District energy in cities: A novel methodology to assess emerging markets

Pablo Campos[1], Eduardo Andrzejewski[1], Stéphane Coucke[1] and Catalina Ortega[1]

[1] Tractebel Engineering, Santiago (Chile)

Abstract

District energy is an effective strategy that has allowed cities to decouple emissions from sustainable growth. While district energy has supplied cities in Europe for decades, this solution is unknown in emerging markets. In order to identify areas with district energy potential in emerging economies, feasibility studies are developed to compare various district energy configurations with conventional systems. Since emerging markets lack abundant and reliable data, this new methodology considers four different strategies: (1) a reverse economic feasibility estimation to conceptualize a cost-effective system, (2) on-site data collection with low-cost IoT sensors, (3) an uncertainty assessment of the total cost of ownership, and (4) a decision matrix to choose the most promising sector for district energy. The proposed methodology has been successfully applied in 12 cities in Chile and Colombia.

Key words: district energy, heating and cooling, sustainable cities, urban energy, energy systems.

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1. Introduction

Buildings are responsible for 28% of global energy-related CO_2 emissions (IEA 2019), and the decarbonization of cities is critical if global warming is to be limited to 1.5 °C. The impact and role of emerging markets will be crucial to motivate innovative policymaking (BNEF 2018). Cities must act immediately and decisively on climate change while delivering transformational GHG mitigation actions and increasing their resilience (C40 Cities 2019). The trend towards sustainable cities must focus on integrating diverse urban systems, such as the supply of heating, cooling, domestic hot water, electricity, sanitation, sewage treatment, transport, and waste.

District energy systems (DES) are among the main factors in cities that have succeeded in scaling up energy efficiency and renewable energy, and in decoupling growth from GHG emissions (UNEP 2015). District energy is a centralized energy system connected to an underground piping network that delivers heating, cooling, and/or domestic hot water (DHW) services to buildings. These systems can provide affordable and low-carbon energy. District Energy can incorporate waste and renewable energy, and thus support the development of circular economies. Additionally, it provides an opportunity to contribute to resilient, resource-efficient, and low-carbon cities.

District energy is not a new technology, as the first network dates back to the 14th century (Woods and Overgaard 2015). However, recent research has focused on decentralized networks incorporating renewable energy sources such as solar (Huang, Fan and Furbo 2019), geothermal (Soltani, et al. 2019), or industrial waste heat (Bourtsalas, et al. 2019). The Nordic countries are evaluating the integration of renewable energy into district heating in Denmark (Lund, et al. 2010), the stabilization of intermittent energy sources with large-scale heat pumps in Sweden (Averfalk, et al. 2017), and they are also examining the main challenges for district energy evolution in Finland (Paiho and Saastamoinen 2018). These works are being developed in cities where district energy is mature and widely used.

Implementation of district energy systems in emerging markets has been blocked by a lack of conducive policy settings and lack of knowledge of district energy as a potential solution. These barriers are now being lifted, through the development of technical regulations and increased awareness from stakeholders. Furthermore, energy planning now considers district energy (MinEner, 2018). Chilean and Colombian energy policies have different levels of maturity: Zabaloy et al. state that Chile has the proper conditions to promote energy efficiency policies, while Colombia still presents some barriers (Zabaloy, Recalde and Guzowsi 2019). Moreover, Simsek et al. conclude that renewable energy and energy efficiency is already part of Chilean

doi:10.18086/swc.2019.51.01 Available at http://proceedings.ises.org

strategic planning, yet further instruments are required in the residential, public, and commercial sectors (Simsek, et al. 2019). By contrast, Martinez et al. argue that Colombian energy planning has focused on maximizing exports rather than integrating renewables (Martínez and Castillo 2019).

Nevertheless, Chile and Colombia are the leaders in terms of district energy projects in Latin America. In Chile, district energy is already part of the energy strategy at the national (MinEner 2018) and local levels (MinEner 2015). Currently, the government is collaborating with UN District Energy in Cities Initiative to increase awareness of the benefits, to create a supportive regulatory framework, and to promote the development of pilot projects. The aim of this is for there to be a public tender for the construction of district energy systems before the end of 2020. In Colombia, the Ministry of Environment and Sustainable Development is collaborating with the Swiss State Secretariat for Economic Affairs to promote the implementation of cooling districts as a strategy to mitigate climate change, reduce environmentally damaging refrigerants, and meet energy efficiency goals. As part of this collaboration, La Alpujarra district energy system was built in 2013 to supply cooling water to buildings in Medellín.

Even though conditions are converging to make district energy a cost-competitive solution, there are no studies that have estimated the potential of district energy in cities. Studies have focused on analyzing energy demand scenarios (Nieves, et al. 2019), on quantifying the energy performance of dwellings (Besser and Vogdt 2017), understanding the relationships between energy at urban scales and sustainable development (Pardo 2015), or assessing the potential of other technologies at the urban scale, such as photovoltaics in Chile (Campos, et al. 2016), or wind and photovoltaics in Colombia (León-Vargas, García-Jaramillo and Krejci 2019). Existing assessment methodologies are not very applicable to emerging economies, as they are based on mature markets with a great amount of large data available, clear knowledge of the political and economic barriers, and validated business models. To promote district energy development, it is particularly important to lay the groundwork with the main stakeholders and aid decision-makers in understanding the key parameters for properly including district energy into their energy planning.

Therefore, the main objective of this study is to present a validated methodology for feasibility studies of district energy for cities in emerging economies. The methodology is robust for scenarios with low data availability and it focuses on collaboration with government officials and major stakeholders to promote the solution in early stages for cities where district energy is unknown. The outcomes of this work indicate that some cities already meet the conditions for making district energy cost-effective, and that this solution is gaining traction due to the high interest and support from government officials and potential customers.

2. Methodology

The methodology starts with a contextualization of the conditions where the district energy will be developed in order to properly understand the opportunities and barriers surrounding district energy. Next, a city characterization is presented with an emphasis on geographic, economic, and climate aspects, potential energy sources, and city strategies or initiatives that could be aligned with district energy solutions. In collaboration with relevant stakeholders, High Potential Sites (HPS) are identified where district energy is more likely to succeed. The potential sites are selected using a decision matrix based on 7 parameters: key/anchor clients, energy availability, building diversity, land background, future urban plan, and energy demand density (heating and cooling). The selection of the area is validated by local government officials to ensure that projects are aligned with city strategy plans. Energy consumption profiles may be obtained based on local measurements, energy bills, previous studies, and available literature. The analysis compares different alternative technical configurations to supply heating and/or cooling. Technical models are developed based on hourly data for equipment sizing and performance calculations, while yearly results are used as input for the economic studies. Once the technical models are completed, the most cost-effective configuration is selected and compared with business as usual (BAU) or substitute products. Finally, the environmental benefits are estimated, and recommendations are given. These recommendations include applicable business models, and steps required to advance in the development of district energy. The methodology is summarized in Figure 1.

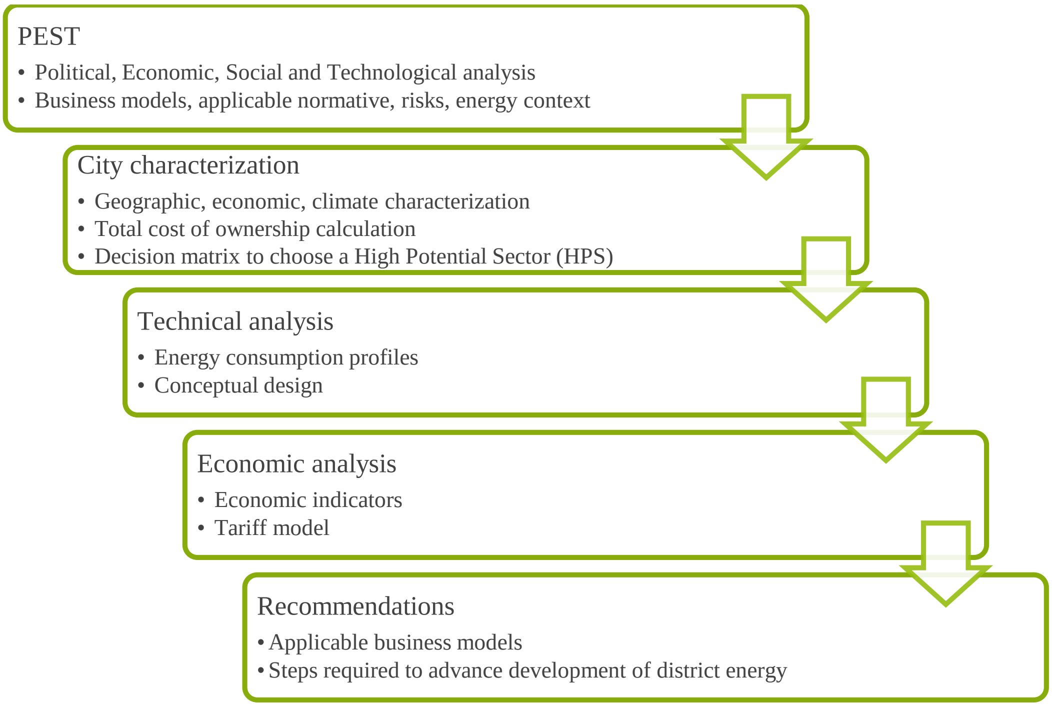

Figure 1: Methodology for district energy feasibility studies.

The methodology has been applied to 7 cities in Colombia and 5 cities in Chile. It has been adapted based on the data availability and goals of the assessment in each city. For instance, rather than using the decision matrix, in some cities, high potential sites are validated in meetings with major stakeholders, where relevant sites and key clients were identified. The selection is then validated using a reverse economic feasibility estimation, i.e. a total cost of ownership (TCO) calculation for various lengths and installed power configurations, which is compared to a standard heating and cooling system's TCO.

Additionally, the methodology considers a Monte Carlo analysis to understand the full range of variation of prices that a conventional solution may have. One of the ways in which the methodology can be adapted is in digitalization for energy characterization, where Internet of Things (IoTs) sensors are installed in potential key customers to precisely estimate energy load profiles. This approach also allows relationships to be established with potential customers in early stages, to promote district energy, and understand their interests and concerns regarding a potential connection to a network. In the following sections, the steps of the methodology are further described.

2.1 PEST analysis

The purpose of a PEST (Political, Economic, Social and Technological) analysis is to spot business opportunities. It provides insight on the changes within the market, so any adaptation can be foreseen. It also identifies threats, so that projects that are likely to fail for external reasons are not pursued. Through a PEST analysis, unconscious assumptions are challenged, and an objective view can thus be developed. The PEST analysis is structured as shown in Table 1.

Table 1: PEST analysis structure

Political	Economic	Social	Technological
Policies and Regulations Applicable technical regulations Energy and urban plans/strategies	Applicable business models Risks Taxes	Social aspects Health implications Energy poverty	Applicable solutions Stakeholder barriers Piping and network construction

2.2 City characterization

2.2.1 City description

The characterization includes identifying major consumers, potential sources of energy, and development areas. Among the main sources of information are local government officials and the city's energy strategy (MinEner 2015), if available. Additionally, understanding the pollutant levels is a key step for the development of district energy in emerging markets, as they are one of the main drivers of these systems. Weather stations have high-resolution data available and air pollutant concentrations. An example is shown in Table 2 of the number of days when particulate matter concentration levels were above Chilean and World Health Organization (WHO) standards in Coyhaique, a southern Chilean city listed as one of the most polluted cities in Latin America (AirVisual 2018). The data shows that PM2.5 concentration levels are above the WHO standard more than 50% of the time, and above Chilean standards nearly 30% of the time.

Table 2: Number of days with 24-hour average pollutant concentration above Chilean and WHO standards for different years in Coyhaique. Data from SINCA (SINCA 2018)

24 hour-concentration	2014	2015	2016	2017	2018
PM2.5 Chilean standard	153	95	138	112	108
PM2.5 WHO standard	234	167	208	184	195
PM10 Chilean standard	39	22	57	30	30
PM10 WHO standard	168	149	170	127	122

2.2.2 Energy demand

There are multiple sources of energy demand for the different typology classifications: modeling, literature, energy efficiency reports, and surveys. Energy demand can be estimated on different bases: current conditions, expected demand when thermal comfort is achieved, and when international construction standards are met. For instance, heating demand in dwellings in Coyhaique can be up to 715 kWh m^{-2} y^{-1}. However, information gathered in surveys establishes energy demand at 446 kWh m^{-2} y^{-1}. This difference is a result of the lack of thermal comfort. Furthermore, if local construction standards were not considered, modeling would likely yield values similar to the ones reported in surveys, i.e. nearly 400 kWh m^{-2} y^{-1}. Dwellings subject to thermal conditioning must achieve 4 air changes per hour (ACH) (MMA 2016); however, the current median value of 20 ACH in Coyhaique is extremely high (CITEC UBB, DECON UC 2014). Thus, it is fundamental to engage with local experts that can provide site-specific information.

Inefficient construction standards yield higher energy density, thereby increasing the profitability of a district energy project. However, poorly performing buildings also pose a risk, as any improvement in thermal insulation results in an oversized system. Because district energy in Coyhaique is conceived of as a response to excessive PM2.5 pollution, the development of district energy may be coupled with improvement of the thermal insulation of houses.

Poor thermal insulation is not a problem exclusive to houses. Potential customers were visited to gather information on consumption through energy bills, and to understand the operation parameters of the systems. During these visits, uninsulated gaps of up to 30 mm in office buildings were identified, as shown in Figure 2.

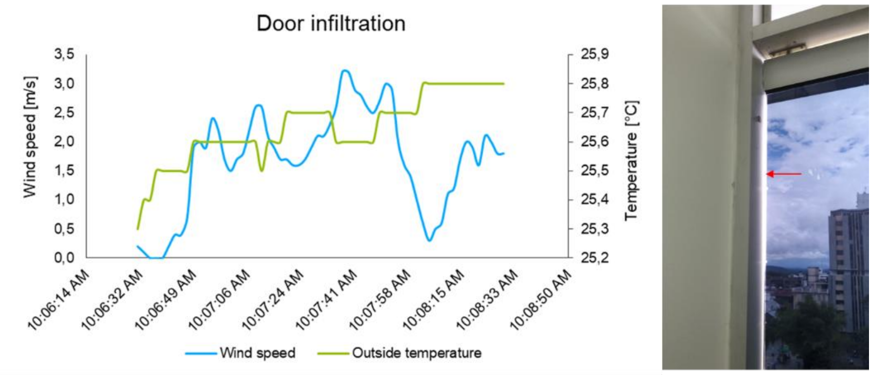

Figure 2: Deficient thermal insulation in an office building

The aggregated district energy demand profile is based on hourly consumption data for an average building of the identified typologies. The methodology aims to reduce uncertainty linked to the energy demand by validating the consumption profiles through on-site measurement campaigns using Internet of Things (IoTs) sensors. These campaigns also served to promote awareness of the potential pilot project. Contacting customers on site also eased the collection of information such as energy bills and other relevant data, which may be used to validate or adapt consumption profiles. Figure 3 shows the consumption profile of a hospital obtained through data collected on site.

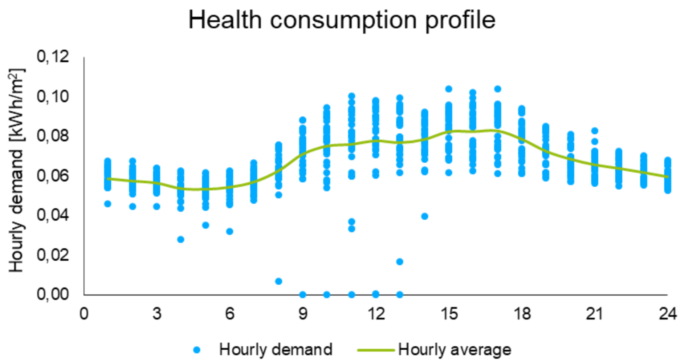

Figure 3: Consumption profile for a hospital

2.2.3 BAU Total cost of ownership

Local cooling and heating solutions must be accurately understood in order to propose a successful district energy project. While district energy may have many positive externalities, such as circular economy and reduced pollution, the client connection will be based merely on tariff costs.

The conventional (BAU) applicable technologies such as heat pumps, chillers, gas boilers, biomass boilers and wood stoves, electric heaters, and a combination of the above are evaluated and contrasted with a district energy solution. The evaluation covers investment costs, annual maintenance, efficiencies, and the primary energy price, and the total cost of ownership (TCO) in the BAU scenario is proposed as a range rather than a single value.

In order to understand the full scope of possibilities of current energy pricing, a Monte Carlo simulation is performed. The simulations are run through 10,000 iterations to account for the potential differences in: the range of energy sources, equipment price fluctuations based on different suppliers, equipment efficiencies, maintenances requirements per year, building energy demand, and energy tariffs, as applicable. We classify clients and perform analyses by typology and normalize the energy cost with a Levelized Cost of Energy (LCOE). The cost ranges stemming from the analysis can then be directly compared with the energy price of the district energy system to assess the potential connection of the client per typology.

Figure 4 shows an example of a Monte Carlo simulation for Independencia, a municipality in the Santiago

Metropolitan area of Chile. The results provide insight into the potential to connect per building typology. For instance, health buildings have low costs, due to economies of scale, high capacity factors, and simultaneous heating and cooling demands. Offices can reach low energy costs as their systems can operate either in heating or in cooling mode, thus increasing the capacity factor. On the other hand, commercial buildings have a wide range of costs, as they may access different electricity tariffs depending on their size, and in general only have cooling demands.

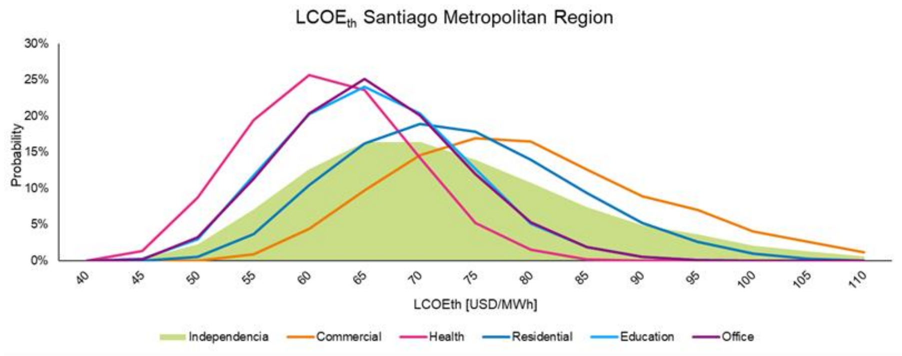

Figure 4: Monte Carlo Simulation results for five typologies in the Municipality of Independencia, Chile

2.2.4 High potential zones

District energy systems have gradually developed over time, and while they may not have supplied numerous customers at the beginning, the networks can grow and even interconnect with other systems in the city. It must be noted that the feasibility of the project is highly dependent on the connection of clients that are initially chosen. Because in this stage there are no contracts nor intention letters signed, not all clients in one specific zone are considered to be initial customers. Risks decrease with this approach: if a client chooses not to connect, it can be easily replaced by others that were initially left out.

Two approaches are considered for the site selection: a decision matrix and a reverse economic feasibility estimation.

2.2.4.1 Decision matrix.

In collaboration with local and central government officials, high potential zones are chosen, i.e. areas where the development of district energy is more likely to succeed. A decision matrix then selects the area to conduct the feasibility study from among the possible high potential zones. The decision matrix considers seven parameters, with a maximum of five points each, shown in Figure 5. The parameters represent various indicators of success of district energy, analyzed as a whole. Among these indicators of success are the availability of key clients, difficulties with building the distribution system, capacity factor, demand density, growth potential, and access to inexpensive energy sources.

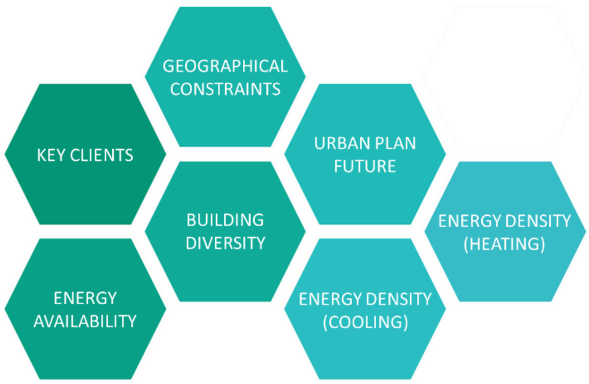

Figure 5: Decision matrix factors

In order to quantify each parameter for the potential locations, key clients are identified, and their energy consumption is estimated. Site visits aid in fully understanding the land background, building diversity, and the availability of energy sources. Additionally, the municipal public planning office may provide insight on the urban development plans. The parameters considered in the decision matrix are:

a. Key customers. This parameter considers the number of key customers in the high potential zone, and assigns one point per key client, with a maximum of five. These are customers with high heating or cooling demands that are likely to connect to the network. Public buildings may also be included if they have emissions reduction targets, which increases their likelihood of connection.

b. Energy availability. An energy source available in the vicinities (e.g. geothermal energy, waste heat, water bodies, etc.) scores five points. Otherwise, one point is assigned.

c. Building diversity. This factor quantifies the potential increase of the capacity factor of the system due to the aggregation of various consumption profiles. The score is the number of client typologies identified (health, office, commercial, education, residential, etc.) for the pilot project, with a maximum of five points.

d. Geographical constraints. It estimates the terrain difficulties for the construction of the network. The score assigned decreases per barrier encountered in the area. Among the barriers are rivers, parks, cemeteries, highways, archeological sites, etc.

e. Energy density (heating and cooling). This represents the energy demand per unit of length of the distribution network. Two parameters are calculated: one for heating and one for cooling. Five points are assigned for an energy density of 20 MWh m^{-1} or higher, and points are reduced by one unit per every 5 MWh m^{-1} reduction; e.g. an energy density of 10 MWh m^{-1} scores 3 points.

f. Urban planning. Similar to energy density, the future urban plan is a measure of the energy density expected from planned constructions in the area. The score follows the same criteria.

Once the parameters are weighted, the averages from all locations are compared with one another. The results are presented to government officials to assure that any strategic consideration was not missed in the analysis. These results can also be validated and promoted to gain support from authorities in the early stages and to manage their expectations.

2.2.4.2 Reverse economic feasibility estimation.

In settings where information availability is low, a second approach estimates the minimum profitable size of a district energy system compared with BAU total cost of ownership costs, as outlined in Figure 6. The main parameters such as capacity factors or efficiencies are estimated. Then, the economics of a district energy system are parameterized as a function of piping length and cooling or heating demand, and the results are compared with an expected LCOE cost through a color-coded table.

LCOE [USD/MWh]		Piping network length [m]							
		150	300	450	600	750	900	1050	1200
Cooling demand [MWh]	125	69	124	179	234	288	343	398	452
	250	42	69	97	124	151	179	206	234
	375	33	51	69	88	106	124	142	161
	500	28	42	56	69	83	97	110	124
	625	26	37	48	58	69	80	91	102
	750	24	33	42	51	60	69	79	88
	875	23	30	38	46	54	62	69	77
	1000	22	28	35	42	49	56	63	69

Figure 6: Reverse economic feasibility estimation for a city in Chile. The LCOE [USD/MWh] is a function of plant demand [MWh] and network length [m].

The goal is to develop a feasibility study that is cost competitive with substitute products, and marginal analysis provides quantitative insight on the economics of a potential pilot project. The tool developed allows areas to be preselected that are likely to be cost-effective, thus reducing the iteration time. This tool was successfully applied to studies in 7 cities in Colombia, where the sites chosen achieved similar tariffs as the conventional systems.

2.3 Technical analysis

After the pilot project and the customers' consumption profiles have been defined, the aggregated demand is calculated as exemplified in Figure 7. The hourly demand serves as a basis to calculate the capacity and the Equivalent Full Load Hours (EFLH), i.e. a measure that represents the corresponding hours at which the plant would operate at full capacity. Care must be taken with data points that show high demand only for limited hours per year. A good alternative to see whether that is the case is through a power - operating hourly diagram or through the diversity factor, i.e. the ratio of installed capacity to the sum of all individual capacities. A standard diversity factor is approximately 0.75 (Moseley 2014).

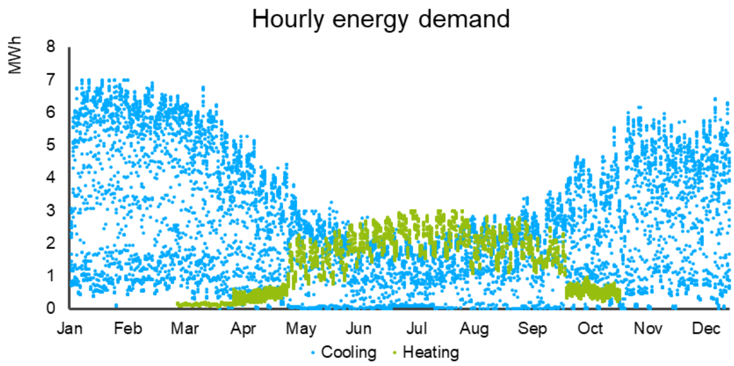

Figure 7: Hourly heating and cooling demand for a pilot project in Independencia, Chile

Several configurations are evaluated, and the results are used as input to the economic model, where the most cost-effective alternative is chosen. The technical outputs, such as efficiencies, capacities, and energy consumption are calculated on an hourly basis, considering that efficiencies are dependent on instantaneous capacity factors. For instance, the hourly coefficient of performance (COP) of five 1.5 MW chillers supplying the cooling demand represented in Figure 7 is shown in Figure 8. Finally, an initial layout of the distribution network is designed, and its pumping requirement estimated.

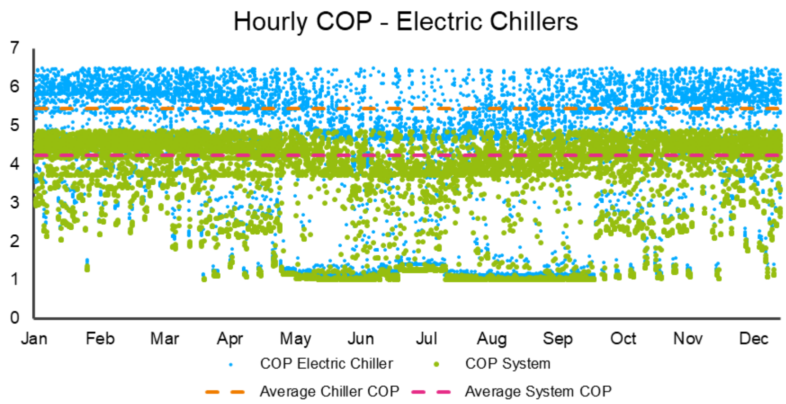

Figure 8: Hourly COP for a pilot district cooling project in Independencia, Chile

2.4 Economic analysis

The district energy configurations are economically evaluated, and the CAPEX and OPEX are calculated according to the technical requirements. Then, depreciation, loan requirements, taxes, etc. are computed to compose the cash flow. The input parameters consider probabilistic distributions to forecast the costs and expenses for a 30-year horizon. A Monte Carlo simulation is run to determine the incomes required to obtain the desired internal rate of return (IRR) for investors. A second approach is also considered for the Colombian cities: to fix the selling energy price based on current tariffs and calculate the resulting IRR.

Additionally, insight is given on the tariff structure that may be applicable to obtain the necessary incomes. The recommended tariff is divided into three parts: connection fee, consumption fee, and capacity fee.

- Connection fee: The payment is structured throughout the contract duration. A fee is estimated to cover the capital investment cost of the piping network from the main piping network up to the respective user's connection point, i.e. only secondary piping.
- Consumption fee: Covers the variable operational costs such as electricity consumption, gas, water, and chemicals for water treatment. It changes monthly or as utilities update their pricing conditions.
- Capacity fee: Covers the capital investment of the energy plant, main piping network, and non-variable costs (administrative, operation, and maintenance costs).

The sum of these three fees is the selling energy price. The energy price of each configuration is compared with the BAU. Economic competitiveness is analyzed and, if required, a subsidy is estimated. Using this and strategic considerations, the best alternative is chosen.

3. Results

The results of the 12 feasibility studies are summarized below. In the case of Chile, the methodology was applied to five cities: four are within the Santiago Metropolitan Area (Santiago, Independencia, Recoleta, and Renca), and there is one city in southern Chile (Coyhaique). The analysis was envisioned to be focused on heating; however, the methodology is unbiased, and the economics show that district cooling can be more cost-effective in the Santiago Metropolitan Area.

Table 3: Summary of the main findings for feasibility studies in Chile

	Santiago	**Independencia**	**Recoleta**	**Renca**	**Coyhaique**
Type of system	Cooling	Cooling	Cooling and Heating	Heating	Heating
Technology	Electric chiller	Electric chiller	Heat pumps	Heat pump	Wood chip boiler
Capacity [MWt]	1.8	7.5	0.80	0.23	4.6
Piping length [m]	1,180	1,600	334	840	2,750
Investment [MUSD]	$4.1	$10.7	$2.6	$1.9	$8.1
IRR	7.8 %	7.8 %	7.8 %	7.8 %	7.8 %
LCOE BAU [USD MWh^{-1}]	48 - 80	52 - 98	49 - 86	52 - 89	34 - 66
DES Energy price [USD MWh^{-1}]	51	45	53	54	55
Subsidies	Free land concession Shared piping infrastructure	Free land concession	Free land concession	$1.5 MUSD subsidy Free land concession	Subsidize dwellings in $2.1 MUSD

Initially, five studies were developed in Colombia. Given the results show that conventional systems are the most cost-effective, two additional cities were analyzed, with a focus on the integration of renewable systems. The approach considered fixes the selling price to the current business as usual price and calculates the resulting IRR, i.e. no cost reduction is achieved. The main findings are summarized in Table 4.

Table 4: Summary of the main findings for feasibility studies in Colombia

City	Type of system	Technology	Capacity [MW_t]	Piping length [m]	Investment [MUSD]	IRR
Bogotá	Cooling	Electric chiller	20	850	24	12%
Villavicencio	Cooling	Geothermal cooling	8.1	1,810	12	10%
Cartagena	Cooling	Electric chiller	32.4	1,800	37	15%
Montería	Cooling	River water Cooling	22.4	2,900	34	16%
Cali	Cooling	Electric chiller	17.4	1,350	23	13%
Bucaramanga	Cooling	Electric chiller	9.0	1,600	15	11%
Medellín	Cooling	Electric chiller	20.3	1,100	37	13%

4. Discussion

District energy is an alternative that requires the coordination of all relevant stakeholders. District energy, as a disruptive project, allows coupling energy efficiency measures or public education regarding energy matters. Among energy efficiency measures is coupling a program to improve thermal insulation in dwellings with district energy development, to achieve international construction standards. Both, energy efficiency and public education, are generally in line with the energy strategies of cities and the central government. Stakeholders must be included in the process in early stages, as the developer will require support from local and central government.

Emerging economies, unlike mature markets, may lack the required data to assess the potential and capacity requirements of district energy. As thermal comfort is often not achieved, differences in consumption among clients may be significant. By developing on-site measurement campaigns, the consumption profiles can be validated, and all operational constraints can be properly identified. On-site measurement campaigns made it possible to identify additional concerns of potential customers. For instance, gas supply contracts had been signed, thus hindering the development of district heating. Another example is some clients had inoperative cooling equipment, which increased their willingness to connect to a district cooling system.

The variation in energy demand results in further increased price differences, as there may be major variations in system costs and primary energy prices. Assessing the connection of customers using a single BAU price does not represent the universe of clients, and it further adds to the uncertainty of the assessment. By developing Monte Carlo Simulations at the BAU prices, the full range of possibilities can be visualized, and non-connection risks can be understood.

The selection of the area of interest of the study is subject to biased influence. Failing to select a site with possibilities of success may delay the implementation of district energy or make it subject to avoidable subsidies. However, despite the fact that including clients with low energy density reduces the profitability of the project, the social benefit may far outweigh the required subsidy, as was the case of Coyhaique. Using quantitative methods and providing insight on costs in early stages proved to be extremely useful in assessing areas, and it ensured that the best sites were considered.

As studies were developed in 12 cities, a high level of support was encountered from various stakeholders. Commitment has been shown at various levels and in different forms. For instance, local governments have offered permit fee waivers, free land concessions and expedited procedures. On the other hand, central governments are willing to collaborate in the development of technical specifications and technical normative considering feedback from potential developers. Key clients and developers have both been approached since the beginning of the project and have shown great interest in the results of the study. By including them in early stages, their needs and concerns regarding a potential connection of a district system can be voiced, and consumption data can be collected. In general, barriers are being lifted and the development of district energy is expected over the short term. It must be noted that even though potential customers were willing to provide consumption data, information could only be effectively gathered through face-to-face meetings.

However, site visits do not only serve to gain support for the development of a potential pilot project, as important information was also collected. Various clients in cities in both Chile and Colombia experienced the operation of cooling equipment that was often faulty. For instance, in some hospital buildings, consumption increased in a month where the personnel were on strike and the building was vacant. Another hospital had two floors with their cooling equipment completely inoperative. Potential customers were largely unsatisfied with their cooling supply, and thus would likely connect to a system where the problems related to operation could be outsourced, even if there is no benefit in terms of price.

The results show that cities in Chile and Colombia already have favorable conditions for developing district energy, as both regulatory and lack awareness barriers are being lifted. As stakeholders have increased their awareness of the benefits of district energy, their support must now be formalized in order to promote the development of pilot projects.

5. Conclusion and future work

The work presented herein is a highly flexible methodology that aims to give an estimation of the potential profitability of district energy systems. It has been successfully applied in 12 cities, with solutions that range from conventional cooling, coupling renewable energy with cooling and heating systems, and a combination of both. The methodology allows conditions to be identified in which district energy can be developed. Among these conditions are the applicable normative, city context, cost-effective system configuration, expected tariffs, required subsidies, and environmental benefits. Future improvements of our methodology include automation heat maps based on widely available, geo-referenced data and deepen the coupling of energy efficiency programs with district energy development.

6. Acknowledgements

The authors would like to acknowledge UN Environment District Energy in Cities Initiative, the Colombian Ministry of Environment and Sustainable Development, and the Swiss State Secretariat for Economic Affairs for the funding provided to develop the studies, their technical input, and their assistance with coordination with local government officials. The authors would also like to thank the team at Hinicio for their collaboration in conducting the studies in Colombia, and Mr. Antonio Di Cecca, Mr. Germán Villaroel, Mr. Javier Vásquez, Mr. Ismael Rodriguez, and Mr. Francisco Bellalta from Tractebel Chile for their technical support throughout the development of this work.

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