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# Study of the Potential of Forest Biomass for the Development of Wood Energy Sectors in Congo Brazzaville

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## ABSTRACT

This research explores the potential of residual forest biomass in Congo-Brazzaville to support sustainable energy transition and reduce greenhouse gas emissions. Despite the country's heavy reliance on wood energy, which accounts for 85% of the energy mix, unsustainable practices threaten forest resources. Meanwhile, residues from logging and local wood processing, combined with the annual consumption of wood energy (firewood and charcoal), represent a significant amount of biomass which, if properly utilized, could generate greater social and environmental benefits than it currently does. A multidimensional approach was adopted to assess this potential. An interactive tool, the Biomass Cogeneration (CHP) Project Analysis System, was developed to model biomass flows, estimate energy production (thermal and electrical), and analyze environmental, economic, and logistical impacts. The results show that optimized utilization of forest residues could generate up to 591.7 MW of energy, representing 99% of the country's installed energy capacity, while avoiding up to 240,005 tons of $CO_2$ emissions annually. By promoting the use of biomass residues for cogeneration, this study supports national energy transition objectives and provides concrete solutions to integrate biomass as a strategic resource within Congo's energy mix.

## INTRODUCTION

Forest biomass, as a renewable resource, plays a central role in global efforts to promote a sustainable energy transition (Burg, 2018) and combat climate change (Kirilenko, 2007). In the Republic of Congo, the vast tropical forests, which cover approximately 65% of the national territory, offer significant potential for the development of wood energy sectors. If sustainably managed, these resources can not only meet the country's growing energy needs (Aguilar, 2009; Sajdak, 1981) but also contribute to diversifying its economy, historically dominated by oil exploitation.

Today, energy consumption in the Republic of Congo highlights the dominance of wood energy, which accounts for approximately 85% of the national energy mix (Figure 1). Within this proportion, firewood and charcoal play a central role, serving as an essential energy source for the majority of Congolese households, especially in urban and rural areas. These fuels are primarily used for cooking and domestic activities (Hall, 2002; Eshiamwata, 2019), with annual consumption remaining high, reaching several million tons.

This dependence underscores the importance of wood energy in meeting basic needs, while also highlighting the pressures on national forest resources (Misra, 2014), often exacerbated by unsustainable practices. In parallel, waste from logging and wood processing constitutes a significant part of forest residual Biomass (Sette Jr, 2020; Lima, 2020). It is estimated that between 40% and 60% of harvested wood and between 60% and 70% of processed wood end up as unutilized residues. This waste, generated by industrial and artisanal activities, represents a considerable energy potential (Gao, 2016) that remains largely untapped (Kashif *et al.*, 2020). To address these challenges, this study proposes a multidimensional approach that explores both the potential of residual forest biomass and the digital tools capable of improving decision-making. In particular, it focuses on the development and integration of an interactive tool, the Biomass Cogeneration (CHP) Project Analysis System, designed to assist decision-makers and planners in evaluating the technical, economic, logistical, and environmental aspects of biomass cogeneration projects.

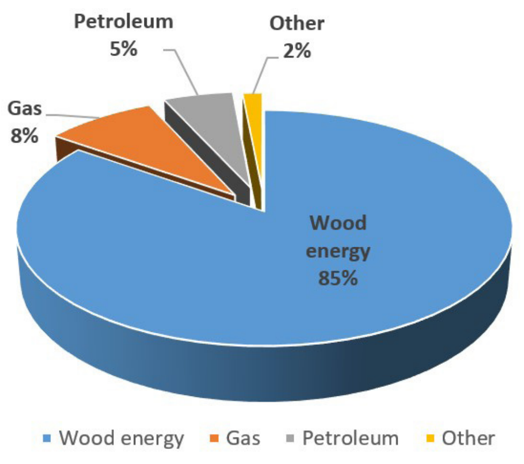


**Figure 1:** Congo national energy mix

This application, developed in HTML with interactive features, enables the modeling of biomass flows,



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estimation of thermal and electrical energy production, and analysis of environmental impacts, particularly in terms of greenhouse gas (GHG) emission reductions. Additionally, it offers a comprehensive financial evaluation, including indicators such as Return on Investment (ROI) and payback period, providing a robust foundation for planning economically viable and sustainable biomass projects.

By incorporating updated data on wood energy consumption, processing residues, and their potential valorization, this study aims to demonstrate how the use of this tool can not only maximize energy efficiency but also promote sustainable forest resource management. By supporting national objectives for energy transition and climate change mitigation, this research seeks to provide concrete and actionable solutions to transform biomass residues and wood energy into strategic resources at the heart of Congo's energy mix.

## LITERATURE REVIEW

The exploration of forest biomass as a renewable energy source has been widely discussed in the context of sustainable development and climate change mitigation. The extensive literature on this subject highlights the dual challenge of meeting growing energy demands while conserving forest ecosystems (Berndes, 2016; Börjesson, 2017). The Republic of Congo, endowed with vast forest resources, represents a critical case study in harnessing forest biomass for energy production. This section reviews the significant contributions of past studies, providing a theoretical basis and justification for the adopted variables, and develops hypotheses aligned with the study's objectives.

### Forest Biomass as a Renewable Energy Resource

Forest biomass has long been recognized as a key component of renewable energy strategies. Majchrzak (2022) identifies forest residues as a sustainable alternative to fossil fuels, emphasizing their role in reducing greenhouse gas (GHG) emissions and supporting energy security. Similarly, Bridgwater (Bridgwater, 2006) underscores the importance of optimizing biomass conversion technologies to maximize energy yield. These studies form the theoretical basis for investigating the potential of residual forest biomass in the Republic of Congo. Further perspectives on biomass utilization are presented in 'Sustainable Biomass Energy Production: A Review of Current Technologies and Future Prospects' published by E-Palli Publishers (Tiewul, 2024), which emphasizes the critical role of technological innovation in maximizing biomass energy efficiency.

### Variables Influencing Biomass Utilization

Several studies have identified critical variables that impact the feasibility and efficiency of biomass utilization. For instance, Field (2008) and Vasileios (2018) highlight the importance of quantifying biomass residues generated from logging and wood processing. These residues, estimated to constitute 40-60% of harvested wood, represent a substantial energy potential if effectively managed. Additionally, technological factors, such as cogeneration systems, have been shown to significantly influence energy recovery efficiency (Jankes, 2012). The role of policy and logistical frameworks further complicates the integration of biomass into energy systems. Similarly, 'Integration of Forest Residues in Developing Nations' Energy Systems' published by E-Palli Publishers (Kumar, 2024) highlights the specific challenges and opportunities in implementing biomass energy systems in developing countries, particularly relevant to the Congo context.

### Sustainable Forest Management and Policy Implications

Sustainable forest management practices are pivotal in ensuring the long-term viability of biomass resources. (Ladanai, 2009) Ladanai and Vinterbäck discuss global frameworks for sustainable biomass use, which align closely with Congo's national forestry policies. Law No. 16-2000 on forest management underscores the need for balancing economic exploitation with environmental conservation (KOUA, 2017). This dual approach is critical in developing biomass as a strategic resource within Congo's energy mix.

### Gaps in Literature and Hypothesis Development

Despite extensive research on biomass energy, gaps remain in understanding the socioeconomic and logistical challenges of integrating biomass into national energy strategies. For instance, while Bakouetila (Bakouetila, 2020) explores wood energy consumption patterns in Congo, limited attention has been given to optimizing residue collection and transportation logistics. This study hypothesizes that leveraging digital tools, such as the Biomass Cogeneration Project Analysis System, can address these gaps by providing data-driven insights for decision-making.

## MATERIALS AND METHODS

This study adopts a multidimensional approach to evaluate the potential of forest biomass for sustainable energy production in Congo-Brazzaville. The methodology incorporates quantitative and qualitative data collection, as well as modeling tools to simulate biomass flow and energy generation.

### Data Sources

Data Data for this study were derived from various primary and secondary sources. The primary sources included field surveys on wood energy consumption patterns, while eight major secondary sources were consulted National forestry reports including the "National Report on the Evaluation of Global Forest Resources 2015", reports from the National Center for Forest Inventory and Management (CNIAF),
World Bank economic data (2016) on forestry sector contributions, FAO forestry statistics and assessments

from 2010 and 2015, Household Survey reports on Wood-Energy Consumption in the Republic of Congo, Ministry of Forest Economy publications, Law No. 16-2000 documentation on the Forest code, and national forestry policy documents covering 2014-2025. These sources provided comprehensive data on forest resources, wood production, biomass residue, and energy consumption patterns.

**Biomass Flow Analysis**

A key methodological tool used in this study is the Biomass Cogeneration (CHP) Project Analysis System, developed specifically to model biomass flow and evaluate energy generation potential. This interactive tool integrates the following inputs:

Volume of wood production and residues (harvesting and processing waste).

Lower Heating Value (LHV) and density of biomass.

Transportation and logistical parameters.

The system enables the estimation of thermal and electrical energy production, taking into account different cogeneration technologies, such as steam turbines, Organic Rankine Cycle (ORC) systems, and Stirling engines.

**Environmental and Financial Analysis**

To assess the environmental impact, greenhouse gas (GHG) emissions were quantified using emission factors and avoided fossil fuel emissions. Financial evaluations included calculations of Return on Investment (ROI), payback periods, and net present value (NPV) based on the selling prices of electricity and heat.

**Hypothesis Testing**

The hypothesis of this study posits that biomass residues, if efficiently utilized, can contribute significantly to Congo's energy mix and climate change mitigation efforts. This was tested using simulation data generated by the CHP system, cross-referenced with real-world data from forestry operations and energy consumption patterns.

By combining digital tools, field data, and analytical models, this study provides a comprehensive understanding of the potential for biomass energy development in Congo-Brazzaville.

**Mathematical Expressions and Symbols**

To evaluate the amount of energy that can be produced from forest biomass, in the form of electricity and heat, when used as fuel in a cogeneration plant, the following formula is used

To convert the volume of residual biomass into bone-dry tonnes, we use the relationship

$$E = TMA \cdot PCI \cdot 1000 \quad (1)$$

Where E represents the energy produced in (in megajoules, MJ), TMA is the mass of forest biomass (in dry metric tonnes, DMT), the PCI corresponds to the lower heating value of the fuel (in MJ/kg) and the constant 1000 converts metric tonnes into kilograms.

$$TMA = VMA \cdot d \quad (2)$$

Where VMA is the volume of biomass in m3 and d is the density in kg/dm3

The electrical power of a cogeneration plant using forest biomass as an energy source is expressed as

$$P_e = (E - \eta_e)/t \quad (3)$$

Where $P_e$ is the electrical power expressed in megawatts electrical (MWe), t is the duration in seconds (s) and $\eta_e$ represents the electrical efficiency of the cogeneration plant.

The thermal power of the cogeneration plant is given by:

$$P_{th} = (E - \eta_{th})/t \quad (4)$$

Where $P_{th}$ represents the thermal power in megawatts thermal (MWth), $\eta_e$ corresponds to the thermal efficiency of the cogeneration plant and the electrical efficiency ($\eta_e$) of a cogeneration plant using forest biomass generally ranges between 20% and 30% [6]. As for the thermal efficiency ($\eta_{th}$ ), it varies from 55% to 70% for modern cogeneration plants.

In our simulation, we opted for an electrical efficiency of 25% and a thermal efficiency of 60%, which provides an overall efficiency of 85% for our plant.

## RESULTS AND DISCUSSION

**Forest Biomass Potential**

Historically, the forestry sector was the main driver of Congo's economy until the discovery of oil. Even today, forestry remains significant, contributing 5.3% to the national GDP (2016, World Bank) and positioning the country as a major producer of tropical hardwoods, including logs, sawn timber, and panels. Despite the vast potential of 300 tree species, only about 50 are commercially exploited, indicating substantial room for diversification and development in the forestry and biomass sectors. The national forestry policy of the Republic of Congo established for the 2014–2025 period, embodies an ambitious and sustainable vision aimed at positioning Congolese forests at the heart of the green economy and national development. Recognizing the critical role of forests in poverty alleviation, improving living conditions, and combating climate change, this strategic vision reflects Congo's commitment to harmonizing economic development and environmental conservation while aligning with global objectives to combat deforestation and climate change.

The Republic of Congo, covering 34.2 million hectares, is rich in forest resources, with over 22 million hectares of forest, making up about 65% of the country's land area and 11% of Central Africa's forest cover (FAO, 2010). Of this, 14.8 million hectares are designated as production forests, all of which are publicly owned, with 11.6 million hectares currently allocated under forest concessions.

FAO estimates the annual deforestation rate in the Republic of Congo at about 0.1%, or roughly 17,000 hectares. In 2015, forest cover was reported at 23.5 million hectares, representing 69% of the country's territory. The annual deforestation and degradation rate was lower, around 0.05%, or 12,000 hectares per year (CNIAF, 2015). This extensive public ownership highlights the government's crucial role in managing these forests sustainably.

A recent estimate on forest land use in Congo, conducted by the FAO and published in the National Report on the Evaluation of Global Forest Resources 2015

**Table 1:** Summary of CNIAF based on satellite imagery from 2003-2004

| Categories | Surface (in hectares) |
|---|---|
| Dense forest on dry land | 13.558.000 |
| Flooded dense forest | 8.472.300 |
| Open forest | 310.000 |
| Forest plantation | 50.895 |
| Mangrove | 5.000 |
| Wooded/shrub savanna | 10,028,700 |
| Grassy savanna | 1,512.500 |
| Agricultural land | 250.000 |
| Total land area | 34.187.395 |

The composition of this vast ecosystem is divided into several categories. Dense forests on dry land represent approximately 39.7% of the total land area, while flooded dense forests account for about 24.8%. Wooded and shrub savannas cover roughly 29.3% of the area. Grassy savannas make up 4.4%, open forests constitute 0.9%, and forest plantations, mangroves, and agricultural land each contribute less than 1%. According to satellite imagery data of 2003 and 2004, the total forested area was covered approximately 65.2% of the country's land.

### Standing Wood

The 2009-2014 National Multi-Resource Forest Inventory of the Republic of Congo, along with the 1984 assessment of the extent and potential of timber forest resources, as reported in a publication by the Ministry of Forest Economy. The total standing volume of living trees (in 1000 $m^3$) with a diameter greater than or equal to 20 cm is estimated at 4 billion cubic meters. Based on their distribution across different land categories: forests, other wooded lands, other lands, and inland waters. Forests are by far the primary source of standing wood, with an estimated volume of 4,313,491 thousand cubic meters, representing nearly 99.7% of the total recorded volumes. Other wooded lands, which include savanna woodlands and other intermediate vegetation formations, contribute approximately 0.05% of the total volume. Other lands and inland waters contribute significantly less, accounting for about 0.26% and 0.016% of the total volume, respectively.

**Table 2:** Standing volumes for trees with a diameter ≥ 20 cm by overall class

| Estimation | Forest | Other Forested Lands | Other Lands | Continental waters | Total |
|---|---|---|---|---|---|
| Wooded areas | 4 313 491 | 2 222 | 11 344 | 708 | 4 327 765 |
| Other, Lands Waters | 196 | 0,5 | 1,5 | 2,5 | 127 |
| Continentales | 3,6% | 43% | 53% | 56% | 3,6% |

The average volume per hectare in Table 2 varies significantly across categories. Forests stand out with a high density of 196 $m^3$/ha, reflecting their substantial carbon storage capacity, while other wooded lands show a very low volume of 0.5 $m^3$/ha, indicating sparse and likely degraded vegetation. "Other lands" and "inland waters" also exhibit modest volumes of 1.5 $m^3$/ha and 2.5 $m^3$/ha, respectively. The relative standard error, which measures data uncertainty, is low for forests (3.6%), ensuring high reliability. However, the high margins of error for other categories (43% to 56%) highlight the need to improve data collection and precision. The low contribution of these categories, which account for a marginal share of the total volume, reduces their impact on the overall uncertainty of the estimates.

### Exploitable Volumes

The Congo has a total exploitable wood volume estimated at 981 million $m^3$, this potential represents 29 $m^3$ of wood per hectare, accounting for approximately 22.7% of the total standing volume Table 3. In forested areas, this density reaches about 45 $m^3$ per hectare. However, outside forest zones, the exploitable volume is significantly lower, with only 223,000 cubic meters in other wooded lands and 1.8 million $m^3$ in non-forested lands.

**Table 3:** Exploitable volumes by global class (in 1000 $m^3$)

| Estimation | Forest | Other Forested Lands | Other Lands | Continental waters | Total |
|---|---|---|---|---|---|
| Volume/(1000 $m^3$) | 981 301 | 223 | 1 762 | 0 | 983 285 |
| Other Lands Waters | 44,6 | 0,1 | 0,2 | 0 | 29 |

Forestry regulations and environmental constraints play a major role in limiting the exploitation of forest resources in Congo-Brazzaville, particularly under Law No. 16-2000 on the Forest code. This law establishes strict rules on sustainable forest management, ecosystem conservation, and exploitation quotas to ensure a balance between the economic use of forests and biodiversity preservation

### National Structure of Wood Production and Wood Energy Consumption

In Congo-Brazzaville, forestry exploitation is mainly divided into two types: industrial forestry exploitation Figure 2 and artisanal forestry exploitation Figure 3, (Lescuyer, 2011; Kimpouni, 2008).

Industrial forestry exploitation is generally carried out by companies or multinational corporations. It is characterized by large-scale logging, often on an extensive scale, to extract wood primarily intended for export around 1.3 million cubic meters of wood each year though some is also sold on local markets for the production of furniture, paper, plywood, and other wood-derived products. This activity is heavily concentrated in regions such as northern Congo, including areas like Sangha, Likouala, and Cuvette, where vast forest concessions are granted to logging companies.

While this activity is quite profitable for the country, generating export revenues of over 300 million USD annually, it mainly focuses on profitability, prioritizing international demand over the local value-added processing of this resource.

Local industrial units of various sizes process logs into finished or semi-finished products. The demand for wood as a construction material is growing rapidly in the country, where it is widely used in sectors such as carpentry, joinery, and flooring.


**Figure 2:** Industrial forestry exploitation

The woodworking and furniture sectors are also experiencing strong demand (Antwi-Boasiako, 2016), with the development of small and medium-sized specialized enterprises that cater to local and regional needs for furniture. Local artisans use wood to produce furniture such as tables, chairs, beds, and wardrobes, as well as decorative objects and handcrafted items

**Table 4:** Total gross standing volume of the ten (10) most common tree species in Congolese

| Commercial name | Density (mc/ha) | Superficie forestière nationale Area (ha) | Material (m3) |
|---|---|---|---|
| Sapelli | 8.62 | 22.471.300 | 193.702.606 |
| Limba | 7.01 | 22.471.300 | 157.523.813 |
| Niové | 4.16 | 22.471.300 | 93.480.608 |
| Tali | 3.50 | 22.471.300 | 78.649.550 |
| Ayous | 3.08 | 22.471.300 | 69.211.604 |
| Kossipo | 2.85 | 22.471.300 | 6443.205 |
| Padouk | 2.31 | 22.471.300 | 51.908.703 |
| Azobé | 1.95 | 22.471.300 | 43.819.035 |
| Iroko | 1.83 | 22.471.300 | 41.122.479 |
| Sipo | 1.43 | 22.471.300 | 32.133.959 |

Based on this national data, the total gross standing volume of the ten (10) most widespread tree species in Congolese forests was documented by the National Center for Forest Inventory and Management (CNIAF/DF) in its national report titled Global Forest Resources Assessment 2005 and presentend in Table 4. This report highlights the availability of biomass and the potential of Congo's forest resources with a total volume of 1.016 billion m³ mainly dominated by two species, Sapelli and Limba, which together account for over 42% of the total volume. Sapelli alone contributes 23.46%, making it the most significant species, followed by Limba at 19.08%. These species illustrate the richness of the Congolese forests and their economic potential (Ifo, 2016). However, they represent only a small fraction of the 150 large tree species present in Congo.

Artisanal forestry exploitation is mainly carried out by local individuals, small operators, or community groups for energy need (Wood energy) in the entire national territory, unlike industrial logging, which is limited to forests rich in high-value timber (Mbete, 2014). It is characterized by selective logging on a small scale, primarily aimed at meeting local and regional needs rather than exports. Each year, this sector processes several thousand cubic meters of wood, it continues to be used in households in the Republic of Congo. Households rely on wood energy for all long cooking processes, such as beans and traditional dishes like saka saka, mouaba, cassava, etc.

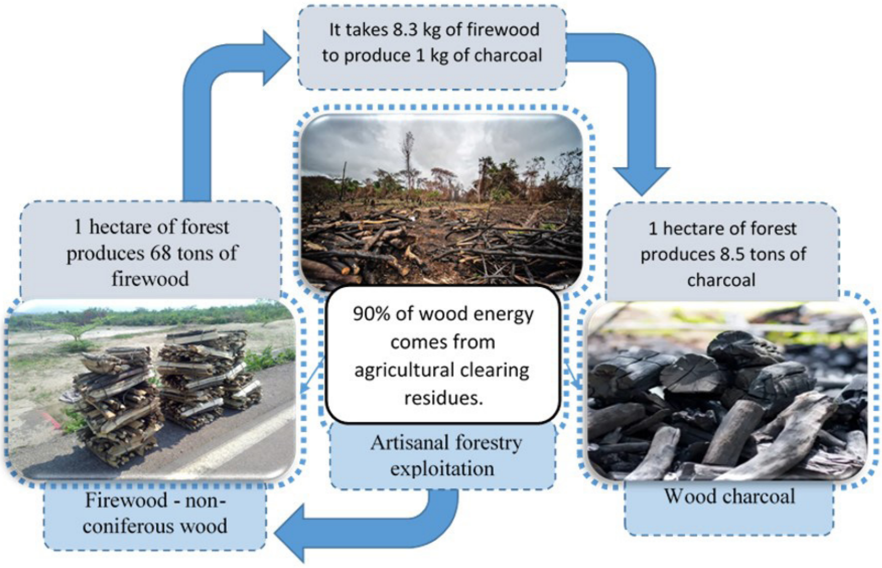


**Figure 3:** Artisanal forestry exploitation

Trees with a diameter of 10 cm or less are widely exploited due to their availability, they are directly used as firewood or transformed into charcoal through rudimentary processes, such as traditional carbonization in earthen kilns or artisanal furnaces. While these practices are essential to meet local energy needs, they lead to uncontrolled deforestation and expose users to risks of intoxication from wood gas emissions (Gauthier, 2012; Öztürk, 2002). The use of wood energy varies significantly across the country's departments Figure 4, which can be categorized into three main consumption areas: high, medium, and low.

Brazzaville and Pointe-Noire, which are respectively the political and economic capitals of the country, represent the high consumption areas, collectively consuming over 60% of the wood energy. Brazzaville accounts for more than 45.23%, and Pointe-Noire for 18.68% of the annual wood consumption. This is due to the high population density and concentrated energy needs in these cities. The medium consumption areas represent 18.2% of the annual wood energy, including the departments of Niari 7.5%, Bouenza 5.99%, and Pool 4.71%.

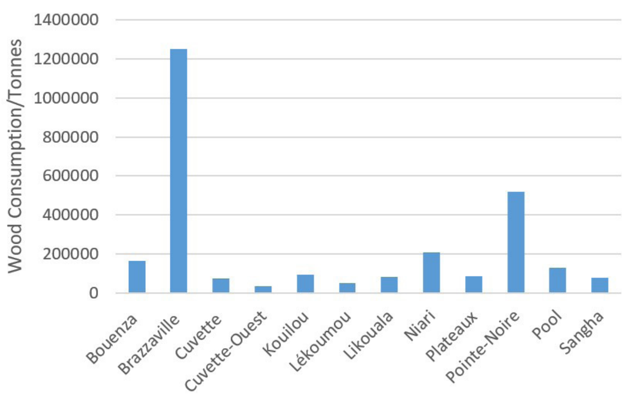


**Figure 4:** Wood consumption by departments in Congo Brazzaville 2024

The departments of Plateaux, Kouilou, Likouala, Sangha, Cuvette, Lékoumou, and Cuvette-Ouest are classified as low consumption areas, with each department consuming below 3%. Collectively, they account for a total of 17.88% of the annual wood consumption.

**Cogeneration**

Cogeneration, also known as Combined Heat and Power (CHP), is an efficient technology that simultaneously produces electricity and heat from a single energy source.

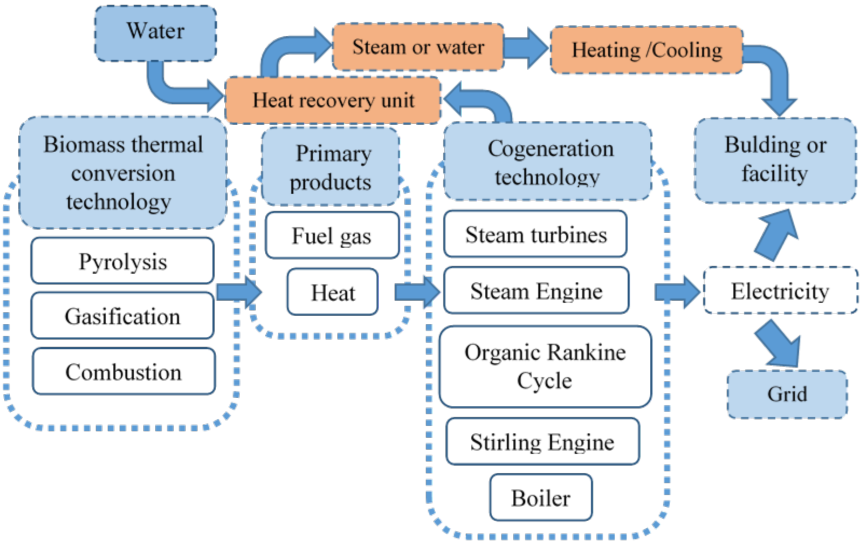


**Figure 5:** CHP cogeneration technology

This approach is highly valued for its energy efficiency, superior to conventional energy production systems (Maraver, 2013). Cogeneration systems can achieve overall energy efficiencies of up to 80-90%, whereas traditional electricity-only production methods often have efficiencies of around 35-40%. The recovery of heat, a key feature of cogeneration, allows the exploitation of heat that would otherwise be lost in conventional systems, using this energy for building heating, industrial processes, or hot water production. Biomass cogeneration technology can employ different cogeneration technology Figure 5 to convert biomass into both heat and electricity (Abbas, 2020), including steam turbines, steam engines, Organic Rankine Cycle (ORC), and Stirling engines. Each of these technologies has distinct characteristics and applications.

**Conversion of Residual Forest Biomass into Energy through Cogeneration**

The total wood production for the year 2018 was estimated at 1.8 million m³ (anhydrous metric volume). According to the study report from the Household Survey on Wood-Energy Consumption in the Republic of Congo, it is estimated that 40% to 60% of harvested wood and 60% to 70% of wood intended for processing end up as waste. To evaluate the volumes of residual biomass available for the year 2022, we used an average of these values, incorporating both harvesting and processing data, to provide a cautious yet realistic estimate of the residual biomass potential. The Low eating value is 17.810mj/kg.

The estimation of biomass residues from industrial forestry operations is based on two main categories: harvested wood and processed wood.

The total wood production for the year 2018 was estimated at 1.8 million m³ (anhydrous metric volume). Assuming that the logging waste percentage ranges from 40% to 60%, the average will be:

Average logging waste = (40 + 60) / 2 = 50%.

If 50% of the total volume is considered waste, the quantity of logging waste is calculated as follows: Logging waste = 1.800000 m³×50% = 900000 m³.

If 44% of the wood produced is exported as logs, the remaining quantity intended for local processing is given by: Wood for local processing =1800000×0.56 = 1008000m³. Of the wood processed locally, 60% to 70% is considered waste. The average of this waste is:

Average waste after processing = (60 + 70) / 2 = 65%.

The quantity of waste after processing will therefore be Waste after processing = 1008000m³ × 0.65 = 655200m³. The total forest waste is the sum of logging waste and waste after processing: Total forest waste = 900000+655200 = 1555200m³.

TMA=1555200×0.69=1073088 tonnes

The calculation of Total energy give

$E=(1000\times1073088\times17.810)/1000=19112592.48GJ$

Electric power

$P_e=(19112592.48\times0.25)/31557600=151.4$ MW

Thermal Power

$P_{th}=(19112592.48\times0.6)/31557600=363.38MW$

According to the law (Law 33-2020), which requires the processing of all logs within the national territory, 100% of the wood produced is allocated for local processing. This means that the entire 1,800,000 m³ is subject to the 65% waste processing average. The waste generated after full processing would amount to: Waste after processing (with law) = 1800000×65% = 1170000m³. The total forest waste after the application of the law is then: Total

forest waste (with law) = 900000+1170000 = 2070000m³.
TMA=2070000×0.69=1428300 tonnes
The calculation of Total energy give
E=(1000×1428300×17.810)/1000=25438023GJ
Electric power
$P_e$=(25438023×0.25)/31557600=201.5 MW
Thermal Power
$P_{th}$=(25438023×0.6)/31557600=483.6MW
To determine the total amount of wood actually felled in the forest, we need to take into account the losses generated throughout the production process where Wood felled will be the some of the Total production and the Logging waste. Wood felled = 1800000 + 900000 = 2700000 m³

**Conversion of Biomass (firewood) into Energy through Cogeneration**

According to the estimation of the evolution of firewood and charcoal consumption by department, conducted as part of the household survey report on wood-energy consumption in the Republic of Congo, the projected consumption for the year 2024 was 482,665 tonnes of firewood and 285,397 tonnes of charcoal.

Taking into account that 8.3 kg of firewood is required to produce 1 kg of charcoal (according to the study on wood-energy consumption in the cities of Brazzaville and Nkayi – FAO and UNDP, 2004), the total wood-energy consumption amounts to 3,457,281.30 tonnes.
TMA=3457281.295×0.8=2765825.036 tonnes
The calculation of Totale energy give
E=(1000×2765825.036×17.810)/1000=49244542442 GJ
Electric power
$P_e$=(49244542.442×0.25)/31557600=390.2 MW
Thermal Power
$P_{th}$=(49244542.442×0.6)/31557600=936.1 MW
If the energy production from the CHP biomass plant, powered by the amount of firewood consumed across the entire national territory for the year 2024, is distributed by the percentage of charcoal consumption per department, this graph is obtained.

Analyzing the regional distribution of this biomass production, based on the amount of firewood consumed in 2024 Figure 6, Brazzaville accounts for 31.3% of electricity production 88.24 MW and 37.7% of thermal production 211.69 MW, followed by Pointe-Noire with 12.9% 36.44 MW and 15.6% 87.43 MW. Other departments are distributed as follows: Cuvette-Ouest 0.8% electricity, 1.0% thermal, Likouala 2.0%, 2.4%, Lékoumou (1.2%, 1.5%), Sangha 2.0%, 2.4%, Niari 5.2%, 6.3%, Pool 3.3%, 3.9%, Plateaux (2.1%, 2.6%), Kouilou 2.4%, 2.8%, and Bouenza 4.1%, 5.0%.

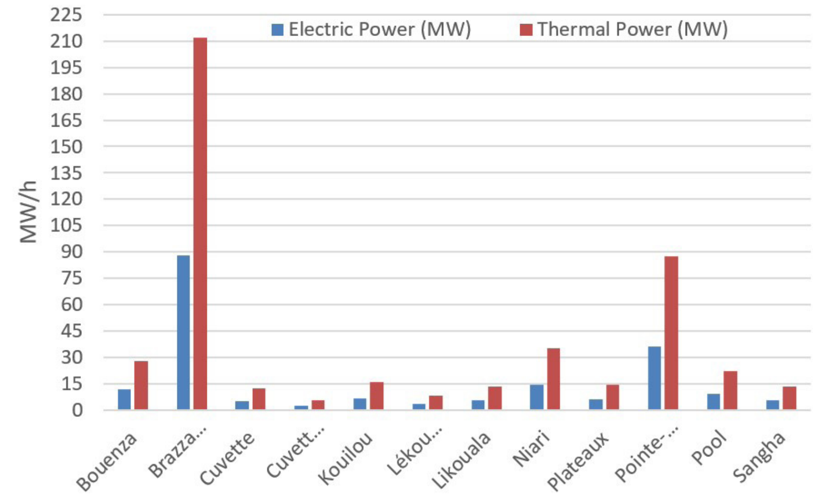


**Figure 6:** Wood Energy disponibility

**Contribution of Biomass Energy to the Congolese Energy Mix**

The total installed capacity in Congo-Brazzaville Figure 7 is estimated at 596 MW, distributed among hydropower, gas power plants, and thermal power plants.

Key infrastructures include the Moukoukoulou hydropower plant 74 MW, the Djoué hydropower plant 15 MW, the Imboulou hydropower plant 120 MW, the Djeno gas power plant 50 MW, the Congo gas power plant 300 MW, as well as the diesel thermal power plants of Brazzaville 32.5 MW and Oyo 4.5 MW. Additionally, there is an electrical interconnection with the Democratic Republic of Congo via the 225 kV Brazzaville-Kinshasa line, providing a transit capacity of 100 MW, though only local production is considered in this analysis.

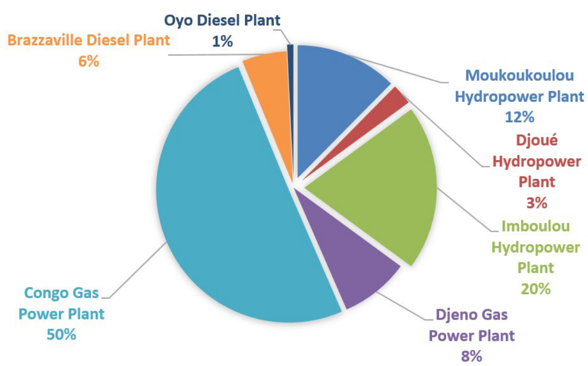


**Figure 7:** Current Distribution of Installed Capacity in Congo-Brazzaville

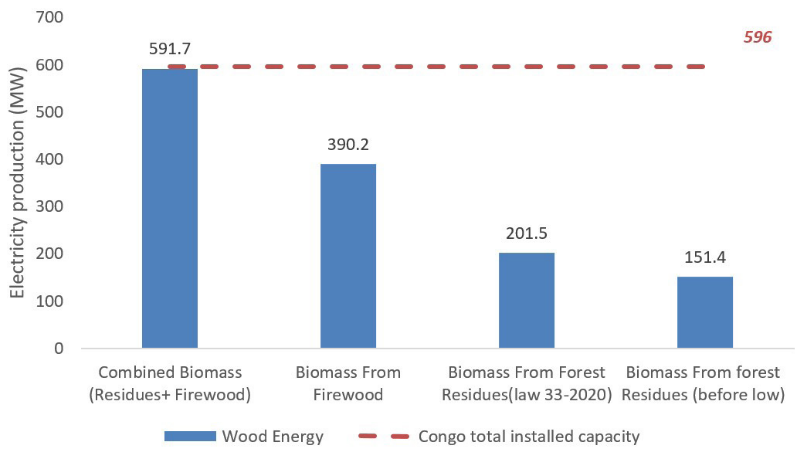


**Figure 8:** Potential Impact of Biomass on the Energy Mix

If we see the potential Impact of Biomass on the Energy Mix Figure 8 by integrating biomass energy from forest residues and logging activities, approximately 151.4 MW of electricity could be added to the Congolese energy mix, representing nearly 25% of the currently installed capacity. With the implementation of Law 33-2020, which mandates the local processing of 100% of logs, biomass energy generated from logging residues could reach 201.5 MW, representing 33.8% of the installed capacity. This specific source could thus become a major contributor to the national energy mix. Furthermore, converting biomass from firewood into electricity is estimated at 390.2 MW, accounting for approximately 65% of the total installed capacity. Combined, the two biomass sources (forest residues and firewood) could supply a total of 591.7 MW, representing 99.3% of the current installed capacity, nearly doubling the existing capacities in the energy mix. Biomass could contribute 65% to 99% of the Congolese energy mix, depending on scenarios for local log processing and firewood conversion into electricity.

### Analysis of clean Energy Projects

As part of the optimization and energy valorization of biomass, the biomass cogeneration (CHP) project

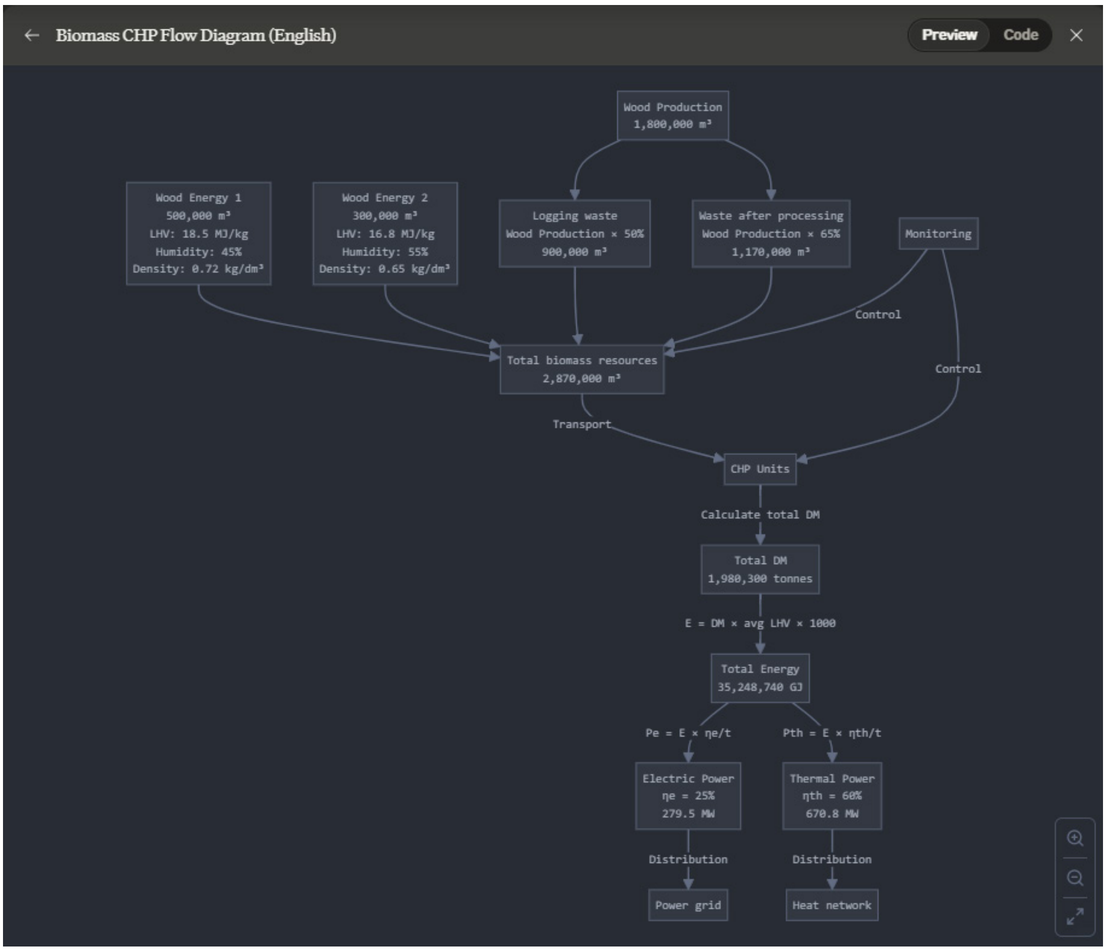


**Figure 9:** Diagram flow of the (CHP) program

analysis system developed provides a methodological tool to assess the technical, logistical, environmental, and economic aspects of projects.

This system relies on key data to model biomass flows, energy production, greenhouse gas (GHG) emission savings, and expected financial returns.

Figure 9 illustrates the flow diagram of data and processes in a biomass cogeneration project. It highlights the main steps, from biomass supply to the production and distribution of thermal and electrical energy. Each element in the diagram plays a specific role in assessing the available resources and their conversion into energy. The system was designed to meet several key needs, including assessing the availability of biomass resources, such as residues from forest operations and processing, and calculating the potential for thermal and electrical energy production. It also analyzes the logistics required for transporting biomass resources and evaluates energy distribution and its impact on local communities. Additionally, the system quantifies environmental benefits in terms of greenhouse gas (GHG) emission reductions and examines the project's economic profitability and financial indicators.

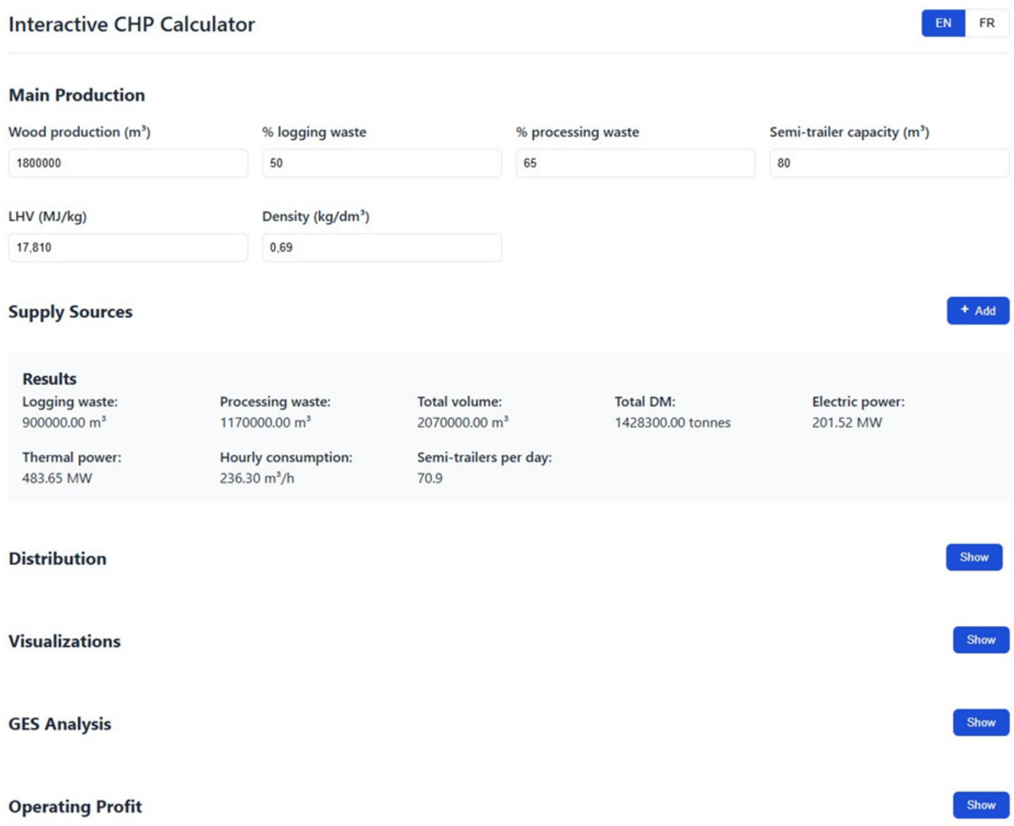


**Figure 10:** Main Page

The main Figure 10 input parameters include the wood production volume (m³), which represents the total annual quantity of wood produced and serves as the basis for waste calculations, and the percentage of cutting and processing waste, which estimates the proportions of residues generated during production. Other key parameters include the capacity of semi-trailers (m³) used for biomass transportation, the Lower Heating Value (LHV) indicating the energy content of the biomass in MJ/kg, and the density (kg/dm³) for converting biomass volumes into mass. Together, these parameters enable accurate modeling of biomass supply and the associated logistical flows.

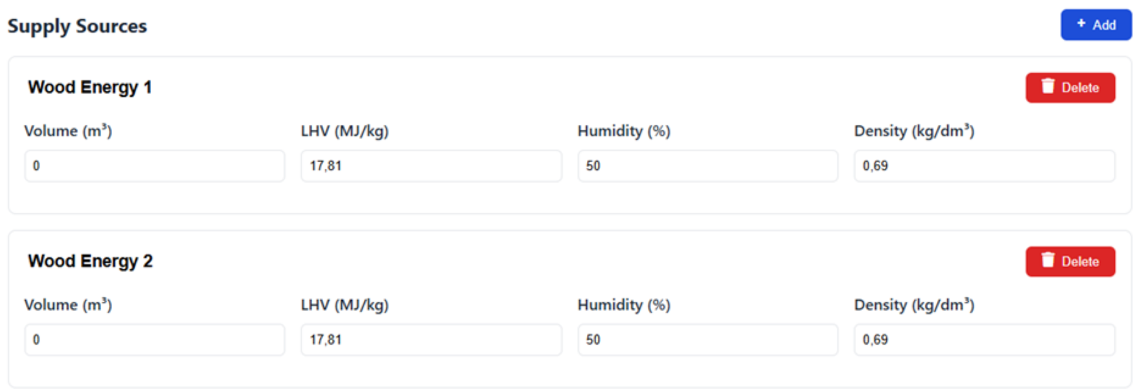


**Figure 11:** Supply source

By clicking on Add Supply Source, the users can configure multiple biomass sources Figure 11 by specifying key parameters such as volume ($m^3$), Lower Heating Value (LHV) in MJ/kg, moisture content (%), which directly affects the quality and quantity of energy produced, and density (kg/$dm^3$).

In the Results section, the system generates key indicators, including the volume of cutting and processing waste, which reflects the total amount of available biomass, and the total dry matter (DM), representing the biomass mass after moisture removal. It also calculates heat and electricity production, indicating the thermal and electrical energy generated, as well as hourly consumption, which is the amount of biomass required to sustain production. Finally, for logistics, the system estimates the number of semi-trailers needed per day to transport the biomass efficiently.


**Figure 12:** Distribution

In the Distribution section Figure 12, the system includes a comprehensive analysis of energy distribution, allowing for the simulation of losses related to energy transportation from production to consumers. It provides key indicators such as the percentage of delivered electricity and heat. It also calculates per capita and household consumption, offering a clear view of the project's impact on households and local communities. Finally, it estimates the project's total reach by determining the number of households and inhabitants that can be served.

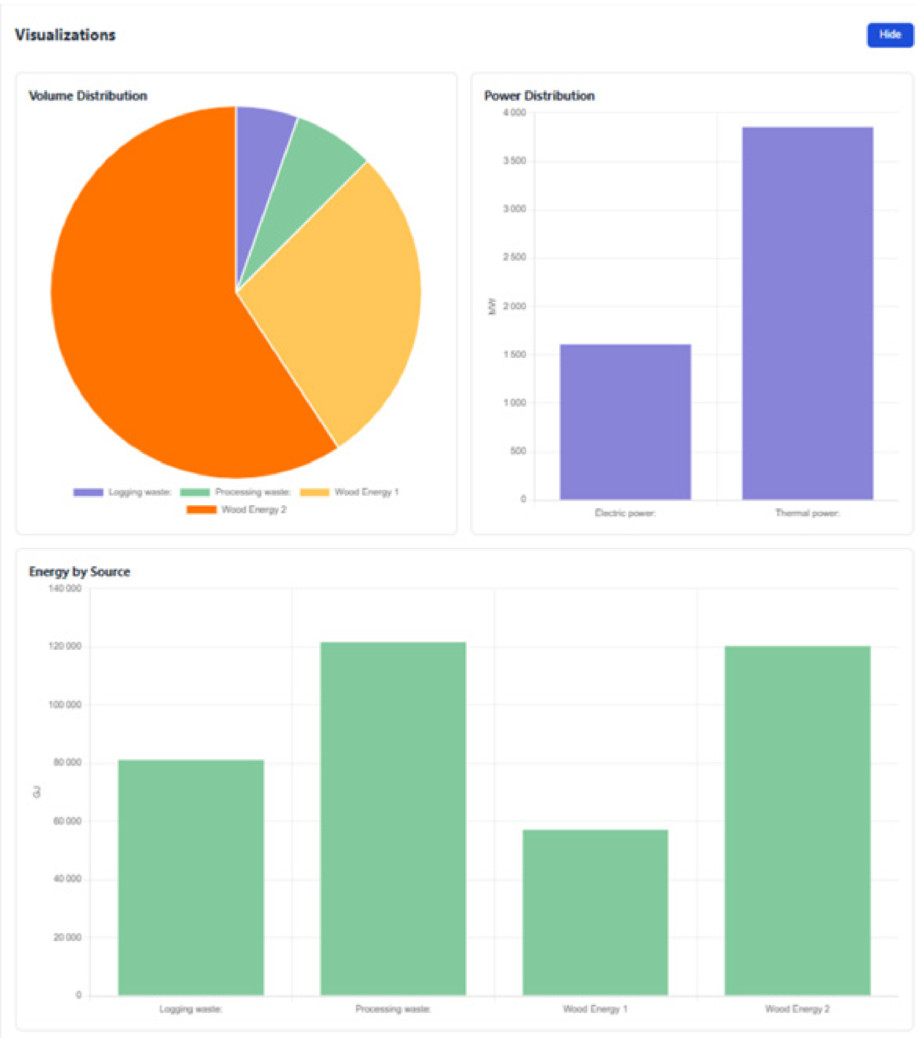


**Figure 13:** Data Visualizations

The Visualizations section Figure 13 provides a clear representation of the data to facilitate its interpretation. The Volume Distribution section allows for an interactive visualization of volume distribution in the form of a diagram, offering a global view of the energy balance. The Power Distribution section enables a comparison of thermal and electrical power, providing an overview of energy production. The Energy By Source section illustrates the energy contributions of each type of biomass, highlighting their respective roles in overall production.

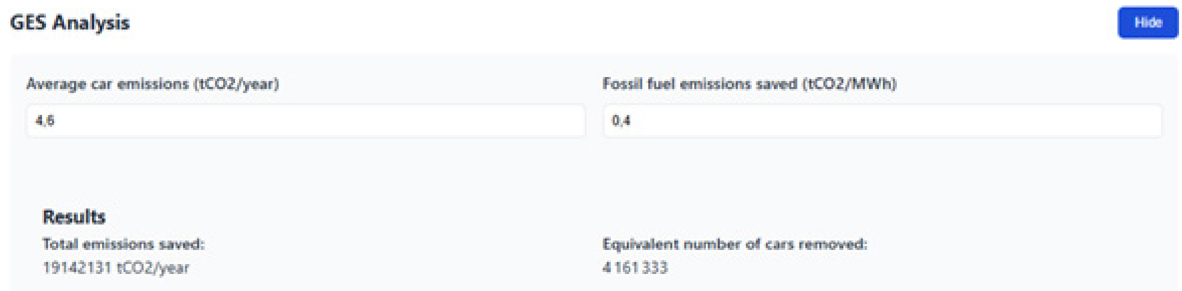


**Figure 14:** GES Analysis

The GES Analysis section Figure 14 provides a detailed analysis of the environmental benefits by quantifying the reductions in greenhouse gas (GHG) emissions. By inputting the average emissions per vehicle ($tCO_2$/year) and the avoided emissions from fossil fuels ($tCO_2$/MWh), the Results subsection displays the $CO_2$ emissions avoided, expressed in tons of $CO_2$ per year, as well as the equivalent number of cars removed from circulation.

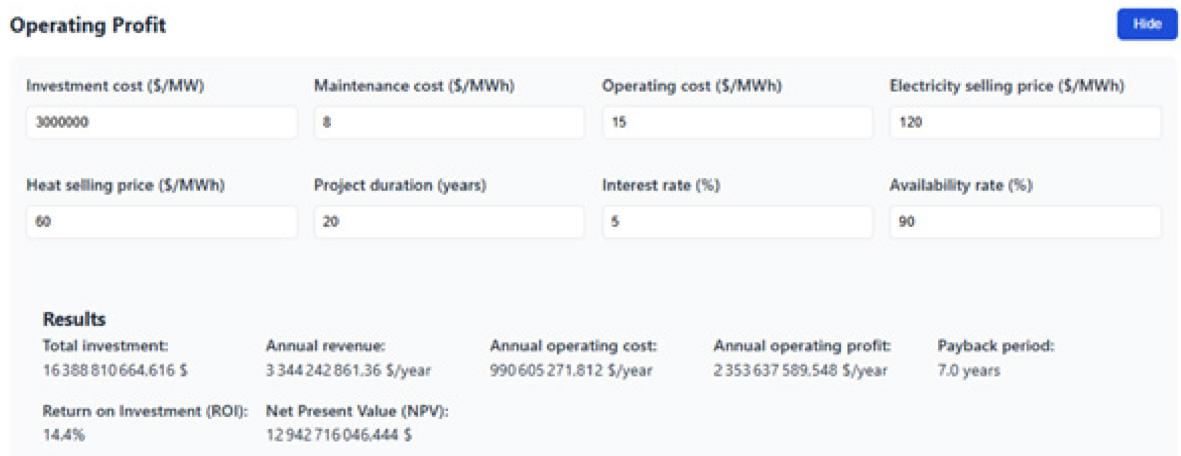


**Figure 15:** Operation profit

The Operation Profit section Figure 15 includes a comprehensive financial analysis, enabling a detailed evaluation of the economic viability of projects. This analysis is based on several key elements, including costs related to initial investment, maintenance, and operation, as well as estimated revenues based on the selling prices of electricity and heat, expressed in \$/MWh. It also considers financial parameters such as the project duration (in years), interest rate (%), and availability rate (%).

In the Results section, the system provides the total required investment, annual revenues generated, and operational profits. Additionally, essential financial indicators, such as Return on Investment (ROI), Net Present Value (NPV), and payback period, are included to assess the profitability and economic sustainability of the project.

### Simulation Results with the Biomass Cogeneration (CHP) Analyzer

2020, which requires all logs to be processed within the national territory, the simulation indicates a total biomass production of 2,070,000 m³, generating an electrical output of 201.52 MW and a thermal output of 403.05 MW. This project could supply energy to 1,048,159 residents and 235,908 households while avoiding 240,005 tons of $CO_2$ emissions annually, equivalent to removing 52,121 vehicles from circulation. On the financial side, with an investment cost of \$300 million and sales prices of \$70/MWh for electricity and \$60/MWh for heat, the project generates an annual profit of \$230.05 million, with a payback period of 8.5 years and an internal rate of return (IRR) of 11.2%.

## CONCLUSION

This study has highlighted the significant potential of forest biomass residues in the context of sustainable energy transition in Congo-Brazzaville. Given the country's heavy reliance on wood energy, which accounts for 85% of the national energy mix, the energy recovery of residues from logging and wood processing activities, as well as wood biomass energy (firewood and charcoal) intended for annual use, emerges as a strategic solution.

The findings demonstrate that an optimized exploitation of these resources could not only generate up to 591.7 MW of energy but also prevent up to 240,005 tons of $CO_2$ emissions per year, thereby significantly contributing to national climate and energy objectives.

The multidimensional approach adopted, combined with the development of an interactive tool for biomass-based cogeneration project analysis, has demonstrated the technical, economic, and environmental feasibility of such valorization. Moreover, the integration of biomass into the national energy mix goes beyond mere energy diversification. It also aligns with a sustainable development framework, supporting the responsible management of forest resources and the creation of socio-economic benefits for local communities.

In a context where the Congolese government is committed to transforming the forestry sector into a driver of a green economy, this research provides a solid foundation for policies and concrete actions. It offers pragmatic solutions to address critical challenges such as reducing energy poverty, mitigating climate change, and preserving natural resources.

Finally, this study calls for collective efforts involving public authorities, private stakeholders, and local communities to turn this potential into reality. Synergy between technological innovation, an adapted regulatory framework, and community engagement will be essential to making forest biomass a cornerstone of sustainable energy development in Congo-Brazzaville.

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