

Improving Sustainability Concept in Developing Countries

Social Urban Metabolism Strategies (SUMS) for Cities

Davis, M.J.M.^{a,b,*}, Jácome Polit, D.^{c,*}, Lamour, M.^{d,b}^a*Evolution Engineering, Design and Energy Systems Ltd., 5 Silver Terrace, Exeter EX4 4JE, UK*^b*Pontificia Universidad Católica de Ecuador (PUCE), Department of Architecture, Av. 12 de Oct 1076 y Roca, Quito, Ecuador*^c*Universidad de las Américas (UDLA), Department of Architecture, Av. de los Granados E12-41 y Colimes esq., Quito, Ecuador*^d*Independent Researcher, la Tola, Quito, Ecuador*

* Corresponding authors. Tel.: +593 (0)988231508, +44 (0)1392 517589.

E-mail address: cdjacomepolit@gmail.com, davismaks@evolutionecoengine.com

Abstract

The city is where important exchanges of resources occur, but where what is received from the environment differs greatly from what is returned to it. Energy, water, materials and food are received, yet other waste energy, wastewater, waste materials and organic waste are returned. In nature waste equals food, where circular metabolisms enable resources to be reinvested. In cities in developing countries, not only are resources wasted, but also many people are left out of the value chain. In this paper a Social Urban Metabolism Strategy (SUMS) for Cities is proposed, where through establishing urban metabolism systems marginal communities become part of the value chain. A hypothetical case study is carried out for Quito, Ecuador. First, residential organic waste is mobilized to produce biogas for electricity generation. Second, the micro-plant is located in a community in need of economic regeneration. Third, Quito increases its own electricity generation capacity.

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1. Introduction*1.1. A methodology for the application of urban metabolism strategies*

The objective of this paper is to propose a strategy for the application of urban metabolism cycles in cities. Quito, the capital city of Ecuador, is taken as a case study. The first step is to identify waste flows in the city that have the potential to be converted to nutrition streams. To this extent a study is made of mobilizing organic waste streams in Quito for electricity production. The second step is to carry out a social analysis, in order to identify the most

vulnerable communities in need of economic development. For this reason a vulnerability analysis is carried out for Quito, where the parish of Calderon is identified as the most vulnerable. Finally, the third step is to carry out an economic analysis of the urban metabolism cycle proposed. For this purpose a preliminary study is carried out in this paper of the increase in electricity generation, the potential revenue from this and the number of jobs created in the region. By proposing the most suited technology and generating a circular economy, a value chain is created where socially depressed zones participate in social-economic reactivation, resilience and climate change adaptation. As such, a method for urban planning based on urban metabolism is achieved.

1.2. Sustainable development in relation to this paper

Sustainable Development has been defined by the Brundtland Report (World Commission on Environment and Development, *Our Common Future*), released in October 1987, as

“development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1].

This is a multi-dimensional model is then supported by spheres or domains, which were recognized as "economic, environmental and social" or "ecology, economy and equity" [2]. Sustainable development consists of bringing these three domains into equilibrium.

In order to do this it is necessary to move away from the notion of linear processes to circular ones. Linear economies are based on receiving a resource flow and transforming this into waste, which brings about negative impacts on the environment, society, as well as generating scarcity of resources [3]. In contrast, urban metabolism can be likened to circular economies, defined as:

“the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” [4].

The notion of urban metabolism was initially defined via an analogy with the metabolism of single organisms, given that cities also consume resources and excrete waste. However, cities are more complex than one single organism, as they have multitude organisms within them. They are therefore more alike to ecosystems. Nevertheless, ecosystems' metabolism is not linear; it is circular process where waste becomes a resource that is consumed in continuous cycles.

Although the use of urban metabolism as a planning tool is a recent phenomenon, there are a few cases where it has been implemented [5]. This is becoming popular for example in the cities of China, where it is recognized as a manner through which to combat resource scarcity in the face of rapid economic growth [6]. In addition, this paper argues for a new, social approach to urban metabolism, where deprived urban areas benefit from the location of the city's infrastructure services.

Quito is a city, like any other city, that consumes streams of resources that are eventually disposed of through linear metabolisms. In this paper, organic household solid waste, and its potential for energy generation is looked into. It is then put forward that a circular economy could be created, where the waste is turned into raw materials for electricity production, and where micro energy plants are located in poverty vulnerable urban areas for social-economic reactivation. As such, in terms of the three spheres of sustainable development this paper covers (Figure 1):

- The environmental sphere: a study of mobilizing organic waste stream flows and their transformation into nutrients for electricity generation, as such mitigating landfill practices and the subsequent generation of methane greenhouse gases.
- The social sphere: a consideration of micro-plants for electricity generation and their optimal location for the social-economic reactivation in deprived areas of Quito.
- The economic sphere: a consideration of the increase in electricity generation capacity, potential revenue and number of jobs created.

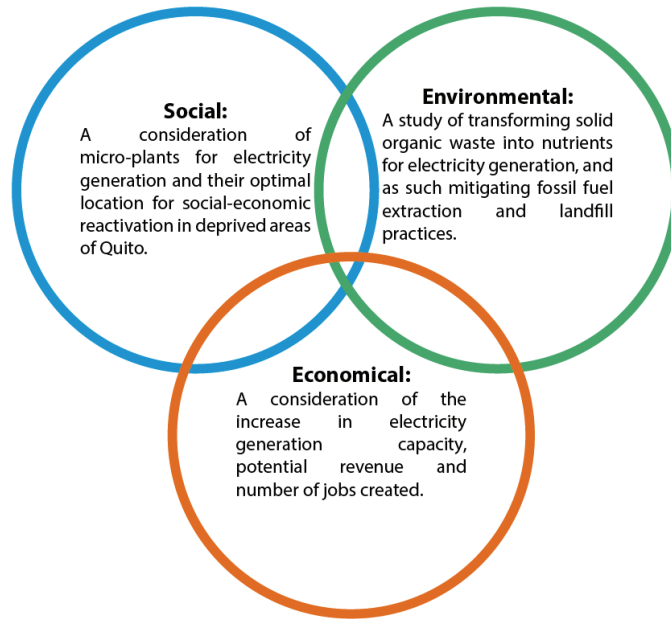


Fig. 1. The three spheres of sustainable development covered.

1.3. The current state of urban metabolism cycles in Quito's waste management

With regard to waste generation and disposal in the Quito, the linearity of the process loses many potential resources along the way. The first resource lost is land. Quito uses two transfer stations and one landfill for its waste management, which are located within the municipality boundaries, have limited capacity and can be said to be degrading for the surroundings [7]. The second resource lost is methane gas emissions that could be used as a resource for energy generation, which are at present only generated by the landfill waste undergoing anaerobic digestion [7]. Finally, a third potential resource is compost derived from organic waste, but where once again this is simply diverted to landfill at present [7]. This paper argues that all of these resources could, and should, be harnessed to generate additional services for the city (Figures 2 and 3).

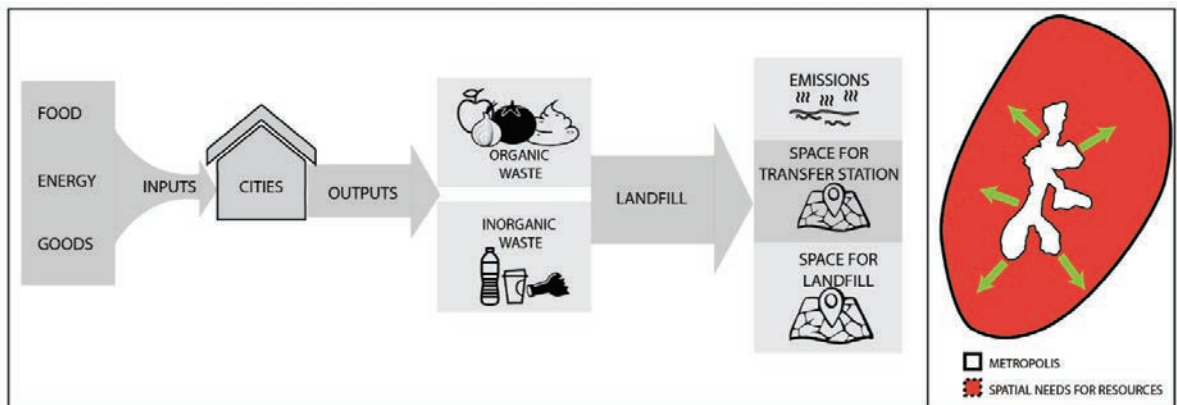


Fig. 2. Linear processes for the management of urban waste, energy and goods.

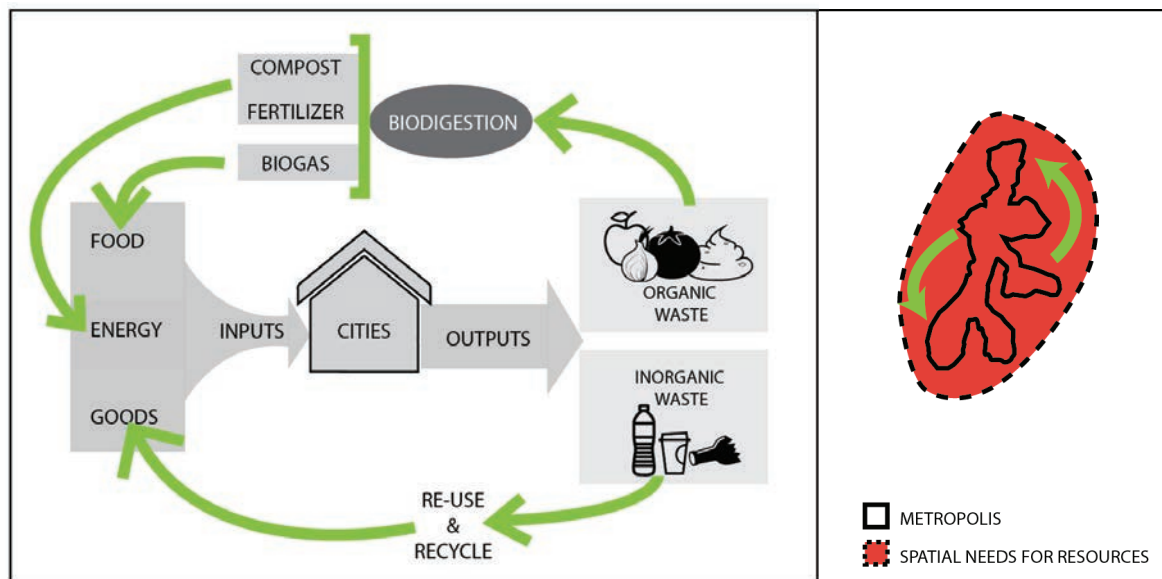


Fig. 3. Urban metabolism processes for the management of waste, energy and goods.

2. The environmental sphere: mobilizing organic waste flows for electricity production

2.1. The energy context in Ecuador and Quito

Castro [8] describes how from 1990 to 2008, the national energy demand of Ecuador grew on average by 6%, meaning that energy imports became necessary. Initially 24 GWh were imported from Colombia and Peru in 1999, but by 2008 this had grown to 500 GWh [8]. According to ARCONEL [9], in 2014 Ecuador generates 96.67% of the electricity that is consumed nationally, with the remainder being imported. 39.22% of the electricity generation is derived from hydroelectric plants, 2.52% from biomass, 0.46% from solar photovoltaics and the remaining 57.43% from fossil fuels. Since 2007, 4 200 million USD has been invested in changing the energy matrix, with the aim of having 93.53% of electricity generated from hydroelectric plants by 2016 [10]. Additionally, the national government aims to reduce the costs of subsidizing liquid petroleum gas (LPG), through the installation of 3 million electric induction cookers and the promotion of electric water heaters [11]. This is in part due to the fact that nearly 80% of LPG is currently imported, leading to costs of some 700 million USD annually [11]. Finally, in the transport sector, it was recently decided to eliminate import taxes for electric vehicles to be sold in Ecuador [12].

In terms of heating and cooling demands, Ecuador has a constant, temperate climate, which is often described as a 'constant spring'. In Quito, Ecuador's capital city, minimum temperatures vary from 9 to 12°C, and maximum temperatures range between 19 and 23°C [13]. It is hotter towards the coast, with minimum temperatures in Guayaquil varying from 20 to 24°C and maximum temperatures ranging between 29 and 32°C [13]. As such, Ecuador has a negligible energy demand for heating/cooling of buildings. Given this context it is argued in this paper that the logical choice for energy from organic waste streams is their conversion into nutrient flows for electricity production. It is put forward that this has the potential to take the burden from the hydroelectric plants, mitigate the need for thermal plants to generate the remainder of electricity needed, and even open up markets for electricity exportation if successful implementation leads to an excess being produced.

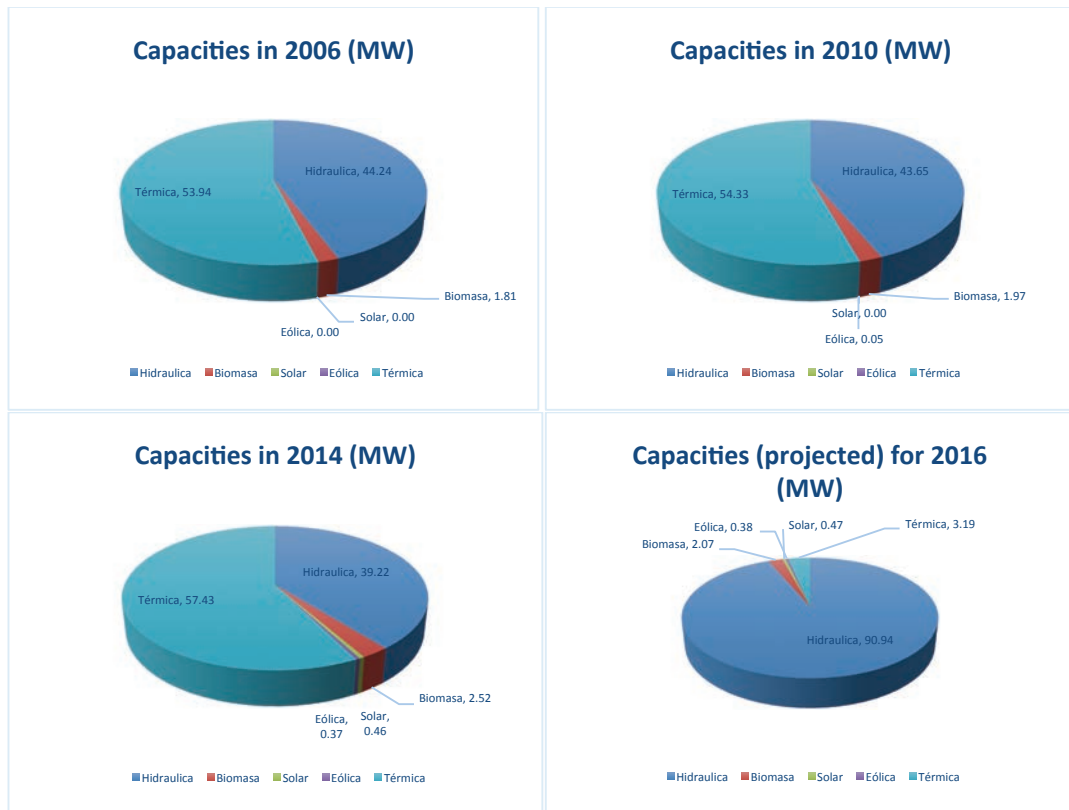


Fig. 4. Projection of change in energy matrix in Ecuador (Adapted from MEER, 2012 & ARCONEL, 2015).

The Quito Electric Company (EEQ) is responsible for supplying sufficient electricity to meet the city's demands. According to the company's annual report, in 2013 it had the capacity to generate 512 GWh from its 5 hydraulic and 1 thermal plants [14]. This was compared to a demand of 3 998.56 GWh that needed to be met. As such, the EEQ was able to meet but 13% of the city's demand in 2013, with the remainder being obtained from the national grid [14]. In terms of the EEQ's own capacity, 67% of the electricity production came from its 5 hydroelectric plants, and the remaining 33% from its 1 thermal plant [14]. This data is shown in Figure 5.

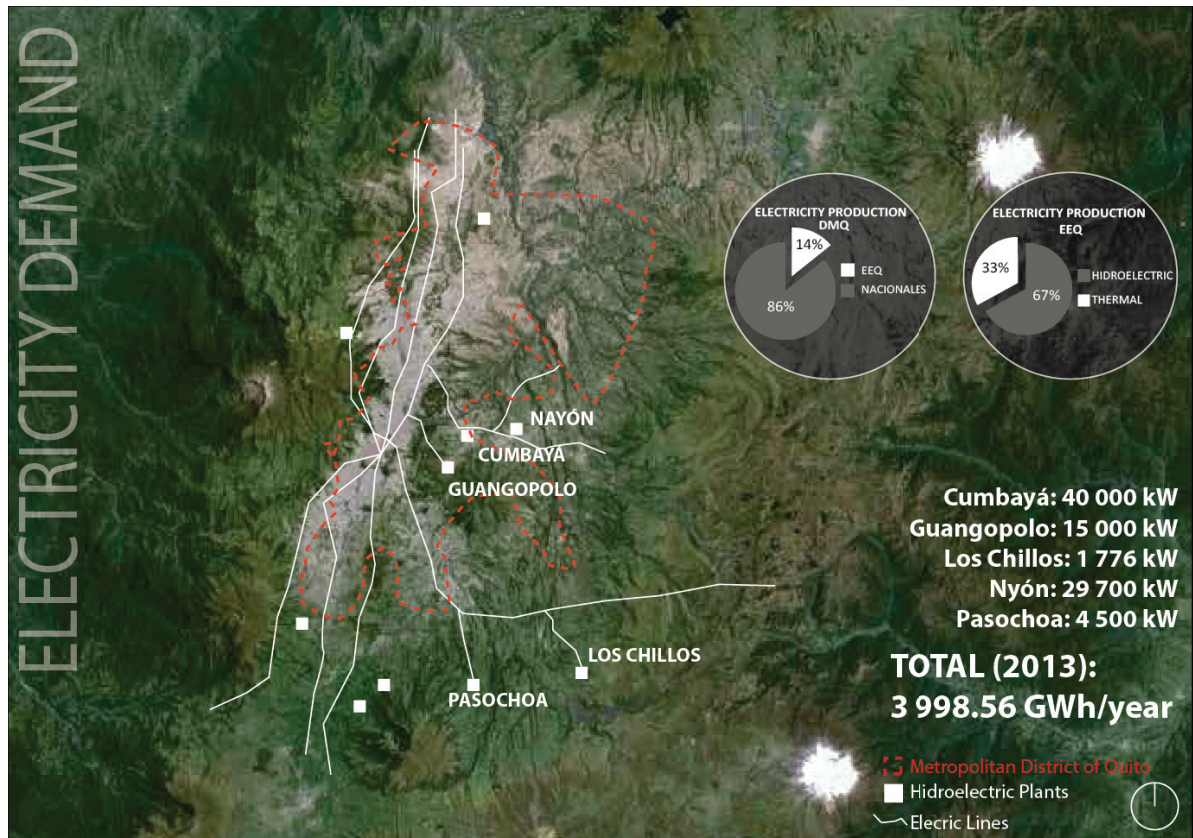


Fig. 5. Electricity demand and supply in the DMQ

2.2. Organic solid waste management in Quito

2.2.1. Organic solid waste management in Quito

Solid waste per capita in the Quito Metropolitan District (DMQ) is 0,850 kg/person per day, which is then further divided into 0,879 kg/person per day within the city and 0.799 kg/person per day in rural areas [7]. Regarding the composition of the solid waste, 62% belongs to household waste, followed by 16% for business, 13% for local markets, 6% for others and 3% for educational facilities [7]. Finally, with relation to the composition of solid waste, 57% represents organic waste, 24% recyclable waste and 19% of other miscellaneous waste [7]. According to the January to June 2014 DMQ indicators, in this period the city collected 329,363 tons of solid waste with a monthly average of 54,894 ton/month [7]. It can therefore be deduced that:

$0.879 \text{ kg/person/day} \times 62\% \text{ household waste} \times 57\% \text{ organic waste} = \mathbf{0.31 \text{ kg organic waste per person per day}}$ in the households of the DMQ.

2.2.2. Solid waste disposal

Solid waste is collected within the city by a variety of manners, where household waste collected from the pavement outside each household by a collection vehicle represents 72% of the total [7]. Once the waste is collected, it is taken to transfer stations (TS), located at the north and south of the city [7]. As a point of interest, the North TS works with traditional low-tech installations and suffers from poor management and social conflicts with the workers. In contrast, the south TS is a high-tech facility with a capacity guaranteed for the next 8 years [7].

The final destination of solid waste is the El Inga landfill (Figure 6), at a rate of approximately 1900 ton/day [7]. El Inga has a capacity of 8200000 tons of waste [15]. The landfill is divided into eight impounding basins, where basins 1 to 7 have been already decommissioned and only No.8 remains operational [7]. Basin 8 is planned to be decommissioned in August 2015. Studies for a ninth basin have been completed, which would ensure El Inga landfill to be operative for a further 1.5 years. Additionally, modifications to impounding basins No.6, 7 and 8 could potentially lead to a further 5 years of the landfill being operative [7]. This can all be seen in Figure 6.

Overall, the practice of El Inga landfill is argued not to be sustainable in the future, where in addition to a deficiency in terms of pure capacity, it also suffers from a lack of long term pricing policy that reflects the actual costs of the service [7]. It is put argued in this paper that the diversion of organic household waste from landfill, would be of benefit in extending the lifetime of El Inga before it reaches full capacity. In addition, the diversion of organic household waste undergoing anaerobic digestion in landfill, reduces the emissions of methane as a greenhouse gas into the atmosphere.

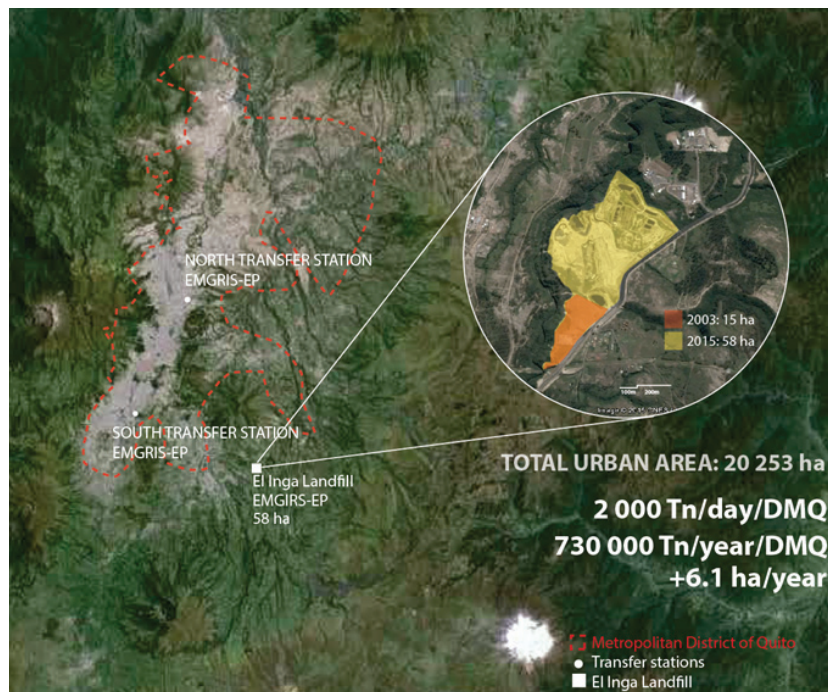


Fig. 6. El Inga Landfill.

2.2.3. Landfill gas management

Sadly, Biogas management in El Inga landfill remains to be a rudimentary operation. El Inga uses a pipeline network to capture and lead the gas to a flume, where it is burned at a rate of 4 hours per day. This operation is a concession to a private operator [7].

2.3. Technologies available for electricity generation from organic solid waste

The three technologies that are currently available and that have been considered for this paper are:

- Biogas
- Biohydrogen
- Direct incineration

2.3.1. Biogas

When organic waste is subjected to biodigestion under anaerobic conditions, microbiological activity converts the residues into biogas and fertilizer [16]. Up to 250-350 m³ of biogas can be produced per tonne of organic waste under optimum conditions [16], where biodigestion plants have an average capacity of 20 to 25 kg/m³ [17]. Biogas is composed primarily of methane, whilst also containing carbon dioxide and residual amounts of other gases, such as hydrogen sulphide, ammonia, and is saturated with water vapor [18]. The energy content of biogas is primarily related to the percentage of methane it contains, where a m³ of methane has a calorific content of 10 kWh and biogas from anaerobic digestion tends to be 65% methane [19]. Among other things, biogas can be used as a combustion fuel for electric generators.

Li, Park & Zhu [20], differentiate between biogas derived from solid and liquid organic waste. In terms of solid organic waste, advantages include a higher efficiency conversion rate, in addition to a lower capacity anaerobic digester being needed. Additionally, less heat energy is required for an optimum digestion process to be achieved, and no agitation processes are required. On the other hand, amongst the disadvantages we find a greater amount of waste input is needed and retention times are greater than for liquid organic waste digesters.

2.3.2. Biohydrogen

On the one hand hydrogen presents itself as a viable energy alternative that is able to produce electricity with zero emissions of greenhouse gases via fuel cell technology. Moreover, biohydrogen has a high-energy content per unit weight at 122-142kJ/g [21]. On the other hand, the main disadvantages of bio hydrogen production are that a great energy input is normally required in order for it to be produced. Additionally, it is a new technology, where it could be argued that it has not yet matured for commercial applications [21]. Biohydrogen can be produced through either: direct biophotolysis, indirect biophotolysis, photofermentation and dark fermentation. Amongst these at present dark fermentation seems to be the most viable in terms of cost-benefit [16]. In dark fermentation, certain anaerobic bacteria grow in a sealed, dark environment, producing hydrogen, carbon dioxide and volatile fatty acids (VFA) as a result [22].

2.3.3. Direct incineration

Ecuador's Ministry of the Environment, Rural and Maritime Affairs [23] describes how waste incineration is carried out in three stages. First, it is mowed and degassed at temperatures between 100 and 300°C. Second, it goes through a process of pyrolysis and gasification, which is carried out at temperatures of between 200 and 700°C and allows for the decomposition of organic substances. Finally, in the third stage combustion gases are oxidized at a temperature that varies between 800 and 1450°C.

The calorific value to the waste to be burned for electricity production depends on factors such as; the composition of the waste, the size of the individual parts to be burned and having a homogeny air circulation through the waste to ensure a complete combustion is achieved [24]. Kathirvale et al. (2003) [25] put the energy content of waste for combustion at approximately 9.2 MJ/kg (2 555.6 kWh/tonne), and the World Bank (1999) [26] at least 7 MJ/kg (1 944 kWh/tonne).

It also needs to be noted that direct incineration entails a complex treatment of flue gases. Large volumes of flue gases must be cooled to 200 C before applying flue gas treatment. Ash, heavy metals, and organic and inorganic compounds such as mercury, dioxins, and NOX then need to be removed through chemical treatment technologies [26].

2.3.4. A comparison of the three technologies

It is necessary to determine the optimum technology for the production of electricity in deprived areas of Quito through the conversion of organic waste. To this end Table 1 compares the advantages and disadvantages biogas, biohydrogen and direct incineration in terms of:

- Energetic yield (kWh of electricity produced).
- Contamination.
- Global costs.

- Social factors

Table 1. A comparison of the advantages and disadvantages of biogas, biohydrogen and direct incineration.

	Advantages	Disadvantages
Biogas	Good energy yield at 250 m ³ /ton waste (1625 kWh/tonne waste). Avoids methane greenhouse gas emissions from the composition of organic waste under anaerobic conditions in landfill. Easily accessible, low cost technology with a proven track record worldwide.	CO ₂ is produced upon combustion of biogas.
Biohydrogen	Very high energy content. No greenhouse gas emissions, with only water and oxygen as a byproduct when passed through a fuel cell.	Potentially high costs, due to implementing a new technology. Need for highly skilled operators presents a high risk of failure, due to a lack of knowledge from local community members on how to run and maintain the plant
Direct incineration	Good energy yield at least 1 944 kWh/tonne. Avoids methane greenhouse gas emissions from the composition of organic waste under anaerobic conditions in landfill. Easily accessible, low cost technology with a proven track record worldwide.	Complex processes and quality control required to regulate the flue gas emissions. High risk of not only organic waste being burned, but where various waste flows are brought into the plant. This in turn could lead to noxious gases being emitted in deprived urban areas of Quito, leading to health and environmental problems.

From Table 1, it is put forward that the most desirable form of transformation of the organic waste to electricity production would be through biogas, where the micro-plants are to be located in deprived urban zones of Quito. It should be noted that electricity production only is considered for this paper, where the use of the fertilizer and excess heat produced is recommended for further research.

3. The social sphere: an optimal location of decentralized biogas fired electricity plants for urban metabolism

As mentioned previously, the concept of urban metabolism as an urban planning design tool is relatively new, although there are cases where urban metabolism has been used to design infrastructure for sustainable cities [4]. Additionally, there is a further paradigm shift when the approach is taken to developing countries. In this case this paper argues that an extra emphasis needs to be made on socially and economically depressed zones. It is put forward that energy plants can be integrated into such deprived zones, in such a manner that social and economic development can be achieved. It should be noted that the various references used in this section of the paper, are all based on data from the 2010 National Census.

3.1. Zone Locating Approach

To date there is no track record for the optimal location of micro-biogas plants for the development of socially deprived areas in developing countries. Nevertheless, there are a number of baseline considerations that can be taken [27], which are applicable or not as given in Table 2.

Table 2. Baseline considerations and its applicability to Quito.

	Baseline consideration (from [27])	Applicability to Quito
1	The site should be located at suitable distance from residential areas in order to avoid inconveniences, nuisance and thereby conflicts related to odours and increased traffic to and from the biogas plant. As a consequence, it is advisable to avoid areas of high urban density.	Applicable.

2	The direction of the dominating winds should be taken into account, to avoid wind born odours reaching residential areas.	Applicable.
3	The site should have easy access to infrastructure. Examples include the electricity grid, for the easy sale of the electricity produced, and roads, to facilitate transport of feedstock and digestate.	Applicable.
4	The soil of the site should be investigated before starting the construction.	Applicable.
5	The site should not be located in a zone at risk from flooding.	Not applicable, due to the geomorphology of the city.
6	The site should be located relatively close to agricultural feedstock production (manure, slurry, energy crops) aiming to minimise distances, time and costs of feedstock transportation.	Not applicable for this paper, since the feedstock identified is residential organic waste.
7	For cost efficiency reasons, the biogas plant should be located as close as possible to potential users of the produced heat. Alternatively, other potential heat users, such as greenhouses, can be brought closer to the biogas plant site.	Not applicable, due to the fact that in Quito there is no demand for heating.
8	The size of the site must be suitable for the activities performed and for the amount of biomass supplied.	Applicable

The first step is to find a suitable place within the city boundaries of Quito, with a low urban density and large land parcels available, whilst at the same time being located in a deprived area that stands to benefit from the installation of micro-biogas plants.

Quito is divided politically, first in administrative zones and then in parishes. In 2015, the General Secretary of Planning of the Municipality of Quito, released its report on Urban Development and Territorial Planning 2015-2025[7]. This is an extensive document, divided into various sections, and which has been used as the basis for the studies in this section of the paper on choosing an optimal location for the biogas plants.

While the average population density of Quito as a whole stands at 58 inhabitants per km², for administrative zones such as Eloy Alfaro or Manuela Saenz this density is much higher (131 and 98 respectively) [7]. This is also the case for certain parishes, such as Solanda, San Juan, Covenant Gualea, Cotocollao, Kennedy, Cochapamba, San Bartolo, La Mena, La Magdalena, Railway, Chimbacalle Chilibulo [7].

On the other hand, in parishes such as Calderon (located within the Calderon Administrative Zone, including the parish of Carapungo), the population is concentrated in urban centers and large areas or parcels of uninhabited land are to be found [7]. In the case of Calderon, 7.8% of the population of Quito sits in this parish. For other parishes such as El Condado, Quitumbe or Conocoto, a similar concentration of Quito can be found, with 4.05%, 4.04%, and 3.99% of the total population respectively. It can therefore be concluded that nearly 2 in 10 people in Quito live in these four parishes [7].

This means that on the one hand, a significant portion of the population can be found in these 4 parishes (Calderon, El Condado, Quitumbe and Conocoto). On the other hand, the availability of land space means that micro-biogas plants could potentially be located here. In summary, it can be said that these 4 parishes satisfy points 1, 3, 5, 8, listed in Table 2.

Figure 7 shows the population density of Quito, with the four parishes of Calderon, El Condado, Quitumbe and Conocoto highlighted. The maps were developed for this paper, using data from the 2010 National Census and by modifying maps provided by the Land, Habitat and Dwelling Secretary, MDMQ.

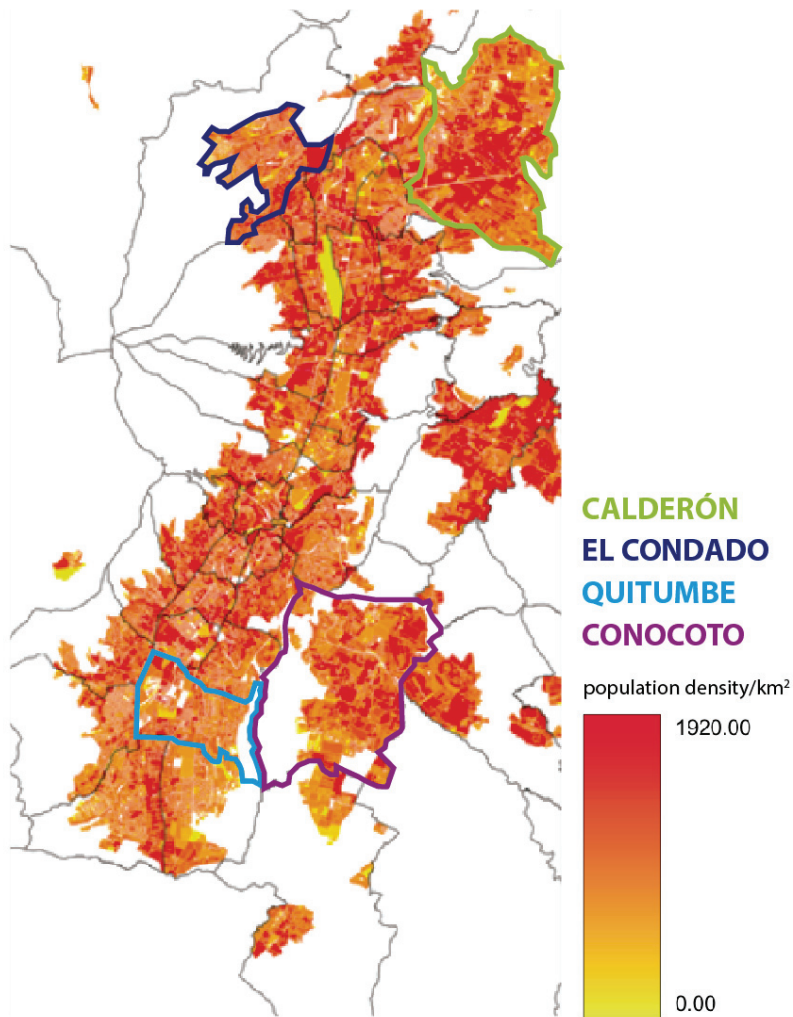


Fig. 7. Density map of Quito and the Parishes studied.

3.2. Identifying the optimal locations of micro-biogas plants for social and economic development of deprived urban areas of Quito

The literature on risk, vulnerability and poverty is both broad and extensive, and definitions may vary depending on the concepts used. Additionally, the terms ‘vulnerability’ or ‘vulnerable groups’ are commonly used, but different meanings tend to be associated with the same term. On one hand, vulnerability does not mean poverty, since if there is no risk present (hence vulnerability), poverty could still persist. On the other hand, in the absence of poverty, vulnerability as an exposure to risk often ceases to be an issue [28]. In this paper a simple vulnerability index has been constructed. It should be recognized however that for a full analysis of the social domain, a more elaborate vulnerability index is needed where each component is weighted on its importance.

A full study of vulnerable group identification methodology is out of the scope of this paper, and further research can be done on a later stage. In this study vulnerability is taken as the combination of climatic hazards, socio-economic conditions, and the ability to adapt. The first two establish the present conditions and can help identify vulnerable groups [29]. Given the above, socio-economic conditions have been adopted for this paper as the

selection criteria, through which the population groups can be chosen that would benefit the most on the micro-biogas infrastructure location.

3.3. Social and economic analysis of the selected parishes

There is much debate on Quito and its so called “demographic bonus”, which points to a economic growth due to the working age population (that is economically active) being greater than the dependent one (children and old age pensioners) [7].

1 in 4 people in Quito (26.93%) are between 30 and 49 years old. 28.11% are between 15 and 29 years old, and 27.49 % are under 14 years old (MDMQ, 2015). These three groups make up the majority of Quito’s population (82.53%), and it is expected that this tendency will continue in the future [7].

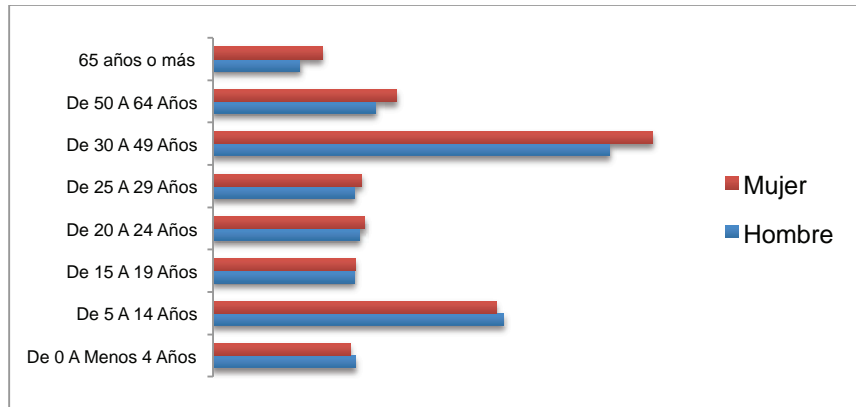


Fig. 8. DMQ population by age and sex. Adapted from Datos Abiertos (n.d.), cited in MDMQ (2015) [7].

While this is advantageous for the city, it does not mean that vulnerable groups are not still to be found among the population. For this paper, a Vulnerability Index is constructed to examine the 4 parishes selected. The aim is to establish which one would benefit the most from the installation of a micro-biogas plant. Regretfully, there is no income-related index of the parishes, and therefore this does not form part of the analysis. Table 3 shows socio-economic data of the four parishes, which has been collated from the database of the Instituto de la Ciudad (Institute of the City), which is in turn based on data from the 2010 National Census. It is argued in this paper that, based on the data below, formal jobs and a secure source of income is desirable to work towards mitigating vulnerability in the parishes studied.

Table 3. Socio-economic data of the four parishes.

	Calderon	El Condado	Quitumbe	Conocoto
Total population in parish	152,242	85,845	79,057	82,072
% population living in urban centres	93.45	24.39	24.72	49.20
Economically active population*	73,351	41,151	35,434	39,957
% Population not contributing to IESS/General Insurance**	45.70	51.20	49.70	41.00
Dependency ratio %***	51.58	54.29	49.99	48.62

* The sum of the employed and unemployed population, who are able to provide labor, goods and/or services.

** The IESS is the Ecuadorian Institute of Social Security, the population that does not contribute to the IESS or any other type of social insurance is an indicator of those working in the informal sector and an unprotected sector of the population.

*** The number of children (from 0 to 14 years) compared to adults of working age (15 to 64) per 100 habitants, which defines the family type by the ratio of the members who depend on the other members.

3.4. Selection of the optimal location of the biogas plant via a Vulnerability Index Analysis

The data from Table 3 needs to be aggregated into an overall score to build a Vulnerability Index as in common practice [29]. Formal multi-criteria approaches in relation to vulnerability indices are often generic and frequently contentious, and it is preferable to use multi-attribute profiles instead [29]. Data from Table 3 can be seen in Figure 9, where the following three dimensions of vulnerability are plotted:

- % Population not contributing to IESS/General Insurance (x-axis).
- Dependency ratio (y-axis).
- Total population in parish (bubble size)

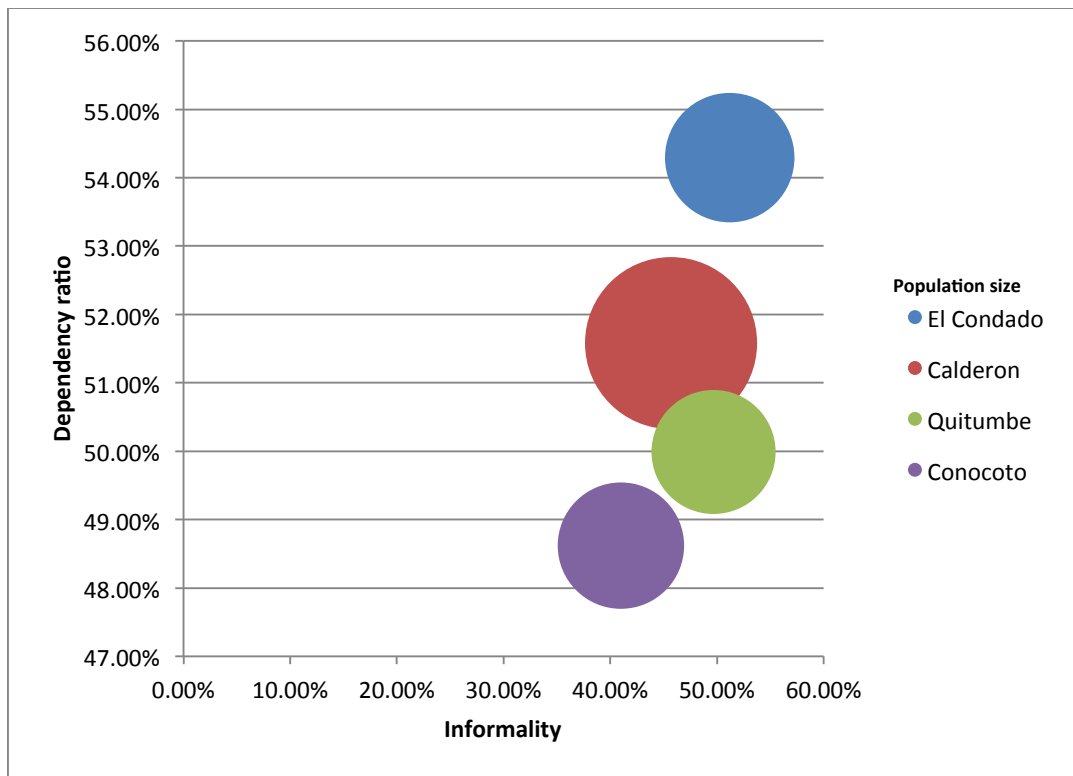


Fig. 9. Vulnerability index showing: informality (x-axis), dependency ratio (y-axis) and population (bubble size).

On one hand, El Condado has the most vulnerable population with the highest % of informality and dependency ratio combined. On the other hand however, Calderon has the biggest population, and as such the highest amount of vulnerable inhabitants per se. The population density of the Calderon parish is shown in greater detail in Figure 10.

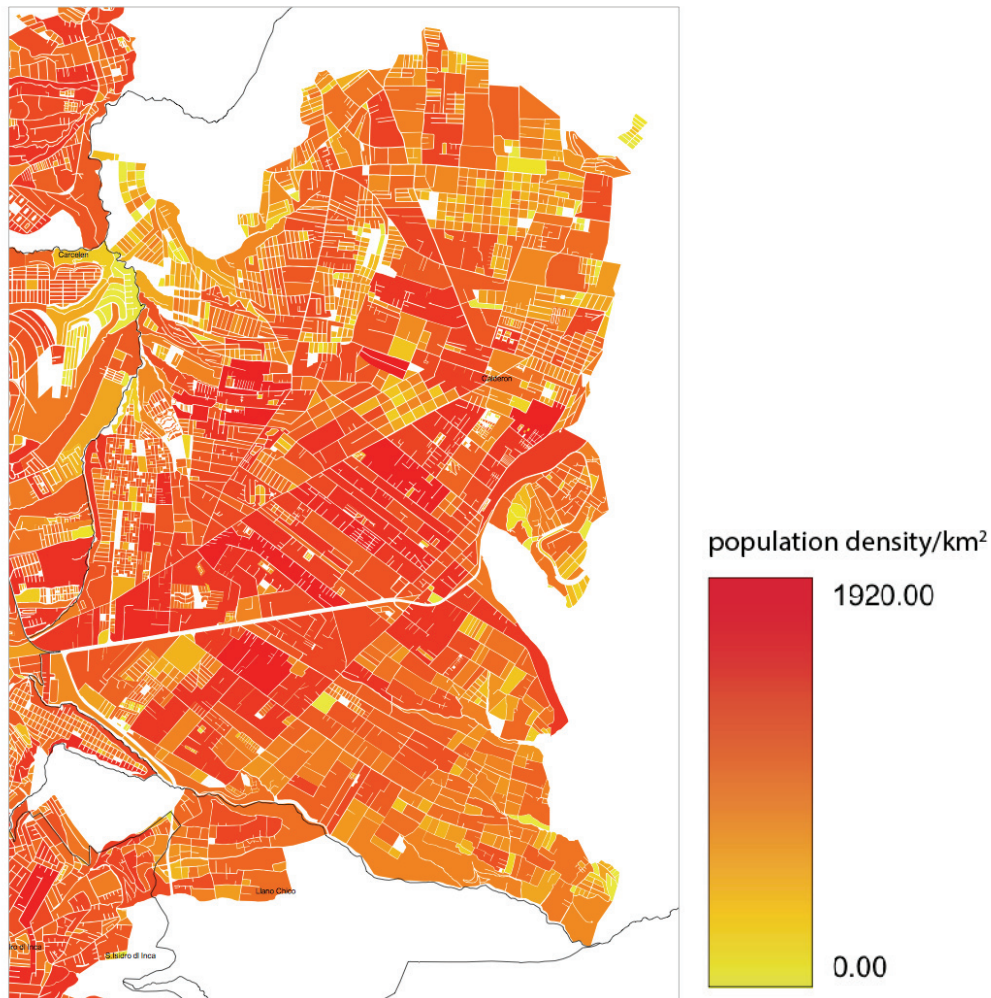


Fig. 10. The population density of the Calderon parish.

4. The economic sphere: a consideration of the electricity production and creation of jobs

4.1. Expected electricity production from a decentralized biogas plants

It should be noted that electricity production only is considered for this paper, where the use of the fertilizer and excess heat produced is recommended for further research. The simplest manner by which to generate electricity from biogas is through an internal combustion motor [30]. The electricity production from biogas can be estimated by:

$$E_{elec} = Q_{biogas} \times F_{CH_4} \times Cp_{(CH_4)} \times \eta_{elec} \quad (1)$$

Where:

- E_{elec} = the electrical energy produced per tonne of organic residues (tres), in kWh/tres.

- Q_{biogas} = the amount of biogas obtained from the organic residues via a biodigester, in m³/tres.
- F_{CH_4} = the of methane (CH₄) contained in the biogas, in %
- $C_{p(\text{CH}_4)}$ = the specific heat of methane (kWh/m³)
- η_{elec} = the electrical efficiency, in %

Q_{biogas} y F_{CH_4} depend on the exact chemical composition of the organic waste, which is particular to each and every waste collection point. They are also dependent on the anaerobic digestion process. Given the lack of publications that are specific to Ecuador, reference has been made for this paper to other studies and international experiences. These give an idea of the ranges of values, from which parameters have been derived for this study.

The exact ratio of CH₄ to CO₂ of biogas is related to the type and concentration of organic input, the feedstock of the micro-organisms at work during the anaerobic process, and the process of fermentation. Bothi [31] puts the fraction of CH₄ as between 55 and 70% of the total, and uses an intermediate value of 60%. According to Mes, Stams and Zeeman [32],

“Anaerobic digestion is an established technology for the treatment of wastes and wastewater. The final product is biogas: a mixture of methane (55-75 vol%) and carbon dioxide (25-45 vol%).” [32]

Furthermore, the Global Methane Initiative [33] brings collates the following values for biogas production from organic solid municipal waste:

- The Institute for Global Environmental Strategies (IGES) GHG Calculator for Solid Waste (Japan): 118 m³/t_{res}, with 60% CH₄.
- The Regional Information Service Centre for South East Asia on Appropriate Technology (RISE-AT): 100 a 200 m³/t_{res}, with 55-70% CH₄.
- The California Integrated Waste Management Board: 100 a 150 m³/t_{res}, with 50-70% CH₄.

For the purposes of this research the value is adopted of $Q_{\text{biogas}} = 125 \text{ m}^3/\text{t}_{\text{res}}$, with $F_{\text{CH}_4} = 60\%$.

With relation to the specific heat of methane (also known as net heating value or lower heating value), Banks [34] puts $C_{p(\text{CH}_4)}$ at 10 kWh/m³, whilst the Swedish Gas Centre [19] and the University of Madeburg [35] put $C_{p(\text{CH}_4)}$ at 9.97 kWh/m³. In this case $C_{p(\text{CH}_4)} = 10 \text{ kWh/m}^3$ has been adopted for this paper.

Finally, in terms of η_{elec} , this depends on the technology used. According to Weiland [18], the efficiency varies between 25 and 31%, but where certain technologies are capable of up to 43%. Dueblein & Stainhauser [36] offer a table of values ranging from 25 to 40%, but where the majority of technologies presented have minimum efficiencies of 30%. As such, for this paper a value of $\eta_{\text{elec}} = 30\%$ is deemed reasonable.

Overall, the values give:

$$E_{\text{elec}} = Q_{\text{biogas}} \times F_{\text{CH}_4} \times C_{p(\text{CH}_4)} \times \eta_{\text{elec}} = 125 \times 0.6 \times 10 \times 0.3 = 225 \text{ kWh}/\text{t}_{\text{res}} \quad (2)$$

It is therefore put forward that a conservative estimate for the expected electricity production from a decentralized biogas plant to be 225 kWh per tonne of organic household waste.

In the context of the Calderon parish, the following estimate can be made:

Calderon total population: 152 242 people.

Organic waste per person in Quito: 0.31kg/person/day.

Total daily organic waste production in Calderón: 152 242 x 0.31 = 47195 kg/day = 47.2 tonnes/day.

Total potential electricity generation: 47.2 x 225 = 10 620 kWh/day = 3.9 GWh/year.

This is shown graphically in Figure 11.

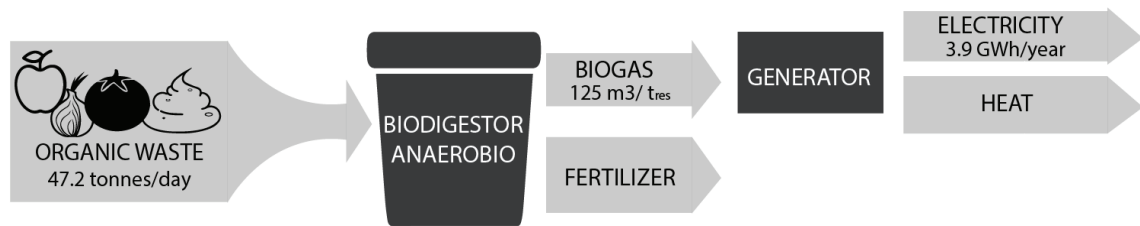


Fig. 11. Inputs and outputs from biogas plant.

4.2. Potential employment and revenue to be created from a decentralized biogas plant

The Electric Company of Quito (EEQ) has a total number of personnel of 1622 members of staff [14]. This is in relation to its annual electricity generation capacity of 512 GWh from its 5 hydraulic and 1 thermal plants [14]. It can therefore be said that the relation of personnel to annual generation capacity is:

$1622 \text{ member of staff} \div 512 \text{ GWh/year} = 3.2 \text{ members of staff per GWh annual electricity production}$

The generation potential from the conversion of organic household waste in the Calderon parish into biogas for electricity generation, 3.9 GWh annually.

This represents an overall increase of nearly 1% of the EEQ's generation capacity. By applying the relation of staff to annual GWh of electricity production, it is determined that the production of biogas from household residual waste would equate to:

$3.9 \text{ GWh annual electricity production} \times 3.2 \text{ member of staff per GWh/year} = 13 \text{ members of staff for the micro-biogas plant.}$

Whilst this may not seem like a great number, it should be noted that it does not include all the support services for the operation of the plant, such as:

- Waste collection and sorting services. First point
- Removal distribution and sales of fertilizer by-product.

In term of potential revenue, the EEQ currently puts the sale price of every kWh consumed at approximately 0.09 USD [37]. This gives a potential revenue of from the micro-biogas plant of:

$3.9 \text{ GWh/year} \times 0.09 \text{ USD/kWh} \times 1000000 \text{ kWh/GWh} = 351\,000 \text{ USD annual revenue.}$

Overall, it can be said that the installation of a biogas plant that processes the residential household organic waste from the parish of Calderon, would:

- Add nearly 1% to the generation capacity of the EEQ
- Create a small number of jobs for the parish directly with relation of the operation of the plant, as well as a further indirect employment from the generation of support services
- Have a potential annual revenue of 351 000 USD

Conclusions

Urban planning is crucial to address resilience and climate change adaptation. An approach to urban planning that heeds circular metabolism should recognise the existence of diverse contexts, and avoid prescribing generalised interventions. In this sense, a comprehensive strategy for circular economy urban planning should be based on inter-sectorial interventions. The planning methodology proposed in this paper encompasses social and economic needs for wellbeing, which are related to the city's most vulnerable groups, with job opportunities generated from services and/or goods, which are created from the city's organic residential waste flows.

In addition, sustainable development requires comprehensive planning that fuses the environmental, economic and social domains together. Otherwise there is a risk of promoting unbalanced development, by allowing the advancement of one or two domains to the detriment of the others. There is also the risk of a false development that is exclusive, or a fragile development that lacks the necessary means of support for it to be sustained. The methodology of Social Urban Metabolism Strategies for Cities (SUMS for Cities) proposed in this paper, enables equilibrium to be reached between these three domains in the context of developing countries. In the environmental sphere, city waste is converted to nutrition to meet urban electrical energy demands. In the social sphere, infrastructure is located in order to decrease vulnerability and poverty. In the economic sphere, the infrastructure creates local economies and decreases the city's need to import electricity from the national grid.

For this research, biogas was found to be the optimal technology for the conversion of residential organic waste into electricity. The simplest conversion process was considered, via an anaerobic digester to produce biogas and a combustion motor to generate electricity. Heat and fertiliser were also recognised as important products, which are recommended for further research into how they can best be mobilised.

An initial vulnerability index was constructed for this paper, which found the parish of Calderon to stand to benefit most from the insertion of a biogas plant for electricity generation. It should be recognised however that for a full analysis of the social domain, a more elaborate vulnerability index is needed where each component is weighted on its importance.

It was found that by mobilizing the residential organic waste stream of Calderon, potentially up to 3.9 GWh electricity could be produced annually, which would add nearly 1% capacity to the Quito electricity company's (EEQ's) internal capacity and could be sold at 351 000 USD based on current prices. Also it would seem that whilst a small number of jobs are created in the running of the plant, it is expected that further research could quantify the benefits of the indirect employment created for support services.

With regard to section 1.2, the proposal presents clear ecological benefits to the city. The city is not only able to close the organic waste cycle to generate electricity, but it also mitigates the loss of land to landfills and the production of landfill greenhouse gas emissions. In addition, regarding the social sphere of sustainable development, the optimal location for the infrastructure and socio-economic revitalization are first studied. This means that by bringing urban metabolism cycles into Quito, the Calderon parish of the city with the most vulnerable population group also stands to benefit. Overall, the city gains 1% self-sufficiency in terms of electricity production capacity, plus the generation of a significant source of additional revenue. In this sense, not depending on electricity generated outside Quito, having local jobs and a permanent source of income, all lead to building the foundations for a resilient community in Calderon. To summarize therefore, the main ecological benefits can be listed as follows:

- Nearly 60% of the waste production in Quito (organic waste) would be treated and converted into energy and fertilizer.
- Land use would be optimized through a reduction in the demand for landfill areas within the city.
- Landfill greenhouse gas emissions would be mitigated.

Recommendations for further research

There are a number of areas highlighted in this paper that would benefit from further research. First, it is recommended to look into how the excess heat and fertilizer produced from the biogas plant could be mobilized. Other organic waste streams from Quito such as from its municipal parks could also be studied, with the aim of increasing the biogas plant capacity. Second, a more in-depth economic study is recommended. Here, employment for support services for the running of the plant could be quantified. An economic study into the investment required for the insertion of the plant, in addition to the payback periods required, would also be of interest. Third, in the social sphere it is recommended to carry out an in-depth vulnerability index study, in order to verify the results found in this research. Finally, it would be interesting to carry out further research into the practicalities of installing a biogas plant in the Calderon parish of Quito. For example, social research is needed in order to determine the architecture of the plant, and whether it would be welcomed or not by the community members.

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