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Elaboration of Energy Flow Sankey Diagrams for the Central American Region to Improve National Energy Planning

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Abstract
This article addresses the development of energy flow diagrams for the Central American region, based on the World Energy Balance for the year 2019. The main objective of this work is to provide a diagnosis of the efficiency of the energy systems, as well as the components that integrate them, which help to identify the improvement areas for the reduction of energy consumption. The development of the energy flow diagrams follows a model stablished by the International Energy Agency, divided in: primary energy resources, conversion technologies, and sectors of demand. In addition to the model stated before, energy flow diagrams shown in this article contain energy services and energy losses, calculated through the efficiencies found for each sector of demand. Six energy flow diagrams were developed to represent the energetic outlook of the region in regards to energy efficiency, primary energy resource consumption, and final energy consumption by the sectors of demand, as well as the estimation of greenhouse gases (GHG) emissions. This work can serve as a guide for energy planning, by tracking the energy flows to reduce energy losses and CO2 emissions by improving the low efficiency areas.

Keywords: Energy Flow, Sankey Diagrams, Central America, Energy Planning.

Introduction

Energy systems can be considered as a tool for the development of a country or region, due to the necessity of different forms of energy to improve economy and life quality. The Economic Commission for Latin America and the Caribbean (ECLAC, CEPAL in Spanish) states that for 2010, the population of Central America was near 43 million people, and for 2075, the number will increase to 73 million people around the region [1]. It is the responsibility of energy planning entities, through energy systems of each country, to assure the supply for the increasing demand, seeking to implement efficient and low-cost technologies to meet this objective through an effective energy planning.

Global warming and climate change have affected the Central American region with natural disasters such as floods, droughts, hurricanes, and rising sea levels, becoming the most vulnerable region worldwide according to the director of the Instituto InterAmericano para la Investigación del Cambio (Inter-American Institute of Investigation for Change, IAI), Marcos Regis Da Silva [2]. With the rising problematic of the climate change, energy entities that manage energy systems must consider renewable alternatives to supply the countries´ demand as well as the increase of efficiencies for the sectors of demand to reduce the levels of energy consumption, with the purpose of decreasing the quantity of CO2 emissions and achieving a low-carbon region that contributes with the combat of global warming.

Various articles have developed an energy flow analysis to do a diagnosis of an energy system. [3] Analyzed the feasibility of a low-carbon society in Japan through the development of an energy flow, carbon flow, and cash flow for the year 2015. This work was the main reference for the development of our article. [4] developed a World Energy Balance that includes an energy Sankey diagram for each country in the balance. These diagrams show the energy flow, from primary energy resource, conversion, and final energy consumption or demand. [5] developed an energy flow analysis in a paper carton manufacturing unit in India to quantify the energy-saving potential by implementing energy conservation technologies. [6] developed a prediction of the primary energy resource flow for the energy sector of Czech Republic for the year

2040, and showed how a new energy policy implemented by the government can affect the stability of the power grid of the surrounding countries that import electricity from Czech Republic. [7] developed Sankey diagrams to track the energy structure, conversions, efficiencies, and final consumption, as well as calculating the number of CO2 emissions by China´s energy system for the year 2015.

The purpose of this article is to estimate the efficiency for each sector of demand that will help estimate the total efficiency of each country energy systems. These efficiencies will be represented through energy flow diagrams, which will help to identify the most demanded primary energy resources, the conversion technologies associated to these resources, and the sectors of final demand. The identification of these parameters can work as a tool to understand the actual outlook of each country and the region as a whole, and guide energy entities to make decisions that help to improve energy efficiency in the sectors of demand, as well as a reduction of the dependence of the region to non-renewable primary energy resources.

This article is made by five chapters. The first chapter is the approach to the problem, where the problem is defined, as well as the objectives expected to accomplish with the actual outlook. The second chapter is the theoretical framework, where all the energy systems´ terms such as: primary energy resource, conversion technology, efficiencies, demand, and energy planning are explained to have a better comprehension of the energy systems of Central America. The third chapter includes the article methodology, as well as the dependent and independent variables taken into account for the article. The fourth chapter presents the results and the analysis made for these results based on the objectives sought to be met. Finally, the fifth chapter presents the conclusions and recommendations provided for future articles made related to the topic adressed in this investigation.

Data and Methodology

The first step for the development of energy flow diagrams is to gather the necessary information of every process involved in an energy system. Energy systems data will be gathered from the World Energy Balance (WEB) for the year 2019, elaborated by the International Energy Agency (IEA). According to the World Energy Balance (WEB) Documentation, the main source for the data gathered in the energy balances for Central American countries proceeded form the United Nations Statistics Division Energy Statistics database. This energy balance offers the data for supply, transformation processes, energy industry own use and losses, and final consumption needed to develop the energy flow diagrams for the countries analyzed. To allow the users to stablish a relation between every energy usage throughout the energy flow diagram, it is necessary that the entire system is presented under the same type of units. The International Energy Agency (IEA) facilitate the unit conversion enabled for every energy process, which can be expressed in: ktoe (thousand tons of oil equivalent), TJ (Terajoules) or GWh (GigaWatt per hour). For this article it will be used the unit of Petajoules, which is equivalent to 1,000 Terajoules or 0.2778 Terawatt hour. (IEA 2020).

Structure of an Energy Flow Diagram

Figure 1 shows the structure used in this article for an energy flow diagram, which will be divided in 4 columns. Column 1 will represent the primary energy resources that feed the energy systems. Column 2 will represent the conversion sector, integrated by the electricity sector of each country. Column 3 will represent the different sector of demand, integrated by the transportation sector, the industrial sector, and the residential/commercial sector. Column 4 will represent the efficiency of the energy systems, integrated by the rejected energy, energy service, and other forms of energy which are not taken into account inside the energy flow diagrams such as stock changes, statistical differences, non-energy use, own use, bunkers, exports, and electricity inputs.

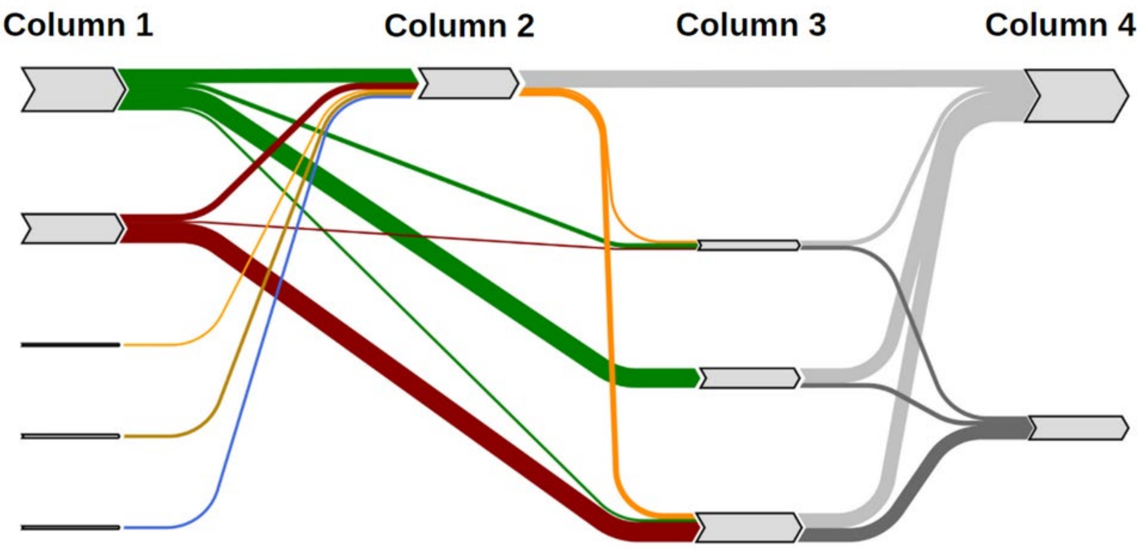


Figure 1: Example of an Energy Flow Diagram

Calculation of efficiencies

To determine the total amounts of used and non-used energy for every country analyzed in this article, it is necessary to calculate the efficiencies associated to each sector located on the final energy consumption column, given that the energy balances from the International Energy Agency (IEA) only calculate the losses for the two previous columns (primary energy resources and conversion technology shown in figure 1). For the calculation of these efficiencies the sectors were divided into the three main types: transportation, residential/commercial, and industrial.

The European Parliamentary Article Service (EPRS) define energy efficiency as "the ratio of output of performance, service, goods or energy, to input of energy." [8]. to calculate the efficiency of the energy system, it was used the following equation (1).

$$Efficiency\ [\%] = Total\ Energy\ Used\ /\ \sum Primary\ Energy\ Resources \times 100 \quad (1)$$

Transportation sector efficiency

To calculate the efficiency associated to the transportation sector, it was necessary to look for the national vehicle inventory and analyze the types of vehicles in circulation for each country, to later classify them by the type of engines each car type included. Tables 1-6 show the description of the types of vehicles in circulation, as well as the type of engine that each vehicle uses.

Efficiencies of the Transportation Sector

VEHICLE	*ENGINE*	*EL SALVADOR*	*HONDURAS*	*GUATEMALA*	*NICARAGUA*	*COSTA RICA*	*PANAMA*
Car	Gasoline 4 Strokes	14.77%[1]	14.77%[1]	14.77%[1]	14.77%[1]	14.77%[1]	14.77%[1]
Motorcycle	Gasoline 2 Strokes	14.77%[1]	14.77%[1]	14.77%[1]	14.77%[1]	14.77%[1]	N/A
Pickup	Diesel IC	30%[2]	30%[2]	30%[2]	30%[2]	N/A	30%[2]
Heavy Truck	Diesel IC	30%[2]	30%[2]	N/A	N/A	30%[2]	30%[2]
Light Truck	Diesel IC	30%[2]	30%[2]	N/A	N/A	30%[2]	30%[2]
Minibus	Diesel IC	30%[2]	N/A	30%[2]	30%[2]	N/A	N/A
Trailer	Diesel IC	30%[2]	30%[2]	30%[2]	30%[2]	N/A	N/A
Truck Head	Diesel IC	30%[2]	30%[2]	30%[2]	30%[2]	N/A	N/A
Bus	Diesel IC	30%[2]	30%[2]	30%[2]	30%[2]	30%[2]	30%[2]
Tricycle Motorcycle	Gasoline 2 Strokes	14.77%[1]	N/A	N/A	N/A	N/A	N/A

ATV	Gasoline 4 Strokes	14.77%[1]	N/A	N/A	N/A	N/A	N/A
Ambulance	Gasoline 4 Strokes	14.77%[1]	N/A	N/A	N/A	N/A	N/A
SUV	Gasoline 4 Strokes	N/A	14.77%[1]	N/A	14.77%[1]	N/A	14.77%[1]
Jeeps	Gasoline 4 Strokes	N/A	14.77%[1]	14.77%[1]	N/A	N/A	N/A
Vans	Gasoline 4 Strokes	N/A	N/A	14.77%[1]	14.77%[1]	N/A	14.77%[1]
Cranes	Diesel IC	N/A	N/A	30%[2]	N/A	N/A	N/A
Tractor	Diesel IC	N/A	N/A	N/A	30%[2]	N/A	N/A
Minivan	Gasoline 4 Strokes	N/A	N/A	N/A	N/A	N/A	14.77%[1]

Once the inventories were defined, based on other article works, an efficiency associated with each type of engine was stablished so an average could be made to define the average efficiency of transportation sector for each country analyzed.

Table 1: Vehicle Inventory of El Salvador

ITEM	***ENGINE***	***EFFICIENCY***
Car	Gasoline 4 Strokes	14.77%[1]
Motorcycle	Gasoline 2 Strokes	14.77%[1]
Pickup	Diesel Internal Combustion	30%[2]
Heavy Truck	Diesel Internal Combustion	30%[2]
Light Truck	Diesel Internal Combustion	30%[2]
Minibus	Diesel Internal Combustion	30%[2]
Trailer	Diesel Internal Combustion	30%[2]
Truck Head	Diesel Internal Combustion	30%[2]
Bus	Diesel Internal Combustion	30%[2]
Tricycle Motorcycle	Gasoline 2 Strokes	14.77%[1]
ATV	Gasoline 4 Strokes	14.77%[1]
Ambulance	Gasoline 4 Strokes	14.77%[1]

Table 2: Vehicle Inventory of Honduras

ITEM	***ENGINE***	***EFFICIENCY***
Pickup & Jeep	Diesel Internal Combustion	30%[2]
Car	Gasoline 4 Strokes	14.77%[1]
Motorcycle	Gasoline 2 Strokes	14.77%[1]
SUV	Gasoline 4 Strokes	14.77%[1]
Truck	Diesel Internal Combustion	30%[2]
Bus	Diesel Internal Combustion	30%[2]
Heavy Trucks	Diesel Internal Combustion	30%[2]
Other Categories	Gasoline 4 Strokes	14.77%[1]

Table 3: Vehicle Inventory of Guatemala

ITEM	*ENGINE*	*EFFICIENCY*
Motorcycle	Gasoline 2 Strokes	14.77%[1]
Car	Gasoline 4 Strokes	14.77%[1]
Pick Up	Diesel Internal Combustion	30%[2]
Vans	Diesel Internal Combustion	30%[2]
Truck Heads	Diesel Internal Combustion	30%[2]
Buses	Diesel Internal Combustion	30%[2]
Boxcars	Diesel Internal Combustion	30%[2]
Jeeps	Gasoline 4 Strokes	14.77%[1]
Trailers	Diesel Internal Combustion	30%[2]
Cranes	Diesel Internal Combustion	30%[2]
Trucks	Diesel Internal Combustion	30%[2]

Table 4: Vehicle Inventory of Nicaragua

ITEM	*ENGINE*	*EFFICIENCY*
Bus	Diesel Internal Combustion	30%[2]
Car	Gasoline 4 Strokes	14.77%[1]
Minibus	Diesel Internal Combustion	30%[2]
Motorcycle	Gasoline 2 Strokes	14.77%[1]
Pick Up	Diesel Internal Combustion	30%[2]
Truck Head	Diesel Internal Combustion	30%[2]
Truck	Diesel Internal Combustion	30%[2]
SUV	Gasoline 4 Strokes	14.77%[1]
Van	Gasoline 4 Strokes	14.77%[1]
Trailer	Diesel Internal Combustion	30%[2]
Others	Gasoline 4 Strokes	14.77%[1]
Tractor	Diesel Internal Combustion	30%[2]

Table 5: Vehicle Inventory of Costa Rica

ITEM	*ENGINE*	*EFFICIENCY*
Car	Gasoline 4 Strokes	14.77%[1]
Bus	Diesel Internal Combustion	30%[2]
Truck ≤ 3,500 kg	Diesel Internal Combustion	30%[2]
Taxis	Gasoline 4 Strokes	14.77%[1]
Trucks ≥ 3,500 kg	Diesel Internal Combustion	30%[2]
Special Equipment	Diesel Internal Combustion	30%[2]
Motorcycle	Gasoline 2 Strokes	14.77%[1]
Others	Gasoline 4 Strokes	14.77%[1]

Table 6 Vehicle Inventory of Panama

ITEM	*ENGINE*	*EFFICIENCY*
Car	Gasoline 4 Strokes	14.77%[1]
Luxury Car	Gasoline 4 Strokes	14.77%[1]
SUV	Gasoline 4 Strokes	14.77%[1]
Minivans	Gasoline 4 Strokes	14.77%[1]
Vans	Diesel Internal Combustion	30%[2]
Pick Ups	Diesel Internal Combustion	30%[2]
Buses	Diesel Internal Combustion	30%[2]
Trucks	Diesel Internal Combustion	30%[2]
Others	Gasoline 2 Strokes	14.77%[1]

Residential/commercial sector efficiency

For the calculation of the residential/commercial sector a similar process as the transportation sector was followed. In this sector, it was taken into account the technologies used for cooking in the region, as well as a model created with the most used appliances based on data from national entities. Table 7 shows a description of the items taken into account for the models made for each country related the residential/commercial sector.

Table 7: Residential/Commercial Model for Central America

COOKING	*EFFICIENCY*
Wood	7% [1]
Propane Gas	49.7% [2]
Electricity	29.7% [3]
Others (Waste)	9% [4]
APPLIANCES	
Refrigerator	65% [5]
Washing Machine	55% [5]
Drying Machine	40% [5]
Iron	42.8% [6]
Air Conditioning	75% [5]
Laptop	65.12% [5]
Desktop	58.54% [5]
TV	68% [5]
Roof Fan	67.5% [7]
LED Light bulb	67.05% [5]
Halogen Light bulb	21% [5]
Incandescent Light bulb	14.77% [5]
Chargers (Cellphone, Computers, …)	80% [5]

Once the model was defined, as well as in transportation, an efficiency was stablished to each item to make an average efficiency for the residential/commercial sector of each country analyzed.

Industrial sector efficiency

The process for the calculation of the efficiency of industrial sector was similar to the procedure for transportation sector. An inventory was made, bases on the results from other article works, to determine the industrial sectors of each country and later classify them by the type of equipment used; for example, diesel or electric motors. Tables 8-13 show a description of the items taken into account for the industrial sector. Big Table 2

Efficiencies of the Industrial Sector

INDUSTRY	*ENGINE*	*EL SALVADOR*	*HONDURAS*	*GUATEMALA*	*NICARAGUA*	*COSTA RICA*	*PANAMA*
Textile	Electric	85% [1]	85% [1]	85% [1]	85% [1]	85% [1]	85% [1]
Drinks	Electric	85% [1]	N/A	N/A	N/A	N/A	N/A
Plastics	Electric	85% [1]	N/A	85% [1]	N/A	N/A	N/A
Pharmacist	Electric	85% [1]	N/A	85% [1]	N/A	85% [1]	85% [1]
Construction	Diesel IC	30%[2]	30%[2]	N/A	30%[2]	N/A	30%[2]
Metallurgy	Electric	85% [1]	N/A	85% [1]	85% [1]	85% [1]	85% [1]
Cardboard and Paper	Electric	85% [1]	N/A	N/A	N/A	N/A	N/A
Mining	Diesel IC	N/A	30%[2]	30%[2]	30%[2]	N/A	30%[2]
Fishing	Diesel IC	N/A	30%[2]	N/A	N/A	N/A	N/A
Agriculture	Diesel IC	N/A	30%[2]	30%[2]	30%[2]	N/A	N/A
Agroindustry	Diesel IC	30%[2]	30%[2]	N/A	N/A	30%[2]	30%[2]
Pasteurized	Electric	N/A	85% [1]	85% [1]	N/A	N/A	N/A
Meat	Electric	N/A	N/A	85% [1]	N/A	N/A	N/A
Logistics	Diesel IC	N/A	N/A	30%[2]	N/A	N/A	30%[2]
Chemicals	Electric	N/A	N/A	N/A	85% [1]	85% [1]	85% [1]
Wood	Diesel IC	N/A	30%[2]	N/A	30%[2]	N/A	N/A
Tourism	Diesel IC	N/A	N/A	N/A	N/A	30%[2]	N/A
Technology	Electric	N/A	N/A	N/A	N/A	85% [1]	N/A

Table 8: Industrial Sector Efficiency of El Salvador

INDUSTRY	*ENGINE*	*EFFICIENCY*
Textile	Electric	85% [1]
Food	Diesel Internal Combustion	30% [2]
Drinks	Electric	85% [1]
Plastics	Electric	85% [1]
Pharmacist Products	Electric	85% [1]
Construction	Diesel Internal Combustion	30% [2]
Metallurgy	Electric	85% [1]
Cardboard and Paper	Electric	85% [1]

Table 9: Industrial Sector Efficiency of Honduras

INDUSTRY	*ENGINE*	*EFFICIENCY*
Mining	Diesel Internal Combustion	30%[2]
Forest	Diesel Internal Combustion	30%[2]
Fishing	Diesel Internal Combustion	30%[2]
Agriculture	Diesel Internal Combustion	30%[2]
Agroindustry	Diesel Internal Combustion	30%[2]
Construction	Diesel Internal Combustion	30%[2]
Pasteurized	Electric	85%[1]
Textile	Electric	85%[1]

Table 10: Industrial Sector Efficiency of Guatemala

INDUSTRY	*ENGINE*	*EFFICIENCY*
Agriculture	Diesel Internal Combustion	30% [2]
Pharmacist Products	Electric	85% [1]
Pasteurized	Electric	85% [1]
Metallurgy	Electric	85% [1]
Meat	Electric	85% [1]
Textile	Electric	85% [1]
Plastics	Electric	85% [1]
Mining	Diesel Internal Combustion	30% [2]
Logistics	Diesel Internal Combustion	30% [2]

Table 11: Industrial Sector Efficiency of Nicaragua

INDUSTRY	*ENGINE*	*EFFICIENCY*
Agriculture	Diesel Internal Combustion	30%[2]
Chemicals	Electric	85%[1]
Metallurgy	Electric	85%[1]
Wood	Diesel Internal Combustion	30%[2]
Mining	Diesel Internal Combustion	30%[2]
Construction	Diesel Internal Combustion	30%[2]
Textile	Electric	85%[1]

Table 12: Industrial Sector Efficiency of Costa Rica

INDUSTRY	*ENGINE*	*EFFICIENCY*
Textile	Electric	85%[1]
Agroindustrial	Diesel Internal Combustion	30%[2]
Tourism	Diesel Internal Combustion	30%[2]
Metallurgy	Electric	85%[1]
Electric Materials	Electric	85%[1]
Chemicals	Electric	85%[1]
Pharmacist Products	Electric	85%[1]
Technology	Electric	85%[1]

Table 13 Industrial Sector Efficiency of Panama

COUNTRY	*TRANSPORTATION*	*RESIDENTIAL/COMMERCIAL*	*INDUSTRIAL*
El Salvador	24.92%	47.09%	71.25%
Honduras	25.24%	48.12%	46.00%
Guatemala	25.56%	48.05%	66.67%
Nicaragua	24.92%	47.36%	53.57%
Costa Rica	23.47%	52.44%	71.25%
Panama	22.39%	50.34%	57.50%

Once the types of industries and the equipment used to develop the industrial activities were defined, a calculation was made to obtain the average efficiency for the industrial sectors of each country.

Greenhouse Gases (GHG) Emissions

For the calculations of Greenhouse Gases (GHG) emissions, it was used a tool developed by the Greenhouse Gas Protocol, named The GHG Emissions Calculation Tool. This tool is an Excel spreadsheet which calculates an estimate of emissions of a certain input. For this article, the tool was used to calculate the emissions caused by the non-renewable sources of energy such as oil, coal, biomass, and natural gas, based on the emission factors provided by the database of the tool.

Results and Discussion

In this chapter will be presented the results from the energy flow diagrams obtained through the data gathered from de World Energy Balance (WEB) for the year 2019, as well as the technical analysis developed from these results, with the purpose of answering the article questions.

The results will be divided in three sections, where the first section will be the calculations of the efficiencies for the transportation, residential/commercial and industrial sectors of demand. The second section will be integrated by the energy flow diagrams for the countries analyzed in this article. Finally, the last section will be the calculations of the Greenhouse Gases (GHG) emissions for each country.

Average Efficiency for the Transportation Sector of Demand

To estimate the efficiency of the transportation sector of each country, an average was made based on the vehicle inventory for each country, relating the types of vehicles with the efficiency associated with its engine. Table 14 shows the results of the average efficiency obtained, where the efficiency values go between 22% to 25%, giving the region an average of 24% in their transportation sector of demand.

Table 14: Average Efficiency of the Sectors of Demand

COUNTRY	*EFFICIENCY*
El Salvador	47.09%
Honduras	48.12%
Guatemala	48.05%
Nicaragua	47.36%
Costa Rica	52.44%

Average efficiency for the residential/commercial sector of demand

To estimate the efficiency of the residential/commercial sector, an average was made based on household models created with information from governmental entities of each country which describe the most used appliances and cooking devices for each country. Table 15 shows the results of the average efficiency obtained based on each item taken into account into the countries' models, where the efficiency values go between 47% to 52%, with an average efficiency of the region of 49% in their residential/commercial sector of demand.

Table 15: Average Efficiency of the Residential/Commercial Sector

SECTOR	*ENGINE*	*EFFICIENCY*
Mining	Diesel Internal Combustion	30%[2]
Textile	Electric	85%[1]
Construction	Diesel Internal Combustion	30%[2]
Agroindustrial	Diesel Internal Combustion	30%[2]
Metallurgy	Electric	85%[1]
Chemicals	Electric	85%[1]
Pharmacist Products	Electric	85%[1]
Logistics	Diesel Internal Combustion	30%[2]

Average efficiency for the industrial sector of demand

To estimate the efficiency of the industrial sector, an average was made based on the different type of industries developed on each country analyzed, establishing a relationship between the activity made, and the equipment needed to develop such activity. Table 16 shows the results of the average efficiency obtained, where the values go from 46% to 71%, with an average efficiency for the region of 61% in the industrial sector of demand.

Table 16: Average Efficiency of the Industrial Sector

COUNTRY	*EMISSIONS (MT OF CO_2)*
El Salvador	7,035.6
Honduras	9,352.2
Guatemala	24,382.8
Nicaragua	6,146.6
Costa Rica	8,403.2
Panama	28,862.15

Energy flow diagram of Guatemala

Figure 2 shows the energy flow of Guatemala. The total amount of primary energy resources that feed the energy system is equal to 675.2 or 187.56 TWh, becoming the biggest energy system of the region. In Guatemala, the non-renewable offer reaches 296.7 PJ representing about 44% of the total primary offer. Oil and coal have a direct impact on transportation and electric sectors with 196.3 PJ destined for these two sectors.

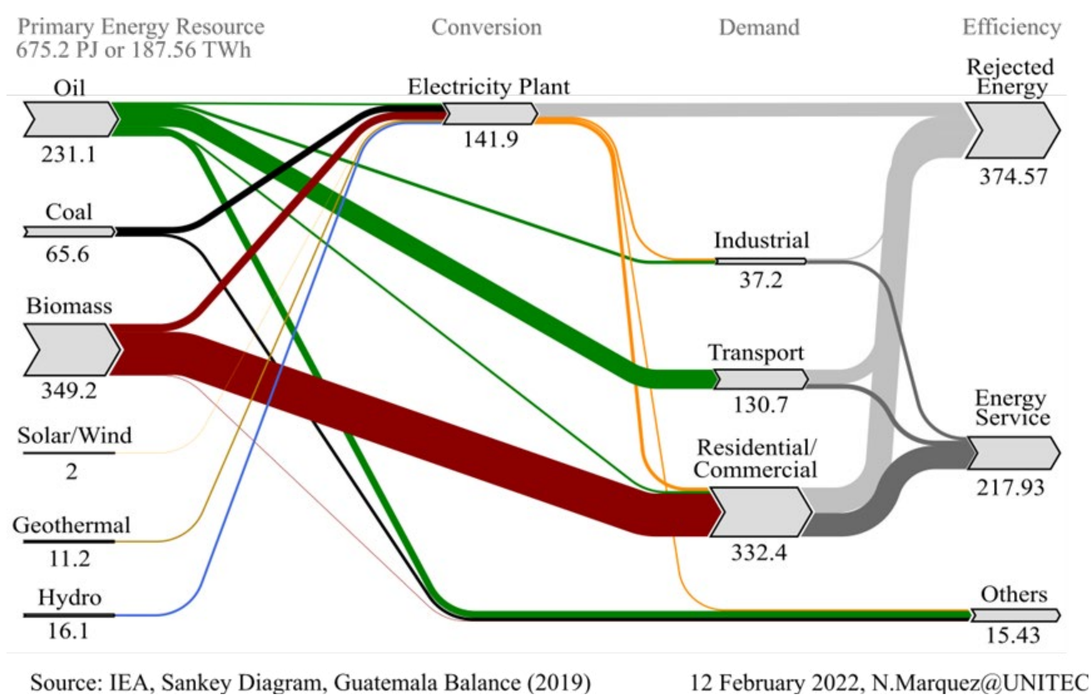


Figure 2: Energy Flow Diagram of Guatemala

On the other hand, renewable offer for primary energy resources reach 378.5 PJ, representing about 56% of the total primary energy offer, nevertheless, only 82.7 PJ are destined for electricity production, given that 292.2 PJ of biomass in form of woody biomass are used in households as fuel for heat. This value is an alarming indicator due to the consequences of the overuse of wood as a fuel in households, such as deforestation and health issues.

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 141.9 PJ that come from oil, coal, biomass, geothermal, solar/wind, and hydro. The electric sector in Guatemala has an inclination towards non-renewable, powered by coal in thermal plants with 65.6 PJ, representing 46% of the total electric generation input. According to the World Energy Balance (WEB), the electricity losses in Guatemala for 2019 were equivalent to 92.2 PJ.

For the demand column, the energy consumption is divided in 3 sectors. Industrial sector has a consumption of 37.2 PJ, supplied by electricity and oil; followed by transportation sector with a consumption of 130.7 PJ. Finally, the residential/commercial sector has a consumption of 332.4 PJ, supplied in its majority with woody biomass, becoming the most pollutant sector. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 12.4 PJ in industrial, 97.3 PJ in transportation, and 172.7 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total rejected energy is equal to 374.57 PJ, as well as the energy service, with an equivalent of 217.93 PJ, which can be used to determine the total efficiency of Guatemala´s energy system with a value of 32%.

Energy flow diagram of Honduras

Figure 3 shows the energy flow of Honduras. The total amount of primary energy resources that feed the energy system is equal to 258.98 PJ or 71.94 TWh, where the non-renewable offer reaches 144.812 PJ representing about 56% of the total primary offer. In Honduras the only non-renewable resource is oil, which is mainly used in transportation and electricity.

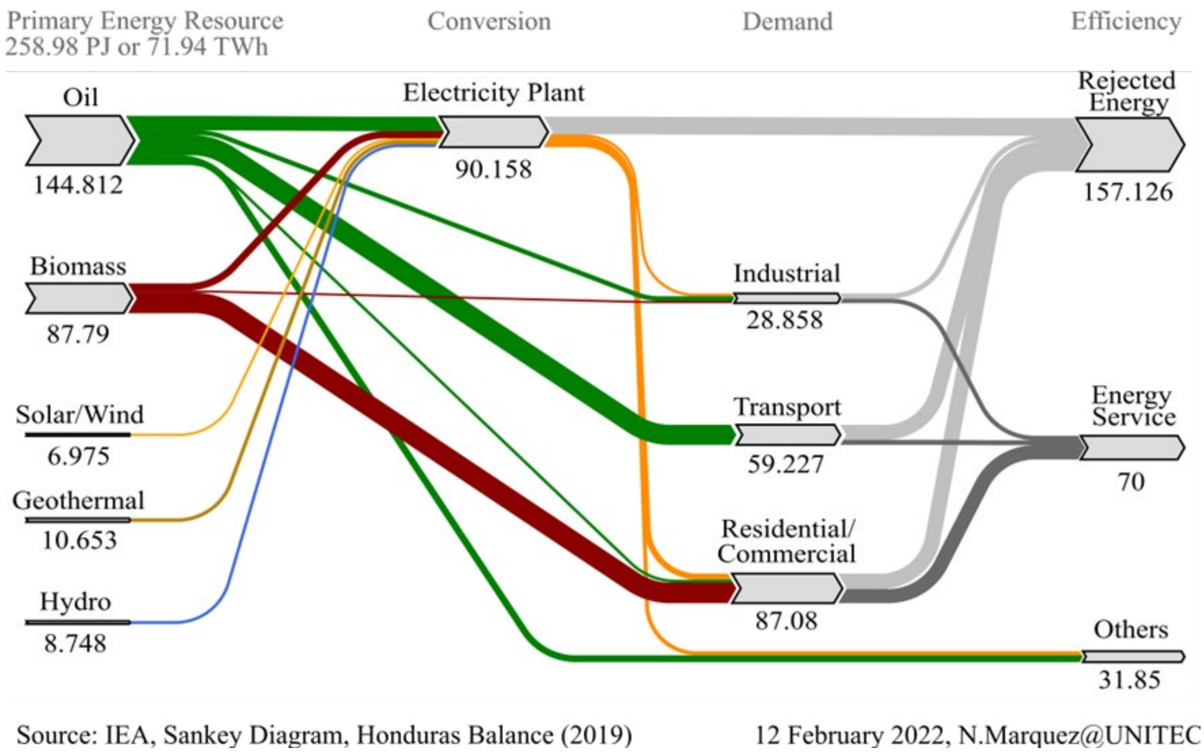


Figure 3: Energy Flow Diagram of Honduras

On the other hand, renewable offer for primary energy resources reach 114.16 PJ, representing about 44% of the total primary energy offer. Inside of the renewable primary energy offer, Honduras has pushed the generation through geothermal and hydro energy, representing 17% of the total renewable primary resources. The renewable energy offer is used for electricity production, nevertheless, biomass represents 53% of renewable energy offer given that 60.511 PJ are consumed in households in form of woody biomass as fuel for heat, becoming an alarming indicator.

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 90.16 PJ that come from oil, biomass, geothermal, solar/wind, and hydro. The electric sector in Honduras has an inclination towards non-renewable, powered by oil in thermal plants with 42.7 PJ, representing 47% of the total electric generation input. According to the World Energy Balance (WEB), the electricity losses in Honduras for 2019 were equivalent to 52.23 PJ.

For the demand column, the energy consumption is divided in 3 sectors. Industrial sector has a consumption of 28.58 PJ, supplied by electricity and oil; followed by transportation sector with a consumption of 59.227 PJ. Finally, the residential/commercial sector has a consumption of 87.1 PJ, supplied in its majority with woody biomass, becoming the most pollutant sector. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 15.44 PJ in industrial, 44.28 PJ in transportation, and 45.18 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total of the rejected energy is equal to 157.126 PJ, as well as the energy service with an equivalent of 70 PJ, which can be used to determine the total efficiency of Honduras´ energy system with a value of 27%.

Energy flow diagram of El Salvador

Figure 4 shows the energy flow of El Salvador. The total amount of primary energy resources that feed the energy system is equal to 194.82 PJ or 54.12 TWh, where the non-renewable resources offer reaches 112.6 PJ representing about 60% of the total primary offer. Oil and coal are mainly used to supply the industrial and transportation sectors, representing 66% of the total demand of non-renewable resources.

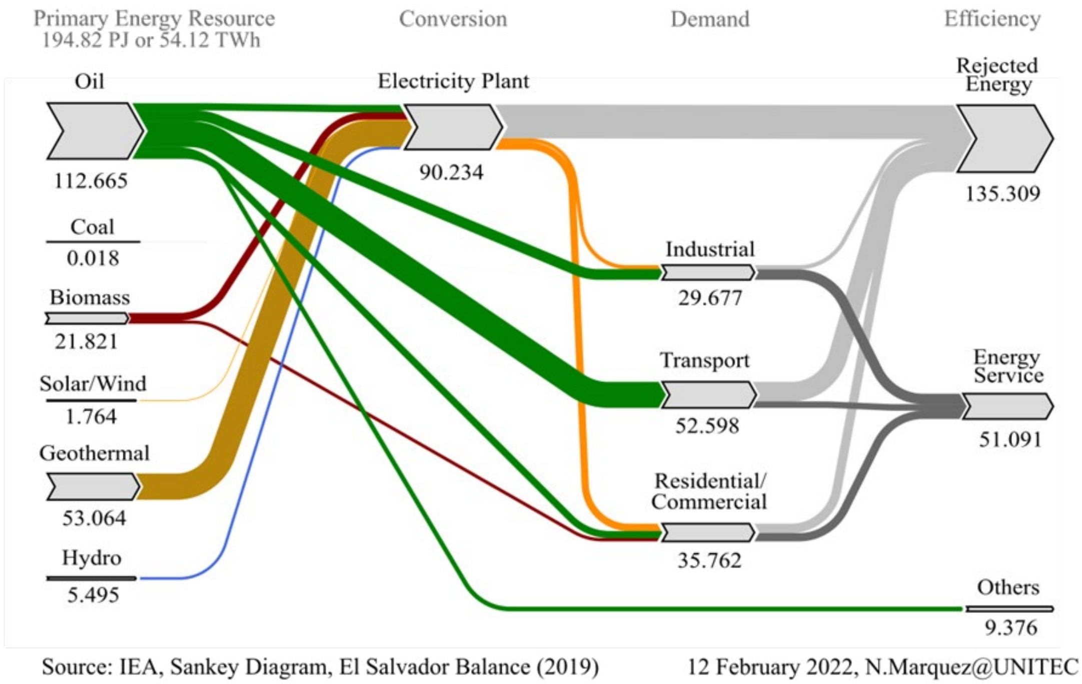


Figure 4: Energy Flow Diagram of El Salvador

On the other hand, renewable resources offer for primary energy resources reach 82.14 PJ, representing about 40% of the total primary energy offer. Inside of the renewable primary energy offer, El Salvador has pushed the generation through geothermal energy, representing 65% of the total renewable primary resources. The renewable offer is mainly used to create electricity, except for biomass, which has a percentage of 6 PJ destined to the residential/commercial sector due to the consumption of woody biomass as a fuel for heat, mainly used for cooking.

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 90.2 PJ that comes from oil, biomass, geothermal, solar/wind, and hydro. The electric sector in El Salvador has an inclination towards renewable resources, powered by geothermal energy with 53 PJ, representing 60% of the total electric generation input. According to the World Energy Balance (WEB), the electricity losses in El Salvador for 2019 were equivalent to 68.36 PJ.

For the demand column, the energy consumption is divided in three sectors. Industrial sector has a consumption of 29.7 PJ, supplied by electricity and oil; followed by transportation sector with a consumption of 52.3 PJ, supplied in its totality by oil, being the most pollutant sector. Finally, the residential/commercial sector has a consumption of 35.8 PJ, which is supplied by electricity, oil and biomass. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 8.5 PJ in industrial, 39.5 PJ in transportation, and 18.9 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total of the rejected energy is equal to 135.31 PJ, as well as the energy service with an equivalent of 51.1 PJ, which can be used to determine the total efficiency of El Salvador´s energy system with a value of 26%.

Energy flow diagram of Nicaragua

Figure 5 shows the energy flow of Nicaragua. The total amount of primary energy resources that feed the energy system is equal to 170.7 or 47.42 TWh, becoming the smallest energy system of the region. In Nicaragua, the non-renewable offer reaches 74.78 PJ representing about 43% of the total primary offer. Oil is the only non-renewable primary energy resource that integrates the Nicaraguan primary offer, mostly used in transportation with 29.97 PJ.

On the other hand, renewable offer for primary energy resources reach 95.92 PJ, representing about 56% of the total primary energy offer. Renewable resources in Nicaragua are used for electric generation, as well as biomass in households, with 44 PJ of woody biomass as fuel for heat.

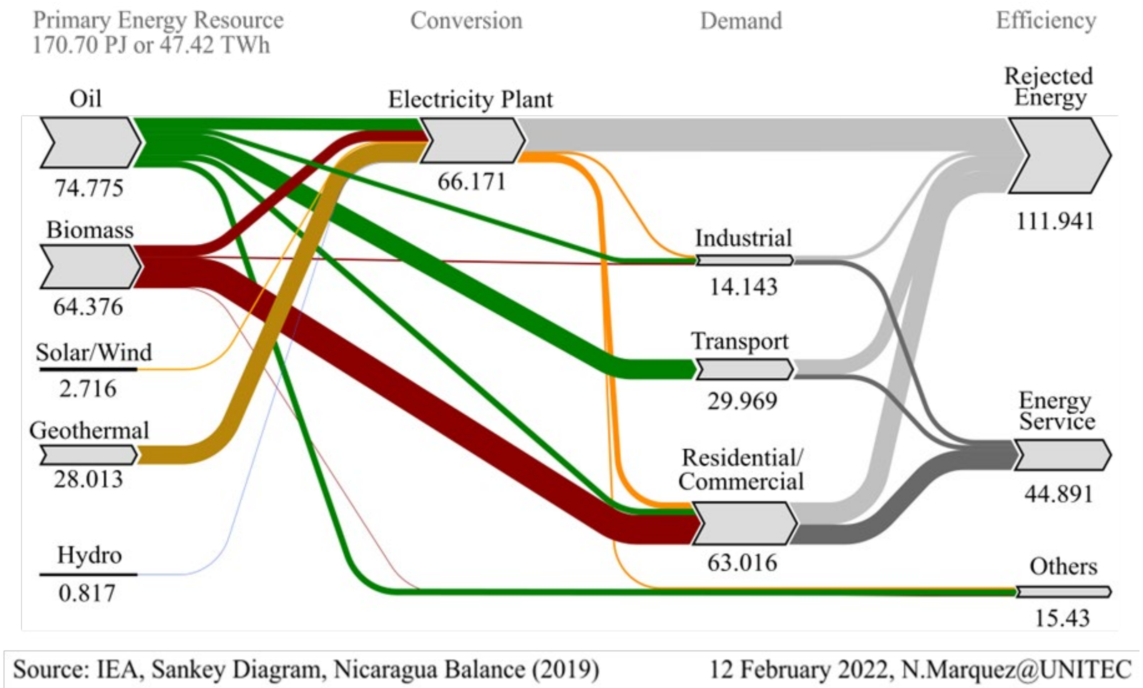


Figure 5: Energy Flow Diagram of Nicaragua

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 66.171 PJ that come from oil, biomass, geothermal, solar/wind, and hydro. The electric sector in Nicaragua has an inclination towards renewable resources, powered by geothermal energy with 28.013 PJ, representing 42% of the total electric generation input. According to the World Energy Balance (WEB), the electricity losses in Nicaragua for 2019 were equivalent to 49.704 PJ.

For the demand column, the energy consumption is divided in 3 sectors. Industrial sector has a consumption of 14.143 PJ, followed by transportation sector with a consumption of 29.969 PJ. Finally, the residential/commercial sector has a consumption of 63.016 PJ, supplied in its majority with woody biomass, becoming the most pollutant sector. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 6.567 PJ in industrial, 22.501 PJ in transportation, and 33.169 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total rejected energy is equal to 111.941 PJ, as well as the energy service, with an equivalent of 44.891 PJ, which can be used to determine the total efficiency of Nicaragua´s energy system with a value of 26%.

Tables 14-16

Energy flow diagram of Costa Rica

Figure 6 shows the energy flow of Costa Rica. The total amount of primary energy resources that feed the energy system is equal to 232.705 PJ or 64.64 TWh, where the non-renewable offer reaches 120.75 PJ representing about 52% of the total primary offer. The non-renewable offer of Costa Rica is principally occupied by oil, where 70% of it is used to supply the transportation sector.

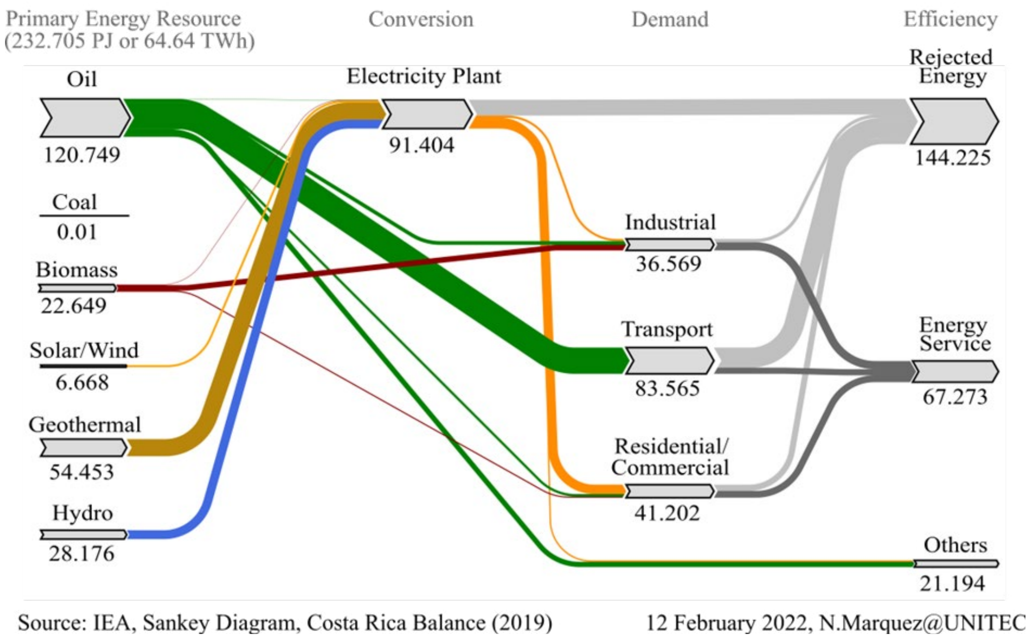


Figure 6: Energy Flow Diagram of Costa Rica

On the other hand, renewable offer for primary energy resources reach 111.95 PJ, representing about 48% of the total primary energy offer. Renewable resources in Costa Rica are used for electric generation, as well as biomass in households and in industry, with 44 PJ of woody biomass as fuel for heat and 17.787 as biofuels and waste.

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 91.404 PJ that come from oil, biomass, geothermal, solar/wind, and hydro. The electric sector in Costa Rica has an inclination towards renewable resources, powered by geothermal and hydro energy with 82.63 PJ, representing 90% of the total electric generation input. Costa Rica is the country of the region with less dependence on fossil fuels for their electric generation, with only 0.91 PJ destined to power stations. According to the World Energy Balance (WEB), the electricity losses in Costa Rica for 2019 were equivalent to 50.162 PJ.

For the demand, the energy consumption is divided in 3 sectors. Industrial sector has a consumption of 36.569 PJ, followed by transportation sector with a consumption of 83.565 PJ, supplied by oil, becoming the most pollutant sector. Finally, the residential/commercial sector has a consumption of 41.202 PJ, supplied mainly by electricity. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 10.514 PJ in industrial, 63.952 PJ in transportation, and 19.597 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total of the rejected energy is equal to 144.225 PJ, as well as the energy service, with an equivalent of 67.273 PJ, which can be used to determine the total efficiency of Costa Rica's energy system with a value of 29%.

Energy flow diagram of Panama

Figure 7 shows the energy flow of Panama. The total amount of primary energy resources that feed the energy system is equal to 201.407 PJ or 55.946 TWh, where the non-renewable offer reaches 166.165 PJ representing about 83% of the total primary offer, the biggest in the region. The non-renewable offer of Panama is mainly occupied by oil, where 23% of it is used to supply the transportation sector and 62% for bunkers. Also, Panama is the only country of the region which has natural gas as part of their primary energy resources.

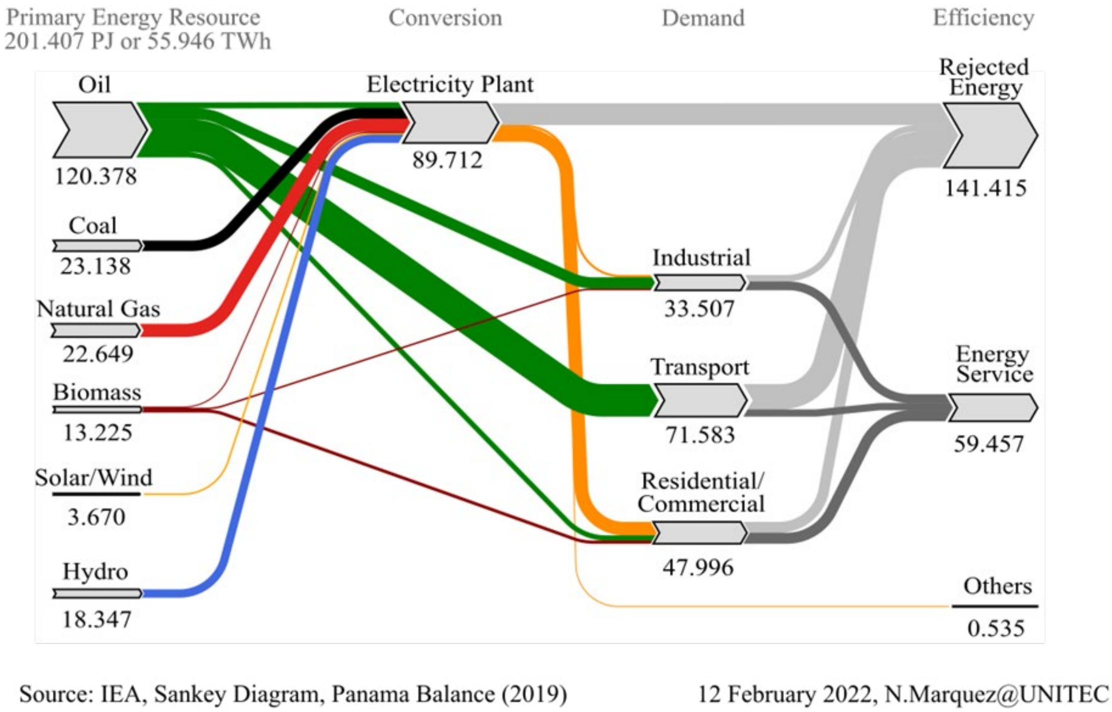


Figure 7: Energy Flow Diagram of Panama

On the other hand, renewable offer for primary energy resources reach 35.242 PJ, representing about 17% of the total primary energy offer, the lowest in the region. Renewable resources in Panama are used for electric generation, as well as biomass in households.

For the conversion column, the International Energy Agency (IEA) focuses on electricity plant, which has an input of 89.712 PJ that come from oil, coal, natural gas, biomass, solar/wind, and hydro. The electric sector in Panama has an inclination towards non-renewable resources, powered by natural gas and coal with 52.01 PJ, representing 58% of the total electric generation input. According to the World Energy Balance (WEB), the electricity losses in Panama for 2019 were equivalent to 47.785 PJ.

For the demand, the energy consumption is divided in 3 sectors. Industrial sector has a consumption of 33.507 PJ, followed by transportation sector with a consumption of 71.583 PJ, supplied by oil, becoming the most pollutant sector. Finally, the residential/commercial sector has a consumption of 47.996 PJ, supplied mainly by electricity. Based on the efficiencies calculated and presented on Tables 14-16, the energy losses in these sectors are equivalent to 14.241 PJ in industrial, 55.556 PJ in transportation, and 23.833 PJ in residential/commercial sector. By adding all of these energy losses including electric losses, the total of the rejected energy is equal to 141.415 PJ, as well as the energy service, with an equivalent of 59.457 PJ, which can be used to determine the total efficiency of Panama´s energy system with a value of 30%.

Total emissions per country

Given that the emission factor used from the GHG Emission Calculation Tool was in units of kgCO2/kWh, it was necessary to convert the number of energy consumed by each country from Petajoules to its equivalent to Terawatt hour, to later calculate the number of emissions of Greenhouse gases (GHG) emitted by each country multiplying the energy consumed in Terawatt hour with the emission factor granted by the tool. The emission factor used to stablish the relation between the amount of energy consumed and the emissions related to that amount of energy was of 0.13 kg CO2/kWh, giving a result in kilograms which were later converted into tons.

Table 17 shows the results obtained through the calculations, where Guatemala is the leading country of the region in the amount of emissions of these gases, due to the great consumption of woody biomass in their residential sector, followed by Panama and their consumption of hydrocarbons due to their logistic industry, with a great consumption of oil in bunkers. For the rest of the countries, the amount of emission is similar, locating inside a range between 6,000 to 9,000 tons of CO2 per country, coming mainly from the transportation sector due to oil and the residential/commercial sector due to woody biomass.

Table 17: Total CO2 Emissions per Country

COUNTRY	*EFFICIENCY*
El Salvador	71.25%
Honduras	46.00%
Guatemala	66.67%
Nicaragua	53.57%
Costa Rica	71.25%
Panama	57.50%

These results can work as an indicator for energetic entities to develop a better energy planning and creating energy efficiency policies to reduce the GHG emissions, especially in the main pollutant sectors stated before.

General outlook of the Central American region

This section presents a summary of the energetic outlook of the region as a whole, with the purpose of showing the total amount of primary energy resources consumed, an average efficiency for each sector of demand, and the amounts of rejected energy and energy service of the region.

Figure 8 shows the total consumption of primary energy resources for the region, equivalent to 1,733.82 PJ, where the most consumed primary resource is oil, with an amount of 803.41 PJ, followed by biomass with 559.061 PJ and geothermal with 157.383. Given the dependence on non-renewable primary energy resources, the actual outlook for the region leaves a room for improvement for new efficient and renewable technologies.

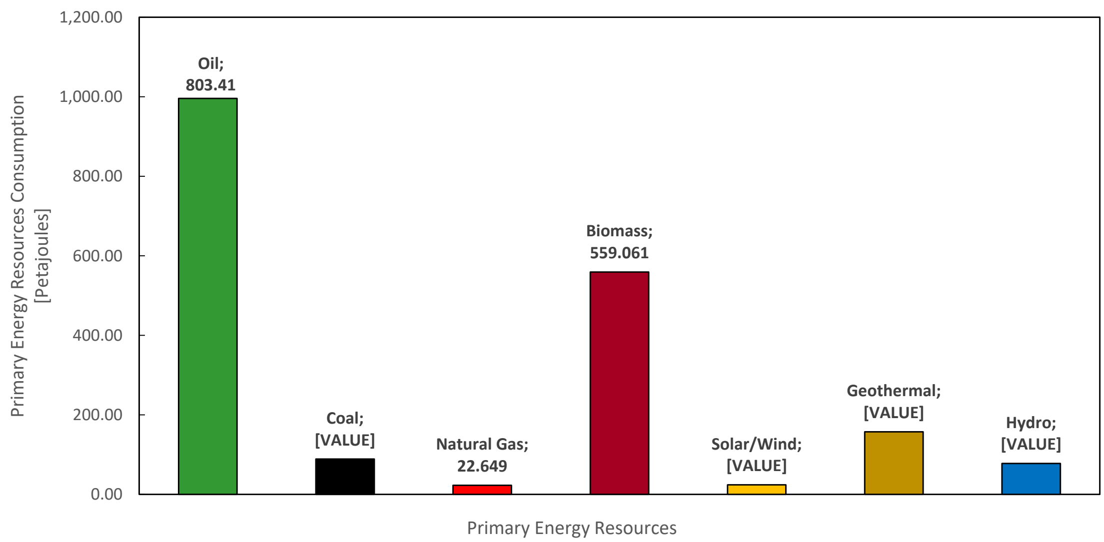


Figure 8: **Primary Energy Offer for Central America, 2019**

Figure 9 shows the general outlook for the demand sector of all the Central American region, where the biggest demand comes from the residential/commercial sector, followed by the transportation sector, and finally, by the industrial sector. The high demand produced by the residential/commercial sector explains the high demand of biomass as a primary energy resource used in this sector as a principal source of heat, mainly for cooking; as well as the high demand of oil to satisfy the demand of the transportation sector given that there are no other alternatives such as electric vehicles or public transportation infrastructure. These results can work as an indicator for energy planning entities to develop a plan to supply these demands in an efficient and renewable way.

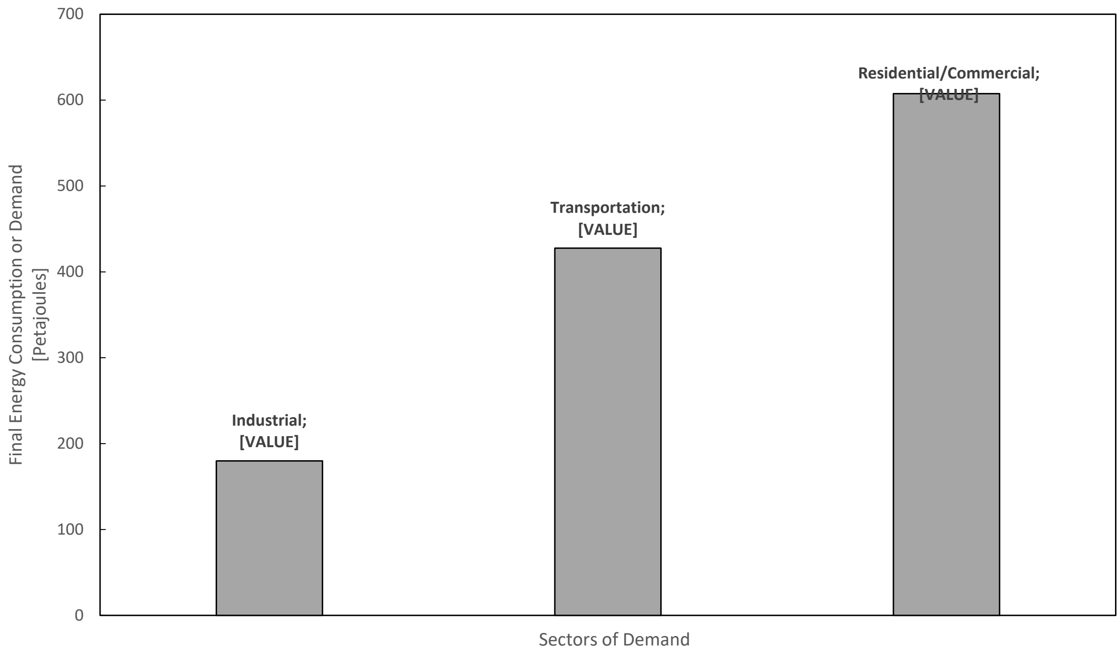


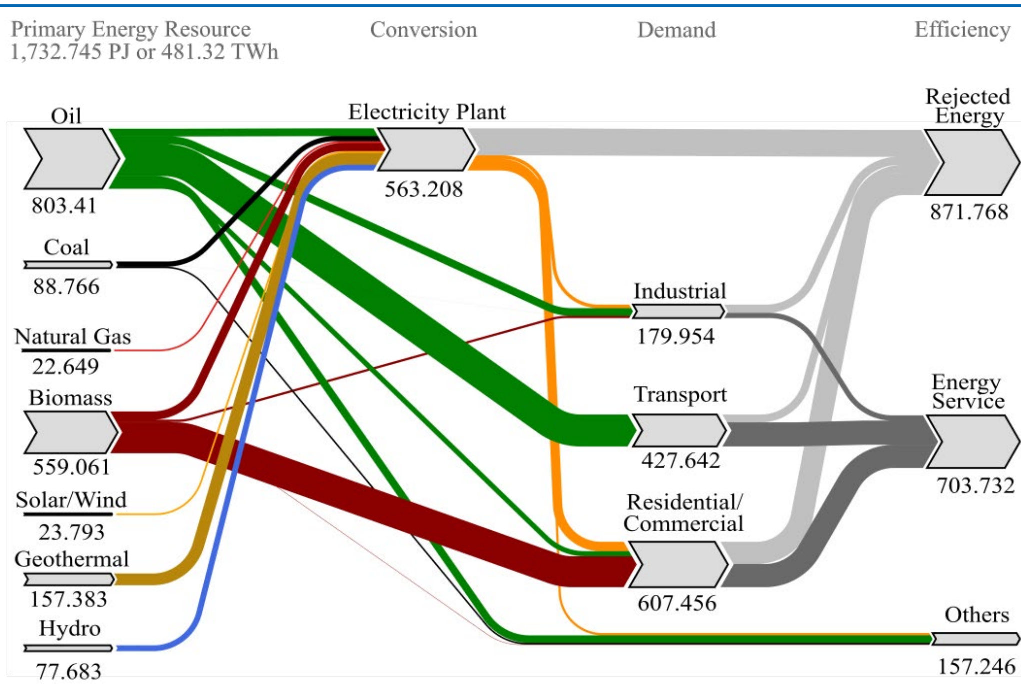
Figure 9: Final Energy Consumption for Central America, 2019

For the efficiency of the region, Table 18 shows the results of the calculations made based on a weighted average with the efficiencies shown in Tables 14-16 for each sector, giving as a result a total efficiency for each sector of demand, which helps calculate the amount of useful energy, as well as the rejected energy.

Table 18: Total CO_2 Emissions per Country

COUNTRY	*ENERGY SERVICE [PJ]*	*EFFICIENCY*
Transportation	104.57	24.42%
Residential/Commercial	291.176	48.90%
Industrial	112.12	61.04%

For the total efficiency of the region, based on the total average efficiencies calculated, it can be determined that total rejected energy in the region is equal to 1,064.58 PJ. On the other hand, the energy service is equal to 510.64 PJ, which can be used to calculate the total efficiency of the region by stablishing a relation between the total primary energy resource offer and the amount of energy service, which gives a total efficiency of the region of 27%. Figure 10 shows the energy flow of Central America, summarizing the results exposed before in this section.



Source: IEA, Sankey Diagram, Central American Balance (2019) 12 February 2022, N.Marquez@UNITEC

Figure 10: Energy Flow Diagram of Central America

Conclusions

This article was based in the development of energy flow diagrams that helped to create a technical analysis of the energetic outlook for the Central American region for the year 2019, as well as showing the improvement areas of each energy system to help reach a sustainable and efficient region in the energy sector. Based on the results gathered, the conclusions of this article are shown below:

• The primary energy resources offer for Central America is composed by oil, coal, natural gas, biomass, solar/wind, geothermal, and hydro, representing a total offer of 1,733.82 PJ for the region, with 675.2 PJ for Guatemala, 258.98 PJ for Honduras, 194.82 PJ for El Salvador, 170.70 PJ for Nicaragua, 232.71 PJ for Costa Rica, and 201.41 PJ for Panama.

• The region presents a dependence for non-renewable primary resources like oil and biomass, where 803.41 PJ were supplied by oil and 559.061 by biomass, representing 79% of the total primary energy resource offer for 2019.

• The efficiencies associated to the demand sector composed by transportation sector, residential/commercial sector, and industrial sector, reflect an average of 24.42% for transportation, 48.9% for residential/commercial, and 61.04% for industrial for the region, where Guatemala leads in transportation sector with an efficiency of 25.56%, Costa Rica leads in residential/commercial sector with an efficiency of 52.44%, and El Salvador leads in industrial sector with an efficiency of 71.25%.

• With the efficiencies calculated, the total energy losses for each sector presented losses of 323.071 PJ for the transportation sector, 313.38 PJ for the residential/commercial sector, and 67.69 PJ for the industrial sector, placing the transportation sector as the less efficient sector of the region, giving as well a total value of rejected energy of 1,064.58 PJ adding the energy losses of conversion for electricity sector with 360.45 PJ. The total amount of energy service is 510.64 PJ.

• The residential/commercial sector has the biggest demand, with a consumption of 607.46 PJ, where 414.04 PJ are supplied by biomass, representing 24% of the total primary energy resource demand.

• The total number of CO2 emissions for the region in 2019 reached an amount of 84,182.55 Mt of CO2, being Panama the most pollutant country with a number of emissions of 28,862.15 Mt of CO2.

A limitation presented through the development of this article was the lack of data related to the variables taken into account for the calculation of the efficiencies. With more accurate data, like detailed description of the engines used in transportation and industrial sectors, would have given a more precise calculation of the efficiency of these sectors. As well, the lack of data about the different type of households of the region, given that there are different socio-economic areas where the houses and the type energy consumption varies.

Despite these limitations, this article can be useful for the decision making related to future projects of energy efficiency that help improve the energy systems of the countries analyzed, given that it presents the improvement areas inside the systems. The relevant points of this article come from the calculation of the efficiencies for each demand sector, which helps to calculate the efficiency of the whole system, as well as the improvement areas inside the demand sector that will have a direct impact in the other sectors of the energy system by a reduction of energy consumption. This type of article provides a detailed view of the energetic outlook of a system, and can be used for a smaller scale such as cities, or in a bigger scale such as a country or an entire region.

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