:1.1; NPV: 1.586 IRR:723%; Inv: 0.058	1.46	3,668	RE, HRSG, ARS	Payback:Ind; NPV: -1.439 IRR:Ind; Inv: 1.430	1.46	3,115	RE, HRSG, ARS REE=0.59; C=0.72	Payback:Ind; NPV: −1.439 IRR:Ind; Inv: 1.430
Food-V	0.526	CBCNGU	Payback:1.1; NPV: 1.410 IRR:732%; Inv: 0.051	0.56	1,630	RE, HRSG, ARS	Payback:11.4; NPV: -0.130 IRR:7%; Inv: 0.746	1.01	2,150	RE, HRSG, ARS REE=0.51; C=0.87	Payback:5.5; NPV: 0.963 IRR:22%; Inv: 1.101
Food-VI	0.549	CBCNGU	Payback:0.8; NPV: 3.634 IRR:2380%; Inv: 0.054	0.29	1,132	RE, HRSG, ARS	Payback:1.8; NPV: 2.914 IRR:118%; Inv: 0.386	1.05	2,240	RE, HRSG, ARS REE=0.45; C=1.1	Payback:3.2; NPV: 2.917 IRR:45%; Inv: 1.115
Beverage-I	6,977	CBCNGU	Payback:1.1; NPV: 17.754 IRR:881%; Inv: 0.592	5.58	18,444	GT, HRSG, ARS	Payback:6.4; NPV: 5.570 IRR:18%; Inv: 10.157	8.56	21,320	GT, HRSG, ARS REE=0.65; C=0.54	Payback:3.9; NPV: 22.060 IRR:35%; Inv: 11.901
Beverage-II	1,383	CBCNGU	Payback:1.1; NPV: 3.312 IRR:768%; Inv: 0.118	0.98	3,632	RE, HRSG, ARS	Payback:5.6; NPV: 1.059 IRR:21%; Inv: 1.293	2.41	5,498	RE, HRSG, ARS REE=0.52; C=0.84	Payback:3.7; NPV: 4.118 IRR:37%; Inv: 2.043
Beverage-III	0.468	CBCNGU	Payback:1.1; NPV: 1.267 IRR:750%; Inv: 0.046	1.37	3,917	RE, HRSG, ARS	Payback:Ind; NPV: -1.953 IRR:Ind; Inv: 1.384	1.37	3,134	RE, HRSG, ARS REE=0.70; C=0.61	Payback:Ind; NPV: −1.953 IRR:Ind; Inv: 1.384
Beverage-IV	1,108	CBCNGU	Payback:1.1; NPV: 2.826 IRR:756%; Inv: 0.101	0.71	2,716	RE, HRSG, ARS	Payback:5.2; NPV: 0.952 IRR:23%; Inv: 0.972	1.93	4,408	RE, HRSG, ARS REE=0.50; C=0.88	Payback:3.7; NPV: 3.369 IRR:37%; Inv: 1.649
Beverage-V	0.559	CBCNGU	Payback:1.1; NPV: 1.466 IRR:700%; Inv: 0.055	0.32	1,289	RE, HRSG, ARS	Payback:5.0; NPV: 0.523 IRR:25%; Inv: 0.484	0.97	2,222	RE, HRSG, ARS REE=0.49; C=0.91	Payback:5.7; NPV: 0.894 IRR:21%; Inv: 1.136
Cement-I	34,168	CBCNGU	Payback:1.1; NPV: 91.837 IRR:997%; Inv: 2.900	27.41	64,240	GT, HRSG	Payback:3.6; NPV: 71.178 IRR:38%; Inv: 33.668	27.41	64,240	GT, HRSG REE=0.56; C=0.63	Payback:3.6; NPV: 71.178 IRR:38%; Inv: 33.668
Ceramic-I	2,955	CBCNGU	Payback:0.8; NPV: 22.800 IRR:9291%; Inv: 0.251	3.53	8,284	GT, HRSG	Payback:4.2; NPV: 12.689 IRR:31%; Inv: 8.202	3.53	8,284	GT, HRSG REE=0.42; C=0.93	Payback:4.2; NPV: 12.689 IRR:31%; Inv: 8.202
Ceramic-II	3,473	CBCNGU	Payback:0.9; NPV: 23.706 IRR:4298%; Inv: 0.295	1.02	5,108	RE, HRSG	Payback:1.3; NPV: 22.025 IRR:338%; Inv: 1.240	2.42	5,669	GT, HRSG REE=0.65; C=0.54	Payback:2.5; NPV: 23.113 IRR:68%; Inv: 5.331
Ceramic-III	2,559	CBCNGU	Payback:1.1; NPV: 6.129 IRR:767%; Inv: 0.218	0.52	3,400	RE, HRSG	Payback:1.9; NPV: 5.011 IRR:110%; Inv: 0.708	1.78	4,180	GT, HRSG REE=0.65; C=0.54	Payback:4.4; NPV: 5.608 IRR:29%; Inv: 3.930

Table A2
Results of energetic and economic analysis for technical solutions.

	Without cogeneration			Cogeneration designed on the electric load base				Cogeneration designed on the heat load base			
	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis
Paper-I	11,633	CBCNGU	Payback:1.1; NPV: 28.971 IRR:838%; Inv: 0.988	7.04	17,614	GT, HRSG	Payback:4.3; NPV: 19.683 IRR:31%; Inv: 12.785	8.64	18,970	GT, HRSG REE=0.65; C=0.54	Payback:3.0; NPV: 36.463 IRR:51%; Inv: 11.889
Paper-II	6,049	CBCNGU	Payback:1.1; NPV: 15.065 IRR:838%; Inv: 0.514	4.13	9,556	GT, HRSG	Payback:5.2; NPV: 8.261 IRR:24%; Inv: 8.324	4.49	9,868	GT, HRSG REE=0.65; C=0.54	Payback:4.1; NPV: 14.973 IRR:32%; Inv: 8.924
Paper-III	4,653	CBCNGU	Payback:1.1; NPV: 11.589 IRR:838%; Inv: 0.395	2.43	6,716	GT, HRSG	Payback:4.7; NPV: 6.813 IRR:27%; Inv: 5.520	3.45	7,588	GT, HRSG REE=0.65; C=0.54	Payback:4.1; NPV: 11.263 IRR:32%; Inv: 6.862
Paper-IV	1,255	CBCNGU	Payback:1.2; NPV: 2.997 IRR:660%; Inv: 0.114	1.03	2,798	RE, HRSG	Payback:5.7; NPV: 0.823 IRR:21%; Inv: 1.047	2.68	5,278	RE, HRSG REE=0.39; C=1.53	Payback:4.5; NPV: 2.778 IRR:29%; Inv: 2.014
Textile-I	16,472	CBCNGU	Payback:1.0; NPV: 65.565 IRR:6880%; Inv: 1.398	6.86	22,302	GT, HRSG	Payback:2.3; NPV: 57.343 IRR:74%; Inv: 12.067	12.23	26,860	GT, HRSG REE=0.65; C=0.54	Payback:2.4; NPV: 75.108 IRR:70%; Inv: 16.834
Textile-II	13,310	CBCNGU	Payback:0.9; NPV: 70.811 IRR:1890%; Inv: 1.130	4.11	16,800	GT, HRSG	Payback:1.8; NPV: 64.595 IRR:121%; Inv: 8.351	9.88	21,710	GT, HRSG REE=0.65; C=0.54	Payback:2.1; NPV: 78.021 IRR:89%; Inv: 13.603
Textile-III	9,507	CBCNGU	Payback:0.9; NPV: 50.579 IRR:1890%; Inv: 0.807	3.03	12,084	GT, HRSG	Payback:2.0; VPL: 44.593 IRR:96%; Inv: 7.230	7.06	15,510	GT, HRSG REE=0.65; C=0.54	Payback:2.5; NPV: 51.463 IRR:65%; Inv: 12.592
Textile-IV	7,034	CBCNGU	Payback:1.0; NPV: 23.373 IRR:2021%; Inv: 0.597	2.68	9,310	GT, HRSG	Payback:3.1; NPV: 18.095 IRR:48%; Inv: 6.264	5.22	11,470	GT, HRSG REE=0.65; C=0.54	Payback:3.2; NPV: 24.185 IRR:44%; Inv: 9.316
Textile-V	4,398	CBCNGU	Payback:1.0; NPV: 15.811	1.62	6,834	RE, HRSG	Payback:1.8; NPV: 13.152	3.26	7,173	GT, HRSG REE=0.65;	Payback:3.7; NPV: 14.287

Table A2 (*continued*)

	Without cogeneration			Cogeneration designed on the electric load base				Cogeneration designed on the heat load base			
	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis
			IRR:2986%; Inv: 0.374				IRR:130%; Inv: 1.593			C=0.54	IRR:37%; Inv: 7.144
Textile-VI	2,991	CBCNGU	Payback:1.0; NPV: 10.684 IRR:2875%; Inv: 0.254	1.28	4,918	RE, HRSG	Payback:2.1; NPV: 8.433 IRR:91%; Inv: 1.436	2.22	4,880	GT, HRSG REE=0.65; C=0.54	Payback:3.7; NPV: 9.991 IRR:37%; Inv: 4.861
Textile-VII	0.898	CBCNGU	Payback:1.1; NPV: 2.311 IRR:771%; Inv: 0.082	1.05	2,477	RE, HRSG	Payback:8.8; NPV: 0.095 IRR:11%; Inv: 1.036	1.92	3,786	RE, HRSG REE=0.39; C=1.53	Payback:4.2; NPV: 2.260 IRR:31%; Inv: 1.445
Chem-Pharma -I	0.934	CBCNGU	Payback:1.1; NPV: 2.469 IRR:822%; Inv: 0.085	1.16	2,674	RE, HRSG	Payback:9.3; NPV: 0.028 IRR:10%; Inv: 1.136	2.00	3,939	RE, HRSG REE=0.39; C=1.53	Payback:4.1; NPV: 2.437 IRR:32%; Inv: 1.503
Chem-Pharma-II	0.589	CBCNGU	Payback:0.9; NPV: 4.287 IRR:3250%; Inv: 0.058	0.52	1,376	RE, HRSG	Payback:2.3; NPV: 2.979 IRR:75%; Inv: 0.621	1.26	2,484	RE, HRSG REE=0.39; C=1.53	Payback:3.2; NPV: 3.290 IRR:45%; Inv: 1.252
Chem-Pharma-III	0.395	CBCNGU	Payback:1.1; NPV: 1.358 IRR:1401%; Inv: 0.039	0.29	0.832	RE, HRSG	Payback:3.9; NPV: 0.646 IRR:34%; Inv: 0.352	0.85	1,663	RE, HRSG REE=0.39; C=1.53	Payback:6.0; NPV: 0.615 IRR:20%; Inv: 0.895
Chem-Pharma-IV	0.127	CBCNGU	Payback:1.1; NPV: 0.918 IRR:1669%; Inv: 0.024	0.80	1,580	RE, HRSG	Payback:Ind; NPV: −1.165 IRR:Ind; Inv: 0.788	0.80	1,580	RE, HRSG REE=0.34; C=4.62	Payback:Ind; NPV: −1.165 IRR:Ind; Inv: 0.788

Table A3
Results of energetic and economic analysis for technical solutions.

	Without cogeneration			Cogeneration designed on the electric load base				Cogeneration designed on the heat load base			
	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis	Capacity (MW)	NG comsuption (MMm^3/yr)	Technological solution	Economic analysis
Glass and plastic-I	10,182	CBCNGU	Payback:1.1; NPV: 27.128 IRR:996%; Inv: 0.865	3.21	13,453	GT, HRSG	Payback:3.3; NPV: 21.155 IRR:44%; Inv: 8.172	6.30	16,610	GT, HRSG REE=0.65; C=0.54	Payback:3.2; NPV: 30.344 IRR:45%; Inv: 11.525
Glass and plastic-II	7,637	CBCNGU	Payback:1.1; NPV: 20.412 IRR:996%; Inv: 0.649	2.08	9,763	GT, HRSG	Payback:3.0; NPV: 16.459 IRR:50%; Inv: 5.409	4.72	12,460	GT, HRSG REE=0.65; C=0.54	Payback:3.5; NPV: 21.145 IRR:39%; Inv: 9.603
Fish processing-I	14,732	CBCNGU	Payback:1.1; NPV: 36.691 IRR:838%; Inv: 1.250								
Fish processing-II	8,839	CBCNGU	Payback:1.1; NPV: 22.014 IRR:838%; Inv: 0.750								
Hospital-I	1,156	CBCNGU	Payback:1.1; NPV: 3.094 IRR:998%; Inv: 0.099	1.17	3,255	RE, HRSG, ARS	Payback:5.8; NPV: 0.988 IRR:20%; Inv: 1.330	2.48	4,880	RE, HRSG, ARS REE=0.79; C=0.55	Payback:3.4; NPV: 4.437 IRR:42%; Inv: 1.863
Hospital-II	0.763	CBCNGU	Payback:1.1; NPV: 1.826 IRR:767%; Inv: 0.065	0.64	1,915	RE, HRSG, ARS	Payback:6.4; NPV: 0.463 IRR:18%; Inv: 0.827	1.63	3,217	RE, HRSG, ARS REE=0.79; C=0.55	Payback:4.1; NPV: 2.185 IRR:32%; Inv: 1.348
Hospital-III	0.920	CBCNGU	Payback:0.9; NPV: 7.127 IRR:9400%; Inv: 0.079	0.31	1,485	RE, HRSG, ARS	Payback:1.7; NPV: 6.074 IRR:151%; Inv: 0.642	1.97	3,873	RE, HRSG, ARS REE=0.79; C=0.55	Payback:2.2; NPV: 7.299 IRR:82%; Inv: 1.386
Hospital-IV	0.362	CBCNGU	Payback:1.1; NPV: 0.865 IRR:767%; Inv: 0.031	0.16	0.650	RE, HRSG, ARS	Payback:5.3; NPV: 0.313 IRR:23%; Inv: 0.335	0.78	1,532	RE, HRSG, ARS REE=0.79; C=0.55	Payback:6.7; NPV: 0.381 IRR:17%; Inv: 0.783
Shopping centers-I	3,764	ARS	Payback: Ind; NPV: -0.952 IRR:Ind; Inv: 0.864	3.47	7,923	RE, ARS	Payback: Ind; NPV: -5.442 IRR: Ind; Inv: 3.103	5.00	9,847	RE, ARS REE=0.79; C=0.55	Payback:6.8; NPV: 1.880 IRR:17%; Inv: 4.057
Shopping centers-II	1,932	ARS	Payback: Ind; NPV: -0.486 IRR:Ind; Inv: 0.444	1.78	4,069	RE, ARS	Payback: Ind; NPV: -3.150 IRR: Ind; Inv: 1.725	2.57	5,055	RE, ARS REE=0.79; C=0.55	Payback:6.8; NPV: 0.968 IRR:17%; Inv: 2.083
Supermarket-I	1,676	ARS	Payback: Ind; NPV: -0.486 IRR:Ind; Inv: 0.384	1.55	3,529	RE, ARS	Payback: Ind; NPV: -3.067 IRR: Ind; Inv: 1.496	2.22	4,376	RE, ARS REE=0.79; C=0.55	Payback:6.8; NPV: 0.840 IRR:17%; Inv: 1.804
Supermarket-II	0.967	ARS	Payback: Ind; NPV: -0.244 IRR:Ind; Inv: 0.221	0.89	2,037	RE, ARS	Payback: Ind; NPV: -1.838 IRR: Ind; Inv: 0.930	1.28	2,530	RE, ARS REE=0.79; C=0.55	Payback:13.8; NPV: -0.454 IRR:5%; Inv: 1.363
Supermarket-III	0.644	ARS	Payback: Ind; NPV: -0.160 IRR:Ind; Inv: 0.148	0.59	1,357	RE, ARS	Payback: Ind; NPV: -1.464 IRR: Ind; Inv: 0.761	0.86	1,685	RE, ARS REE=0.79; C=0.55	Payback:14.2; NPV: -0.326 IRR:4%; Inv: 0.932
Supermarket–IV	0.237	ARS	Payback: Ind; NPV: -0.060 IRR:Ind; Inv: 0.055	0.22	0.501	RE, ARS	Payback: Ind; NPV: -0.620 IRR: Ind; Inv: 0.317	0.32	0.619	RE, ARS REE=0.79; C=0.55	Payback:Ind; NPV: -0.250 IRR:Ind; Inv: 0.416
Supermarket-V	0.099	ARS	Payback: Ind; NPV: -0.023 IRR:Ind; Inv: 0.023	0.09	0.211	RE, ARS	Payback: Ind; NPV: -0.373 IRR: Ind; Inv: 0.187	0.14	0.274	RE, ARS REE=0.79; C=0.55	Payback:Ind; NPV: -0.287 IRR:Ind; Inv: 0.257
Hotels-I	0.151	CBCNGU	Payback:0.8; NPV: 0.839 IRR:1867%; Inv: 0.021	0.19	0.554	RE, HRSG, ARS	Payback:6.7; NPV: 0.187 IRR:17%; Inv: 0.400	0.50	0.985	RE, HRSG, ARS REE=0.79; C=0.55	Payback:5.7; NPV: 0.493 IRR:21%; Inv: 0.616
Hotels-II	0.101	CBCNGU	Payback:0,8; NPV: 0.567 IRR:1867%; Inv: 0.014	0.13	0.367	RE, HRSG, ARS	Payback:7.0; NPV: 0.115 IRR:16%; Inv: 0.285	0.33	0.657	RE, HRSG, ARS REE=0.79; C=0.55	Payback:5.9; NPV: 0.306 IRR:20%; Inv: 0.435

gas penetration, it is necessary to keep current trends in the country's economic growth and pipeline expansion projects, shown in Table 2. Furthermore, this must be strongly complemented with energy policies that seek to give greater security to investors regarding the supply of natural gas in the medium and long term. In this scenario, the share of cogeneration in electricity production in Peru would be 2.5%, in 2020, but these values are small compared to those achieved by Spain (11%), in 2007 (Cogen España, 2011), and by United States (12%), in 2010 (C2ES, 2011).

For further development of cogeneration projects in these sectors, as discussed in the optimistic–advanced scenario, it is needed to work on: review of current regulation that defines qualified cogenerators, in order to have greater industrial and commercial facilities with access to natural gas wellhead price similar to electricity generators, the possibility of sell surplus electricity and cogeneration systems designed to operate in thermal base; encouraging the entry of companies interested in BOT or similar projects, in order to be able to assist managers in industry or commercial sectors with cogeneration potential in their decisions; greater support and participation of the government through training seminars, energy efficiency programs and the introduction of new regulations, to increase the participation of electric distribution companies in cogeneration projects. Assuming that all of these conditions would be put into practice, in 2020, the share of the cogeneration in electricity production in Peru would be 9.9%.

Appendix A

See Tables A1–A3.

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