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CARBON FRONTIERS

POTENTIAL FROM FORESTRY WASTE FOR THE CONTRIBUTION TO THE URBAN ENERGY MATRIX

POTENCIAL DE LOS RESIDUOS FORESTALES PARA LA CONTRIBUCIÓN A LA MATRIZ ENERGÉTICA URBANA

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Abstract

Nowadays, fossil fuels are the main source for energy supply in urban centers. Therefore, development of renewables from endogenous resources has become a strategy to reduce its consumption. Within that framework, this study case proposes a methodology to estimate the energy potential of urban forestry wastes in Cuenca-Ecuador city, which are obtained from maintenance activities at the public green areas, as an alternative energy source. It has been determined by laboratory analyses the average of the net calorific value of some biomass samples taken at the local area, and its result is about 0.38 tep/ton. From a statistical database, it has been calculated that forestry waste mass available per year in Cuenca city is 608.63 ton. Its energy potential is around 233.13 tep/year and the electrical generation efficiency is approximately 41 tep/year, corresponding to the average consumption of 110 local families. Finally, it is concluded that this energy source could rise significantly through the increase of maintenance activities of public green areas. Furthermore, it represents an alternative for the effective use of this kind of waste.

Keywords: Renewable energies, energy potential, endogenous resources, forestry wastes.

Resumen

Los combustibles fósiles son por ahora la principal fuente de abastecimiento energético de las ciudades. Una estrategia para reducir este consumo es el desarrollo de energías renovables desde recursos endógenos urbanos. Se propone una metodología para determinar el potencial energético que poseen los residuos forestales urbanos en la ciudad de Cuenca-Ecuador, obtenidos mediante las actividades de mantenimiento (poda) de las áreas verdes públicas, con el propósito de transformarlos en fuente energética. Mediante análisis en laboratorio de muestras tomadas en el medio local, se determina que el poder calorífico inferior promedio que posee la biomasa es de 0.38 tep/ton. A partir de ello, con una base de datos estadísticos se calcula que en la ciudad de Cuenca se dispone de 608.63 ton de masa forestal anualmente. Ésta cuenta con un potencial energético de 233.13 tep/año y una eficiencia para la producción de energía eléctrica de aproximadamente 41 tep/año, que permite cubrir el consumo promedio de 110 familias. Se concluye que esta fuente de energía puede crecer significativamente con el incremento de las actividades de mantenimiento de las áreas verdes públicas y además constituye una estrategia para el aprovechamiento secundario de esta clase de residuos.

Palabras clave: Energías renovables, potencial energético, recursos endógenos, residuos forestales.

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1 Introduction

The diversification of Renewable Energy (RE) sources is key to sustainable supply systems, especially when urban waste can be leveraged (Arrese and Blanco, 2016). Energy self-supply from endogenous resources is essential to reduce the need for energy imports into cities (Barragán et al., 2019). The energy matrix in Cuenca-Ecuador mostly depends on fossil fuels, whose extraction methods and processes transformation are an important environmental issue (Bristow and Kennedy, 2013). Forest biomass within an energy context refers to the set of renewable elements of organic origin or their derivatives, whose energy comes from solar radiation that is transformed into chemical energy during the photosynthesis process conducted by plant species (Manzano et al., 2012). This chemical energy can be used directly from combustion processes or transformed by thermal methods (gasification) or biological methods (bioethanol production), according to the final requirement of use (Yaman, 2004).

Forest waste from urban pruning operations can be used as a RE for the production of electricity from thermal processes (Pérez et al., 2010). One of the advantages of residual forest biomass is the lack of an ecological or agricultural value, unlike other types of non-arboreal plant waste (Barragán, 2018). Maintaining the Green Public Areas (GPA) is also a need for the urban development, which generates a continuous production of the resource. In five cities in South Korea (Seoul, Daegu, Daejaeon, Gwangju, Busan)the energy Potential (EP) of the biomass from urban forest products has been analyzed in order to establish adequate management for its conversion to energy; obtaining maximum and minimum capacities of 2 625 753 tep/year and 76 760 tep/year, respectively (Kook and Lee, 2015). In General Pueyrredón (Argentina), the usable potential energy of the pruning of public spaces has been assessed, determining that these can meet about 4.37% of the city's electricity consumption (Roberts et al., 2015). However, each locality has its own conditions, either by quantity or by the characteristics of the vegetation (Barragán, 2018). Additionally, the type of energy consumption, the sizing and the supplying also differ, which means great variability in each of the researches in this area.

In analyzing these case studies, it has been established that the determination of the EP requires the knowledge of the Lower Calorific Power (LCP) of the species that make up the forest waste, the annual production mass and the percentage of efficiency that the resource has for the power generation. In the city of Cuenca, the Municipal Public Company of Toilet for Cuenca (EMAC EP), is responsible for the maintenance of the GPAs of the city. These are distributed in three categories: parks, riverbanks and parterres (Ortiz, 2018), which constitutes these spaces in sources to obtain the aforementioned renewable resource.

2 Materials and methods

2.1 General aspects of the area under study

The study area comprises the GPAs: parks, parterres and riverbanks (Figure 1), of Cuenca, located in the province of Azuay in the south-central region of Ecuador. The city center has an area of about 72 km^2 and a population of 391 657 inhabitants (INEC, 2016). Cuenca is located at an approximate height of 2550 $m.a.s.l.$ and has an average temperature of 15,6°C, which can range from 27,2°C to $-1{,}7$°C (Plan Estratégico Cuenca 2020, 2004). For this investigation, mapping information for the GPAs established within the *Cinturón Verde de la ciudad de Cuenca* project was used as well as satellite images from April 20, 2018, with a resolution of 3,14m × 3,14m per pixel and 19% cloud percentage.

2.2 Identification of forest species that are part of the GPA prunin

In order to evaluate the EP of forest waste, it is necessary to know what plant species of the study area are (Roberts et al., 2015). In this case, it was considered appropriate to identify them directly in the GPAs assisted by EMAC Public Company. This is because urban pruning consists of several small forest elements, a situation that makes it difficult to establish the identification of the species. According to the methodology suggested by Gutiérrez et al. (2015) monitoring was carried out during August 2018 for the identification of species. For this purpose, the sites of the GPA that met two criteria were chosen, those that had: (i) an area $\geq$ 0,05 and

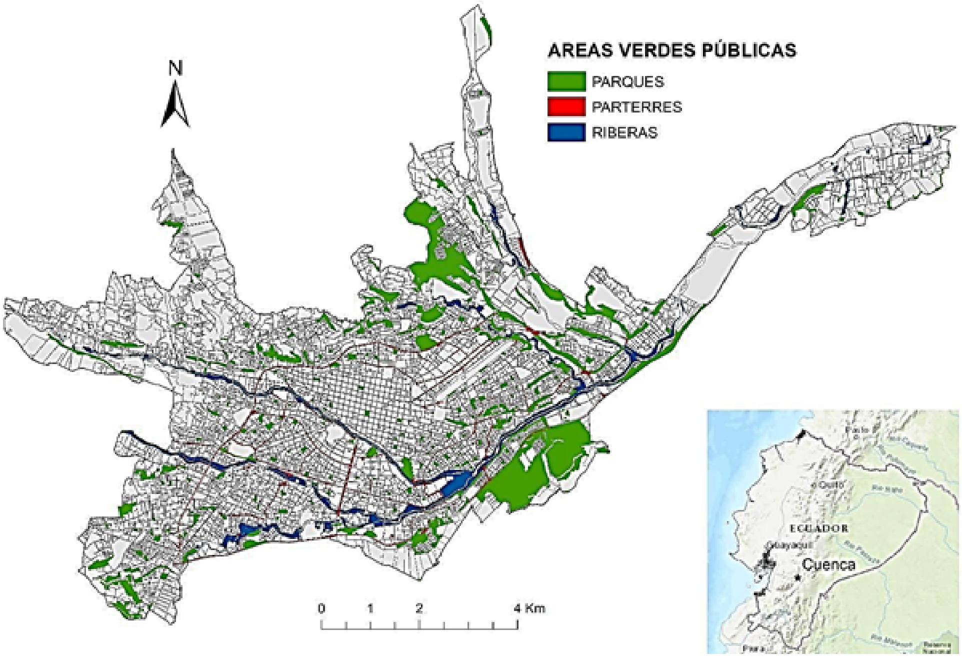

Figure 1. Study area.

≤ 1,21 ha, and (ii) a Normalized Difference Vegetation Index (IVDN) ≥ 0.26.

The minimum and maximum surface limit was obtained through Equation 1 proposed by Olsson (2005), which corresponds to the reliability index, for which a 90 % confidence level was used. The value of 0.26 represents the average IVDN data, calculated for GPAs using the SIG ARCMap® program. Where, χ (ha) corresponds to the average area of GPA, σ (ha) is the standard deviation of the areas considered as GPA, *n* refers to the total number of GPA, *Z* (%) is the confidence level, and μ indicates the total number of GPAs found within the confidence interval (Olsson, 2005).

$$\chi - \frac{Z*\sigma}{\sqrt{n}} \leq \mu \leq \chi + \frac{Z*\sigma}{\sqrt{n}} \quad (1)$$

This index suggested by Rabatel et al. (2011), analyzes the biophysical characteristics of plants and the vegetative distribution of the study area (Parthiban et al., 2015) by using Equation 2. Where, IRC (μm) refers to the Near Red Infra band that possess the satellite images and R (μm) corresponds to the Red band (Rabatel et al., 2011).

$$IVDN = \frac{IRC - R}{IRC + R} \quad (2)$$

The monitoring of plant species distributed in GPA (selected under the criteria described above) was carried out on plots of 0.4 ha. With the ODK technology tool, which uses an online server to collect, manage, and store information in a given area, data was collected regarding: location coordinates, photo, common name, and scientific name of the individuals found.

2.3 The obtaining of the calorific power of forest biomass

In order to assess forest biomass energy, it is considered appropriate to pre-analyze its NCV. This parameter allows to estimate the amount of usable energy per unit of mass when the resource is in fully combustion (Arroyo and Reina, 2017). The calculation of the NCVis given by Equation 3 stated by Francis and Lloyd (Budí, 2016). Where, HHV (kcal/kg) corresponds to the Higher Heatig Value, 597 (kcal/kg) is an indicator that refers to the heat from the condensation of the water vapor formed in the combustion test. Number 9 indicates the kg of water generated by oxidizing 1 kg of hydrogen, H (%) is the percentage of hydrogen quantification and *w* (%) refers to the percentage of moisture that the biomass has (Budí, 2016).

$$NCV = HHV - 597 * 9H + w \quad (3)$$

Nine forest species were identified as the most abundant in urban pruning, corresponding to 59.49% of individuals found during field monitoring. They were listed in the study as representative species and their HHV and moisture percentage were determined by laboratory analysis. The quantification of the HHV was carried out in a calorimetric pump (IKA C200); samples consisting of branches and leaves of an individual, whichwere taken for each of the 9 species (Ortiz T., 2013), following the criteria of the STANDARD $UNE - EN - ISO18135 : 2018$ (Solid biofuels Sampling). These individuals were selected according to the morphometric characteristics of an adult-considered specimen (Barahona, 2005; Minga and Verdugo, 2016; CONAFOR, 2013)

The samples were conditioned according to the parameters established by UNE-CEN/TS 14918: 2011 (Solid biofuels. Determination of the calorific power), subjecting them to a drying process at a temperature of $105°C \pm 1$, for 24 hours. Subsequently, the analysis of the HHV was carried out in the calorimetric pump, obtaining a digital result in units of energy by mass. As Vassilev et al. (2010) indicate, the forest biomass is usually composed of 6% hydrogen, and this was the value used. The percentage of moisture for representative species was calculated using the criteria described in UNE-CEN/TS 14774: 2010 (Solid biofuels. Determination of moisture content. Method of drying in stove), where Equation 4 is established for its calculation. Where, $m1$ (g) is the weight of a crucible with the sample before drying and $m2$ (g) is the weight of the same crucible with the dry sample (UNE-CEN/TS 14774: 2010).

$$w = \frac{m1 - m2}{m2} * 100 \quad (4)$$

2.4 Estimation of the energetic potential of forest wastes

Özdemir and Gencer (2016) allows relating the NCV (tep/ton) to the mass of forest waste generated annually from the maintenance operations of the GPAs. The latter is represented in Equation 5 as m (ton/year). The NCV corresponds to the average lower heating value of representative species, whose units were transformed from kcal/kg to tep/ton. This value is considered conservative since the biomass evaluated was only of forest species (woody), whose organic composition is similar (cellulose, hemicellulose and lignin) (Déjardin et al., 2010). The total mass of the pruning was obtained through statistical data presented in Table 1 by the Green Areas Department of the EMAC Public Company, during 2018.

$$EP = NCV * m \quad (5)$$

Table 1. Register of urban prunning, 2018. Taken from Emac (2018).

Month	Mass (ton)
January	50.71
February	50.72
March	50.72
April	43.93
May	66.08
June	58.35
July	47.52
August	44.37
Septembre	64.42
October	41.01
November	64.95
December	25.81
TOTAL	**608.63**

2.5 Estimation of the energetic efficiency of forest wastes

Because urban forest waste can be exploited by converting it into electricity through thermal processes (Barragán, 2018), as a first approach to the energy valuation of this resource in Cuenca city, the energy efficiency has been estimated with Equation 6 (Panepinto et al., 2014). Considering 18 % as the percentage of forest biomass yield for conversion to electric energy.

This percentage allows the establishment of usable energy and refers to the efficiency of converting chemical energy of plant species to electricity; this factor taken from a study developed in the Basilicata–Italy region, where forest pruning has been evaluated as an RE source through an energy balance, allows to estimate electrical production by thermal processes. In the research of PPanepinto et al. (2014), a similar methodology is used, establishing as a hypothesis that it is possible to assess the efficiency for obtaining electricity by 18 %, based on a scenario that has data on the available energy power (calculated with the ratio of biomass amount and NCV).

On the other hand, there are methodologies that differ and that use efficiencies for the production of electricity of 10 % (Shi et al., 2013) and 4.37 % (Roberts et al., 2015). However, as this is a first analysis of the energy potential of urban pruning in the area, it has been relevant to use 18 % as a reference data. For specific cases, a more in-depth study is required that considers the efficiency of different power conversion devices, among other variables.

$$EE = EP * E \tag{6}$$

Where, EE (tep/year) refers to the energy produced in one year, EP (tep/year) is the Energy Potential of forest biomass and E (%) corresponds to the efficiency percentage for the generation of electricity from the resource (Panepinto et al., 2014).

3 Results and Discussion

3.1 Forest species that are part of pruning in GPAs

According to the sampling developed in GPAs of Cuenca, urban pruning is formed by 72 forest species in total. Table 2 shows the species found, which are sorted in descending order with respect to abundance. For the purposes of the study, it was established that 59.49 % of the individuals correspond to 9 species listed as representative (*Eucalyptus globulus, Salix humboldtiana, Prunus serótina, Tecoma stans, Baccharis latifolia, Fraxinus excelsior, Callistemon salignus, Pinus radiata, Acacia dealbata*), since these are abundant.

3.2 Calorific power of forest biomass

From laboratory evaluations, the HHV of biomass from the representative species was determined (Table 3). By incorporating these values into the NCV calculation, it was possible to define that Pinus radiata specie is the one that has the greatest capacity to shed heat during the complete combustion processes, being the most efficient resource for obtaining energy. This is followed by Callistemon salignus and Prunus serotina. The latter is considered as one of the native species of Cuenca city, which is recommended to be incorporated into the reforestation plans managed by the EMAC Public Company, as it is an appropriate alternative for the use of GPAs as a source of energy resources.

The study states that for the use of biomass focused on energy generation in a sustainable scenario, it is better to use the waste of pruning of existing GPAs. In other words, the idea is not to sow plant species for energy purposes, but to use the existing ones with environmental, ornamental and landscape criteria.

The data presented in Table 3 allows to define the NCV average for forest species distributed in GPAs, which is about 0.38 tep/ton. It should be mentioned that to obtain this value it was considered appropriate to evaluate the NCV only of the 9 most abundant species (59.49 %), due to the restriction of the number of samples to be analyzed for the study. Because of the difference in the moisture content (Table 3), each requires a separate analysis and a minimum number of three tests. In addition, having worked only with forest species, whose organic composition is similar (Déjardin et al., 2010), it is possible to establish an average value. The result obtained (0.38 tep/ton) is close to which was determined by Panepinto et al. (2014), who show in their research that forest waste have a NCV of 0.34 tep/ton.

Table 2. Forest species identified in public Green areas.

Scientific name	Abundance	Scientific name	Abundance
Eucalyptus globulus	459	*Tipauna tipu*	7
Salix humboldtiana	80	*Acacia baileyana*	6
Prunus serótina	47	*Ferreyranthus verbascifolius*	6
Tecoma stans	47	*Rubus glaucus*	6
Baccharis latifolia	45	*Morella sp.*	6
Fraxinus excelsior	43	*Yucca guatemalensis*	6
Callistemon salignus	41	*Ficus Robusta*	4
Pinus radiata	37	*Eucalyptus citriodora*	4
Acacia dealbata	35	*Cotoneaster acuminatus*	4
Jacaranda mimosifolia	32	*Liabum floribundum*	4
Schinus molle	30	*Buddleja davidii*	3
Chionanthus pubescens	29	*Laurus nobilis*	3
Sambucus mexicana	27	*Monnina ligustrina*	3
Hibiscus rosa-sinensis	26	*Citrus x sinensis*	3
Juglans neotropica	26	*Arecaceae*	3
Alnus acuminata	25	*Myrcianthes hallii*	2
Cupressus lusitánica	24	*Buxus sínica*	2
Podocarpus sprucei	22	*Bougainvillea spectabilis*	2
Populus alba	21	*Annona cherimola*	2
Morella pubescens	21	*Cestrum nocturnum*	2
Syzygium paniculatum	17	*Brugmansia sanguínea*	2
Inga insignis	17	*Psidium guajava*	2
Acacia retinodes	16	*Lantana cámara*	2
Ambrosia arborescens	16	*Fuchsia boliviana*	2
Ficus benjamina	14	*Robinia Pseudoacacia*	1
Eriobotrya japónica	14	*Acalypha australis*	1
Ligustrum Japonicum	13	*Populus balsamífera*	1
Acacia melanoxylon	10	*Prunus persica*	1
Myrsine guianensis	10	*Mimosa andina*	1
Jasminum polyanthum	10	*Ligustrum sinense*	1
Callistemon citrinus	9	*Crataegus pubescens*	1
Duhaldea cappa	9	*Oreopanax ecuadorensis*	1
Erythrina edulis	8	*Buddleja americana*	1
Nerium oleander	8	*Rosmarinus officinalis*	1
Grevillea robusta	8	*Rosa gallica*	1
Delostoma integrifolium	7	*Citharexylum ilicifolium*	1
Delostoma integrifolium	7		

3.3 Energetic potential of forest wastes

Equation 5, which establishes the ratio of the amount of biomass available over a year to its usable energy corresponding to the NCV, determined that the EP for forest waste is approximately 233.13 tep/year. This energy comes from the pruning currently carried out by the EMAC Public Company in public areas that have forest biomass, which occupy 618.76 ha of the total area of Cuenca city.

Biomass from maintenance operations of the GPAs can become an alternative renewable resource to meet the city's energy needs, as proposed by Kook and Lee (2015), who in a study in South Korea's urban centers have determined that forest waste has a minimum potential of 76,760 tep/year. This difference of the Asian cities and the urban area of Cuenca is largely due to two main factors: first the size of the cities, wich is related to the available area to extract the resource and second, the final use that pruning currently has in each place. The cities in South Korea are classified as major metropolises, with green spaces producing abundant biomass (Kook and Lee, 2015), meanwhile Cuenca has 7,200 ha of a total area. On the other hand, the town lacks a comprehensive forest waste management plan, a situation that differs from Korean cities, where the real importance of urban pruning has been understood as a resource for RE generation.

The research developed by Kook and Lee (2015) shows some limitations to be taken into account in integrating forest biomass as an energy source in cities; for example, the accelerated and continuous cities increase, whose area for buildings tends to incorporate more space compared to the surfaces of green areas (Franco, 2012), as well as the number increase of inhabitants and thus in energy needs (Lahoz, 2010). These factors need to be analyzed in advance, in order to avoid overexploitation and unsustainable management of biomass due to pruning.

From a diversified source use perspective, forest waste is an available endogenous resource that can be supplemented by intermittent renewable energies such as solar and wind (Brown et al., 2018). For Cuenca, an appropriate alternative is the conversion of biomass to electricity, considering the minimum thermal demand available due to climate, unlike other latitudes where the need for spatial environment is predominant.

Table 3. Calorific power of representative species.

Scientific name	**HCP (tep/ton)**	**Moisture content (%)**	**NCV (tep/ton)**
Eucalyptus globulus	0.41	16.9	0.37
Salix humboldtiana	0.43	61.1	0.36
Prunus seótina	0.46	51.65	0.4
Tecoma stans	0.43	46.2	0.37
Baccharis latifolia	0.43	61.25	0.36
Fraxinus excelsior	0.42	45.02	0.42
Callistemon salignus	0.48	46.53	0.43
Pinus radiata	0.5	49.46	0.39
Acacia dealbata	0.45	41.22	0.3
Average			**0.38**

3.4 Estimated energetic efficiency for forest wastes

The city of Cuenca has a total electricity demand of 423 800 MWh/year (Barragán, 2018), of which 38 % corresponds to the residential sector. In this context, when assessing forest waste as a resource that has 18 % energy efficiency, it was obtained that the electricity generation from it will be approximately 476.83 MWh/year (41 tep/year). This production allows to supply about 0.30 % of the demand in the residential sector, representing the coverage for 110 typical families with four members (average of the city families), considering that each of these households has a total annual consumption of 4.33 MWh/inhabitant (Barragán, 2018).

Today Cuenca has a RE model that uses domestic solid waste that reaches the landfill for the operation of a biogas generating plant, through which 502.60 tep/year of electricity are produced (Barragán et al., 2016). These levels of energy generation are higher than those obtained from forest waste due to management implemented for the secondary recovery of the household waste mentioned.

Energy from renewable sources could increase as technologies for the use of forest waste, such as an energy resource, are developed and incorporated as has been done in countries such as South Korea. The latter is an encouraging scenario, considering that forest biomass allows to strengthen a model of diversification of the energy matrix, in which endogenous resources can have an added value (Barragán, 2018). The use of residual biomass in bioenergy systems will require prior cost analysis for the transportation of urban pruning to power generation centers, which can be diminished by an assessment of the existing spatial energy density in each location (Kook and Lee, 2015). The value of industrial process of conversion to energy and the cost of systems for the distribution of electricity to users (Yemshanov et al., 2014) should also be taken into account, then the real capacity of the resource can be analyzed.

4 Conclusions

A methodology is presented to determine the energy potential of urban forest waste applicable to any city. The evaluation of forest biomass for the purpose of electrical production represents an alternative for the pruning management from the GPAs belonging to the urban area of the city of Cuenca, Ecuador.

The information on the amount of energy per unit of mass (NCV) of the species studied allows to establish which work better to reforest the city. Prunus serotina is recommended for this activity, because it has been cataloged as a native species, which will allow the conservation of ornate. In this context, the proposal for reforestation of existing GPAs with species of heating also generates the possibility of meeting the minimum parameters of green area per inhabitant, established by the World Health Organization (WHO), as well as it helps increasing the share of renewable energy in the local energy matrix.

Annually in Cuenca city there are 608.63 ton of forest waste from the maintenance operations of GPAs, which is responsible for EMAC Public Company. In this sense, secondary recovery (energy production) will also represent a circular management model for urban pruning, giving them added value.

This study concludes that the energy potential of forest waste in the city of Cuenca is valued at 233.13 tep/year. This represents approximately 41 tep/year (476.83 MWh/year) of power generation. This production is marginal in relation to local electricity consumption, covering the needs of 110 average families. However, local pruning levels are low compared to other urban areas where a landscape work is done, because there is only a schedule of activities for the maintenance of GPAs where it is strictly necessary or in cases where forest species are interfering with public lighting cables. Therefore, if planning is established for the continuous management of GPAs, that contemplates the increase of pruning, it will favor the obtaining of the resource for energy purposes, while it will be possible to optimize their collection. In addition, the amount of the resource could be increased if private, non-sized waste management is incorporated into the analysis.

The technical and economic evaluation is proposed as a future need to identify efficient and cost-effective technologies that are coupled with the characteristics of the natural resource assessed, as well as electricity supply requirements that exist in the area. These analyses should have a sustainable management approach, in order to avoid risks of overexploitation of forest biomass. In addition, they are a complement with intermittent renewable technologies, being able to introduce to the grid the energy generated during peak hours.

Forest waste from the city's pruning is part of the alternatives for diversification of resources that constitute the energy matrix at local and national level. Therefore, its assessment, within the framework of renewable energies, allows to strengthen a model of energy self-sufficiency consistent with the need to reduce dependence on fossil fuels.

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