Chapter

Selection of Optimal Localization for a Biomass Energy Plant that Uses Residual Biomass as a Raw Material in the Araucanía Region of Chile

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Abstract

Residual biomass is used for energy purposes, such as producing heat and electricity. The potential raw materials are wheat, oat and barley straw, corn stover from the agricultural industry, and wood chips from forest residuals and the wood industry. In Chile about 10 MM t year^{-1} residues are produced; however, most of these are burned, increasing the greenhouse gas emission. This study evaluated the energy production from the residual biomass in the Araucanía Region of Chile. The optimal location for installing an energy generation plant was determined, according to various conditions, such as the distance from the villages, energy demands, industry location, etc. A multi-criteria evaluation and analytic hierarchy process were performed for determining the optimal location, and a proposal for its installation was created. A total of 19 districts were selected as suitable location that met the requirements for the three scenarios.

Keywords: biomass, gasification, combustion, wheat straw, bioenergy, energy production

1. Introduction

A close relationship exists between an increase in energy consumption and the economic growth for a particular country. In South America, it is estimated that a 1% increase in energy consumption translates to a 0.42% increase in economic growth [1]. In countries, such as Chile, where 59.3% of the primary energy matrix is imported, with 90.2% of this from fossil fuels [2], uncertainty and insecurity arise in the energy supplies and dependence on foreign markets, obliging the assumption of risk in the face of possible fluctuations [1].

Alternative sources of energy that are renewable and have a reduced environmental impact are required to reduce the use of nonrenewable energy sources, such as fossil fuels [3], which have negative effects, such as climate change, forest destruction, and the extinction of species [3, 4].

Renewable energy offers environmental benefits and increases the standard of living for various populations, diversifies the energy matrix, improves the infrastructure, promotes technology transfer, and provides other positive effects [4, 5]. Biofuels are nonconventional renewable energy sources (NCRECs) that may replace fossil fuels, lowering the dependence on international markets and the atmospheric emissions of greenhouse gases (EGGs) [6].

Chile promised, in 2010, to reduce emissions by 20% below the 2020 projection [7]; however, according to current trends, an increase of 360% is projected in carbon dioxide (CO_2) emissions in electricity generation and transportation. The aforementioned items currently represent 0.3% of the total emissions globally [8].

Firewood and biofuels are the second source of energy for Chile. They are entirely produced within the country, representing 28.9% of the primary energy matrix in 2013 [9]. Here, 36% of the national population is concentrated between the O'Higgins and Aysén Regions, with 74% of these homes consuming firewood or its derivatives [10] for heating or cooking systems. Biofuel is used for self-produced electricity [11].

The residual biomass from agricultural activities has an average caloric power of 17,500 kJ kg^{-1} [12] and is underused in Chile [2, 13]. Cereal production residue is concentrated in the central south area of the country, particularly in the regions of Araucanía (29.3%) and Libertador Bernardo O'Higgins (19.8%) as the main cereal residue producers [14].

Wheat is the main cereal produced in Chile, representing 32.9% of the planted agricultural surface during the 2016/2017 agricultural season [15]. The Araucanía Region is the main wheat production region in the country. During the 2016/2017 agricultural season, 42.0% of the total surface area of planted wheat was concentrated here, yielding a production of approximately 597,835 tons [16].

Román-Figueroa et al. [2] determined that, in the Araucanía Region, 50% of the production of wheat residuals was concentrated in 23 (of 299) census districts, while 10 of these districts produced 27.8% of the residues. The majority was produced in the central valley of the region, specifically in the province of Malleco, which has a regional coverage of 60,800 ha [2]. Currently, the agricultural residue is burnt [17, 18], which causes environmental problems owing to the emission of EGGs, as well as public health problems owing to particulate matter emissions [17, 19].

Electricity production from agricultural residue biomass has been widely studied and recommended, owing to the low production costs, high conversion efficiency, and environmental benefits because it is carbon neutral [20, 21]. Singh [21] determined, in the Punjab, India region, production of between 2375 and 2937 MW_{el} was possible depending on the efficiency of the conversion plant, with more than 22,000 million tons of residue. In the Araucanía Region, a 5.0 MW_{th} plant and 27,000 tons of residue, between 3.17 MW_{el} and 4.89 MW_{el}, can be produced using fluidized bed combustion technology with a generation turbine (C/ST) and gasification of the fluidized bed followed by a combined cycle of gas and vapor (G/CC), respectively [2].

Various studies have determined the optimal location of a biomass-based energy production plant using geographic information systems (GIS) [21–25]. With GIS, evaluation using different attributes and maps to determine the optimal energy production plant location is feasible, [23, 25]. A multi-criteria analysis (MCA) evaluates, using different criteria or factors, a group of opposed real alternatives, considering different development visions and objectives [25]. Therefore, an evaluation considering economic, social, and environmental criteria is possible, optimizing the decision-making process [23].

In Chile, Villamar et al. [23] evaluated the possibility of installing an anaerobic co-digestion plant using discarded agribusiness materials (animal dung and agricultural residues) in the Biobío Region. Using a hierarchical analysis process, they considered factors that were social (distances to residential areas and roads) and economic (residue production, distance to residue production sites, proximity between residue production sites, and closeness of the production plant to roads) [23]. This is the only evaluation of the installation of a residual biomass-based bioenergy plant in the country.

The objective of this study was to determine the optimal location for an energy production plant, which was based on wheat residue in the Araucanía Region of Chile. Three different types of demands were considered: current, potential, and social demands. Three scenarios were used to determine the location of the energy production plant based on wheat residue biomass.

2. Materials and methods

2.1 Area of study

The area of study was the Araucanía Region, located between 37°35′ and 39°37′ southern latitude and from 70°50′ western longitude to the Pacific Ocean, an area of 31,842 km^2 (**Figure 1**). The study was realized at a district level

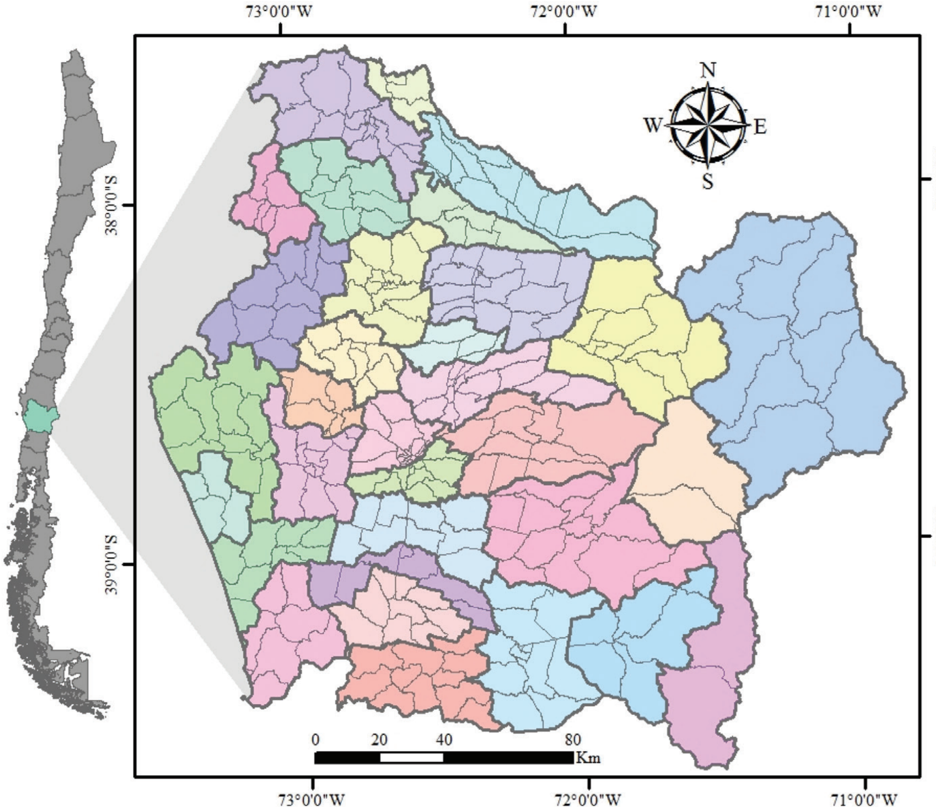

Figure 1.
Study area of Araucanía region, Chile, on a district scale.

according to the census boundaries determined by the National Institute of Statistics [26].

2.2 Areas with an energy demand

The areas were determined with priority assigned to the energy supply, according to three types of demand: current (or high demand), potential, and social. The current demand refers to the sectors with a high consumption. The potential demand refers to the non-covered demand, such as the districts without electricity. The social demand refers to areas where heating or electrical energy should be locally supplied to homes, schools, or treatment centers.

Different criteria were employed to determine the demand in each case. The current demand considers consumers in the industrial [27] and residential sectors [28]. For the potential demand, the demand for electrical services that are not yet provided is considered [29]; and in the social demand, the demand for energy (thermal and electrical) for services (education and healthcare) and rural homes is considered.

2.2.1 Standardization of criteria for determining the areas with an energy demand

Each criterion was standardized with values between 1 and 7, with 1 representing the worst condition and 7 representing the best condition for each criterion.

For the current demand, the distance to the industries, industries quantity per district [30], and the residential energy consumption were considered [30, 31]. All criteria were discretized with values between 1 and 7 (**Table 1**). For the potential demand, those districts with an electrical coverage of less than 40% were considered, according to the 2006 CASEN [28]. These were discretized with values between 1 and 7. However, only odd values were used owing to the quantity of

Value	Current			Potential	Social		
	Industries (m)	**Industries (number)**	**Energy consumption (MW)**	**Coverage (%)**	**Villages (m)**	**Primary healthcare (m)**	**Rural educational (m)**
7	0–21,300	7–8	2000–12,000	0–10	0–9531	0–4572	0–4019
6	21,300–42,600	6	1600–2000	—	9531–19,062	4572–9145	4019–8038
5	42,600–63,900	5	1300–1600	10–20	19,062–28,593	9145–13,717	8038–12,057
4	63,900–85,201	4	1000–1300	—	28,593–38,124	13,717–18,289	12,057–16,076
3	85,201–106,501	3	700–1000	20–30	38,124–47,655	18,289–22,861	16,076–20,095
2	106,501–127,801	2	400–700	—	47,655–57,186	22,861–27,434	20,095–24,114
1	127,801–149,101	1	0–400	30–40	57,186–66,717	27,434–32,006	24,114–28,133

Table 1.
Discretization of the values to determine the supply of energy in the Araucanía region, according to the different demand criteria.

Current demand		**Potential demand**		**Social demand**	
Criterion	**Weighting**	**Criterion**	**Weighting**	**Criterion**	**Weighting**
Distance to the industries	0.25	Electrical coverage	1.0	Primary healthcare	0.33
Industry quantity	0.25			Rural educational	0.33
Energy consumption	0.5			Villages	0.33

Table 2.
Consideration of the criteria analyses in the MCE to determine the locations with the highest energy demand (high, potential, and social).

ranges available (**Table 1**). For the social demand, the distance to rural settlements, which corresponded to the villages, as well as the distances to primary healthcare centers and rural educational establishments were considered [32]. These were discretized with values between 1 and 7, with 7 representing the shortest distance (**Table 1**).

Based on the type of demand and the multi-criteria evaluation (MCE), weights or considerations were assigned to each criterion (**Table 2**). The priority sites were determined, considering each type of demand (current, potential, and social). Finally, the set of demands was evaluated, where each demand was given a consideration value of 0.33. Thereafter, the energy demand information was used to determine the location of an energy production plant based on biomass in the Araucanía Region.

2.3 Determination of the priority sites for installing an energy production plant based on biomass

Determining the location of an energy production plant based on biomass was carried out according to a decision rule, where the MCE was used with an analytic hierarchy process (AHP). The use of these combined techniques is a common methodology employed to determine the installation location of energy production plants [29, 33].

2.3.1 Definition of criteria

Criteria selection is required for making decisions. Possible alternatives must be quantified and must contribute to the decision-making process [33–35]. These criteria may be factors or limiters. A factor is a criterion that negatively or positively affects the possible location for the energy production plant, while a limiter (or exclusion criterion) restricts the location potential, excluding possible installation [33, 34].

The factors employed in this evaluation were as follows:

a. Availability of biomass: The districts with a greater production of wheat residue biomass according to the estimates by Román-Figueroa et al. [2] were considered the most appropriate; however, this was not established as an exclusion criterion.

b. Energy consumption priority areas: These were established according to the energy demand scenarios previously calculated: high demand, social demand,

and potential demand. The selected sectors with a high demand were considered a priority and more suitable.

c. Land use/coverage: The installation of an energy production plant must comply with the legal requirements and land usage. Competition with other current uses of the land must be avoided, allowing current activities to continue. The areas considered feasible for the installation of a plant were those without vegetation, meadows, or scrub and were industrial use lands. Urban areas and lands of agricultural use were considered unsuitable because other activities are carried out there that are relevant to society [33, 34].

d. Roads: Connectivity is essential for the supply of raw materials to the plant; thus, the transport of raw materials should be considered [33, 36]. Therefore, a maximum distance of 1.0 km between the energy plant and the road was considered a priority. Moreover, the type of road material affects accessibility, and thus, this was considered a factor.

e. Electrical network: Wheat residue was considered the raw material for electricity production [2]. The distance from the energy production plant to the electrical network is relevant to the electricity generated in the electrical supply network. Nonconventional renewable energy (NCRE), such as a generation less than 9.0 MW_{el}, can directly connect to the Chilean distribution network [37]. This would provide an economic benefit to plant installation. A maximum distance of 3.0 km between the energy plant and the electrical network was considered a priority.

Each of these factors was discretized with values between 1 and 7, with 7 as the most suitable (**Table 3**).

Conversely, the following limiters were considered:

a. Restricted areas: This represents zones where installation is not viable for environmental, legal, or other reasons [33, 34]. These areas include those covered by the protected forest areas system (SNASPE), protected private areas (PPAs), bodies of water, cities, and the current road network. A value of 0 was assigned to the limiter areas, and 1 was assigned to those without restrictions.

Value	Residual biomass ($t\ year^{-1}$)	Land use/coverage	Road types	Electrical network (m)
7	23,217–27,086	Grassland and scrubland	Asphalt	0–1000
6	19,347–23,217	—	—	1000–2000
5	15,478–19,347	Industrial and urban area	Gravel	2000–3000
4	11,608–15,478	—	—	3000–12,000
3	7739–11,608	Primary and secondary forest	Dirt	12,000–21,000
2	3869–7730	—	—	—
1	0–3869	Agricultural land and plantations	—	—

Table 3.
Discretization of the values for the factors used to determine the optimal location of an energy production plant based on the wheat biomass in the Araucanía region.

b. Availability of biomass: Districts where the minimum quantity of wheat residue is required for the production of 1 MW_{el} were considered as feasible, such as the districts with a residue production less than 8534.8 t $year^{-1}$, for a plant with fluidized bed combustion and a generating turbine (C/ST), and 5536.1 t $year^{-1}$, for a plant with fluidized bed gasifiers followed by a combined cycle of gas and steam (G/CC), based on the study carried out by Román-Figueroa et al. [2]. A value of 0 was assigned to the districts with residue production less than the minimum required to produce 1 MW_{el}, while other districts with higher production were assigned a value of 1. Depending on the situation, the availability of biomass was used as a factor, with the production of biomass being classified with values from 1 to 7 (**Table 3**). C/ST and G/CC were considered independently as technologies for energy production.

2.3.2 Proposals for energy production plant placements according to the energy demand scenarios

An AHP was used to determine the best location for an energy production plant using wheat biomass as a raw material. The main criterion for the plant location was the biomass supply, by which other major criteria were determined. The analysis was carried out considering the energy demand scenarios (current, potential, and social) as part of the analysis.

In the AHP, an importance value was assigned to each criterion according to its objective. The value scale ranged from 1 to 9, where 1 was considered to be equally important for two criteria (a and b) and 9 was considered to be more important for one criterion than another (a over b) [38, 39]. Therefore, when the relative importance of a over b was established, a value of 1/9 was automatically established [39].

a. Social scenario: The objective was to satisfy rural sector energy needs, supplying services to healthcare, educational, and rural resident sectors. This scenario was based on social and potential demand, and therefore, industrial and residential (that already have supply) sectors were not considered in this scenario. The availability of biomass, use of land, roads, and electrical supply network were considered as factors. Each of these factors was considered with a different relative weight (**Table 4**).

b. Feasibility scenario: The objective was to install an energy production plant based on the biomass, and thus, the residual biomass was considered as a limiter, 8534.8 t $year^{-1}$ for C/ST and 5536.1 t $year^{-1}$ for G/CC [2]. The areas with an energy demand had less relevance than other criteria because the availability of the raw material is most relevant (**Table 4**).

c. Demand scenario: The objective was to satisfy large consumer demand; therefore, the high-demand scenario was used, where priority was assigned to industrial and residential sectors that currently receive electricity. This was not considered relevant for rural sectors that do not receive. The electrical network had a greater relevance in this scenario because of the goal to satisfy the current energy demand (**Table 4**).

Criterion	**Social scenario**					
	Biomass	**Social demand**	**Potential demand**	**Land use**	**Roads**	**Electrical network**
Biomass	1	3	3	5	5	5
Social demand	1/3	1	1	3	3	3
Potential demand	1/3	1	1	3	3	3
Land use	1/5	1/3	1/3	1	1	1
Road	1/5	1/3	1/3	1	1	1
Electrical network	1/5	1/3	1/3	1	1	1
	Feasibility scenario					
	Priority areas	Land use	Roads	Electrical network		
Priority areas	1	1/7	1/7	1/7		
Land use	7	1	1	1		
Road	7	1	1	1		
Electrical network	7	1	1	1		
	Demand scenario					
	Biomass	Current demand	Land use	Roads	Electrical network	
Biomass	1	3	7	7	7	
Current demand	1/3	1	7	7	7	
Land use	1/7	1/7	1	1	1	
Road	1/7	1/7	1	1	1	
Electrical network	1/7	1/7	1	1	1	

Table 4.
Valorization of the different criteria used to determine the optimal location of a production plant based on the biomass according to the social, feasibility, and demand scenarios.

3. Results and discussion

3.1 Areas with energy demand

a. High demand: This scenario was created based on the number of industries, distance to the industry, and current energy consumption existing in the region. The industries in the Araucanía Region are concentrated in the municipalities of Angol and Temuco. This is because the municipalities are the capitals of the provinces of Malleco and Cautín, respectively. They are also the cities with a large labor and economic importance, along with Villarica, in the Araucanía Region [40]. Conversely, the current energy consumption in the region generally occurs in the municipalities of Temuco, Ercilla, Cunco, Perquenco, and Freire and to a lesser degree in Angol, Villarrica, and Pucón. These municipalities concentrate the populations; besides, they are located in Ruta 5 road or they are the main touristic centers in the Araucanía Region [40]. Because of the greater consideration placed on the residential electrical consumption (0.5) than that of the quantities of and distances to the industries (0.25 for each one; **Table 2**), the high-demand scenario concentrated on the same municipalities (**Figure 2a**).

b. Potential demand: This scenario was created based on the existing rural electricity required in the Araucanía Region, which is one of the regions with the least amount of rural electricity in Chile [41]. Therefore, the districts with electrical coverage less than 40% were given priority. These districts are principally located in the mountain or costal area of the region and the extreme north and south. The total surface area of the districts with these characteristics was 447,954 ha (**Figure 2b**).

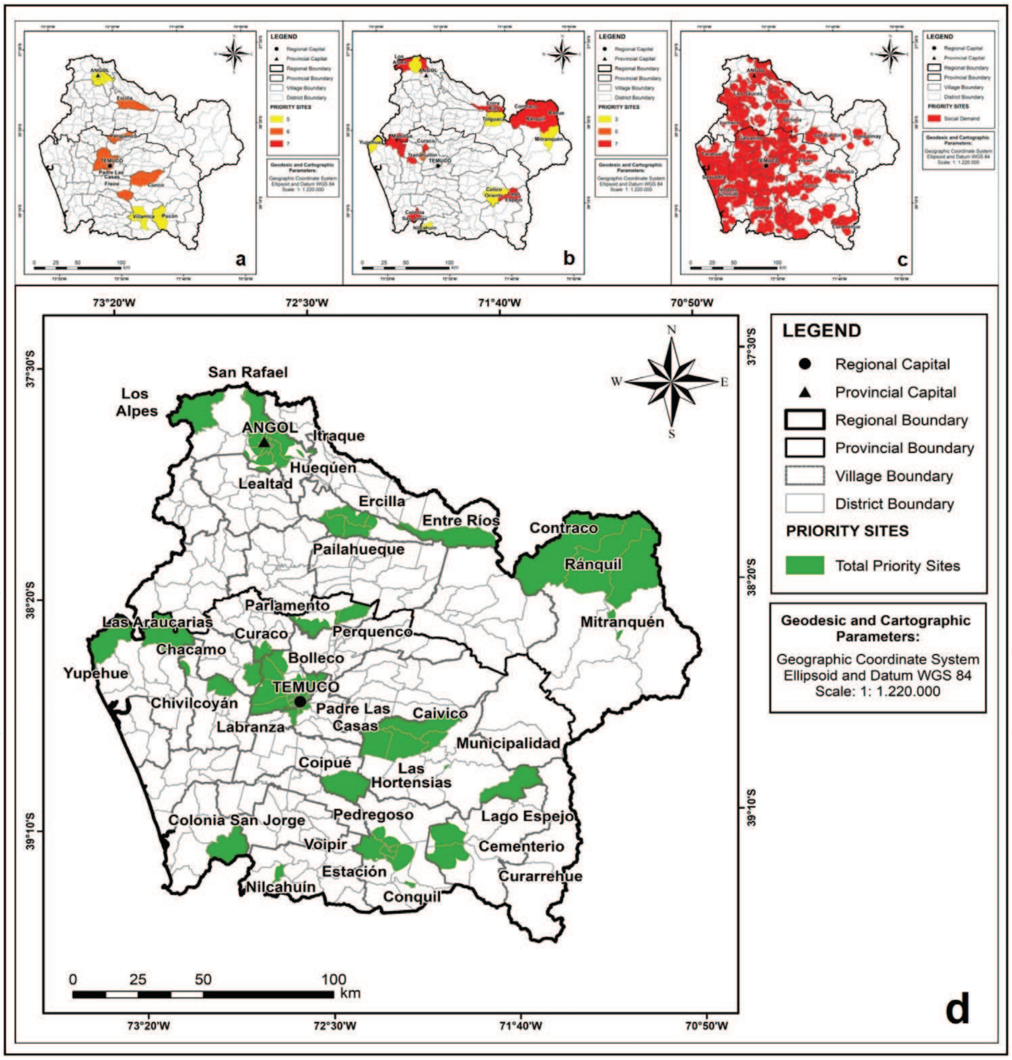

Figure 2.
Sites with a higher energy demand according to the (a) high demand, (b) potential demand, (c) social demand scenarios, and (d) priority energy demand sites according to the three demand scenarios in the Araucanía region.

c. Social demand: This scenario was based on rural establishments (educational and healthcare facilities and villages), prioritizing the energy supply to these locations. All priority sites under this scenario were located following the central axis with the most populated municipalities, Angol, Victoria, and Temuco [40], distributing to west and southwest of Temuco, covering rural coast municipalities, Carahue, Teodoro Schmidt, Saavedra, and Nueva Toltén (**Figure 2c**).

Information for each of the scenarios was cross-matched linearly to determine the priority energy demand sites. The priority sites occupied an irregular distribution in the territory (**Figure 2d**) and covered approximately 548,134 ha (17.2% of the regional surface).

3.2 Priority sites for installing an energy production plant based on biomass in the Araucanía region

The availability of the wheat biomass residue, considered a biomass production of 8534.8 t year^{-1} for C/ST and 5536.1 t year^{-1} for G/CC in the Araucanía Region, was concentrated in the central valley, in the south of the Malleco Province and in the north of the Cautín Province (**Figure 3a**) [2]. The usable land for installing an energy production plant is mainly located in the peripheral areas of the region, to the south and in the Andes Cordillera. The central area has a greater level of agricultural and industrial development (**Figure 3b**); however, the distribution of

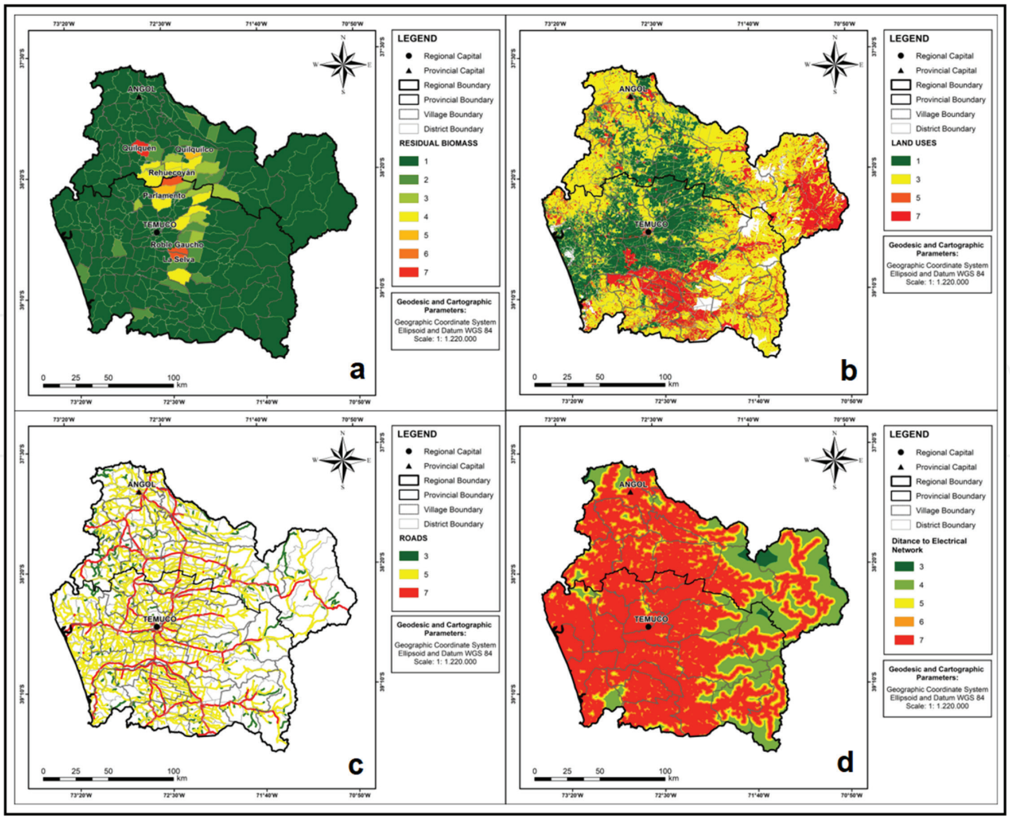

Figure 3.
Prioritization of the criteria established for the installation of an energy production plant based on the wheat residue biomass in the Araucanía region: (a) biomass production on a district-wide basis, (b) land use, (c) road network, and (d) distance to the electricity distribution network.

the development could be modified by reducing the use of scrubland meadows; the locations with a higher priority for an energy plant may be hindered by agricultural use [42].

The road network is a central paved axis, which corresponds to Route 5 that runs from the north to the south of the region. There are a series of secondary paved roads that run perpendicular to this route. Generally, paved roads are scarce, while gravel roads represent the densest network of roads in the region and are distributed toward the coastal area. Finally, dirt roads are found in the peripheral areas and are scarce (**Figure 3c**). The distance to the electrical distribution network displayed a similar pattern to that of the road network. A concentration of smaller distances to the network in the central and west areas was observed, while places with larger distance were found in the northeast region. Distances greater than 21,000 m were recorded (**Figure 3d**).

3.2.1 Determination of the priority placement areas

Standardized matrixes and priority vectors were established (or standardized vectors) for each of the priority placement scenarios (social, feasibility, and demand) for each energy production plant based on the wheat biomass (**Table 5**).

An evaluation of the consistency in the priority evaluation matrices is relevant in AHP to avoid inconsistencies in the final matrix [33, 38, 43, 44]. Thus, a consistency reason (CR) was used. A consistency index (CI) and a randomness index (RI) were used to calculate the CR [33, 38, 44]. The CRs in the social and demand scenario matrices were 0.019 (CI: 0.023 and RI: 1.24) and 0.049 (CI: 0.056 and RI: 1.12), respectively. This showed that the matrices were consistent, since the inconsistencies of the chosen weights were less than 10% [38, 44]. For the feasibility scenario matrix, the column values were the same for all criteria, showing that the weights (values) used were consistent; therefore, a consistency analysis does not need to be performed [44, 45]. The CR would be equal to 0. Mu and Pereyra-Rojas [44] recommended performing a consistency analysis whenever the criteria were more than two. The CR for the feasibility scenario was 0 because the CI values obtained from the priority vector was 0.

Value of priority vectors were considered as the final relative weight to each one of the variables in this analysis, for determining the optimal locations according to the three priority site scenarios [33, 43]. Here, under the social site scenario, the biomass availability was the most relevant (41.2%), while under the social demand and potential scenarios, the biomass availability was secondary (18.7% relevance for each). The same pattern was found in the demand scenario, where the availability was most relevant (49.6%), followed by the high-energy demand (33.0%). Finally, in the feasibility scenario, where biomass was considered a limiter, the land use, road network, and distance to the electrical distribution network were considered the factors with the greatest weight (31.8%).

Using the three scenarios for determining the best location for an energy production plant based on the wheat residue biomass, a similar behavior was observed in the priority establishment sites (**Figure 4**). In the social scenario, the optimal locations were dispersed in the central valley of the region, with a greater quantity in the south of the province of Malleco and the north of the province of Cautín, covering a surface of 226,414 ha (**Figure 4a**). In the feasibility scenario, the availability of the residue biomass was considered as a limiter; therefore, the best sites were clustered in areas similar to the distribution of the residues, which was concentrated in the central area of the region. For a G/CC plant with a minimum biomass requirement of 5536.1 t year^{-1}, the available surface was 54,795 ha. However, for a C/ST plant, with a minimum biomass requirement of 8534.8 t year^{-1}, the

Criterion	**Social scenario**						
	Biomass	**Social demand**	**Potential demand**	**Land use**	**Roads**	**Electrical network**	**PVE**
Biomass	0.4412	0.5000	0.5000	0.3571	0.3571	0.3571	0.4188
Social demand	0.1471	0.1667	0.1667	0.2143	0.2143	0.2143	0.1872
Potential demand	0.1471	0.1667	0.1667	0.2143	0.2143	0.2143	0.1872
Land use	0.0882	0.0556	0.0556	0.0714	0.0714	0.0714	0.0689
Road	0.0882	0.0556	0.0556	0.0714	0.0714	0.0714	0.0689
Electrical network	0.0882	0.0556	0.0556	0.0714	0.0714	0.0714	0.0689
	Feasibility scenario						
	Priority areas	**Land use**	**Roads**	**Electrical network**			**PVE**
Priority areas	0.0455	0.0455	0.0455	0.0455			0.0455
Land use	0.3182	0.3182	0.3182	0.3182			0.3182
Road	0.3182	0.3182	0.3182	0.3182			0.3182
Electrical network	0.3182	0.3182	0.3182	0.3182			0.3182
	Demand scenario						
	Biomass	**Current demand**	**Land use**	**Roads**	**Electrical network**		**PVE**
Biomass	0.5676	0.6774	0.4118	0.4118	0.4118		0.4961
Current demand	0.1892	0.2258	0.4118	0.4118	0.4118		0.3301
Land use	0.0811	0.0323	0.0588	0.0588	0.0588		0.0580
Road	0.0811	0.0323	0.0588	0.0588	0.0588		0.0580
Electrical network	0.0811	0.0323	0.0588	0.0588	0.0588		0.0580

Table 5.
Standardized matrices and priority vectors used to determine the optimal location of an energy production plant in the Araucanía region, according to the social, feasibility, and demand scenarios.

available surface was 41,949 ha (**Figure 4b**). In the high-demand scenario, a similar distribution to that of the feasibility scenario was observed, with a concentration of the optimal areas in the center of the region. The available space was 183,235 ha (**Figure 4c**).

Finally, 19 districts that met the requirements for the three scenarios were found. Thus, the installation of the plant may be considered an integrated solution for different types of demand (social, feasibility, and high demand). These districts were Chufquén, Coipué, Colonia Lautaro, Dollinco, General López, Huichahue, La Colmena, La Selva, Manzanaco, Parlamento, Perquenco, Quilquén, Quilquilco, Quino, Quintrilpe, Rehuecoyán, Roble Gaucho, Santa Ana, and Tricauco (**Figure 4d**).

In this study, the possibility of producing electrical energy using wheat residue biomass was evaluated based on two different combined cycle technologies (C/

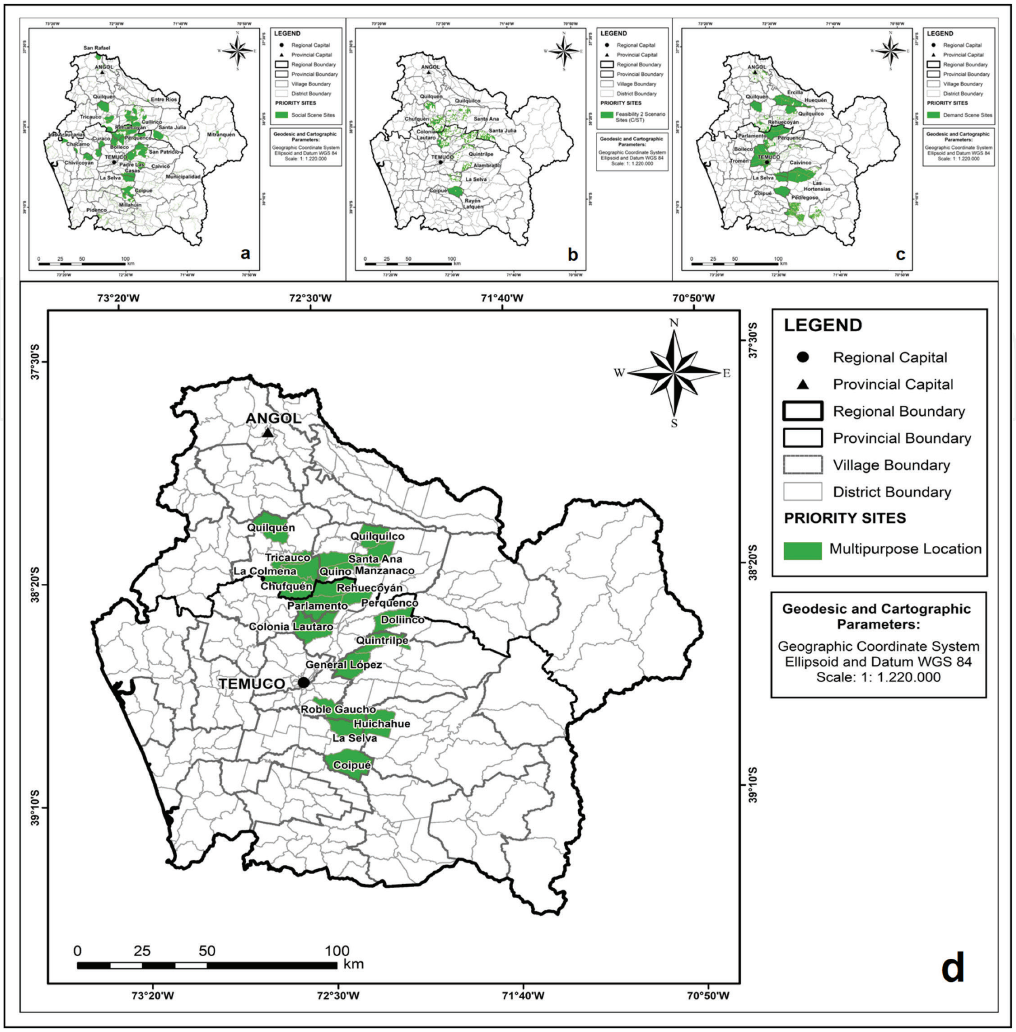

Figure 4.
Priority sites for energy plant installation an energy production plant based on the wheat biomass in the Araucanía region obtained by AHP under different scenarios, (a) social scenario; (b) feasibility scenario for C/ST plant with 8534.8 t year^{-1} *biomass as minimum requirement; (c) current demand scenario; and (d) multipurpose priority sites based in three scenarios for installation an energy production plant based on the wheat biomass in the Araucanía region.*

ST and G/CC), where the biomass was submitted to a thermic process and then generated electricity [2]. These technologies must be economically evaluated to determine their viability in the Araucanía Region. In addition, there are other potential uses for residual biomass. Recently, Azócar et al. [46] evaluated the production of pellets from wheat residue biomass using a roasting process that optimized energy production from this raw material. Therefore, there are multiple alternatives for creating energy from this raw material that should be evaluated to avoid burning these residues and the environmental consequences from these actions [17].

4. Conclusions

The multi-criteria analysis determined the sites where energy demand was present based on various scenarios. The energy demand contained a distribution in different sectors of the region. The current demand (high demand) was concentrated in the main economic and residential centers of the region, and because the residential demand was prioritized over the industrial demand, the municipalities of Carahue, Cunco, and Temuco had the highest demand. The potential demand was found in the rural zones, where there is a minimal electrical service. These areas are mainly located in the mountain and/or coastal zones, which are far from the city of Temuco, the regional capital. The social demand showed greater distribution in the region, because there are dispersed rural settlements that require energy.

The optimal location for an energy production plant was determined using relevant information, such as the availability of the biomass, road network, etc. The biomass availability was the criterion with the greatest influence on a placement decision in the three scenarios (social, feasibility, and demand). Therefore, in the three scenarios, the optimal locations had a distribution similar to the availability of the biomass. The districts were Chufquén, Coipué, Colonia Lautaro, Dollinco, General López, Huichahue, La Colmena, La Selva, Manzanaco, Parlamento, Perquenco, Quilquén, Quilquilco, Quino, Quintrilpe, Rehuecoyán, Roble Gaucho, Santa Ana, and Tricauco, where the energy-producing plant, using wheat residue biomass, had greater viability because it meets the demand for the three scenarios under evaluation.

Author details

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