National University of Lesotho

Energy Supply Management System for Lesotho

User Interactive System

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Contents

Abstract

There is inadequate energy data in Lesotho due to lack of data collection tools that would assist in collecting and storing data from supply through transformation to final use of each energy form. This report describes a development of a full web-based system that captures and stores energy products in database from various supply sources using Personal Home Page (PHP) programming language. This system is user interactive and allows specified users to insert and/or retrieve energy products from the database while other users can register into the system to view, query or fetch as well as download stored energy products data and system generated energy commodity account (ECA) and energy balance (EB) for a specified year. From the 2017 and 2018 energy data that has been inputted into the Energy Supply Management System (ESMS), an ECA and EB reports are generated for the energy supply part which is where the system's emphasis is on. The report provides analysis on Lesotho's energy supply mix which is mainly from biomass with 73% of the total supply for both 2017 and 2018, with almost no traces of renewable energy penetration for both years. The supply of petroleum fuel constitutes 19% and 18% for 2017 and 2018 respectively which indicates a significant contribution to the greenhouse gases (GHG) emissions to the environment. It further gives analysis from the system generated EB on Lesotho's self-reliance on energy supply which shows 75% and 76% for 2017 and 2018 respectively from indigenous production mainly covered by unsustainable biomass used inefficiently by major population of Lesotho. The major portion of energy supply is from imports of electricity from Eskom and EDM, coal and coal products, petroleum fuel and liquefied petroleum gas from South African mines and refineries respectively which indicates Lesotho's reliance on imports and hence less security of energy supply.

1. Introduction

1.1 Background

For each and every country to be very observant and particular about its energy situation, it should adopt an accounting framework around the energy sector. The energy situation involves knowledge about energy supply, energy flow in the economy as well as final use by different sectors on the demand side. This framework collects, analyses and stores all forms of energy products data in the form of energy commodity account and energy balance. Majority of the countries have set out collection and reporting on energy statistics as a legal requirement. As a result, data for products such as coal, natural gas, oil and oil products, electricity, renewable energy products, etc., are reported on annual basis in their fuel physical units [1].

To achieve the stated accounting framework of energy products, energy products data should be collected and stored on a regular basis for it to be accessed anytime. There are however no tools available at Lesotho's Department of Energy (DoE) or Bureau of Statistics (BoS) to assist in capturing and storing such data. This makes it difficult for BoS through energy statistics to compile complete accounting framework with respect to energy products from supply, transformation and finally to the consumption level by different economic sectors.

Looking at Lesotho's energy reports and energy balance reports produced by energy statistics, particularly the energy balance reports and energy reports for the years 2011 and 2017 [2, 3], they are very sketchy, incomplete and in most cases do not portray the true picture of the energy situation in the country. For instance, in 2011 the renewables and waste which presents mainly biomass energy source shows no data as the report suggests that projections for such energy source was only made up to 2010 hence there is incomplete energy balance in 2011 [3].

Furthermore, the 2017 energy report covers all energy supply products used in Lesotho except biomass which experts through available historical data shows that it covers the majority of rural residents at an estimated value of 24 600 TJ per annum [2, 4]. It is therefore worth noting that this topic is very crucial in finding a lasting solution to the prevailing energy data availability challenges in Lesotho even though the emphasis for this system is on energy supply data.

1.2 Problem Statement

As indicated in the previous sub-section, there is a challenge of energy products data availability due to the deficiency in data collection in Lesotho's energy sector. This makes it difficult for the energy sector to embark on developing the energy accounting framework so that its energy status could be visible to every stakeholder in the country. It further hinders future decisions on the energy situation such as the energy security of supply, self-reliance, renewable energy penetration as well as management of greenhouse gases (GHG) emissions.

The sectors which are particularly constrained by this issue of data unavailability include the environmental sector which would need to account for the country's contribution to climate change due to GHG emissions through supply and consumption of fossil fuel energy sources. On the other hand, legislation is constrained from developing laws and policies that would enhance domestic energy production in order to reduce reliance on imports. This would further affect the socio-economic sectors such as labour, manufacturing, mining, education and training, agriculture as well as transport and household. It is worth noting that some sectors are directly affected by this problem while others are indirectly affected.

Sectors such as domestic household, transport, mining and manufacturing are those that are directly affected by energy data unavailability due to the fact that if there is no energy data to account for the amount of petroleum fuel supply, transport and agriculture may suffer energy shortages when demand increases without knowing if supply has to increase as well. Household, mining and manufacturing sectors may also be faced with electricity shortage if there is no electricity accounting framework that would assist in informing projected increase in electricity supply due to increased electricity demand.

This has triggered motivation to develop a web-based system that would capture energy products data particularly from the energy supply side. The system would capture data as input on the user interface (UI) and store it in a database. Such data would then be accessed anytime for reports on the complete statistical accounting of energy products.

1.3 Objectives

The main goal of the thesis is to develop a well-designed user interactive Energy Supply Management System (ESMS). This system should respond to the energy sector's needs to capture various energy products and store them in the database. It should also be able to produce reports in the form of Energy Commodity Account (ECA) whereby different energy products would be reported in their fuel physical units from supply side through transformation to the final end use by different economic sectors on the demand side. However, transformation and demand sections will not form part of the study as emphasis is mainly on the energy supply in Lesotho.

The ECA can then be translated into an Energy Balance (EB) whereby the same energy products data is converted into common energy units in terms of their energy content from each product's calorific value. This common energy unit is chosen as tonnes of oil equivalent (***toe***) [5], which is the equivalence of oil's calorific value to a tonne of any energy product relationship such as coal, natural gas, petroleum products, indigenous fuel (wood, cow dung and crop residues) and as well as electricity.

1.4 Justification

The existing studies related to system development of this nature have concentrated much on the use of energy data at consumption level. These systems would capture data consumed by different sectors or energy appliances at household level and make use of such data to monitor the degree of consumption so as to have a view on the energy efficiency portrayed by different sectors or appliances. For instance, J.E. Seem developed a system that captures energy data consumed by different elements in a building and such data is analysed to establish the most consuming part of the building [6]. Moreover, there are no studies in Lesotho that have ever dealt with issues of energy data availability as most energy studies are more into the potential of supply through renewable energy resources and energy efficiency methods as energy forms part of a crucial topics in Lesotho.

On that note, energy plays a vital role in every country's economic development. It is therefore very crucial for Lesotho to adopt an energy accounting framework that seeks to unpack all energy supply resources so as to understand the country's energy situation. When energy products statistics is well informed by proper data collection and recording, it would be easy for policy makers to suggest and make informed decisions on energy.

These decisions could be for instance, increase in energy stock change on petroleum products so that a risk of running out of either petrol, diesel or kerosene could be reduced should anything negative happen in South Africa around oil refineries. There could also be on issues of sustainable development, that is to have a closer look at fossil fuel share and its impact on the environment, and also how much the renewable energy resources has penetrated the market and exploration of technologies that are used to harness these renewable energies into sustainable energy use.

1.5 Organisation

This thesis is structured in a way that chapter 2 discusses the review of literature around energy systems and flows. It gives a detailed background overview on energy flows from primary energy form, secondary, final to useful energy in their physical units and their conversion to common energy units. Moreover, chapter 3 discusses the methodology to be followed in designing a web-based energy supply management system that would capture, store and retrieve energy data on aggregated daily, monthly and annual basis. Furthermore, in subsequent chapters, particularly chapter 4, the presentation of system functionality in terms of data input, data processing and storage as well as retrieval of crucial energy reports such as energy commodity account and energy balance of Lesotho for the years 2017 and 2018 will form basis of discussion under this chapter. Lastly, chapter 5 will provide recommendations on the enhancements that could be done on the ESMS and in conclusion, major system results and observations will be summarized.

2. Literature Review

Energy is a useful commodity that every country needs for its economic development. It is therefore crucial for each country to establish a clear policy framework around energy supply stemmed from available primary energy resources, transformation processes as well as managing energy efficiency indicators to meet energy demand in a sustainable way [5]. It is vital to keep trend of primary energy requirement of a country in relation to demand over time [7]. Likewise, transformation process should clearly show energy conversion efficiency and the change of aggregate conversion over a specified period of time [7]. All these information is properly presented in Energy Commodity Account and Energy Balance reports.

This chapter will take a closer look at the energy flows from the supply perspective, transformation as well as energy consumption as they form the basis for energy balance construction. The two energy accounting frameworks, namely the energy commodity account and energy balance will be interrogated at length with the main focus on the energy carrier that relates to developing countries such as Lesotho. The literature behind similar web-based data capturing systems, their strengths and flaws together with methodologies used in their design will be detailed. Finally, the web-based system development literature will be unpacked in detail with more emphasis on web-based system designs, data capturing systems, data dissemination as well as database management.

2.1 Energy Flows

This section discusses the flow of energy as it is extracted from nature in primary energy form, transformation process to secondary energy and final energy use for consumption by different economic sectors.

2.1.1 Energy Supply

Energy supply for each country forms the basis for energy flow where energy is extracted from nature as primary energy such as coal, natural gas, crude oil, wood, geothermal or nuclear energy. This energy could be produced from within the country and form the country's production or come as imports or exports. Generally, the principle used in the physical energy content method is that primary energy form constitutes the very first form of energy in the energy production process [1].

The conversion process employs the method of physical energy content within each energy carrier which are categorized by their net calorific value for combustible energy products [1]. However, for non-combustible energy carriers such as nuclear, geothermal and solar thermal, heat energy is regarded as primary energy form when physical energy content method is applied. Finally, electricity is classified as primary energy form for energy sources such as solar PV, wind, hydro, etc. under the same method [1].

2.1.2 **Transformation**

Subsequent to extraction from nature in primary energy form, energy products are subjected to conversion from primary energy to secondary energy through different physical or chemical processes as transformation input. This incorporates production of electricity as well as heat energy in power plants, derivation of petroleum products such as kerosene, petrol, diesel as well as other oil products from crude oil through refinery processes [1].

The output resulting from the energy transformation processes as explained above is captured and recorded under transformation output of the energy flow in energy balance [1]. In practice, there is a difference in energy content between transformation input and output emanating from losses. These losses are due to transportation and distribution of energy products as well as technical losses incurred in power plants and refineries during transformation process.

Moreover, some energy is consumed in the industries that are producing or transforming energy and it is referred to as the energy sector. This energy is required for direct support in the transformation processes such as crude oil refineries, power plants, coal mines as well as oil fields [1]. For instance, when the coal oven is heated prior to the actual coal heating production process, energy use at that stage is regarded as energy sector's use and therefore does not form part of energy demand, so it is accounted for differently from the whole of energy use in the economy. Since this kind of energy constitutes a decrease of energy in energy flows, it will bear a negative sign.

2.1.3 Energy Demand

The residual energy left after conversion processes from primary supply is captured in the final section of the energy flows as energy available for final use (EAF)[1]. This is the energy difference between gross inland consumption (GIC) and the sum of transformation input (TRI) plus transformation output (TRO) plus exchanges, transfers and returns (XTR) less energy branch consumption (EBC) and losses from distribution (TDL) as shown in **Equation 1**.

$$EAF = GIC - TRI + TRO + XTR - EBC - TDL \qquad \text{Equation 1}$$

During energy transformation some energy products are not fully combusted in refineries or power plants but they are used for their physical or chemical characteristics[1]. These energy products include coal, oil and gas. For instance, oil lubricants can be used for friction reduction in the machinery of the plant, fossil fuels can be used in chemical industries to assist in chemical reaction process [1], thus their use in such cases is a non-energy usage.

The actual consumption of energy by different economic sectors such as transport, agriculture, mining, industries or manufacturing, household and services is recorded under this section in the energy flow. These sectors can be disintegrated further to enhance or pinpoint the exact sub-sector's energy consumption as well as for detailed energy accounting framework. Petroleum products consumed by vehicles are incorporated by transport sector, district heat used to domestic homes is displayed as other sectors under residential sector's consumption while commercial electricity consumption is captured under services sector as other sectors' energy consumption [1].

2.1.4 Statistical Difference

In order to guarantee the correctness of the energy accounting framework, the net total energy supply should always be equal to the net total energy demand [7]. However, in most cases this does not materialise [1] hence the use of statistical difference as a balancing factor becomes paramount. Its magnitude and sign portrays data quality or integrity as well as whether supply is bigger or smaller than demand and it is calculated from **Equation 2**. If the value of statistical difference is zero or too close to zero, it might be regarded as too good to be true scenario in the aggregate of the energy balance or that it has been derived from data of high quality [1].

$$Statistical\ Difference = Available\ Energy\ for\ consumption - Final\ non\ energy\ consumption - Final\ energy\ consumption \qquad \text{Equation 2}$$

2.2 Energy Commodity Account and Balance

The energy accounting framework is demonstrated by the energy commodity account as well as the energy balance and under this sub-section these two reports are unveiled in detail. It shows what each report entails, how they are constructed, and the information or picture they give around the energy sector. This information includes the supply mix, self-reliance and the extent of GHG emissions due to involvement of fossil fuels against renewable energy penetration.

2.2.1 Energy Commodity Account

As the energy data is being collected, it is captured in its physical units such as GWh, tons, litres and so on [7] as shown in **Table 1**. The resulting table for presenting these energy carriers from supply, through transformation processes all the way to the final energy use at consumption level is referred to as Energy Commodity Account (ECA). The ECA table is a basic input into the Energy Balance construction where data from this table will be transformed into values expressed in single (common) energy unit such as TJ or Mtoe [1].

The major components of ECA are; energy supply information, transformation details as well as demand information[7]. The supply section constitutes indigenous production of energy products, all energy products that enter and exit the country's borders as imports and exports and stock exchange. Energy imports leave as the energy quantities that enter the country but exit as transit to be used by another country. Since imports provide addition to the domestic energy supply, they bear a positive sign while exports will bear a negative sign which indicates a reduction in domestic energy production [7].

Energy consumed by international transport such as ships and marines for global trips and airplanes for international flights are classified with a unique term called bunker and it is treated like energy's import or export trade[7]. The energy products collection or stock of fuel provides an indication on the changes in energy supply and demand and these changes are kept within limits by energy suppliers, energy imports/exporters as well as energy consumers. An increase in energy stock implies reduction in accumulated pile of stock and decrease in energy stock denotes increase in supplies and this is given a term stock exchange[7].

Table 1. Energy Commodity Account in United Kingdom for 2008[7].

	Coal (kt)	Coal products (solid) (kt)	Coal gas (GWh)	Primary Oil (kt)	Petro products (kt)	NG (GWh)	Electricity (GWh)
Supply							
Production	17604	4661	15345	71665	80435	810284	385560
Other sources	449	0	0	0	3135	0	4089
Imports	43875	738	0	60074	23916	407054	12294
Exports	−599	−210	0	−48410	−28811	−122670	−1272
Marine bunkers	0	0	0	0	−2594	0	0
Stock change	−3395	206	0	232	14	−3087	0
Transfers	0	0	−3	−2928	−208	−68	0
Total supply	57935	5395	15342	80633	75887	1091513	400671
Statistical difference	−278	−3	−139	−91	−64	876	1053
Total demand	58212	5398	15481	80725	75951	1090637	399619
Transformation	55621	4363	7900	80725	1170	397246	0
Energy industry use	5	0	4759	0	4531	69196	30632
Losses	0	0	2332	0	0	13634	27425
Final consumption	2586	1036	490	0	70249	610561	341561
Industry	1872	728	490	0	5807	132501	113558
Transport	0	0	0	0	51924	0	8434
Other sectors	714	308	0	0	4035	468788	219570
Non-energy use	0	0	0		8483	9273	0

2.2.2 Energy Balance

As previously defined, energy balance is an accounting framework of all energy carriers or products that enter or leave the country and those that are indigenously produced within the country. This framework entails the energy supply, transformation input and output, as well as final useful energy ready for consumption by different country's economic sectors not excluding records of non-energy use of energy, all in common energy units such as joules or tonnes of oil equivalent. The conversion factors from different physical units to common unit are illustrated on **Table 2**.

Table 2. Conversion factors from different units to common unit.

INTO	***TJ***	***Million Btu***	***Gcal***	***GWh***	***Mtoe***
FROM	MULTIPLY BY				
Terajoule (TJ)	1	947.8	238.84	0.2777	2.388×10^{-5}
Million Btu (Btu)	1.055×10^{-3}	1	0.252	2.9307×10^{-4}	2.52×10^{-8}
Giga Calorie (Gcal)	4.187×10^{-3}	3.968	1	1.163×10^{-3}	10^{-7}
Giga Watt hour (GWh)	3.6	3412	860	1	8.6×10^{-5}
Mega toe (Mtoe)	4.187×10^{4}	3.968×10^{7}	10^{7}	11630	1

There are two different methods of units that are used commonly in energy units' conversion from different energy sources physical units to common units. The first ones are *scientific units* which are sometimes referred to as precise units and they incorporate calorie, Btu, kilowatt-hour as well as joule. These units actually demonstrate energy measurement in terms of heat it produces or amount of work it does. For instance 1 kWh of work done is equivalent to 1000 J/sec in 1 hour period, which means 1 kWh equals 3.6 Million joules [7] as shown on **Table 3**.

Table 3. Scientific units and their relations [7].

1 calorie	4.1868 J
1 Btu	252 cal
1 kWh	3.6 MJ = 853.845 kcal

The second ones are *commercial units* which are also known as imprecise units since they are based on uneven energy content commodities and give a measure of physical quantities of energy. They includes, ton of coal equivalent and ton of oil equivalent, however the most commonly used is the ton of oil equivalent as it is very easy to use and understand [7]. For example, as defined by International Energy Agency (IEA), a mega ton of equivalent is a measure of a ton of crude oil with a net calorific value of 10^7 GCal as shown on **Table 4**.

Table 4. Conversion from precise to imprecise units [7].

Energy Units	
1 Mtoe	10^7 Gcal
1 Mtoe	3.868×10^7 MBtu
1 GWh	860 Gcal
1 GWh	34120 MBtu
1 TJ	238.8 Gcal
1 TJ	947.8 MBtu
1 MBtu	0.252 Gcal
1 MBtu	2.52×10^{-8} Mtoe
1 Gcal	10^7 Mtoe
1 Gcal	3.968 MBtu

National energy balances play a vital role in informing policy makers in decision making around the energy sector, assessment of country's energy security of supply, country's energy self-reliance as well as renewable energy sources penetration into the supply mix [1]. For instance, South Africa once used its national energy balance to collect and establish the level of greenhouse gases emissions from energy sources [8].

As it should be the case in Lesotho, the Republic of South Africa's Department of Minerals and Energy collects and constructs on yearly basis and issues data on indigenous energy production, economic sectoral consumption, outbound and inbound energy as well as energy stock exchanges on all energy carriers in that country [8,9]. The end result of this becomes the national energy commodity account where energy is given in physical units such as tons, GWh, litres and national energy balance table with common energy units (i.e. tonnes of oil equivalent and Tera Joules). A typical national energy balance for South Africa's total primary energy supply in 2017 is shown on **Table 5**.

From this energy balance, it can be deduced that the South African energy supply mix was dominated by coal from indigenous production. The total coal supply constituted 60.7% of the total primary energy supply (TPES). The crude oil has a share of 11% of the TPES where the main source was the imports and significant amount of local production. Petroleum fuel showed a surplus of 3.6% where a much more amount of petroleum was imported as compared to a insignificant amount of exports and marine bunkers.

Subsequent to the above analysis, South Africa would be regarded as one of the major contributors to the greenhouse gas (GHG) emissions which affects the environment negatively due to a major coal supply. The renewable energy penetration seemed to be significant as it can be seen that all nuclear, hydro and renewables combined, constituted approximately 23% of TPES while electricity demonstrated a -0.3% shortage as a primary supply. The good thing that can be observed is that there is a high security of supply as most of the energy supply is sourced locally, followed by exports which implies positive contribution to the country's economy.

Finally, more than 80% and 100% of coal and crude oil supplies respectively are transformed into secondary energy as well as useful energy forms such as electricity, diesel, petrol and paraffin. This is evident from the fact that ESKOM's power plants are mainly generating electricity using coal while Sasol refineries produce diesel, petrol, paraffin and other useful petroleum products to be consumed by economic sectors such as agriculture, transport and domestic household. Policy makers can therefore make informed decisions using the information from this energy balance. They would for instance want to reduce GHG emissions by implementing or strengthening policies around renewable energy sources with the aim of increasing supply from these sources.

Table 5. South Africa's total primary energy supply in Tera Joules (TJ) for 2017 [9].

	Coal	Crude Oil	Petroleum	Gas	Nuclear	Hydro	Renewables & Waste	Electricity	Total
Indigenous Production	5 972 638	4 211	63 404	25 571	171 744	3 041	1 341 810	-	7 582 418
Imports	33 113	729 621	325 091	124 124	-	-	-	37 998	1 249 948
Exports	-1 964 835	-	-149 087	-499	-	-	-	-59 576	-2 173 997
Marine Bunkers	-	-	-122 341	-	-	-	-	-	-122 341
Stock Changes	-	-	-	-	-	-	-	-	-329 875
Total primary energy supply (TPES)	**4 040 916**	**733 832**	**239 408**	**149 197**	**171 744**	**3 041**	**1 341 810**	**-21 578**	**6 658 369**
TPES %	60.7	11	3.6	2.2	2.6	0.05	20.2	-0.3	100
Energy transformation	-3 334 813	-733 832	797 051	-60 762	-171 744	-3 041	-474 096	1 032 177	-2 656 200
Statistical difference	-266 372	-298 859	76 023	73 391	0	-0.01	-437 943	-280 968	-1 134 727
Total final consumption	**439 731**	**-**	**1 112 482**	**155 826**	**0**	**0**	**429 771**	**729 630**	**2 867 441**

2.2.3 **Energy** Mix

As it has been alluded in the analysis of South African primary energy supply, each country comprises different energy sources, some of which are fossil fuels while others are renewable energy sources. It is therefore imperative to have a complete analysis and foresight of penetration of each energy carrier in the supply mix as well as demand side for consumption[7]. Majority of developed countries in North-East Asian region have manifested vast increase in electricity demand from which its production was made through fossil fuels [10]. However these fossil fuels have proven to be unfriendly to the environment leading to severe climate change which affects global economy negatively [11].

Global treaties and agreements such as the United Nations Framework Convention on Climate Change (UNFCCC) that individual countries embark on as far as GHG emissions from fossil fuel energy sources have led to countries being particular about the level of different energy sources contribution and market share in their respective energy supply and demand mix [11, 12]. Therefore, it is basically better to have a diverse pool of energy mix than to have a rather slim range of the mix in the energy supply system regardless of some energy carriers impact on environment[7].

2.2.4 Sankey Diagram

Sometimes tools such as Sankey diagrams become very useful in the illustration of energy flows as well as energy distribution across different energy systems [14]. These are diagrams where energy flow magnitude is represented by a width, energy type is represented by colour, while an arrow shows a direction of energy flow in the system as shown in **Figure 1**. It has major features such as system boundaries, granularity level and energy loss representation [14].

The system boundary marks regions where energy activities are traced and analysed at national level. The definitions of physical boundaries names inflow and outflow energy imports and exports while special boundaries accounts for aggregated energy parts which belong within similar economic activity. These include different sectors such as transformation sector (generation and refining), industrial sector, mining sectors, and household, transport and service sectors.

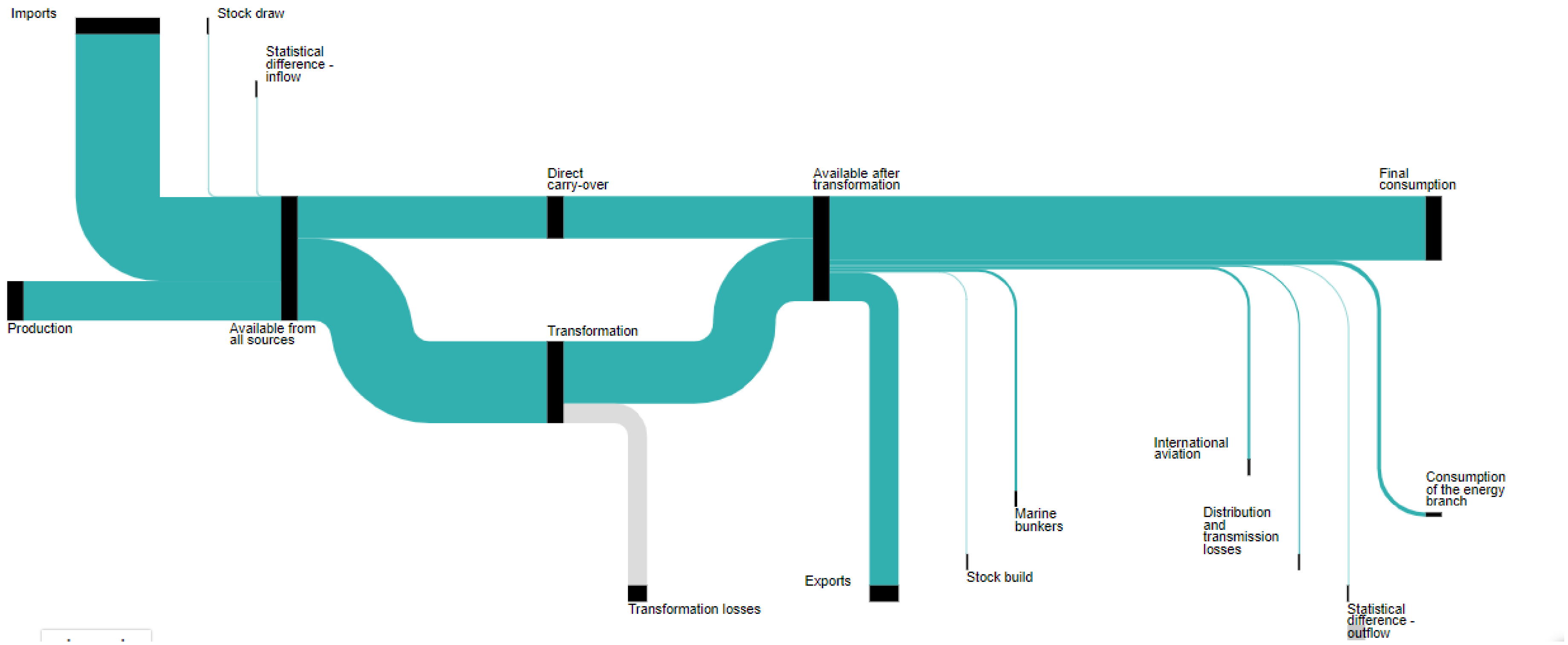


Figure 1. A Typical Sankey Diagram that show energy flows in European Union for the year 2018-2019[1]

2.3 Web-based Systems development

Various energy management systems have been developed across the universe but most of them have been focusing on the energy consumption at household level to give energy users patterns of their daily consumption so as to encourage energy efficiency [15].These systems are often designed based on the optimised functionality and cost effectiveness yet they achieve desired objectives such as data analysis of appliances consumptions and provide trends on household energy consumption. Cloud computing plays a major role in ensuring that systems of this nature perform data analytics on a larger scale under optimized conditions using different persistence frameworks such as Eloquent or MyBatis object relational mapping (ORM) in Personal Home Page (PHP) and Java programming respectively[15].

This sub-section unpacks the details around Laravel as a PHP framework together with associated packages that are critically useful in the development of web-based systems such as energy supply management system. Database management will also be discussed with more emphasis on Structured Query Language (MySQL) database. Furthermore, the user interface designs using page application methods are also illustrated at length under this sub section.

2.3.1 Laravel Framework

Laravel is one of the very powerful PHP frameworks in developing web applications. It is designed in such a way that applications are developed with high quality, time saving coding, low cost of capital and operational and/or maintenance as well as well-designed software architecture[16]. Its documentation is presented in a clear manner that allows easy flow of methods, objects as well as applications and their interactions for better understanding.

It offers the following fundamental features; *eloquent*, for interaction with different databases through create, read, update and delete (CRUD) methods without structured query language (SQL) queries. It supports different types of databases including MySQL, PostgreSQL, MSSQL and SQLite. .*Authentication*, for providing in-build authentication controls to access the application. Other features include *filters* which due to their code modularity, the use of drivers and bundles combination offers authentication functionality, database management, session and caching extension. Finally, *bundles* for allowing customized package of code for re-use purpose or use in the whole laravel system.

2.3.2 Eloquent ORM

This is a persistent framework incorporated with the laravel framework of PHP. It gives a very awesome implementation of database interaction with models that access tables for various operations such as data query, insertion, as well as updating records[17]. The key element with eloquent ORM is creation of models instances to allow usage of already existing models within an application. Then database connection can be set such that models can be able to interact with the database for data access. Over and above all, eloquent provides a very powerful relational management as well as automatic pagination.

2.3.5 Web Page Applications

A web page is designed and developed using PHP, HTML and Cascading Style Sheets with all operations of the web page presented under one page. Application server is spared from managing the page presentation as such activity is handled within the browser [18]. Such a traditional server based web-page design is illustrated on **Figure 2**. Here every HTML view request makes a complete round circle to a server and gets intercepted by a controller object found within a presentation layer [18].

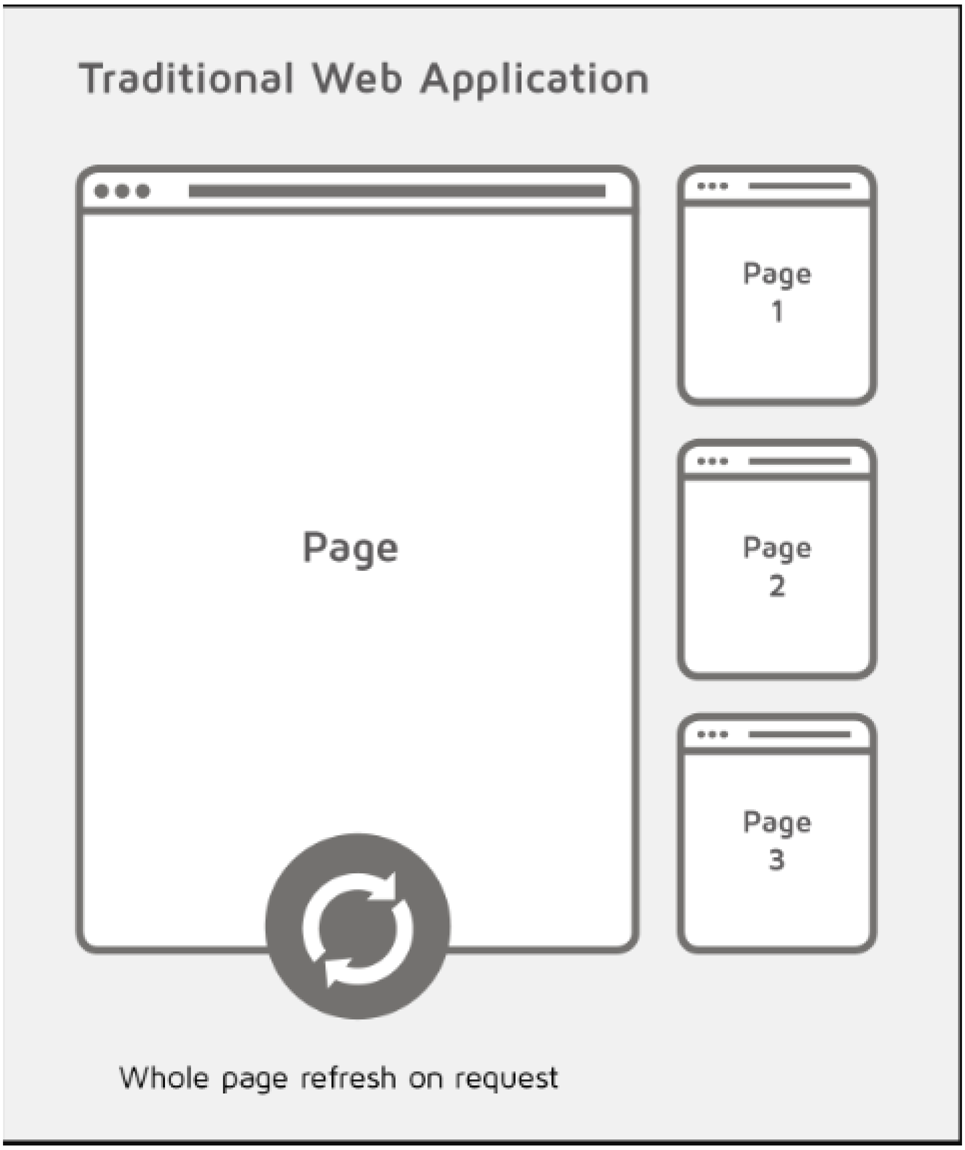


Figure 2. A traditional web page application (HTML view is constructed on the server) [18]

With single page application (SPA), views creation and management in the UI is made independent of the server as demonstrated in **Figure 3**. This simply means that with this design there is no full browser refreshing as server transactions are rendered by the presentation logic which is found within a client.

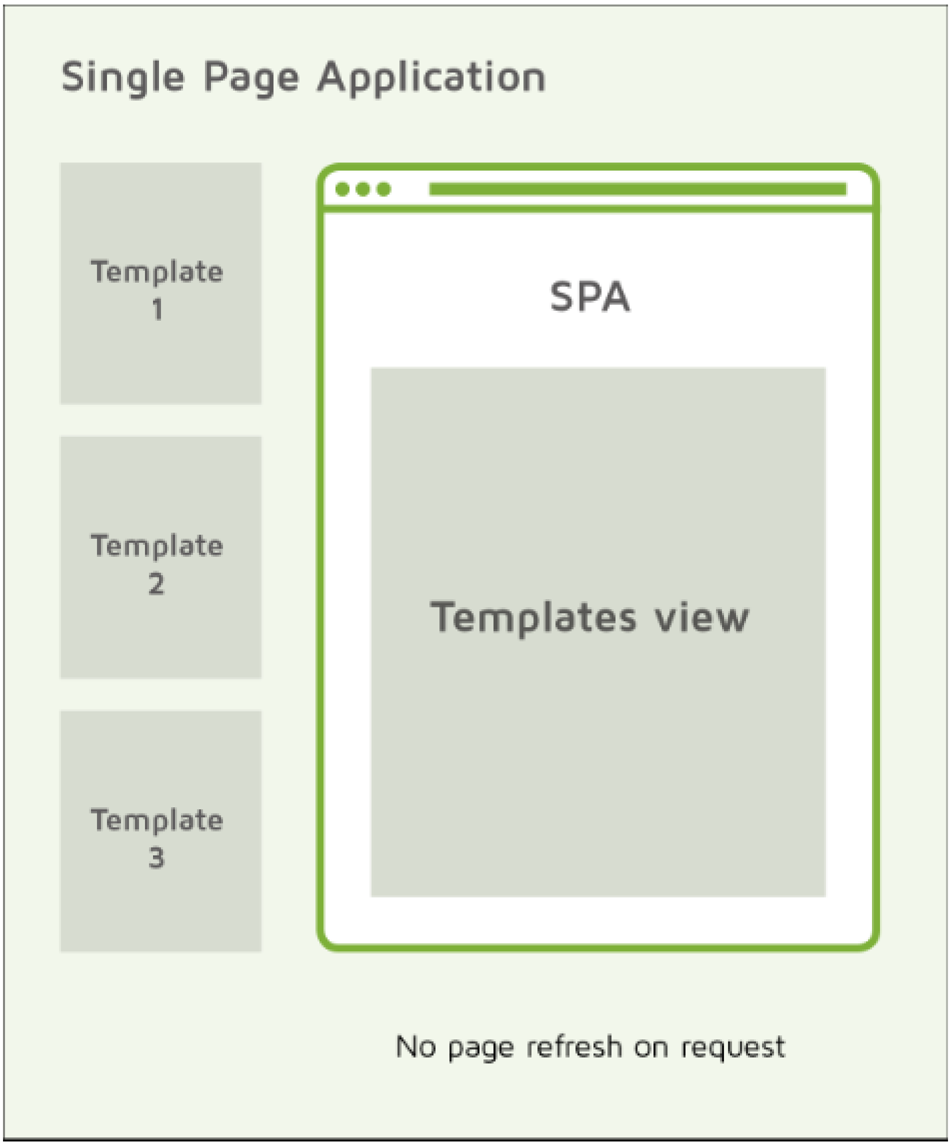


Figure 3. SPA web design, presentation layer moves to the client-side code[18].

2.4 Database Management

Database is defined as a program that deals with data storage, retrieval, creation as well as modification of data in a computer based system[19]. Database management systems (DBMS) allow systems users to logically create, read, update and delete data from the database storage as a way of managing such data. It uses relational data model as a basis for data manipulation, definition and query with a help of SQL [20].

The SQL statements in DBMS are categorised into four processing phases which are; parsing, optimization, code generation and execution which may be separated by random time spaces depending on the source and what is contained in the statement [20].

Traditionally, relational DBMS are supported by data that is modelled with relations with names of distinct types and attributes. Examples of such relational DBMS are MySQL[21] and POSTGRE [22].MySQL database is discussed in detail in the subsequent sub-sections as it forms part of the system development under discussion. Insights about how data is collected and captured into the system as well as details around analysis of such data as it disseminates through the system to the storage in the database are discussed under this subsection.

2.4.1 Data Collection, Analysis and Dissemination

Data collection can be portrayed in many different forms, some of which include surveys, interviews, and focus groups, observation, extraction as well as secondary data sources [23]. The choice of method to use depends entirely on the objective of research under discussion or discipline under which data is needed for. Qualitative method of data collection is based on research interviews which can be conducted in three main forms namely; structured, semi-structured and unstructured interviews [24].

In the case of building web based systems that would assist in collecting data such as energy data, whole web database method which analyses bigger pieces of web as stipulated by Judit Bar-Ilan has been used [25]. However, this method has been proven through studies that it is not feasible especially for applications that are meant to respond to data collection challenges on the web based systems at this latest moment. Thus Judit concludes that in order to overcome challenges experienced by scientist as far as data collection methods are concerned, it is desirable that one should develop his/her own method of data collection to solve the problems at hand [25].

For energy data collection in all European countries, Eurostat has embarked on methodology whereby each country fills in its energy data on the Energy Validation Outlet or a completed questionnaire is sent in CSV or Excel format to a specified email address (eleaq@iea.org) [26]. The Excel questionnaire is delivered to a Single Entry Point via Electronic Data Files Administration and Management Information System (EDAMIS).

This system has clear stipulated procedures on how questionnaires should be filled. They include reporting instructions, units and conversion factors, international standard industrial classification as well as definition on energy products being captured, such as electricity and heat, natural gas, oil, renewables and waste, coal, nuclear, energy consumption in households, combined heat and power generation (CHP) as well as district heating and cooling [26].

It is equally essential to provide detailed analysis of data that has been fed into the system so as to give vivid insights about such data and what it entails. There are different methods of data analysis but just like in the case of data collection, these methods are dependent on the field of study and purpose of collected data for analysis. John E. Seem developed a method of data analysis in which a system detects unusual daily energy consumption on buildings [6].

In his study, he used different methods of data analysis which actually compare current energy consumption and previous one so as to monitor any abnormalities in energy consumption on buildings day by day [6]. Even though analysis is not going to be based on energy consumption under this thesis, the robustness of this method has triggered attention solely to evaluate the possibility of employing it in the energy supply scenario.

As energy data is being captured and transmitted to a central point or database for storage and analysis, it is being disseminated within the system via interfaces which are well defined between subsystems. Ever since cloud computing came into existence and enormous rise in data formation and dissemination over the web, technology has embarked on the use of internet as the basic source of data to be availed to users by the network [27].

These systems pose threat of network overload as information is being delivered end-to-end instead of network devices communication. Hence Fard et al proposed a content-based method of dissemination [27]. The whole idea behind this choice of data dissemination is based on its deployment being structured in such a way that utilization is improved due to redundant capacity as well as reduced computational costs [27].

2.4.2 MySQL database - HaidiSQL

This is a complete open source graphical interface with full features database[21]. It provides a strong platform for MySQL database's administration and development and gives the following features;

- Configuration and setting of privileges for users and groups
- Extraction of SQL query results to files
- Provide backup facility for databases and tables restoration
- Provide for creation, deletion, viewing, modifying and insertion of table spaces, databases tables, schemas and table data
- Execution of SQL queries.

When server connection is established using HaidiSQL, the interfaces displays the session manager as the first instance[28] to database setup (see **Figure 4**). On these session manager the configuration of Network type, Hostname/IP, port and credentials prompt are inserted and saved. Once connection has been setup the database structure will be shown on the left side of the interface while data query navigation buttons together with results and error window will be displayed on the central and lower part of the interface respectively as shown on **Figure 5**.

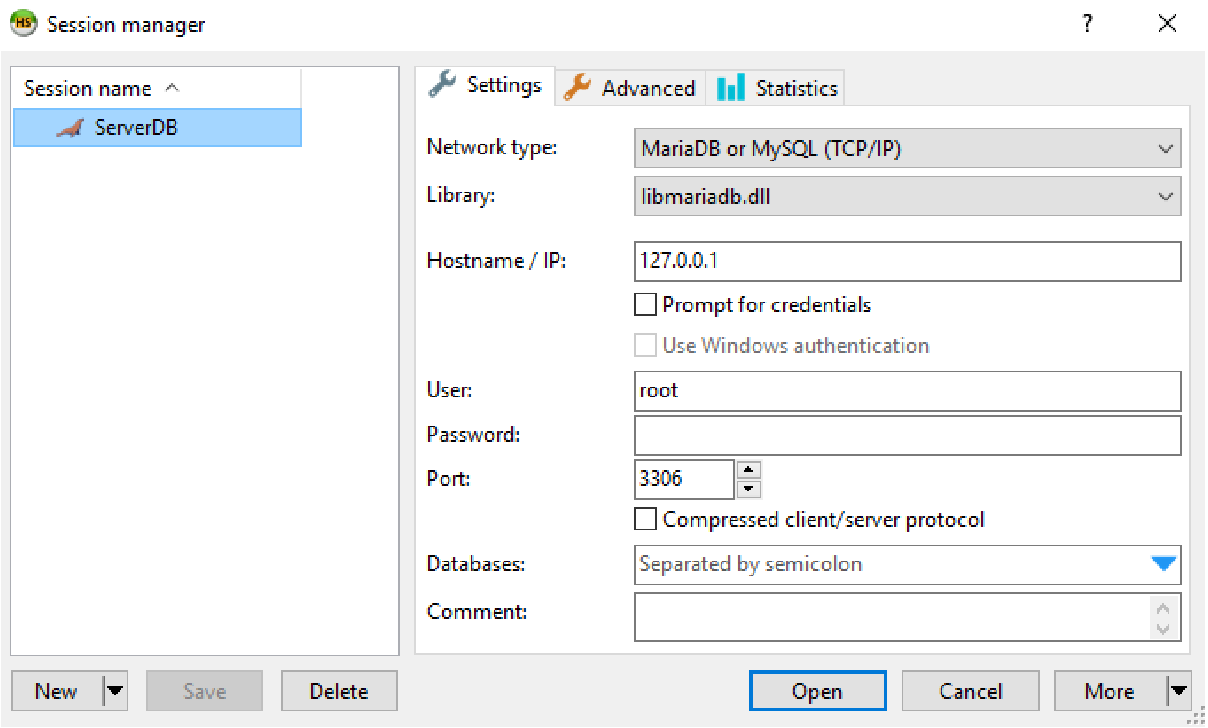


Figure 4. Session Manager for HaidiSQL server[28].

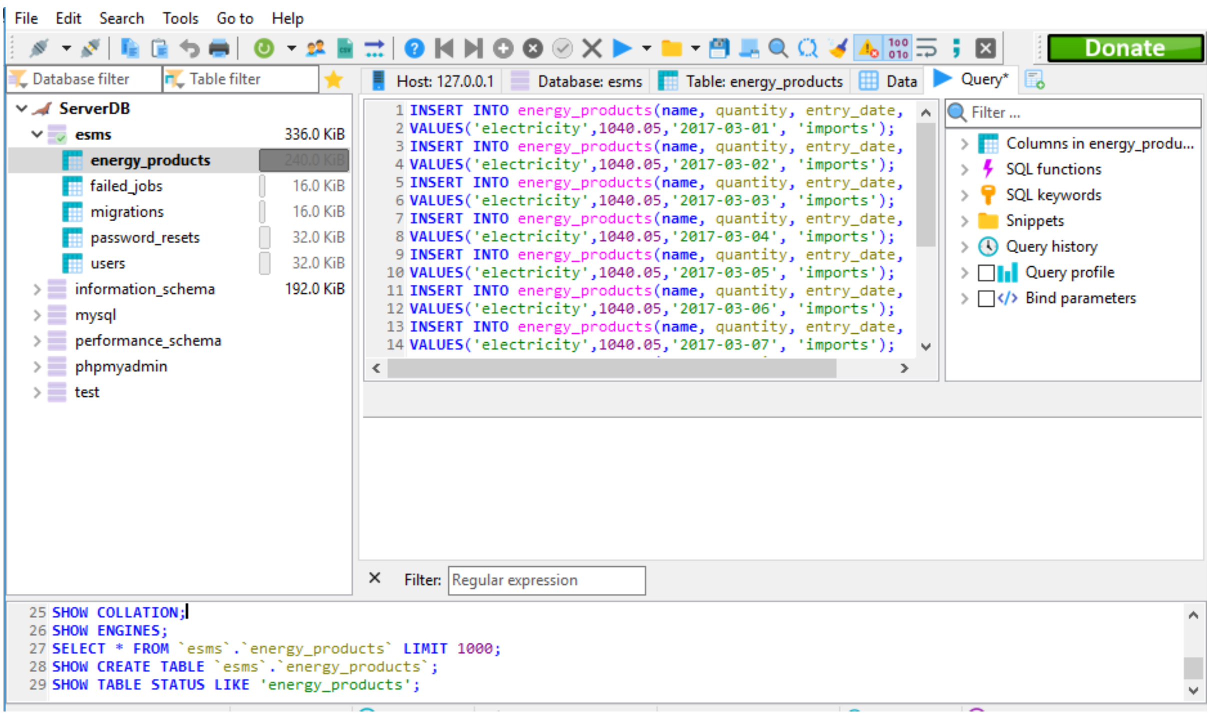


Figure 5. HaidiSQL Query View interface [28].

3. Methodology

The main objective of the study is to develop a user interactive, web based system that would allow capturing and retrieval of energy products data from storage server called database. This energy data can then be used to produce energy accounting framework around Lesotho's energy supply. The approach employed in responding to the above research questions involves use of laravel framework in PHP programming language and MySQL database for storage to develop a fully functional system. As input into the system, 2017 and 2018 energy reports for supply data covering electricity, petroleum fuel, lpgas, renewables (mainly solar PV) as well as coal and coal products have been used[2]. For biomass, data from reliable sources has been used to estimate Lesotho's supply for such energy carrier in both 2017 and 2018 [3].

Methods of data collection, data analysis and data dissemination form a major part of discussion under this chapter. Furthermore, the system design, both high and low level as well as implementation approach covering user interface, data processing and database setup as major sub-systems are elaborated and explicitly demonstrated as part of methodology. Lastly, details of how the major system outputs, ECA and EB are achieved by the ESMS as informed by literature review in the previous chapter are detailed.

ESMS development is hosted on a web server and accessed from anywhere over the internet. The design and implementation methods used are classified into high and low level design as explained in detail under subsequent sub-sections below. Once the system has been implemented and it is functional, energy supply data will be fed into the system over the User Interface (UI) and both ECA and EB will be produced as major system output.

3.1 System Design –High Level

As a way of developing a web-based user friendly system that would interact with individual users and other systems for data capturing, an ESMS is sub-divided into a main module and two sub-systems or modules [29], namely; User Interface Module, Data Processing Module and Data Storage Module.

All these modules have intra-interfaces to each other for information sharing as well as data input/output on the user interface where processed reports such as aggregated energy commodity account, energy balance as well as energy supply trends within specified period of time can be displayed or accessed in either pdf, excel or HTML format. The schematic diagram of an envisaged ESMS system is shown on **Figure 6**. Arrows show the direction of information flow on the interface within a system. Since these interfaces are within the same system they are referred to as internal interfaces [30]. However, there may be external interfaces which are not shown on the schematic diagram for communication and sharing of information particularly energy supply data from other systems.

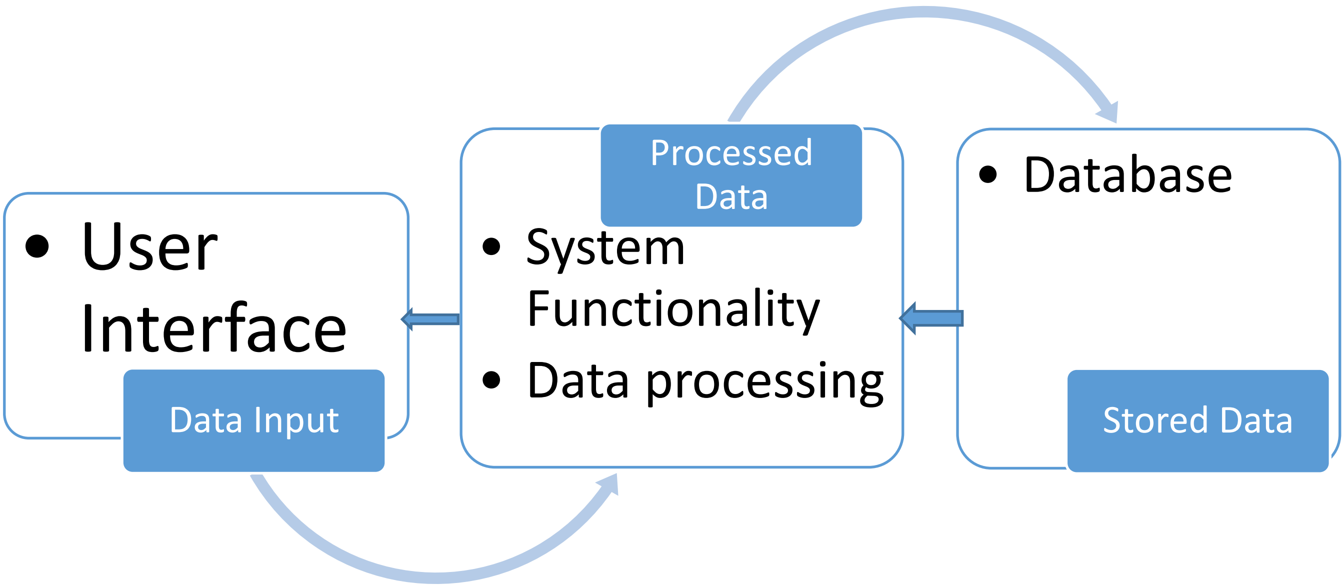


Figure 6. Schematic diagram of an Energy Supply Management System.

3.2 Data Capturing, processing and storage –Low level system design

3.2.1 Data input

Data capturing is done on the system user interface which is a major module of this system. This energy data requires *energy product name, energy product source, and quantity* as well as *entry date* as major attributes entered. The data capturing at the user interface is privileged to Bureau of Statistics (BoS) as the main user who will provide different data input into the system.

On the user interface, *Energy Product Name* and *Energy Product Source* will be selected from a drop-down menu and *Quantity* will be entered while *Entry Date* will be selected from date calendar and a submit button is pressed to save data in the database as demonstrated in **Figures 7a, 7b** and **7c**. This system incorporates energy supply data collection to be used in producing energy commodity account and energy balance together with their analysis with main focus on energy supply. Energy data is captured manually by the defined users via system user interface.

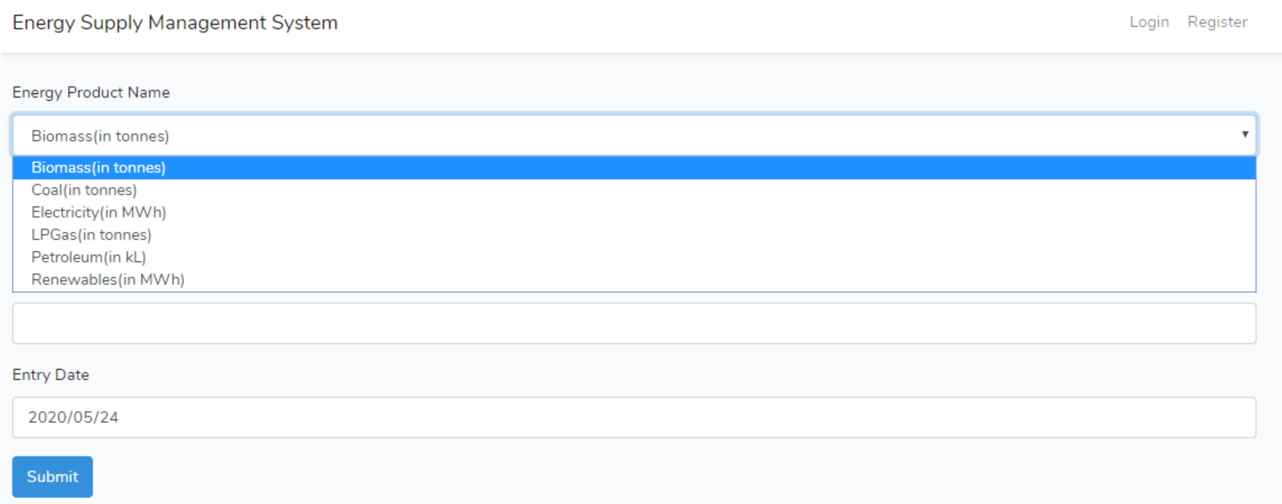


Figure 7a. Energy product name drop-down menu selection.

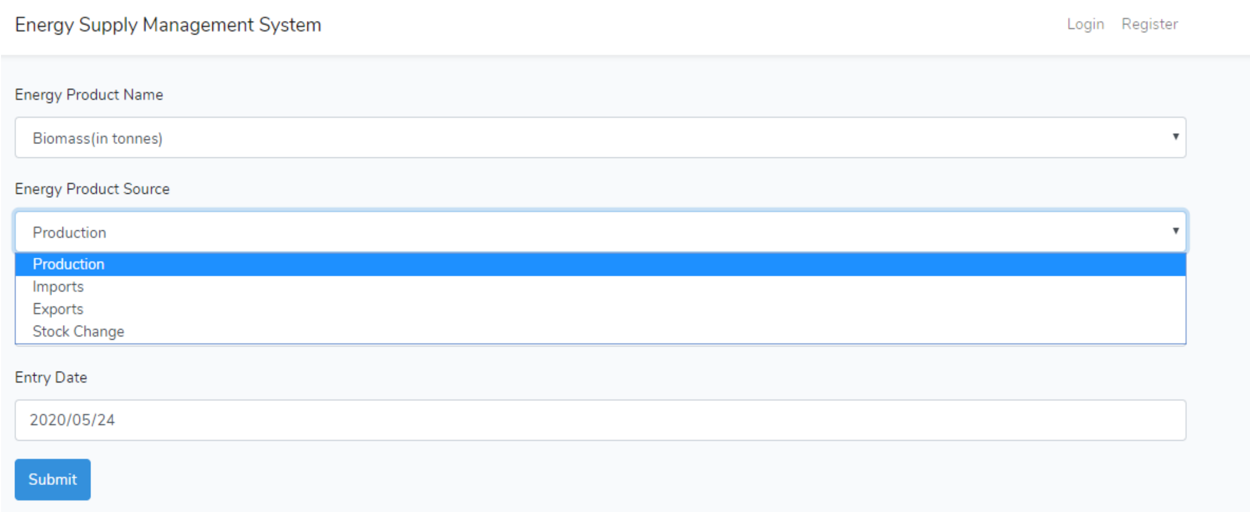


Figure 7b. Energy Product Source drop-down menu selection.

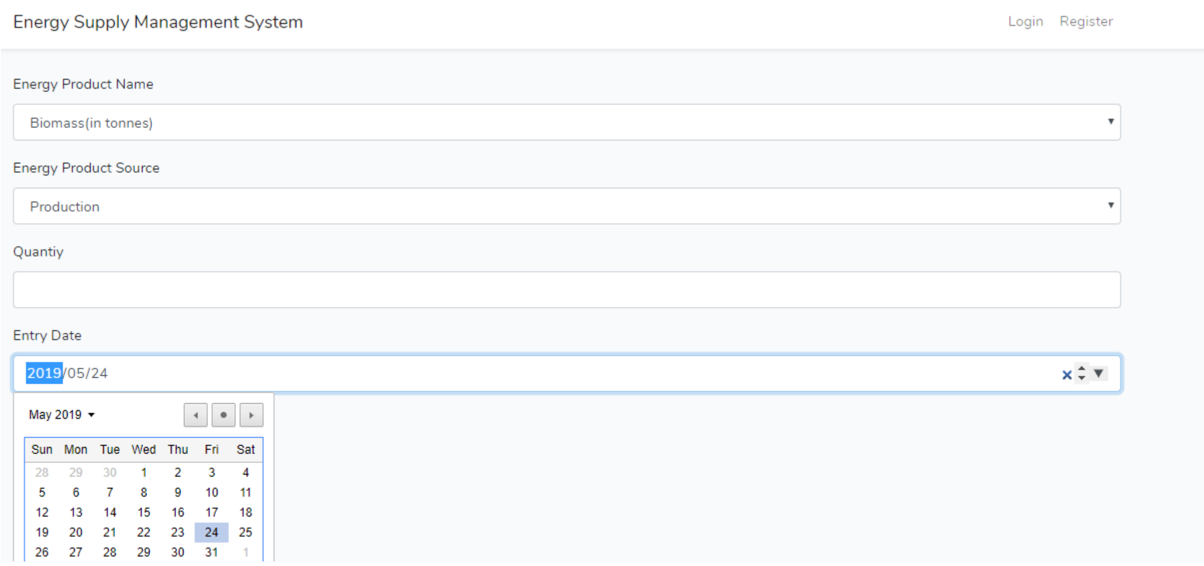


Figure 7c. Entry Date selection.

3.2.2 Data Processing and Storage

All energy data in its physical units disseminate through business logic down to the specified table in the database. Eloquent Object Relational Mapping (ORM) package included in laravel extends *Energy Product* model that stores entered data into the corresponding columns in the database as shown in **Figure 8**. To facilitate successful storage of captured data, a database connection set up is established with existing schemas from which a database and table will be created. MySQL database is created with one main table namely; *energy products*, with its corresponding columns *id*, *name*, *quantity*, *source* and *entry date* as shown in **Figure 9**. The functionality that enables session management for data input into the database is facilitated by data migration package. The migration functionality facilitates table creation and its corresponding columns together with data types according the data they are intended to hold.

```
/**
 * Store a newly created resource in storage.
 *
 * @param  \Illuminate\Http\Request  $request
 * @return \Illuminate\Http\Response
 */
public function store(Request $request)
{
    $request->validate([
        'quantity'=>'required'
    ]);
    EnergyProduct::create([
        "name"=>$request->product,
        "source"=>$request->source,
        "quantity"=>$request->quantity,
        "entry_date"=>$request->date
    ]);
```

Figure 8. Eloquent ORM model extension to database storage.

```
SELECT `DEFAULT_COLLATION_NAME` FROM `information_schema`.`SCHEMATA` WHERE `SCHEMA_NAME`='esms';
SHOW TABLE STATUS FROM `esms`;
SHOW FUNCTION STATUS WHERE `Db`='esms';
SHOW PROCEDURE STATUS WHERE `Db`='esms';
SHOW TRIGGERS FROM `esms`;
SELECT `DEFAULT_COLLATION_NAME` FROM `information_schema`.`SCHEMATA` WHERE `SCHEMA_NAME`='information_schema';
SHOW TABLE STATUS FROM `information_schema`;
SHOW FUNCTION STATUS WHERE `Db`='information_schema';
SHOW PROCEDURE STATUS WHERE `Db`='information_schema';
SHOW TRIGGERS FROM `information_schema`;
SHOW EVENTS FROM `information_schema`;
SELECT *, EVENT_SCHEMA AS `Db`, EVENT_NAME AS `Name` FROM information_schema.`EVENTS` WHERE `EVENT_SCHEMA`='esms';
USE `esms`;
SHOW CREATE TABLE `esms`.`energy_products`;
SHOW COLLATION;
SHOW ENGINES;
SELECT * FROM `esms`.`energy_products` LIMIT 1000;
SHOW CREATE TABLE `esms`.`energy_products`;
SHOW TABLE STATUS LIKE 'energy_products';
```

Figure 9. Database and Table creation with MySQL query.

For a database to communicate with a PHP application, entity classes and service classes are defined in PHP code within a business logic and information is translated into SQL statements which are understandable in the database by Eloquent ORM. This Eloquent ORM is used as it has the capability of mapping classes to defined tables in the database. User Interface (UI) accepts information as it is being entered and it goes through the business logic down to the DB through ORM. As data is being captured on the UI the mapping rules are invoked at business logic level of the system with the help of ORM which works both ways from user interface down to database and from database up to the user interface to provide user with required data for viewing.

3.3.3 Data Preparation and Input

Once database set-up is established, 2017 and 2018 data for all energy products used in Lesotho is prepared in such a way that each energy product's annual data is disaggregated over each month of the year such that data is inserted into the database on daily intervals. **Tables 6** and **7** show prepared import data for petroleum and LP Gas snapshot for 2018 and 2017 respectively, to be inserted into the database via the system user interface sourced from 2017/2018 Lesotho's energy reports [2].

Table 6. Disaggregated import petroleum data for 2018 in *Kilo Litres*.

Months	**Date** →	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**	**12th**
	Total Monthly Imports	**Daily Average Petroleum Imports in KL**											
January	20107.00	648.61	648.61	648.61	648.61	648.61	648.61	648.61	648.61	648.61	648.61	648.61	648.61
February	19029.00	679.61	679.61	679.61	679.61	679.61	679.61	679.61	679.61	679.61	679.61	679.61	679.61
March	21998.00	709.61	709.61	709.61	709.61	709.61	709.61	709.61	709.61	709.61	709.61	709.61	709.61
April	21229.00	707.63	707.63	707.63	707.63	707.63	707.63	707.63	707.63	707.63	707.63	707.63	707.63
May	24529.00	791.26	791.26	791.26	791.26	791.26	791.26	791.26	791.26	791.26	791.26	791.26	791.26
June	22668.77	755.63	755.63	755.63	755.63	755.63	755.63	755.63	755.63	755.63	755.63	755.63	755.63
July	21688.42	699.63	699.63	699.63	699.63	699.63	699.63	699.63	699.63	699.63	699.63	699.63	699.63
August	23559.11	759.97	759.97	759.97	759.97	759.97	759.97	759.97	759.97	759.97	759.97	759.97	759.97
September	20651.67	688.39	688.39	688.39	688.39	688.39	688.39	688.39	688.39	688.39	688.39	688.39	688.39
October	21716.00	700.52	700.52	700.52	700.52	700.52	700.52	700.52	700.52	700.52	700.52	700.52	700.52
November	21597.00	719.90	719.90	719.90	719.90	719.90	719.90	719.90	719.90	719.90	719.90	719.90	719.90
December	24428.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00	788.00

Table 7. Disaggregated import LP Gas data for 2017 in *Tonnes*.

Months	Date ⇨	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
	Total Monthly Imports	**Daily Average LPGas Imports in Tonnes**											
January	2059.54	66.44	66.44	66.44	66.44	66.44	66.44	66.44	66.44	66.44	66.44	66.44	66.44
February	2286.98	81.68	81.68	81.68	81.68	81.68	81.68	81.68	81.68	81.68	81.68	81.68	81.68
March	2094.68	67.57	67.57	67.57	67.57	67.57	67.57	67.57	67.57	67.57	67.57	67.57	67.57
April	1983.14	66.10	66.10	66.10	66.10	66.10	66.10	66.10	66.10	66.10	66.10	66.10	66.10
May	2243.51	72.37	72.37	72.37	72.37	72.37	72.37	72.37	72.37	72.37	72.37	72.37	72.37
June	2970.79	99.03	99.03	99.03	99.03	99.03	99.03	99.03	99.03	99.03	99.03	99.03	99.03
July	2502.2	80.72	80.72	80.72	80.72	80.72	80.72	80.72	80.72	80.72	80.72	80.72	80.72
August	2939.71	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83	94.83
September	2627.28	87.58	87.58	87.58	87.58	87.58	87.58	87.58	87.58	87.58	87.58	87.58	87.58
October	2738.57	88.34	88.34	88.34	88.34	88.34	88.34	88.34	88.34	88.34	88.34	88.34	88.34
November	2012.1	67.07	67.07	67.07	67.07	67.07	67.07	67.07	67.07	67.07	67.07	67.07	67.07
December	2955.62	95.34	95.34	95.34	95.34	95.34	95.34	95.34	95.34	95.34	95.34	95.34	95.34

These data is inserted into the *energy_products* table in database via *Submit* tab on the user interface as shown on **Figures7a, 7b** and **7c**. Since energy products data is either collected on monthly or annual basis, the monthly totals are averaged over each month's day in order to have each energy product's average supply on daily basis. Actual data can also be inserted similarly into the system as it is being collected. The complete code for the whole system is found in the appendix.

3.4 Energy Commodity Account Generation

Having loaded data for energy supply for the years 2017 and 2018 into the system, a pivot incorporated with a WebDataRocks application uses such data in *js* format to produce ECA table rendered on the system user interface. This data has been rendered through *productsAll* instance from *index ()* method defined in the *EnergyProductsController.php.* Once data has been supplied to pivot WebDataRocks, *quantity* is aggregated as sum and arranged in the ECA table with energy products names as columns while energy supply sources are arranged as rows. This table is then rendered for display in the *index.blade.php* method as shown on the code caption in **Figure 10**.

```
  window.__payload = {!! json_encode($productsAll) !!};;


var pivot = new WebDataRocks({
  container: "#wdr-component",
  toolbar: true,
  report: {
    dataSource: {
      data:  window.__payload
    },
    options: {
        grid: {
          showGrandTotals: "columns"
        }
    },
    slice: {
        rows: [
            {
                uniqueName: "source"
            }
        ],
        columns: [
            {
                uniqueName: "name"
            }
        ],
        measures: [
            {
                uniqueName: "quantity",
                aggregation: "sum"
            }
        ]
```

Figure 10. Energy Commodity Account generated by WebDataRocks' pivot application.

3.5 Energy Balance Generation

Subsequent to the ECA generation, the EB report is then generated by assigning each energy product from the database to MySQL selection statement. This statement queries raw quantity data and multiplies it my conversion factor to kilo tonnes of oil equivalent (*ktoe*) as per the conversion in **Table 2** from **Chapter 2.** The SQL statements which have been used to assign each energy product to the converted quantity, *convertedQty* are shown on the code caption in **Figure 11**. After this assignment, converted data is then supplied to the pivot WebDataRocks for arrangement of data in a tabular form with aggregated sum on columns, rows and grand totals in the *index.blade.php* caption similar to **Figure 10**.

```
public function index()
{
    $products = EnergyProduct::latest()->paginate(30);
    $productsAll = EnergyProduct::all();


    $electricity=DB::table('energy_products')->select('name','source', DB::raw('quantity*0.000086 as convertedQty'))
            ->where('name','electricity')->get();
   $biomass=DB::table('energy_products')->select('name','source', DB::raw('quantity*0.00009993 as convertedQty'))
            ->where('name','biomass')->get();
    $lpgas=DB::table('energy_products')->select('name','source', \DB::raw('quantity*0.00000009993 as convertedQty'))
            ->where('name','lpgas')->get();
    $renewables=DB::table('energy_products')->select('name','source', \DB::raw('quantity*0.000086 as convertedQty'))
            ->where('name','renewables')->get();
    $coal=DB::table('energy_products')->select('name','source', \DB::raw('quantity*0.00009993 as convertedQty'))
            ->where('name','coal products')->get();
    $petroleum=DB::table('energy_products')->select('name','source', \DB::raw('quantity*0.00009813 as convertedQty'))
            ->where('name','petroleum')->get();



    $energyBalance= $electricity->concat($biomass)->concat($lpgas)->concat($renewables)->concat($coal)->concat($petrole
     return view("products.index",["products"=>$products,"productsAll"=>$productsAll,"energyBalance"=>$energyBalance]);
}
```

Figure 11. Energy Balance generation by converting physical units to *ktoe*.

3.6 System access

The ESMS system is meant to be accessed over the web using URL which directs users to the hosting web server. This subsection will outline how the system is hosted and accessed. Most hosting web servers require subscription from application owners such that developed systems or applications can be accessed with ease. Cpanel from Web Space Bar has been used to host the system on the web server. The choice for this hosting service is mainly due to provision of high security with full support resources at minimum costs. For purpose of this system demonstration, a monthly fee domain hosting service on cpanel has been adopted for deployment of ESMS with minimum database storage size and simple environment management. The URL for the system is

http://www.dep-energy.co.za/

A Single Page Application (SPA) design has been adopted in setting up a webpage using *app.blade.php* application on Visual Studio Code environment. The webpage has two major components namely; header section which shows the system name and navigation routes for ***login*** and ***registe***r, and main section where all routes are rendered. The *App.js* component is the main component used to render bootstrap.js where a page layout is defined. The page layout is shown on **Figure 12**.

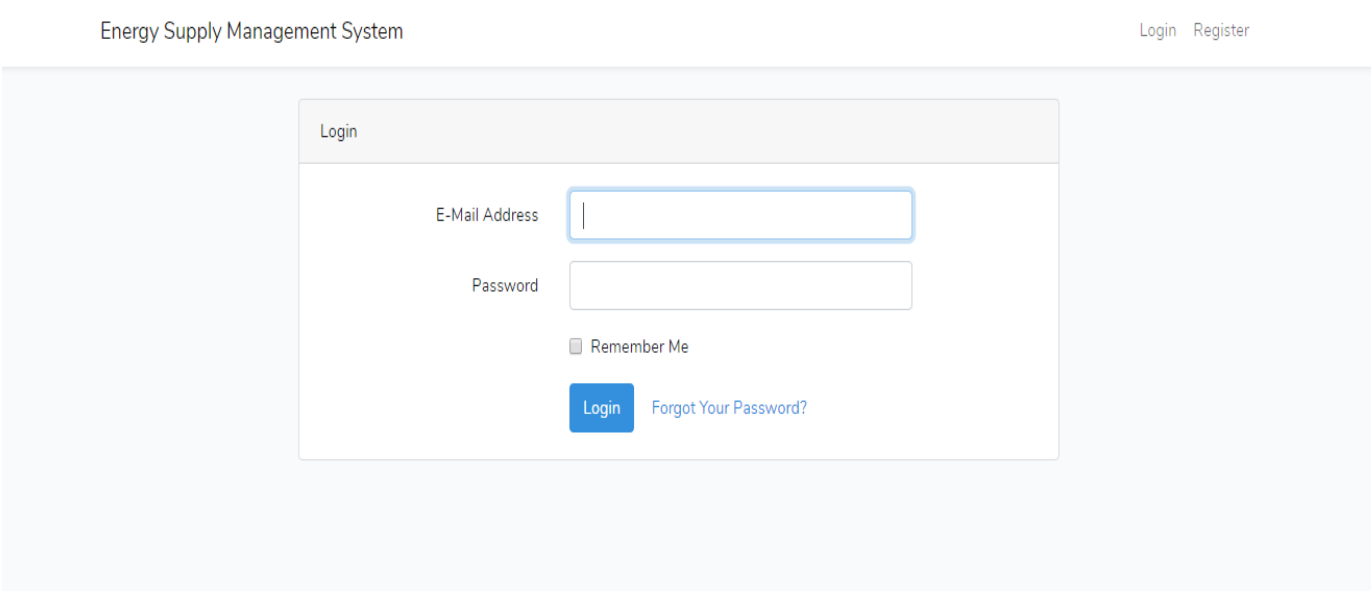


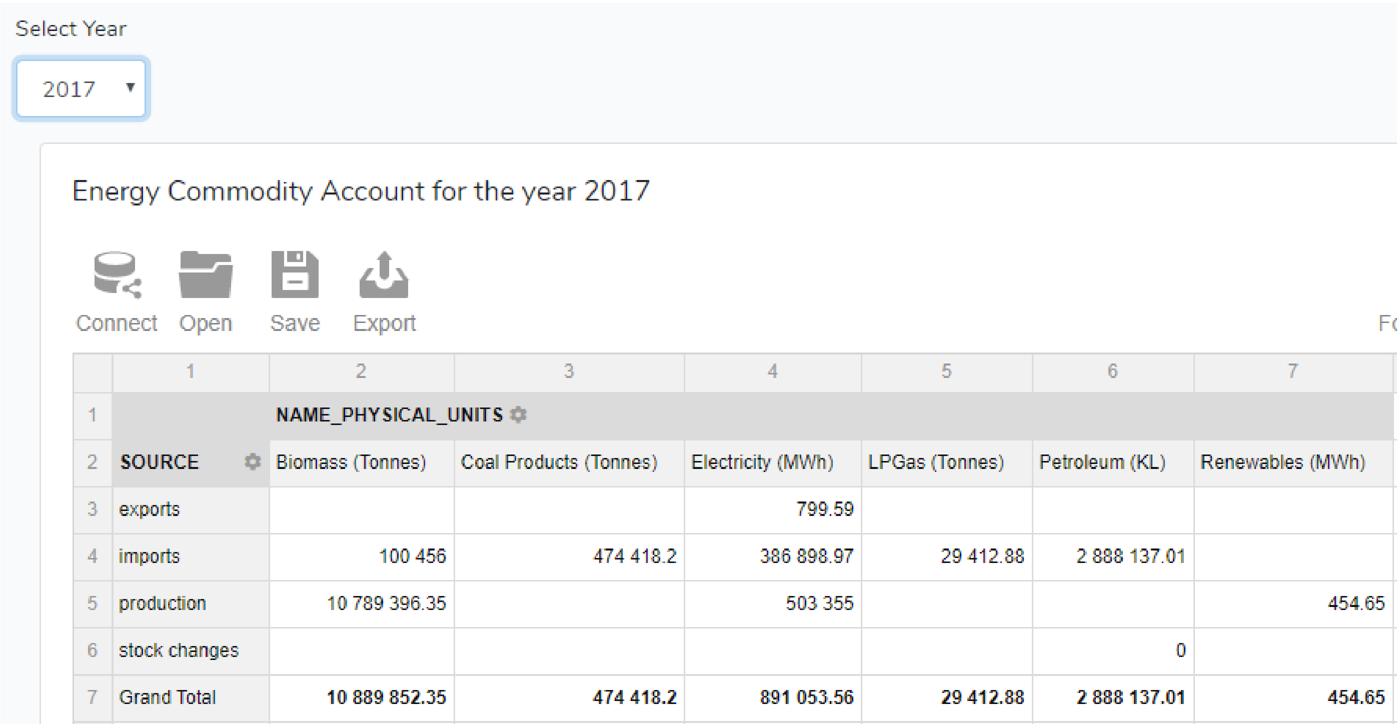
Figure 12. Webpage layout view with login rendered.

4. Results

Under this chapter, presentation of major outputs of the ESMS system namely; energy commodity account and energy balance for the years 2017 and 2018 will be shown. Furthermore, ECA and EB results will be closely interrogated in terms of energy supply mix, renewable energy penetration as well as Lesotho's self-reliance on energy supply. All these facts will be underpinned by results discussions and analysis with energy trends and shares shown on graphical presentations.

4.1 ECA Results

Having loaded energy supply data for 2017 and 2018 into the ESMS's database via the system's user interface, the system was able to produce Energy Commodity Account table for the supply of energy for the chosen year in the *select year* filter. That ECA can be retrieved and be displayed on the system's user interface or downloaded to the external storage as *Excel*, *PDF* or *HTML* file from which energy supply analysis can be made on each energy product for specified year. This is shown on **Figures13** and **14** for 2017 and 2018 respectively**.**



	1	2	3	4	5	6	7
1		NAME_PHYSICAL_UNITS					
2	SOURCE	Biomass (Tonnes)	Coal Products (Tonnes)	Electricity (MWh)	LPGas (Tonnes)	Petroleum (KL)	Renewables (MWh)
3	exports			799.59			
4	imports	100 456	474 418.2	386 898.97	29 412.88	2 888 137.01	
5	production	10 789 396.35		503 355			454.65
6	stock changes					0	
7	Grand Total	**10 889 852.35**	**474 418.2**	**891 053.56**	**29 412.88**	**2 888 137.01**	**454.65**

Figure 13. Energy Commodity Account for the year 2017 as displayed on the user interface.

Select Year

2018

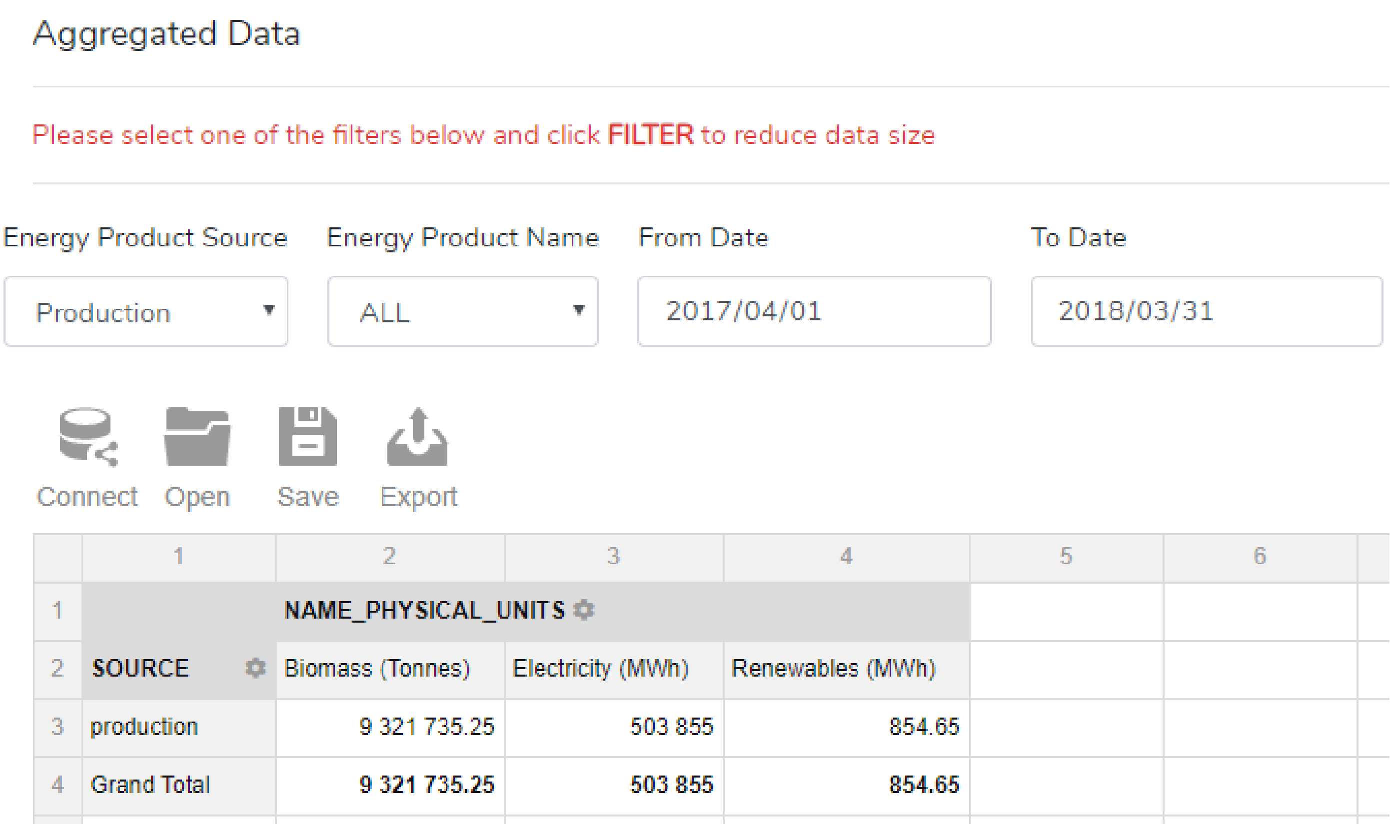
Energy Commodity Account for the year 2018

Connect Open Save Export Format

	NAME_PHYSICAL_UNITS					
SOURCE	Biomass (Tonnes)	Coal Products (Tonnes)	Electricity (MWh)	LPGas (Tonnes)	Petroleum (KL)	Renewables (MWh)
exports			0			
imports	101 004	494 890.03	387 705.86	20 434.55	2 763 092.21	
production	10 899 651.1		503 876.91			403.65
Grand Total	**11 000 655.1**	**494 890.03**	**891 582.769999999**	**20 434.55**	**2 763 092.21**	**403.65**

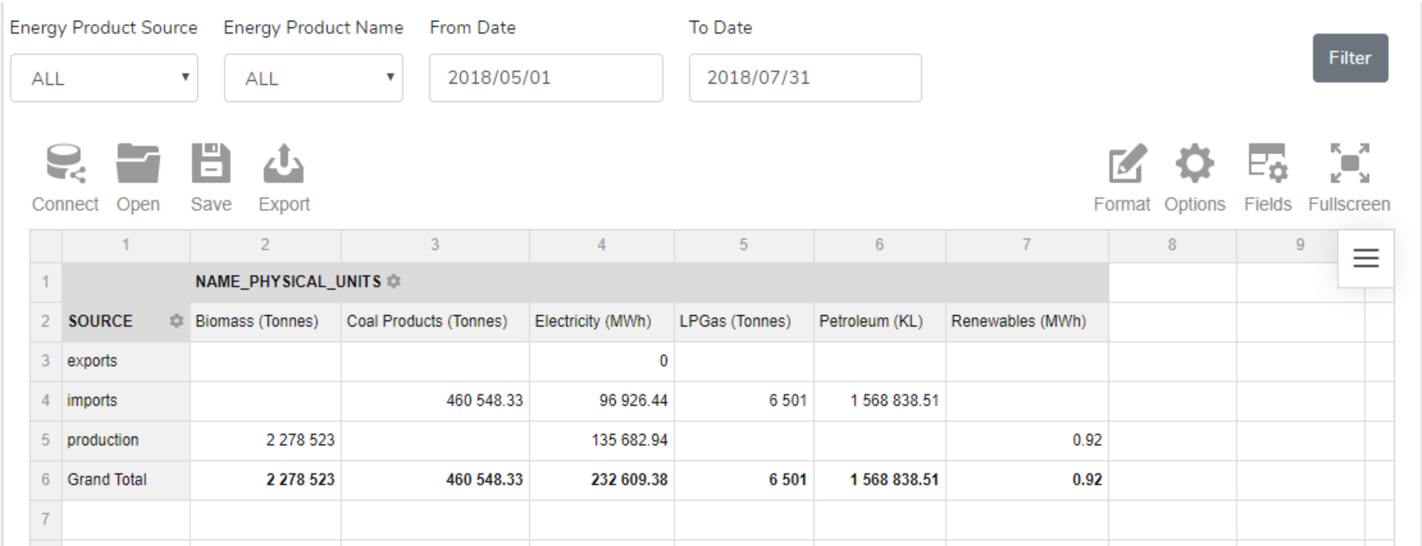
Figure 14. Energy Commodity Account for the year 2018 as displayed on the user interface.

Furthermore, data can be filtered according to the energy product source and name such that it is aggregated into a specified range of date as demonstrated in **Figure 15**. In this case energy data for all energy products are filtered according to production from 2017/04/01 to 2018/03/31. Furthermore, **Figures 16** and **17** illustrate aggregated energy data for all Lesotho's energy sources for winter season (May, June and July) and for three more seasons covering 9 months, that is Spring, Summer and Autumn.



NAME_PHYSICAL_UNITS			
SOURCE	Biomass (Tonnes)	Electricity (MWh)	Renewables (MWh)
production	9 321 735.25	503 855	854.65
Grand Total	**9 321 735.25**	**503 855**	**854.65**

Figure 15. Aggregated energy data for Lesotho's energy production for a period 2017/04/01 to 2018/03/31.



NAME_PHYSICAL_UNITS						
SOURCE	Biomass (Tonnes)	Coal Products (Tonnes)	Electricity (MWh)	LPGas (Tonnes)	Petroleum (KL)	Renewables (MWh)
exports			0			
imports		460 548.33	96 926.44	6 501	1 568 838.51	
production	2 278 523		135 682.94			0.92
Grand Total	**2 278 523**	**460 548.33**	**232 609.38**	**6 501**	**1 568 838.51**	**0.92**

Figure 16. Aggregated energy data for all Lesotho's energy sources for 3 months winter period (2018/05/01 to 2018/07/31)

Energy Product Source: ALL | Energy Product Name: ALL | From Date: 2017/08/01 | To Date: 2018/04/30 | Filter

Connect Open Save Export Format Options Fields Fullscreen

	NAME_PHYSICAL_UNITS					
SOURCE	Biomass (Tonnes)	Coal Products (Tonnes)	Electricity (MWh)	LPGas (Tonnes)	Petroleum (KL)	Renewables (MWh)
exports			333.15			
imports	1 000	481 392.19	290 443.21	20 254.65	2 004 620.05	
production	7 364 440.970000002		368 172.06			853.73
stock changes					0	
Grand Total	**7 365 440.970000002**	**481 392.19**	**658 948.42**	**20 254.65**	**2 004 620.05**	**853.73**

Figure 17. Aggregated energy data for all Lesotho's energy sources for 9 months from 2017/08/01 to 2018/04/30.

4.2 EB Results

The ESMS was able to produce an Energy Balance by converting the output energy products values in the Energy Commodity Account into kilo tonnes of oil equivalent (*ktoe*) as a common energy unit for all different energy products supply. The results are demonstrated in **Figures 18** and **20** for the years 2017 and 2018 respectively while Figures 19 and 21 show the same EB report for 2017 and 2018 respectively with total energy sources from exports, imports and production.

Energy Balance in ktoe for the year 2017

Connect Open Save Export

	NAME					
SOURCE	Biomass	Coal Products	Electricity	LPGas	Petroleum	Renewables
exports			0.069			
imports	10.039	47.409	33.273	2.939	283.413	
production	1 078.184		43.289			0.039
stock changes					0.000	
Grand Total	**1 088.223**	**47.409**	**76.631**	**2.939**	**283.413**	**0.039**

Figure 18. Supply Energy Balance report for the year 2017 as displayed on user interface.

Energy Balance in ktoe for the year 2017

Connect Open Save Export Format Options Fields Fullscreen

	NAME						
SOURCE	Biomass	Coal Products	Electricity	LPGas	Petroleum	Renewables	Total Sum of Total Energy
exports			0.069				**0.069**
imports	10.039	47.409	33.273	2.939	283.413		**377.073**
production	1 078.184		43.289			0.039	**1 121.512**
stock changes					0.000		**0.000**

Figure 19. Supply EB for 2017 showing total sources.

Energy Balance in ktoe for the year 2018

Connect Open Save Export

	NAME					
SOURCE	Biomass	Coal Products	Electricity	LPGas	Petroleum	Renewables
exports			0.000			
imports	10.093	49.454	33.343	2.042	271.142	
production	1 089.202		43.333			0.035
Grand Total	**1 099.295**	**49.454**	**76.676**	**2.042**	**271.142**	**0.035**

Figure 20. Supply Energy Balance report for the year 2018 as displayed on user interface.

Energy Balance in ktoe for the year 2018

Connect Open Save Export Format Options Fields Fullscreen

	NAME						
SOURCE	Biomass	Coal Products	Electricity	LPGas	Petroleum	Renewables	Total Sum of Total Energy
exports			0.000				**0.000**
imports	10.093	49.454	33.343	2.042	271.142		**366.075**
production	1 089.202		43.333			0.035	**1 132.570**

Figure 21. Supply EB for 2018 showing total energy source.

4.3 Results Discussions and Analysis

This section will discuss and analyse the energy balance produced by the ESMS based on the details of Lesotho's energy supply mix, renewable energy supply penetration as well as security of supply or how reliant is Lesotho on energy supply from production within the country as compared to importing energy from abroad. Issues of the country's contribution to the greenhouse gas emissions from the use of fossil fuels will be discussed.

4.3.1 Energy Supply Mix and Renewable Energy Penetration

From the 2017 and 2018 Energy Balance produced from the Energy Supply Management System, it is found that Lesotho's energy is mainly supplied from four main energy carriers namely; biomass, coal and coal products, electricity, lpgas as well as petroleum fuel which constitutes kerosene, diesel and petrol. The renewable resources have shown insignificant contribution brought by a 281kWp solar plant installed at Moshoeshoe I International airport.

Although literature shows abundant renewable energy resources availability in Lesotho through a series of feasibility studies by Taele et al [31], they have not been explored to the extent that they can been seen featuring in the energy supply mix. From the use of available data from 2017 energy report, the energy balance has shown that biomass supply covers 73% (1088 ktoe/1498 ktoe = 73%), electricity 5% (76.6 ktoe/1498 ktoe = 5%), petroleum fuel 19% (283.4 ktoe/1498 ktoe = 19%), coal and coal products 3% (47.4 ktoe/1498 ktoe = 3%) while renewables and lpgas constitutes 0% (0.039 ktoe/1498 ktoe = 0%) and 0.2% (2.939 ktoe/1498 ktoe = 0.2%) respectively of the energy supply as shown in **Figure 22**.

The 73% supply share for biomass demonstrates that Lesotho's major population (66% of total population) mainly from the mountainous rural areas still depends on biomass in the form of wood, crops residues and animal waste for their cooking [4]. Although the government of Lesotho (GoL) has embarked on the electrification programme where the national grid is being extended to rural areas, this does not seem to increase electricity supply. This is due to the fact that the connected households still depend on their usual traditional biomass fuel for cooking because of among other reasons, lack of electricity units buying power due to extreme poverty in such communities. Hence, the electricity supply share remains rather low at 5% as compared to biomass.

The use of biomass energy by majority of people in Lesotho poses a threat of respiratory health diseases amongst the communities' members caused by inefficient use of such fuel through incomplete combustion and release of smoke and other GHG emissions that are also harmful to the environment. In addition to the above, the 18% constituted by petroleum fuel as a result of huge influx of affordable Japanese import cars also contribute to the environmental pollution. Looking at the supply mix for 2018 (**Figure 23**), the biomass supply share still covers 73% as in 2017. Similarly electricity, petroleum fuel, coal and coal products have remained at 5%, 19% and 3% respectively while lpgas slightly decreased from 0.2% to 0.14%. However, biomass is still the major supply followed by petroleum fuel while lpgas covers the least share in the supply mix.

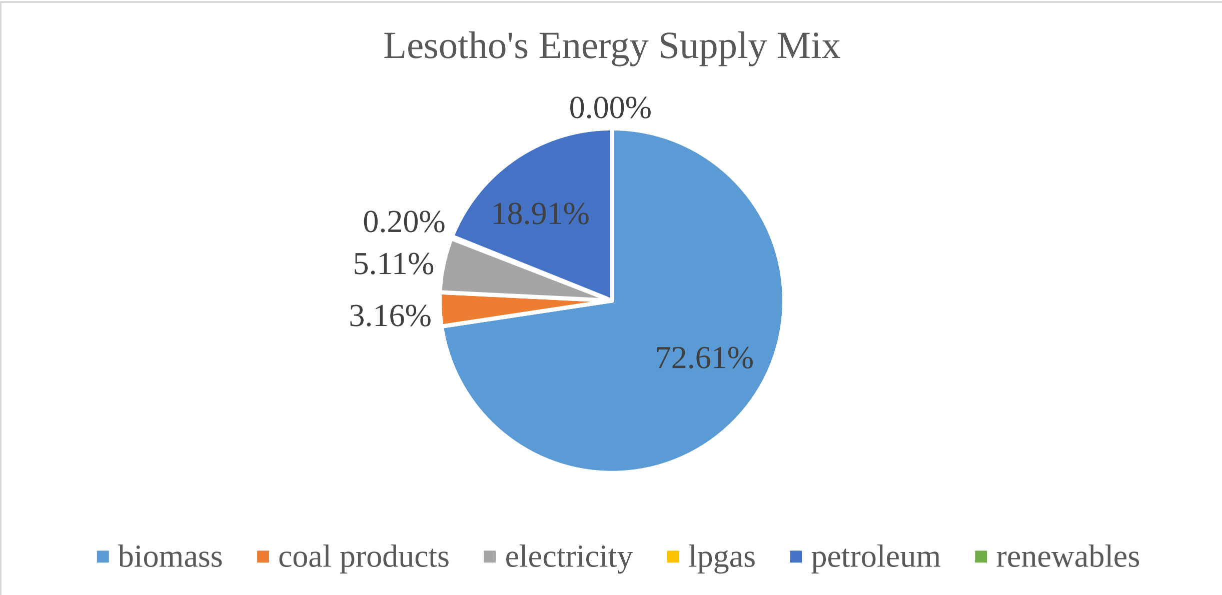


Figure 22. Lesotho's Energy Supply Mix in 2017

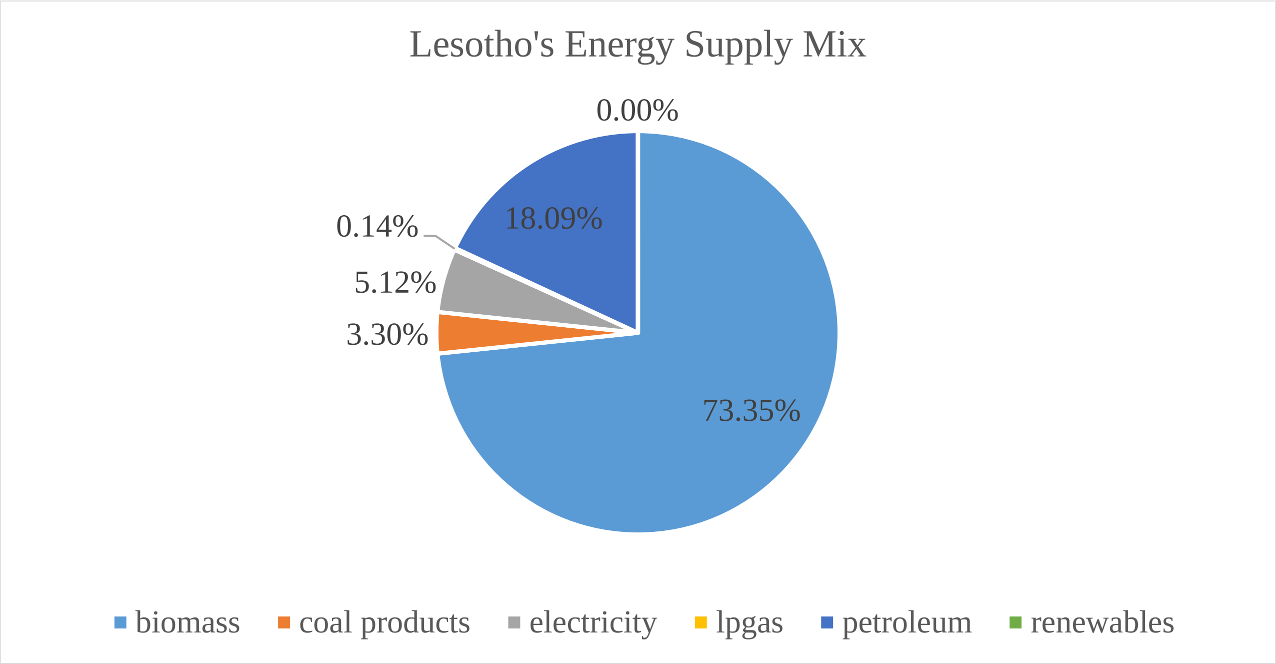


Figure 23. Lesotho's Energy Supply Mix in 2018

4.3.2 Security of Energy Supply

Although indigenous production ((local biomass – 1078.2 ktoe + 'Muela electricity – 43.3 ktoe + Renewables – 0.04 ktoe)/ 1499 ktoe = 75%) covers a larger portion of the supply source, it is mainly constituted by biomass which is being used inefficiently by Lesotho's marginalised population in the rural areas. The remaining 25% ((imported biomass – 10.039 ktoe + coal and coal products – 47.4 ktoe + imported electricity – 33.3 ktoe + petroleum fuel – 283.4 ktoe + lpgas – 2.939 ktoe)/1499 ktoe = 25%) of the energy supply is sourced from abroad as imports. This 25% is constituted by 100% of coal and coal products (47.4 ktoe), 100% of petroleum fuel (282.4 ktoe) and lpgas (2.939 ktoe) while a significant portion (33.3 ktoe imports/ 76.7 ktoe total = 43%) of electricity also comes as imports from Eskom and Electricity De Mozambique (EDM).

The country's energy supply from production is covered by 57% of electricity generation by 'Muela hydropower plant while exports shows an insignificant amount of 0.005% which is constituted by Lesotho Electricity Company (LEC) 's electricity trade through Southern African Power Pool (SAPP) as shown in **Figure 24** for 2017. There is more security of energy supply as most energy comes from local production, however larger portion of this comes from unsustainable biomass which covers (local biomass- 1078.2 ktoe/total local energy supply – 1122 ktoe = 96%) of local production. Moreover, biomass is not a suitable form of energy to be preferred due to its inefficient nature of use hence only 'Muela electricity and renewables are suitably preferred energy forms which covers (('Muela electricity – 43.3 ktoe + renewables – 0.04 ktoe)/total local energy supply – 1122 ktoe = 4%).

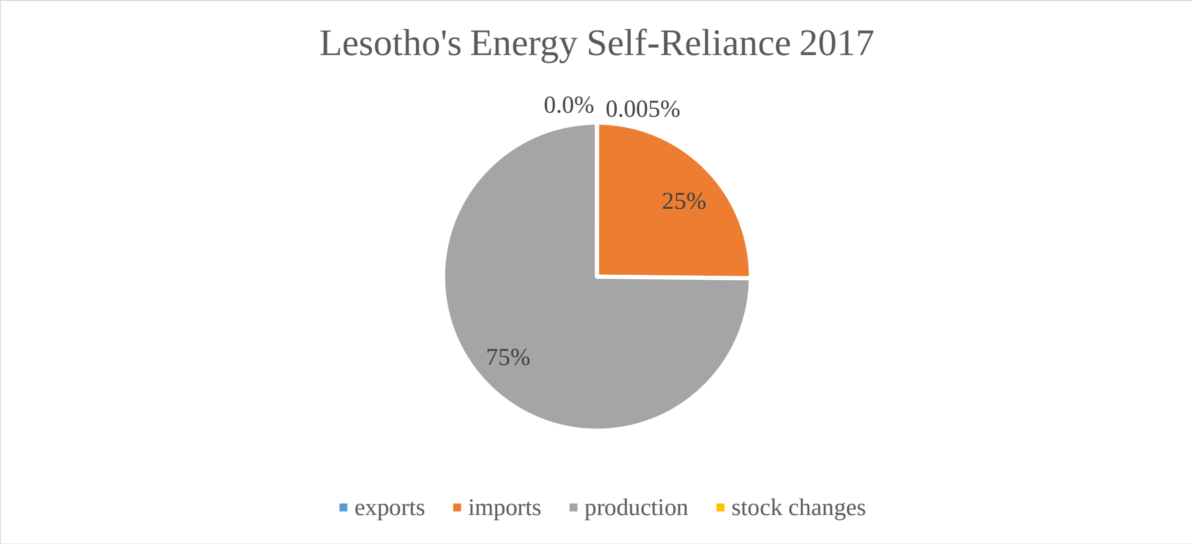


Figure 24. Lesotho's Energy Security of Supply in 2017.

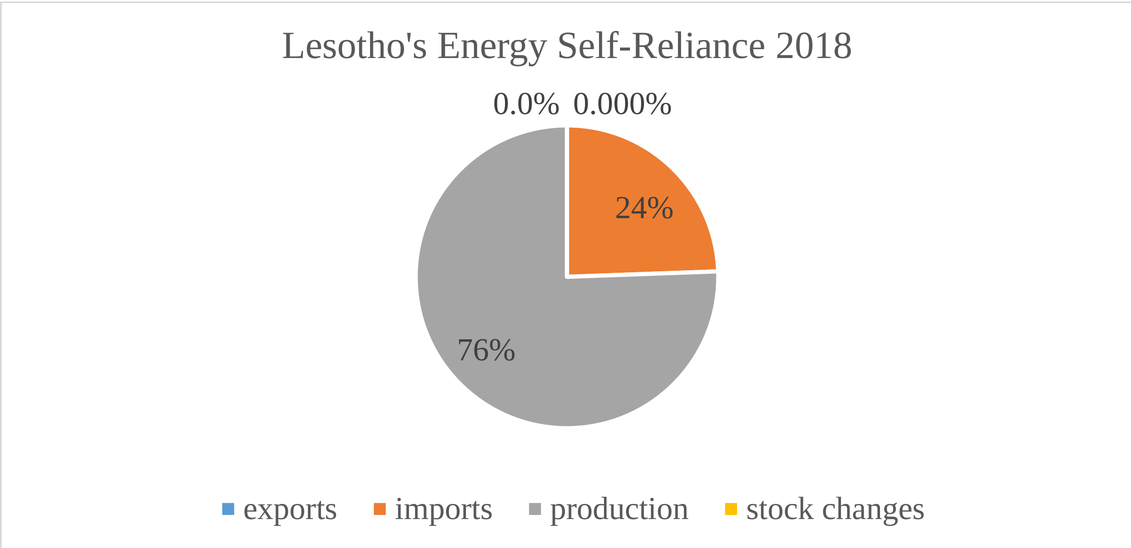


Figure 25. Lesotho's Energy Security of Supply in 2018.

The 2018 data still shows production as the major source of energy supply mainly contributed by biomass with ((local biomass -1089 ktoe + 'Muela electricity – 43.3 ktoe + renewables – 0.035 ktoe)/1499 ktoe =76%). The contribution of electricity supply from production remains unchanged with 57% covered by 'Muela hydropower and the remaining 43% covered by electricity imports from Eskom and EDM. The 100% of other energy carriers (coal and coal products, lpgas and petroleum fuel) still come as imports and imported biomass (10.093 ktoe) and imported electricity (33.3 ktoe) to constitute the ((coal and coal products – 49 ktoe + petroleum – 271 ktoe + lpgas – 2 ktoe + imported biomass – 10 ktoe + imported electricity – 33 ktoe)/1499 ktoe =24%) shown in **Figure 25**.

It is therefore worth noting that Lesotho cannot be ruled out of environment polluters' list as most of its energy comes from fossil fuels and biomass which is being used inefficiently without proper biomass technologies such as cook stoves. Even the major imported electricity from Eskom where generation is done through use of coal, strengthens the reasons for classifying Lesotho's one of the GHG emitters which pollutes the environment and consequently affects climate change.

5. Conclusion and Recommendations

5.1 Conclusion

In conclusion, the developed energy supply management system seems to have addressed the sound challenges raised in the research questions with regard to collection of energy data from supply perspective and also producing a national accounting framework around energy sector which are Energy Commodity Account and Energy Balance for the supply section. The system is able to capture energy products and store them in the database and therefore this clearly serves or meet the primary requirement of energy data collection and storage. This stored data can be retrieved for viewing and it can be used to produce ECA and EB for energy supply analysis of the country which helps decision makers to make sound decisions around energy sector.

Data for the years 2017 and 2018 were able to be captured on a user friendly user interface of the system and stored in the database. From the obtained results, biomass seems to be the major energy carrier supplied to the country with 73% of the energy supply mix for both 2017 and 2018. From the security of supply perspective, Lesotho has shown major percentages (75% and 76% for 2017 and 2018 respectively) of supply source from indigenous production. However, these are mainly contributed by biomass energy carrier which is used inefficiently by the major portion of population. Its supply is also not sustainable as there are no forests that could be harvested on regular basis for sustainable supply of wood, no significant livestock to provide sustained animal waste or no massive agriculture to provide crops residue as fuel.

The remaining 25% and 24% from imports in 2017 and 2018 respectively are contributed by 100% imports of lpgas, petroleum fuel and coal products as well as 43% electricity import. The imported 43% of electricity is constituted by LEC's bulk electricity purchase from Eskom and EDM while petroleum fuel imports are from South Africa's refineries and coal products are from South African mines. Consequently, it is worth noting that Lesotho's energy needs are mainly met through imports and this clearly indicates how the country's economy is being swept out of the country through imports of these energy carriers and this analysis alone sounds a call to decision makers around the energy situation to embark on intensifying domestic production of electricity through renewable energy technologies (RETs) whose exploration could turn things around thanks to ESMS. Finally, it is worth noting that the robustness and improved performance of this system will depend entirely on the energy's stakeholder's involvement and commitment in providing enhancement inputs on issues such as its level of security, system customization as well as its accessibility to the general public.

5.2 Recommendations

Shortcomings identified in the methodology are related to data that was used as input into the system. The system requires data to be captured on daily basis but the available data was aggregated in monthly and annual basis. It is therefore recommended that as data is being collected for different energy carriers, it should be captured on daily basis into the system such that exact amount of data for a specific day can be reflected in the system. Furthermore, the system requires data for different energy products to be captured in certain physical units, that is biomass, lpgas, coal and coal products should be captured in tonnes, electricity and renewables in megawatt hours while petroleum fuel in kilo litres. To avoid confusion of energy data's physical units as it is being captured into the system, it is recommended that energy data should be collected and captured in physical units required by the system.

It is worth bearing in mind that this thesis only concentrated on the data collection system development with more emphasis on the energy supply in Lesotho. It is therefore critical to incorporate all levels of energy flow from supply, transformation as well as final consumption such that the energy balance will be complete covering all energy flow level. Since this system's main objective is to ensure energy data availability in order to close the data gap around energy sector, this objective would not be entirely met if energy data collection cannot be implemented with some level of enforcement on concerned stakeholders.

This enforcement could be facilitated by passing this energy data collection exercise as an act of Parliament as it happens with most of the developed countries in Europe. This would mould and enhance energy sensitivity amongst key stakeholders in the energy sector as well as the entire society thereby causing energy data collection to become a culture. Furthermore, it is recommended that energy policy be effected so that key players in the energy sector could be effective based on the regulations or objectives presented and directed by policy.

Looking at the analysis of results from the ESMS system's produced energy balance for the years 2017 and 2018, it is clear that Lesotho has no security of supply of efficient and sustainable forms of energy as significant portion of its energy supply is met through imports. It is therefore imperative to put methods in place to enhance domestic production of electricity by exploring renewable energy technologies (RET) so that more production can be made from within the country. This would simultaneously address the issue of increasing more renewable energy resources penetration in the supply mix thereby answering the question of GHG emissions on the environment.

For stock change to have some value on different energy carriers especially those whose traces are not found in the country for exploration such as coal, natural gas and oil yet they form a significant part of Lesotho's energy supply mix in their refined form, it is recommended that they should be imported in their primary form and be transformed into secondary forms of energy in the country and possibly be used to produce other forms of energy.

It is further suggested that the system should allow for data capturing supplied by other systems hosted by Department of Energy (DoE), Lesotho Revenue Authority (LRA) and Lesotho Electricity Company (LEC). However, for purposes of this thesis other systems will not be required to supply such data. The system's (API) will be exposed to these systems for them to share data in the format that would be interpreted and stored in the ESMS's database. Data will be retrieved and viewed by any user via the user interface from which data sharing can happen by downloading both ECA and EB tables for user specified periods.

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Appendix

Database Script

```php
<?php

use Illuminate\Database\Migrations\Migration;
use Illuminate\Database\Schema\Blueprint;
use Illuminate\Support\Facades\Schema;

class CreateEnergyProductsTable extends Migration
{
    /**
     * Run the migrations.
     *
     * @return void
     */
    public function up()
    {
        Schema::create('energy_products', function (Blueprint $table) {
            $table->bigIncrements('id');
            $table->string("name");
            $table->float("quantity");
            $table->date("entry_date");
            $table->string("source");
            $table->timestamps();
        });
    }

    /**
     * Reverse the migrations.
     *
     * @return void
     */
    public function down()
    {
        Schema::dropIfExists('energy_products');
    }
}
```

EnergyProductControler Script

```php
<?php

namespace App\Http\Controllers;

use Illuminate\Http\Request;
```

```
use App\EnergyProduct;
use DB;


class EnergyProductsController extends Controller
{
    /**
     * Display a listing of the resource.
     *
     * @return \Illuminate\Http\Response
     */
    public function index(Request $request)
    {

        $dataYears = EnergyProduct::select(DB::raw('YEAR(entry_date) as year')
)
            ->orderby('year', 'DESC')
            ->distinct()
            ->get();

        $yearFilter = $request->input('year') ? $request-
>input('year') : $dataYears->first()->year;

        $yearsArray = $dataYears->pluck('year');

        $productsAll = EnergyProduct::whereYear("entry_date", $yearFilter)-
>get();



        $electricity = DB::table('energy_products')-
>select('name', 'source', DB::raw('quantity*0.000086 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'electricity')
            ->get();

        $biomass = DB::table('energy_products')-
>select('name', 'source', DB::raw('quantity*0.00009993 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'biomass')
            ->get();

        $lpgas = DB::table('energy_products')-
>select('name', 'source', \DB::raw('quantity*0.00009993 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'lpgas')
            ->get();
```

```php
        $renewables = DB::table('energy_products')-
>select('name', 'source', \DB::raw('quantity*0.000086 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'renewables')
            ->get();

        $coal = DB::table('energy_products')-
>select('name', 'source', \DB::raw('quantity*0.00009993 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'coal products')
            ->get();

        $petroleum = DB::table('energy_products')-
>select('name', 'source', \DB::raw('quantity*0.00009813 as convertedQty'))
            ->whereYear('entry_date', $yearFilter)
            ->where('name', 'petroleum')
            ->get();

        // =============== FILTERED DATA ===============
        $source = $request->input('source') == null || $request-
>input('source') == "all" ? null : $request->input('source');
        $productName = $request->input('product') == null || $request-
>input('product') == "all" ? null : $request->input('product');
        $fromDate = $request->input('from');
        $toDate = $request->input('to');



        $productsFiltered = \DB::table('energy_products')
            ->when($source, function ($query, $source) {
                return $query->where('source', '=', $source);
            })
            ->when($productName, function ($query, $productName) {
                return $query->where('name', '=', $productName);
            })
            ->when($fromDate, function ($query, $fromDate) {
                return $query->where('entry_date', '>=', $fromDate);
            })
            ->when($toDate, function ($query, $toDate) {
                return $query->where('entry_date', '<=', $toDate);
            })
            ->get();


        $energyBalance = $electricity->concat($biomass)->concat($lpgas)-
>concat($renewables)->concat($coal)->concat($petroleum);
        return view("products.index", [
            "productsAll" => $productsAll,
            "energyBalance" => $energyBalance,
```

```
            "productsFiltered" => $productsFiltered,
            "availableYears" => $yearsArray,
            "filterYear" => $yearFilter
        ]);
    }
    public function indexApi()
    {
        return EnergyProduct::all();
    }

    /**
     * Show the form for creating a new resource.
     *
     * @return \Illuminate\Http\Response
     */
    public function create()
    {
        return view("products.create");
    }

    /**
     * Store a newly created resource in storage.
     *
     * @param  \Illuminate\Http\Request  $request
     * @return \Illuminate\Http\Response
     */
    public function store(Request $request)
    {
        $request->validate([
            'quantity' => 'required'
        ]);
        EnergyProduct::create([
            "name" => $request->product,
            "source" => $request->source,
            "quantity" => $request->quantity,
            "entry_date" => $request->date
        ]);

        return  redirect(route("product.index"));
    }
    /**
     * Display the specified resource.
     *
     * @param  int  $id
     * @return \Illuminate\Http\Response
     */
    public function show($id)
    {
```

```
        //
    }

    /**
     * Show the form for editing the specified resource.
     *
     * @param  int  $id
     * @return \Illuminate\Http\Response
     */
    public function edit($id)
    {
        //
    }

    /**
     * Update the specified resource in storage.
     *
     * @param  \Illuminate\Http\Request  $request
     * @param  int  $id
     * @return \Illuminate\Http\Response
     */
    public function update(Request $request, $id)
    {
        //
    }

    /**
     * Remove the specified resource from storage.
     *
     * @param  int  $id
     * @return \Illuminate\Http\Response
     */
    public function destroy($id)
    {
        //
    }
}
```

Products Create Script

```
@extends("layouts.app")

@section("content")
```

```
<div class="container">
@if ($errors->any())
    <div class="alert alert-danger">
        <ul>
            @foreach ($errors->all() as $error)
                <li>{{ $error }}</li>
            @endforeach
        </ul>
    </div>
@endif


{!! Form::open(['url' => 'products/create']) !!}
{!!Form::token() !!}
   <div class="form-group">
    <label for="1">Energy Product Name</label>
   {!! Form::select('product',['biomass'=>'Biomass','coal'=>'Coal','electricit
y'=>'Electricity','lpgas'=>'LPGas','petroleum'=>'Petroleum','renewable'=>'Rene
wable']
           ,null,['id'=>'1' ,'class' => 'form-control'])!!}
  </div>
  <div class="form-group">
    <label for="2">Energy Product Source</label>
   {!! Form::select('source',['production'=>'Production','imports'=>'Imports',
'exports'=>'Exports','stockchange'=>'Stock Change']
           ,null,['id'=>'2' ,'class' => 'form-control'])!!}
  </div>
  <div class="form-group">
    <label for="3">Quantiy</label>
   {!! Form::text('quantity',null,['id'=>'3' ,'class' => 'form-control'])!!}
  </div>

  <div class="form-group">
    <label for="input2">Entry Date</label>
   {!! Form::date('date', \Carbon\Carbon::now(),['id'=>'3' ,'class' => 'form-
control'])!!}
  </div>
  <div class="form-group">
   {!!Form::submit('Submit',["class"=>"btn btn-primary"])!!}
  </div>
{!! Form::close() !!}
</div>
@endsection
```

Index-blade Script

Page-layout Script

```
<!doctype html>
<html lang="{{ str_replace('_', '-', app()->getLocale()) }}">
<head>
    <meta charset="utf-8">
    <meta name="viewport" content="width=device-width, initial-scale=1">

    <!-- CSRF Token -->
    <meta name="csrf-token" content="{{ csrf_token() }}">

    <title>{{ config('app.name', 'Laravel') }}</title>

    <!-- Scripts -->
    <script src="{{ asset('js/app.js') }}" defer></script>

    <!-- Fonts -->
    <link rel="dns-prefetch" href="//fonts.gstatic.com">
    <link href="https://fonts.googleapis.com/css?family=Nunito" rel="styleshee
t">

    <!-- Styles -->
    <link href="{{ asset('css/app.css') }}" rel="stylesheet">
</head>
<body>
    <div id="app">
        <nav class="navbar navbar-expand-md navbar-light bg-white shadow-sm">
            <div class="container">
                <a class="navbar-brand" href="{{ url('/') }}">
                    {{ config('app.name', 'Laravel') }}
                </a>
                <button class="navbar-toggler" type="button" data-
toggle="collapse" data-target="#navbarSupportedContent" aria-
controls="navbarSupportedContent" aria-expanded="false" aria-
label="{{ __('Toggle navigation') }}">
                    <span class="navbar-toggler-icon"></span>
                </button>

                <div class="collapse navbar-
collapse" id="navbarSupportedContent">
                    <!-- Left Side Of Navbar -->
                    <ul class="navbar-nav mr-auto">

                    </ul>

                    <!-- Right Side Of Navbar -->
                    <ul class="navbar-nav ml-auto">
                        <!-- Authentication Links -->
                        @guest
                            <li class="nav-item">
```

```
                                <a class="nav-
link" href="{{ route('login') }}">{{ __('Login') }}</a>
                            </li>
                            @if (Route::has('register'))
                                <li class="nav-item">
                                    <a class="nav-
link" href="{{ route('register') }}">{{ __('Register') }}</a>
                                </li>
                            @endif
                        @else
                            <li class="nav-item dropdown">
                                <a id="navbarDropdown" class="nav-
link dropdown-toggle" href="#" role="button" data-toggle="dropdown" aria-
haspopup="true" aria-expanded="false" v-pre>
                                    {{ Auth::user()-
>name }} <span class="caret"></span>
                                </a>

                                <div class="dropdown-menu dropdown-menu-
right" aria-labelledby="navbarDropdown">
                                    <a class="dropdown-
item" href="{{ route('logout') }}"
                                       onclick="event.preventDefault();
                                                     document.getElementById('
logout-form').submit();">
                                        {{ __('Logout') }}
                                    </a>

                                    <form id="logout-
form" action="{{ route('logout') }}" method="POST" style="display: none;">
                                        @csrf
                                    </form>
                                </div>
                            </li>
                        @endguest
                    </ul>
                </div>
            </div>
        </nav>

        <main class="py-4">
            @yield('content')
        </main>
    </div>

    <link href="https://cdn.webdatarocks.com/latest/webdatarocks.min.css" rel=
"stylesheet"/>
```

```
<script src="https://cdn.webdatarocks.com/latest/webdatarocks.toolbar.min.js">
</script>
<script src="https://cdn.webdatarocks.com/latest/webdatarocks.js"></script>

  @yield('page-script')
</body>
</html>
```