Department of Energy
Politecnico di Milano

Milan, 30th May 2023

Project Work Report
Electricity planning for Sub-Saharan countries

Course of Thermoeconomics and Energy Modelling
AA. 2022-2023

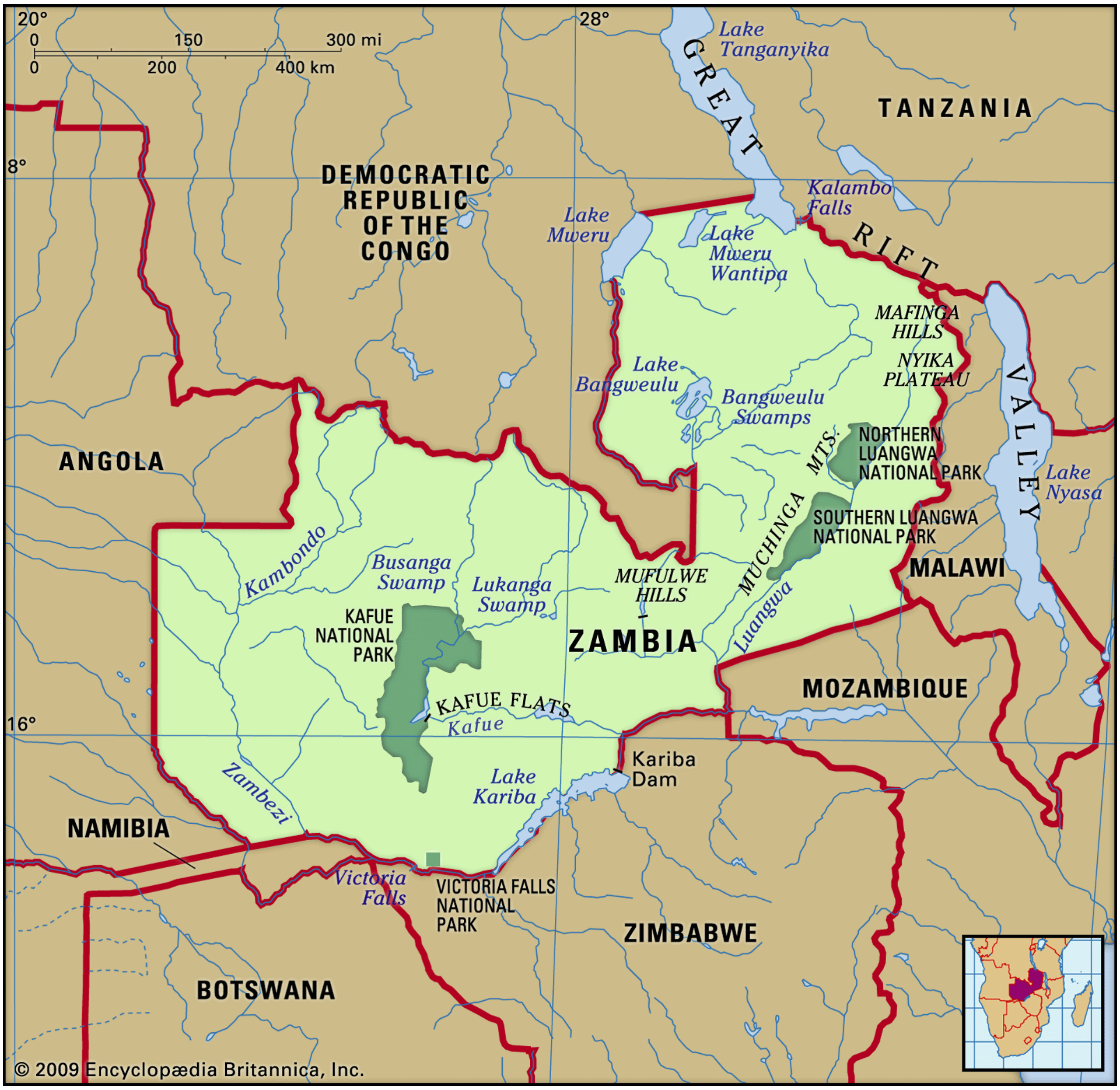
Group 21

Zambia

Virginia Fiameni 223022
Andrea Giudici 233469
Seyed Kian Jafarinejad 215413
Paola Latini 225984
Giuseppe Mastrangelo 226528
Shyno Varghese 221989

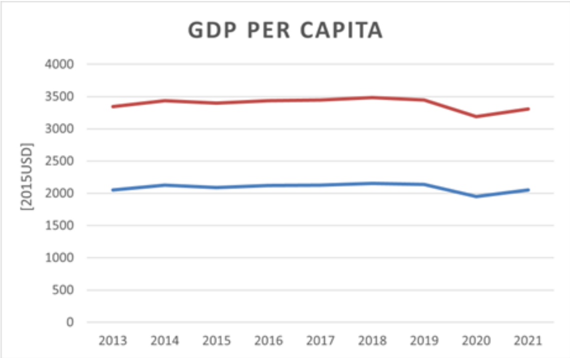
Outline

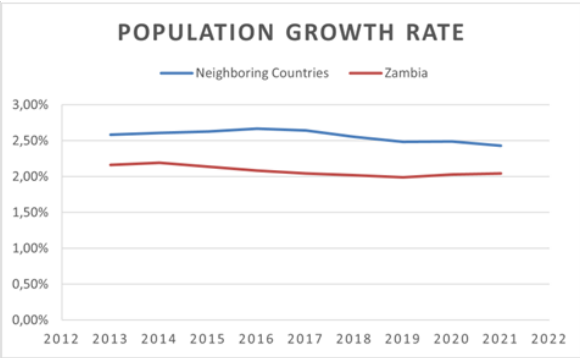
Introduction



POPULATION	19.380 million
GDP	24.09 B$
ENERGY INTENSITY	18.80 GJ/k$
CO2 INTENSITY	0.28 kg/$
CO2 EMISSION	6.65 Mt
ELECTRIC PENETRATION	0.12

Zambia is a landlocked country situated in Sub-Saharan Africa along the equator line, with a GDP of 24,09 billion 2015 USD and a rapidly growing population of 19,380 million inhabitants which is for the most part localized in the central region, while the Western and Eastern regions are scarcely populated. The population growth rate of Zambia has been constantly increasing in the last decade, together with neighbouring countries, while the GDP per capita has not shown any significant growth, but instead it has been negatively affected by the COVID pandemic, as in the whole continent.





The climate of Zambia is characterized by a distinction between dry and wet seasons, with the heaviest rainfalls experienced from January to March and almost absent precipitations from May to October, negatively affecting the Hydroelectric power plants production all over the country.

In fact, 84% of the energy demand is met by Hydro, while Coal and Diesel respectively account for 11% and 4%, with a small capacity of Solar PV recently installed covering the remaining part of the demand.

The exploitation of the country’s large availability of water through Hydro power is responsible for a high penetration of renewable energy. However, this has recently proven to be a threat to Zambia’s energy security, as droughts already represent a frequent reality in this region. To shift towards a more reliable energy mix with a lower dependency on Hydro, while maintaining a sufficient contribution from renewable sources, the investment program “GET FiT Zambia” is encouraging investments in Solar PV and Wind power plants. The introduction of these technologies could indeed represent an opportunity for the country to become a net energy exporter in the future by making the most of Zambia’s abundant solar irradiation in the south-western region, and the possibility of exploiting the wind in the northern part of the country. In fact, in the previous decades Wind power solutions were considered infeasible due to the lack of wind at low altitudes, but now, technological advancements and the consequent decreasing trend of wind power’s LCOE made it a valid alternative to fossil fuels.

However, the implementation of non-dispatchable RES could suffer from changes in the weather conditions and for this reason, the need for fossil fuel power plants is still present in order to keep the overall capacity factor at acceptable levels: the designated strategy to cope with this issue while tackling the lack of a reliable low-voltage grid and addressing the problem of a very low access to electricity in rural regions is to build interconnected microgrids based on Solar PV, Wind and Diesel plants. Some parts of the country are indeed characterized by a substantial lack of electric connection, thus leading to the use of conventional biomass instead of cleaner and safer cooking methods, in addition to not being able to power any of the essential domestic appliances.

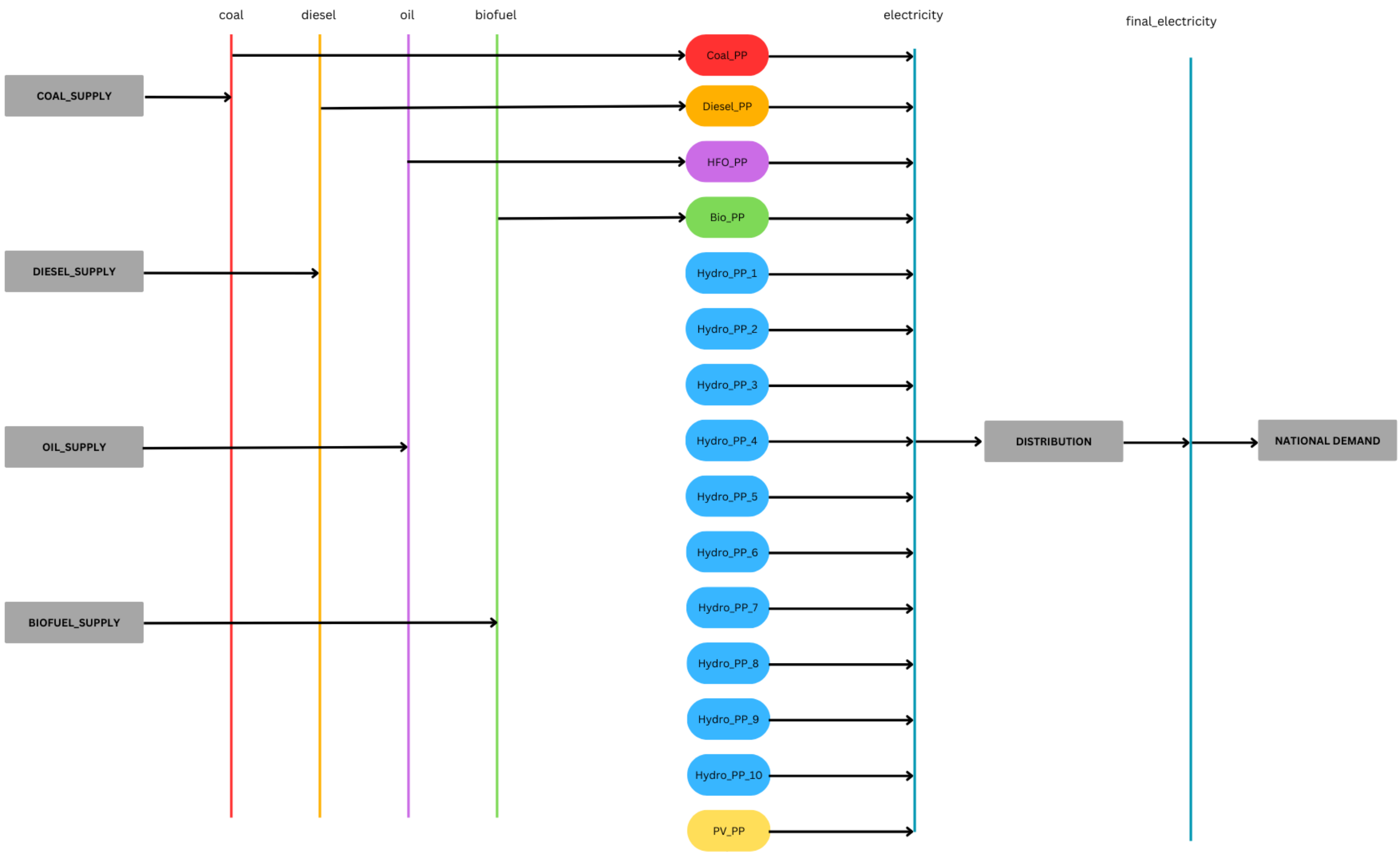
1. Define the problem of interest and gather relevant data

Zambian power sector in 2019 was capable of generating around 11 billion kWh/year, with exchange between neighbouring regions both in export (during the period in which hydro power plants are more reliable) and import (in seasons in which those resources are less available). Namibia and Zimbabwe are the main partners in these fundamental interconnections, coupled with the active participation in the Southern African Power Pool, with the aim of improving the security of supply in African regions.
Considering the situation of power production in the first year of the analysis, it is observed that most of it is concentrated in the central region. It can be also noticed that the country has based its production mainly on hydropower, that covers around 85% of the total generated power.
Other relevant players in the energy production are one coal power plant (Maamba), with 300MW maximum capacity installed and some Heavy Fuel Oil plants (105MW) mainly present in the central region. As far as renewables are concerned, despite the high potential of the county, the installation of PV power plants has only started a few years ago, leading to an 88MW power plant constructed in recent years. (1) The use of biomass has not really been considered in the energy programs, with only 4MW available to the grid.
This electricity production share can be compared with the geography in which Zambia is located. Looking at the neighbouring countries, it can be seen that renewable electricity share is higher, due to the huge hydropower production, but it will drastically drop if we remove hydro from the evaluation.
However, the exploitation of hydro power potential seems to stay a big part of the Zambian energy agenda, with an additional 1200MW power plant already committed in the Batoka Gorge North plant and in Kafue Gorge, an expansion of 750MW estimated to end in 2025. Small new hydro power plants will be built in the eastern region (around 100MW). (2)
Considering the negative possible outcomes regarding the reliability of electricity produced with hydro in the continent due to the climate change, the necessity of a diversification of production is clear. One of the main Zambian goals is reaching a diversification of the energy sector, that would include a lower percentage of hydro power generation to support the inconsistent availability of this energy source. In order to pursue this goal, an expansion of the photovoltaic generation has been commissioned in the central and western regions (installing a total capacity of 620MW before the end of 2024), part of which comes from "GET FiT" program. Furthermore, the potential of wind has been recently re-evaluated in the southern-east region, thanks to the new technology that allows the exploitation of mid- velocity wind at moderate height. This has resulted in the intention of installing 330MW of wind farms by 2023. It has also been considerations in defining the construction of a new small geothermal power plant of 10MW. (2)
Among these signed pledges is the 2016 Paris agreement, which obligates all the committed countries to have a net-zero CO_2 emissions by 2050. (2)
This implies the most ambitious goal of meeting the national demand by 2030 (being totally self-dependent from electricity point of view), while reducing CO_2 emissions dramatically.
There are, however, several difficulties.
First, the population growth trend indicates a higher demand projection in the upcoming years, reaching more than 2.5TW of annual on-grid demand by 2030. (1)
Secondly, the development of energy sector cannot be done without an effective improvement on national grid, which is a big problem of the country. Low distribution and limited efficiency of the lines makes it hard to be relied on by industrial and non-industrial sectors. Part of the allocated funds is already invested to renovate old grid lines and to build new ones, mainly in the less served eastern and western regions, that sometimes could be subjected to shortages in low-production seasons, if not importing energy.
Lastly, the policymakers mindset about the access to electricity shows the will to reach 51% of access in rural areas by 2030. This great challenge has been supported by several projects and funds in the construction of stand-alone PV and mini grids, which base their production both on wind and solar energy. The final goal is to connect these small islands to the existing grid to create a stronger transmission in the country. (2)
These are all valid but difficult to answer questions, that need to be considered to plan a bright future for Zambia.

2. Prepare the application of the model: Energy System definition and policy Implementation with Hypatia

Looking at the map of population intensity of Zambia, and the grid connections and the points of urban and non-urban areas, we decided to divide Zambia in three regions: Central, Eastern & Western, with Central region having the most dense population and share of energy production, and Eastern & Western regions being less served. To get more precise results, we also implemented the regional division to the demand of electricity, based on the population of each region. Due to this division, we had to consider the connections between the regions. The calculations and assumptions regarding this division and infrastructure of grid is mentioned in the appendices. (A1)
Based on the information on existing power plants, we were able to create the Reference Energy System. For capacity factors, we used the exact location of each hydro and PV power plants to keep things as precise as possible. After these decisions, we started modelling.

The Reference energy system was designed for 2019, based on the existing plants and then modified to respond to the new needs coming from the planning.



Global RES for Zambia, 2019

Firstly, to understand the current situation of the energy sector of Zambia, we used the operation mode of Hypatia. Then, we started modelling some scenarios, using the planning mode of Hypatia. With each scenario, we tried to either project the future, or implement the policies. Lastly, with our final scenarios, we try to tackle most of the problems of Zambia's energy sector, by suggesting our own ideas optimized by Hypatia.

1) BAU

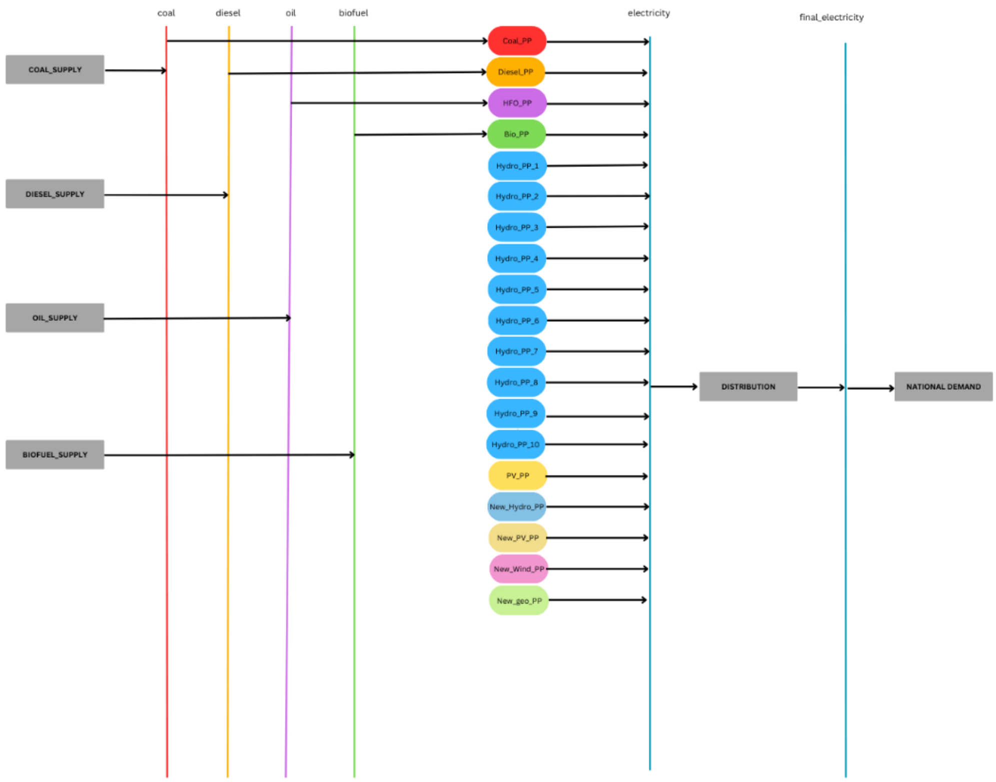
The first scenario, known as the Business-as-Usual (BAU) scenario, serves as a projection of the sector's behaviour based on previous trends in technology implementation. The scenario anticipates an increase in emissions due to the continued utilization of HFO and Coal Power Plants.

Under the Business-as-Usual scenario, the installation of new photovoltaic power plants, coal-based power plants, heavy fuel oil-based power plants, and hydroelectric power plants is permitted in some regions to accommodate the projected increase in electricity demand. Demand in each region & year is projected by us, based on the predictions available on the growth of Population and improved access to electricity. More details on that in the appendices. (A2)

Based on the past trend of adding new capacity, we put a Max_Capacity limit for each year in the future to get a "Business as Usual" projection for the future.

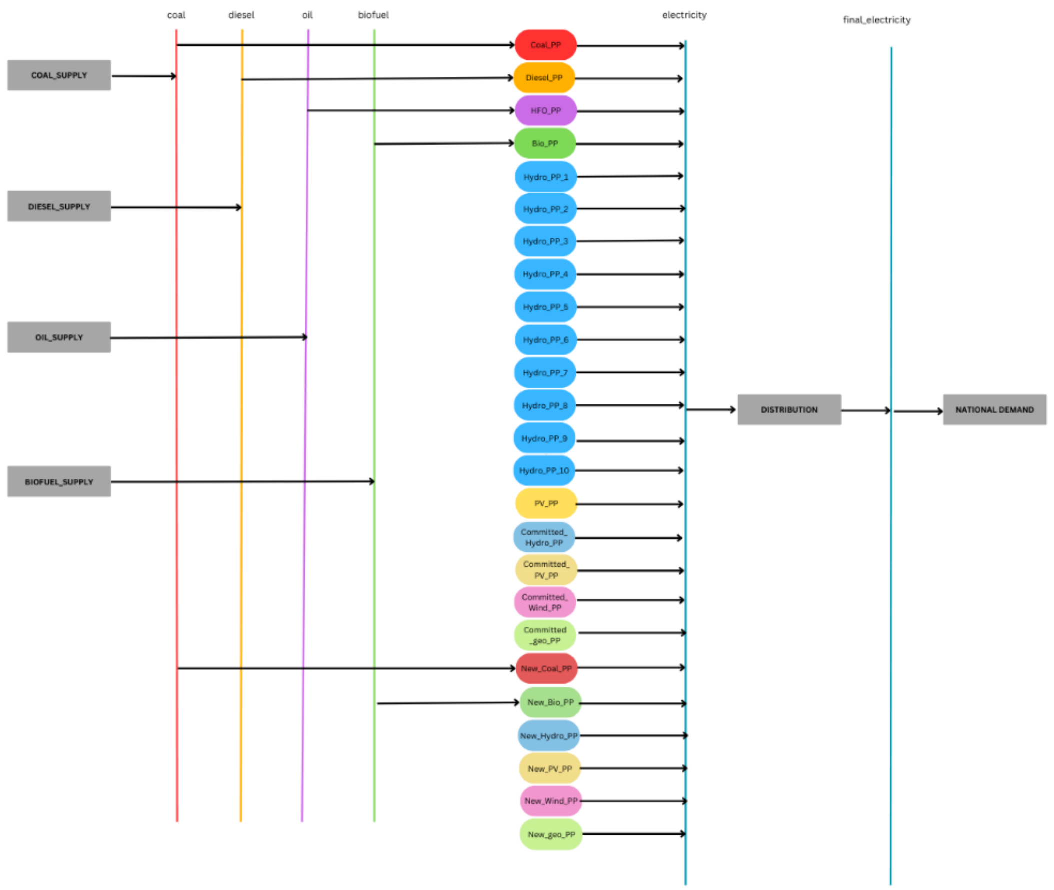
2) STEPS

In the STEPS scenario, the focus shifts towards examining the implications of policies that have already been signed. That includes all the power plants they have already committed to build (most of them already paid for). In addition, as we had no information about the policies that may be committed in the upcoming years, we had to make some assumptions on the possible upcoming committed policies, to keep our scenario realistic. In the scenario, a CO2 cap limit is imposed for 2030 based on policy guidelines, requiring a 25% reduction compared to the 2010 emissions levels. The emissions trend is developed using cubic interpolation, resulting in a gradual decrease in emissions over time. More details on how we calculated the CO2 emissions cap can be found in appendices. (A3)



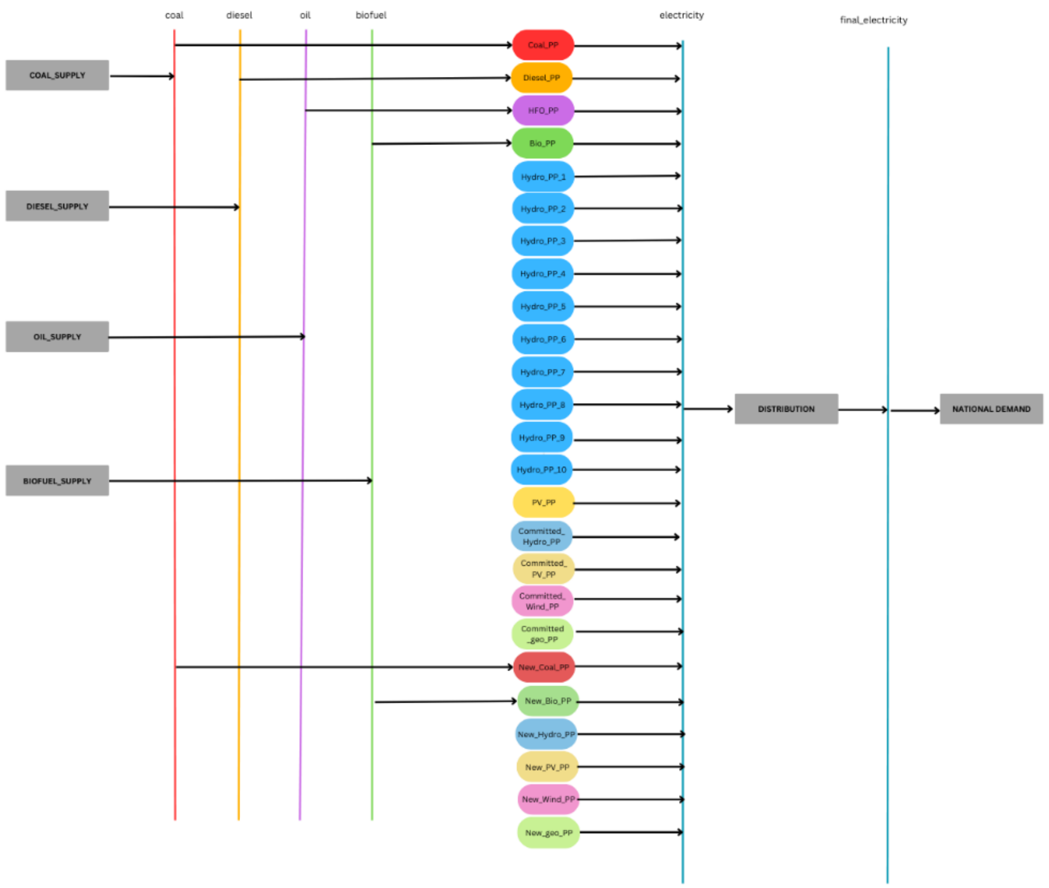
3) Announced Pledges

In this scenario, we implement a very optimistic framework by considering that all the announced pledges by the government of Zambia will be met. In addition to committed power plants, this scenario also includes the candidate power plants to be added in the future, and the ambitious policy of “meeting the national demand by 2030 & be a net exporter of electricity” be achieved. This scenario results in an energy mix, with a strong emphasis on renewable energy sources, including wind and solar power. Regions 2 and 3 prioritize the implementation of these renewable technologies to reduce their dependence on energy imports from region 1. The deployment of such renewables not only contributes to environmental sustainability but also enhances regional energy security and resilience.
Of course, we kept the emission CO2 cap, and let Hypatia find the optimal solution for reaching all policies. Please note that we did limit Hypatia by some realistic constraints, such as limiting the geothermal power plants capacity (as Zambia’s potential in geo energy is considered to be very low) and limiting the new capacity that can be added to the power sector each year close to a realistic value.



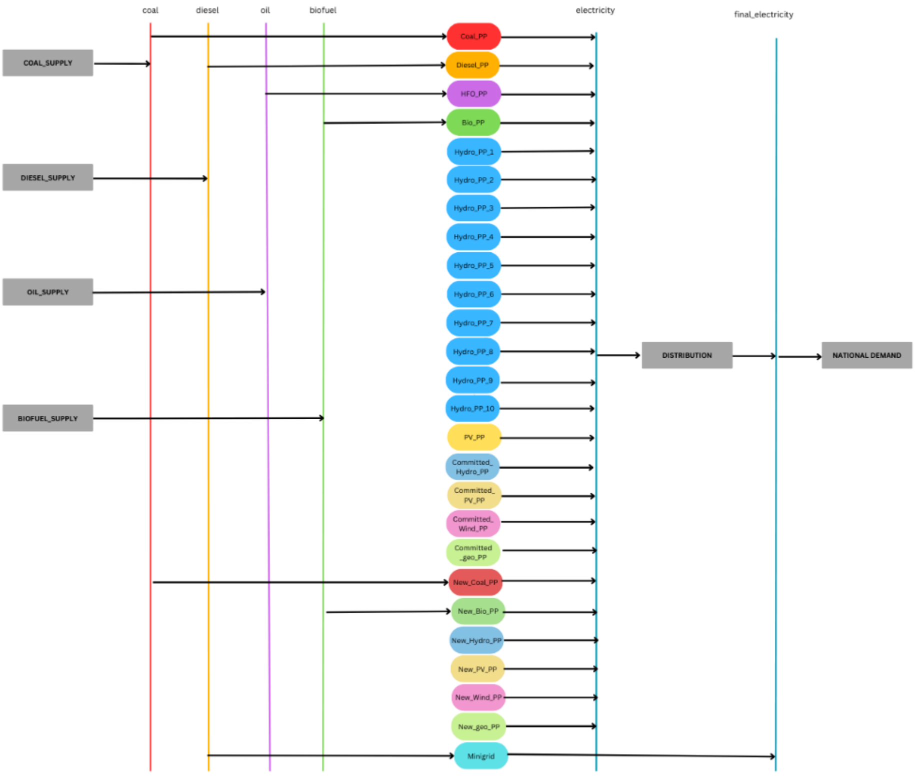
4) Diversification

In response to the imperative of diversifying the energy mix, the Diversification scenario offers a compelling solution. This scenario aims to reduce the share of hydroelectric power in the overall energy mix to below 50% by 2030, to increase reliability of electricity production. We let Hypatia make the decisions to find the optimal way to solve the issues. However, we limit its choices by some logical values to get better results. We used a tool in Hypatia to reduce the hydro power share of electricity generation under 50%. For more details on how we made that possible, you can check the appendices. (A4). On top of that, as we did not want Hypatia to exploit PV power plants unrealistically, we put a maximum land usage limit for this technology. For this limit we made some calculations regarding the area of each region and the area of protected areas in Zambia. More information is availableat appendices. (A5)
We made sure that the national demand is fully met by 2030, while keeping the CO2 emissions lower than the calculated cap.



5) Introducing Mini grids

Although the last scenario solved most of the on-grid problems, there is still one big problem left. One of the biggest challenges in Zambia is the low access to electricity, specially in the rural areas. To tackle this problem, we suggest the use of Mini grid islands in Eastern & Western regions, to not only improve the access to electricity, but also planning a possibility of connecting these islands to the main grid. For the mini grid island, we suggest a combination of PV solar panels, wind turbine, diesel engines and batteries for storage. A detailed scheme of this suggested island and how we were able to implement this technology to Hypatia, is explained in the appendices. (A6). This scenario considers the On-grid Zambia as one region, and two suggested mini grid islands in east and west as two regions, with their own dedicated electricity demand. (A1)



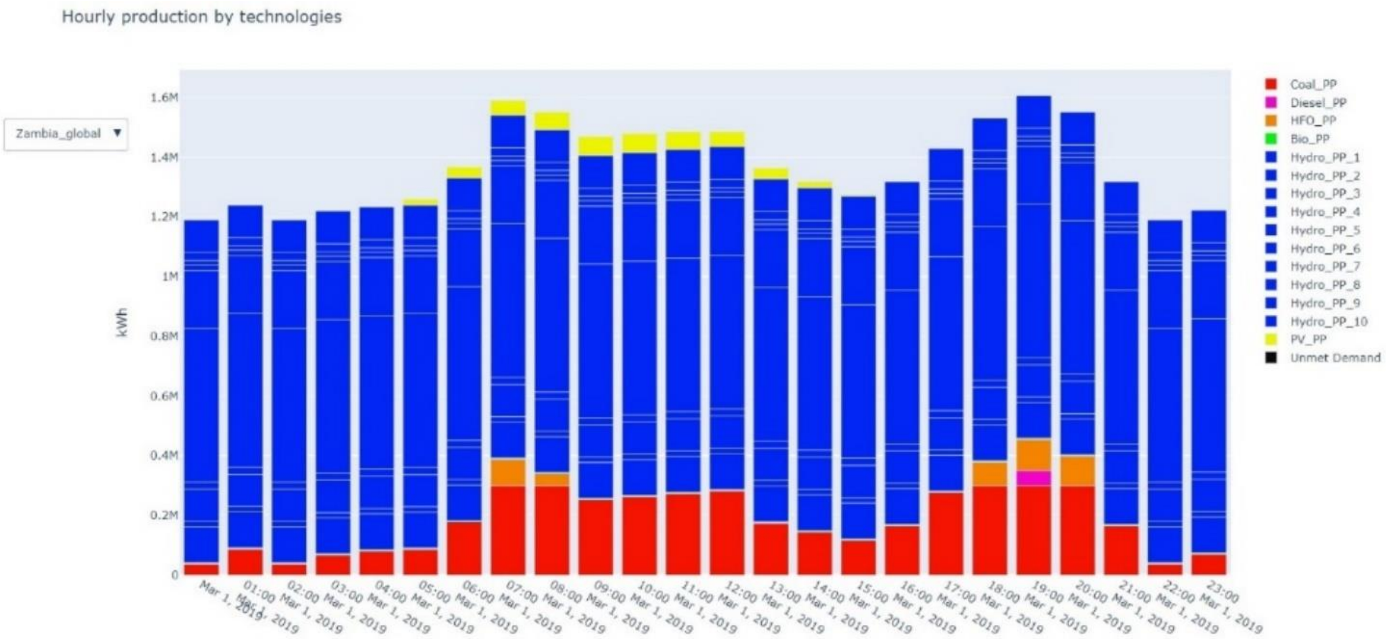
6) HRES Mini grids

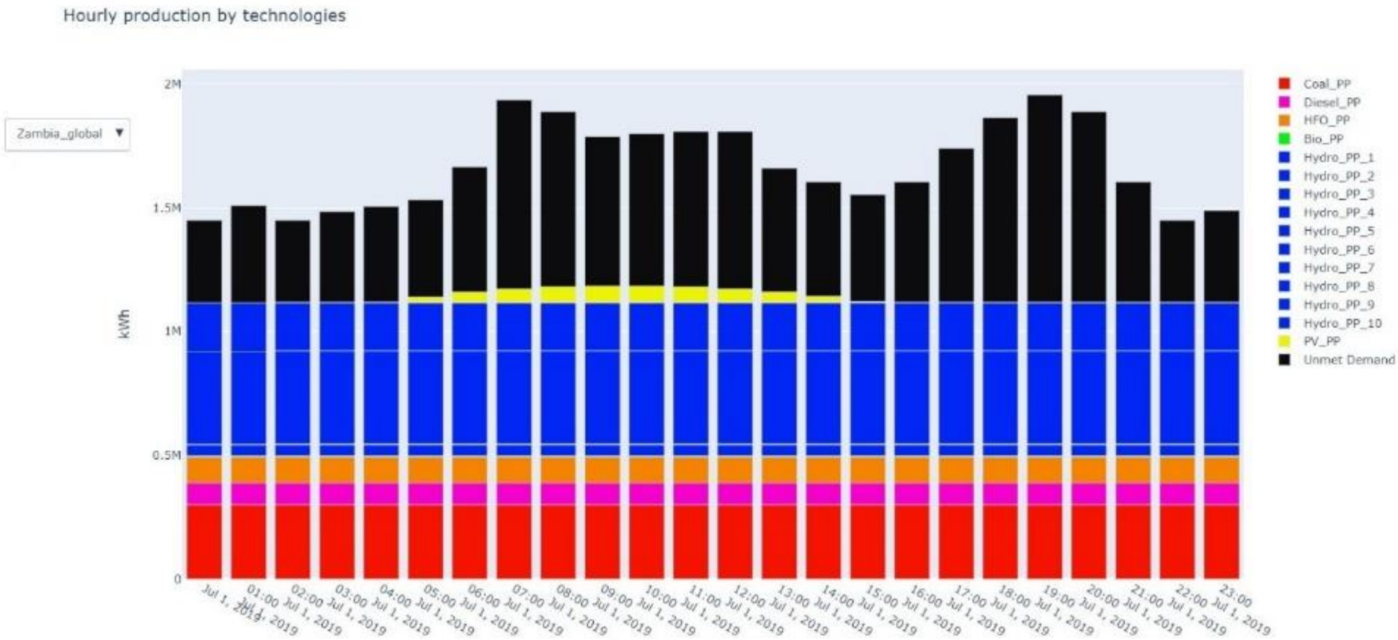
Despite tackling most of the energy sector's problems in Zambia, we were not satisfied with the configuration of the mini grid, as it involves diesel engines, that firstly, they do not have in their own country and must import, and secondly, produces CO2. Therefore, in this last scenario we suggest a different kind of mini grid configuration, known as HRES. In this configuration, the diesel engine is replaced by an electrolyser. We can use the abundance of water available in Zambia to produce H2 using an electrolyser, and this H2 will be used in a fuel cells, instead of diesel engines, to compensate for the seasonal and daily changes in capacity factors of PV panels and wind turbines. More detailed information about this scenario is available in the appendices. (A7)
Unfortunately, due to the lack of time, we were not able to implement this scenario to Hypatia and get results. However, the idea was worth mentioning.

*All data used in the implementations (parameters used in Planning mode of Hypatia) were taken from the following references. (3)(4)(5) This includes values for fixed & variable costs, increasing costs of fuels, lifetime, technical efficiency & others. For the discount rate, we used the Bond's interest rate in Zambia.

3. Critical analysis of the results and policy recommendations

The "Operation" phase serves as a comprehensive scenario and analysing it describes the prevailing situation of the energy sector in the country. It can be seen, that in some months (like March), because of the higher capacity factor for Hydro power plants, the national demand is met. On the other hand, in several months (such as July), we observe a large portion of demand not met.

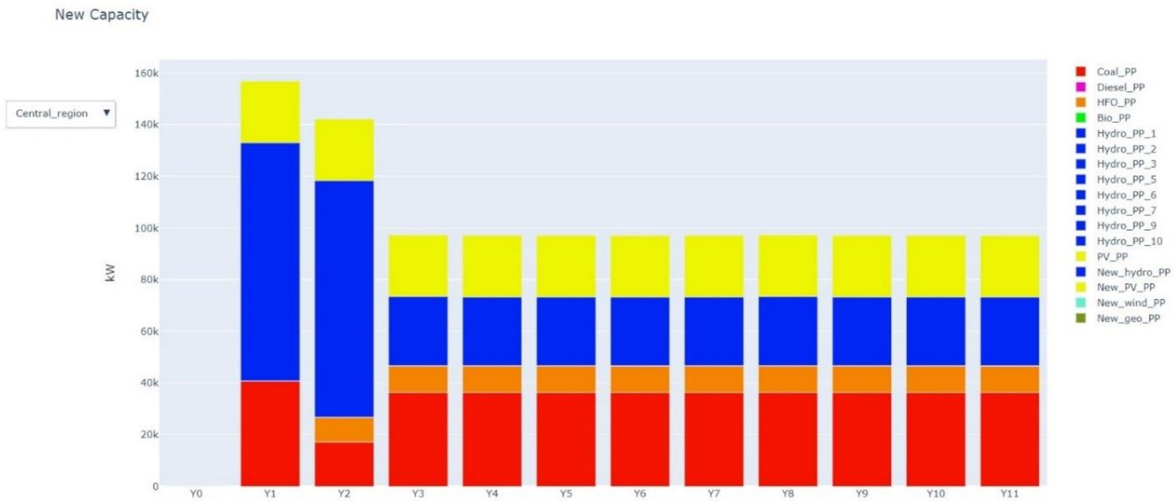


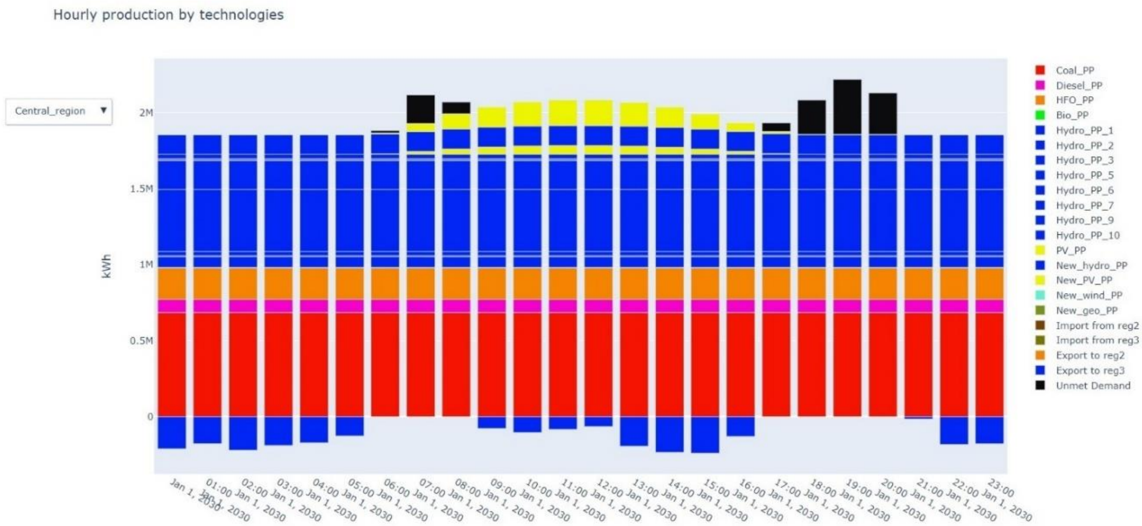


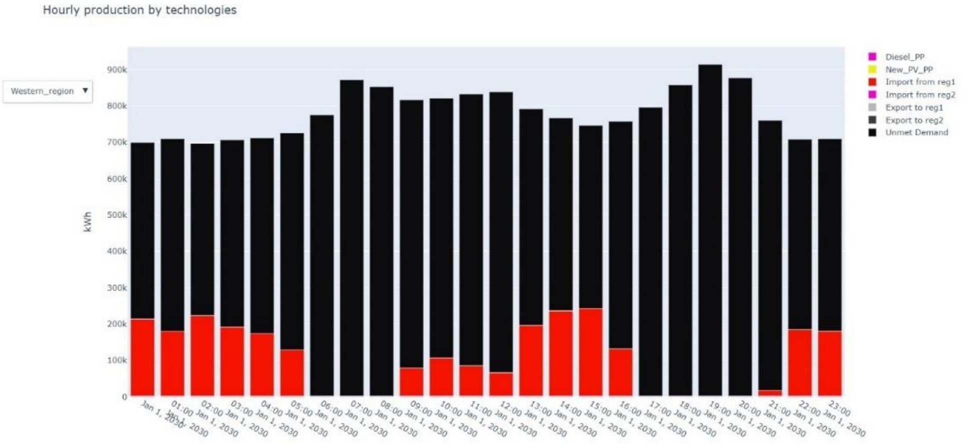
1) BAU

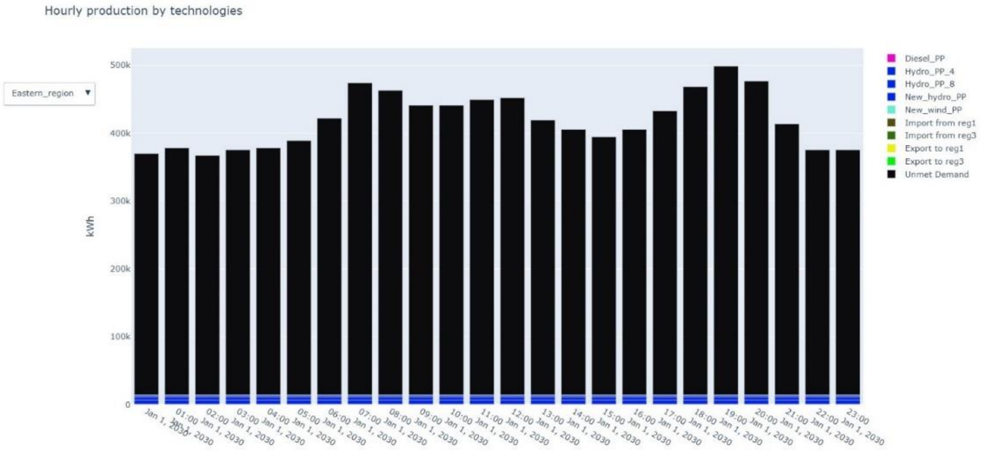
Proceeding with the "business as usual" approach is not the best idea. The demand in all three regions grows at a faster rate than the installed capacity, leading to a higher unmet demand in 2030 compared to 2019. This situation highlights the need to address the challenge of installing additional capacity in regions 2 and 3 and improving the transmission infrastructure. Hypatia selects HFO and coal as preferred options due to their lower cost. As a result, not only we cannot meet the national demand by a large margin, but we are also emitting much larger amounts of CO2. The production by different technologies increases in line with the anticipated projection.

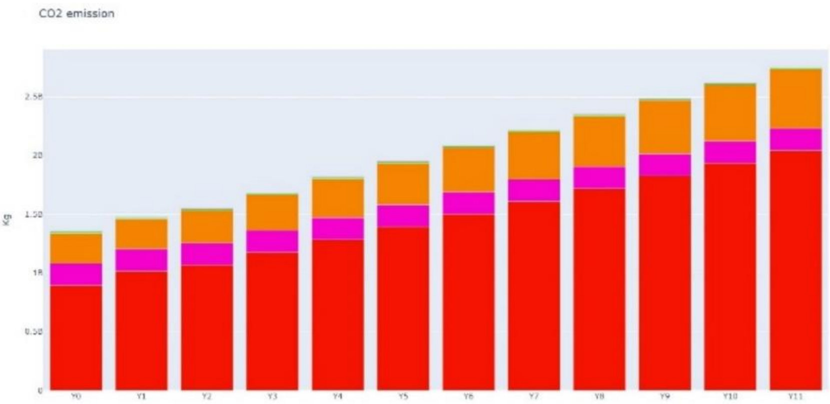
Net Present Cost	
11908000466	$
11.90800047	billion$






Hourly production by technologies
Western_region
kWh
900k
800k
700k
600k
500k
400k
300k
200k
100k
0
Diesel_PP
New_PV_PP
Import from reg1
Import from reg2
Export to reg1
Export to reg2
Unmet Demand

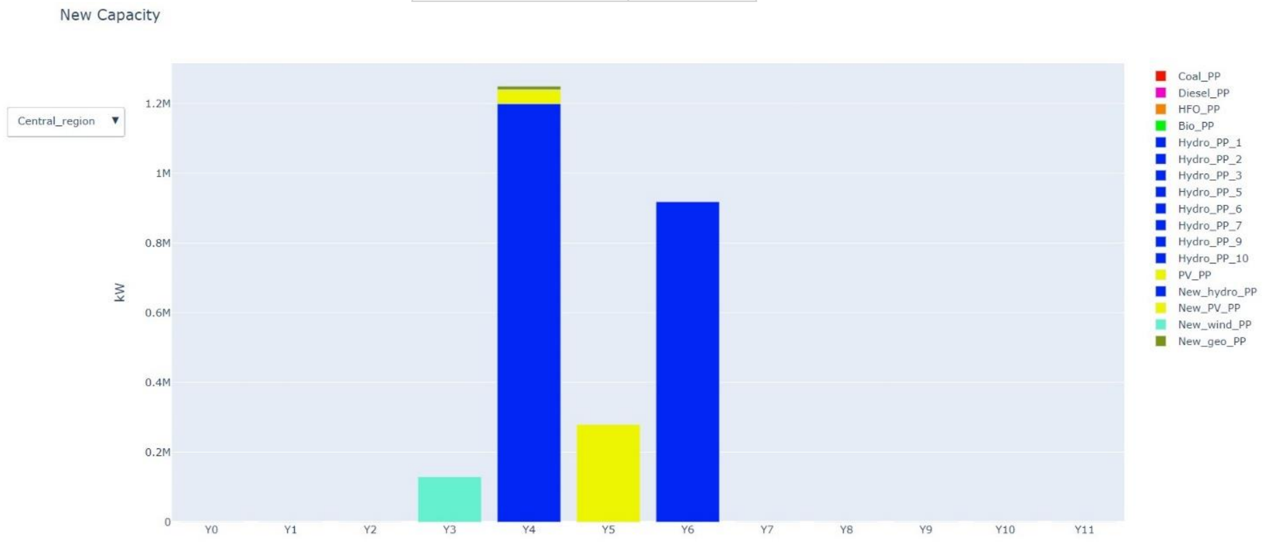

Hourly production by technologies
Eastern_region
kWh
500k
400k
300k
200k
100k
0
Diesel_PP
Hydro_PP_4
Hydro_PP_8
New_hydro_PP
New_wind_PP
Import from reg1
Import from reg3
Export to reg1
Export to reg3
Unmet Demand

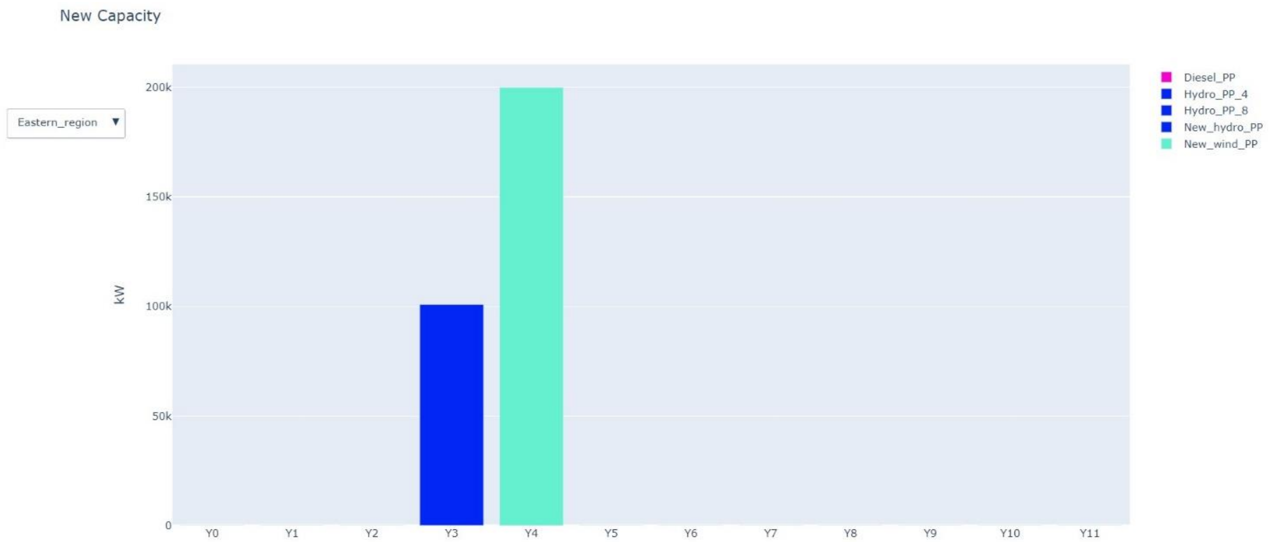

CO2 emission
kg
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11

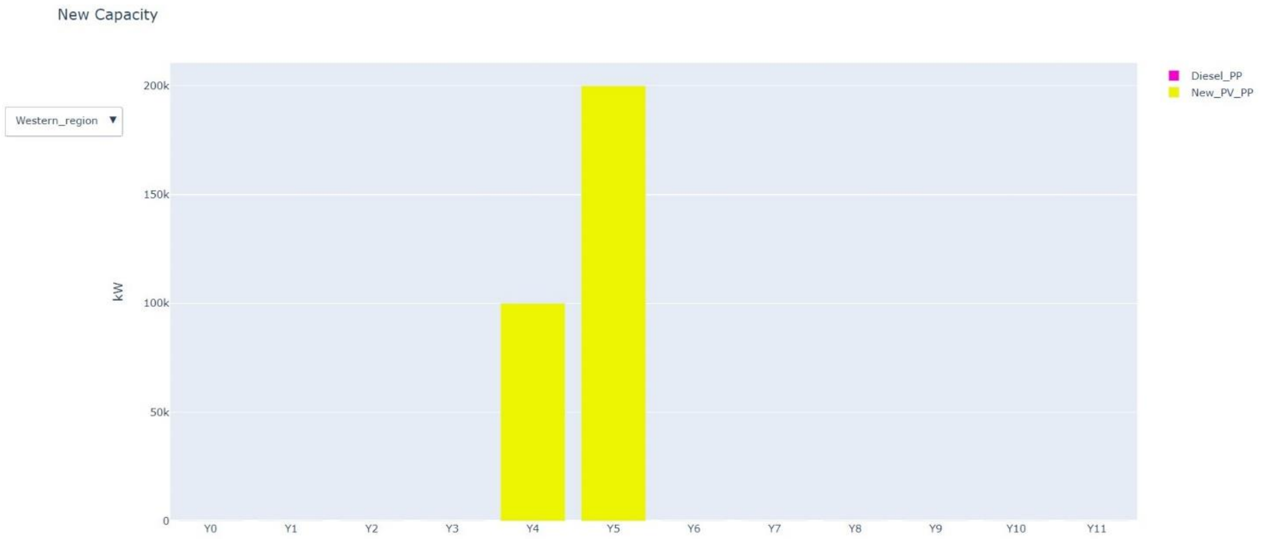
2) STEPS

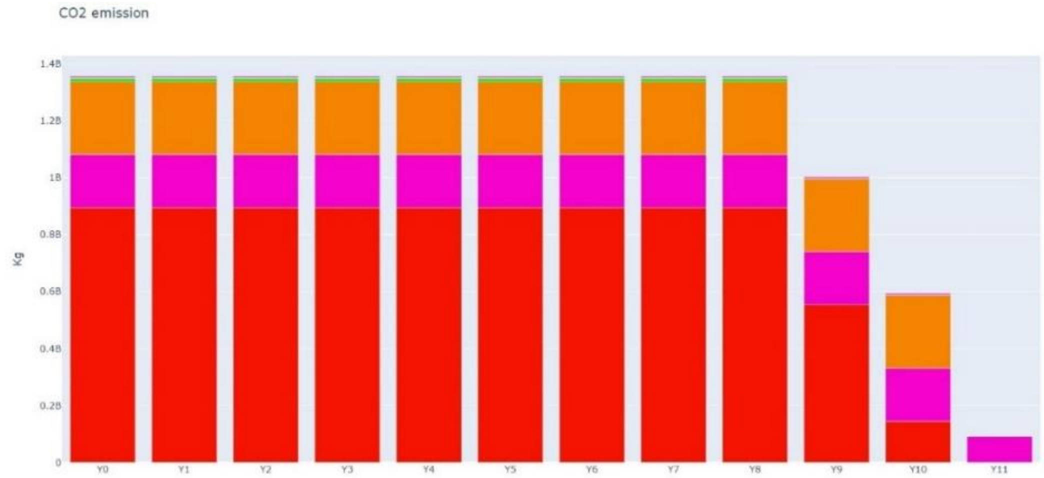
This scenario considered the commitments made to reduce carbon dioxide (CO2) emissions. Consequently, the production from fossil fuel sources progressively declines after 2027 to align with the emission cap while the production from renewable sources increases. Notably, the newly installed capacity, referred to as committed plants, exclusively consists of renewable energy sources. Once the emission cap is reached, these plants are not dismantled but instead operate within the limits specified by the cap. Despite these measures, the unmet demand remains a challenge across all regions.

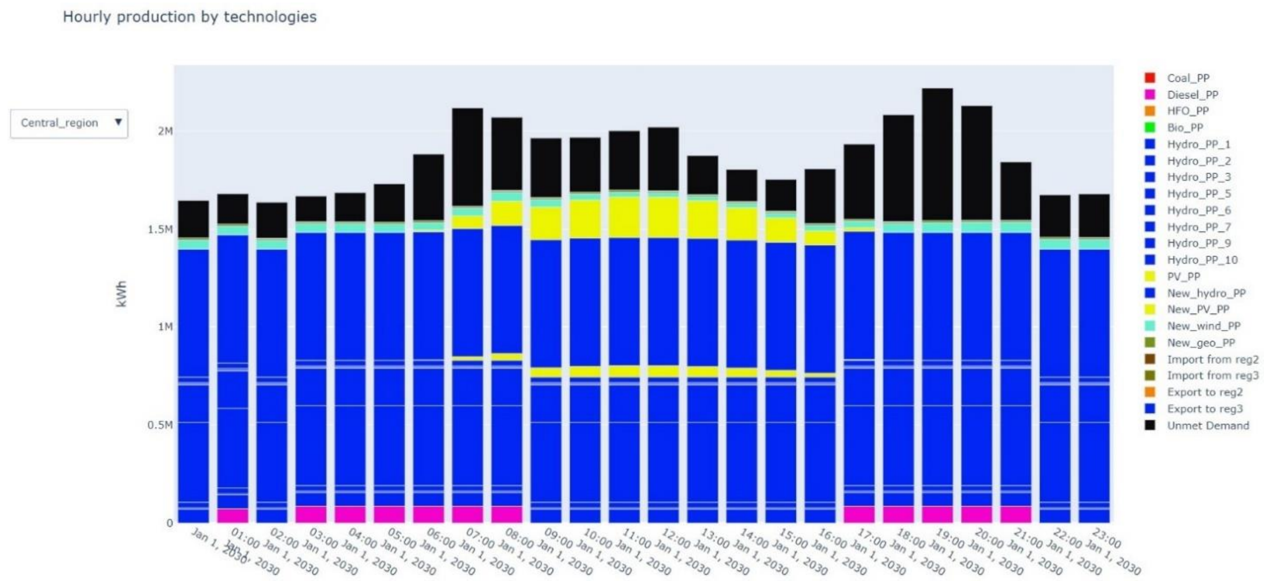
Net Present Cost	
16736486074	$
16.73648607	billion$

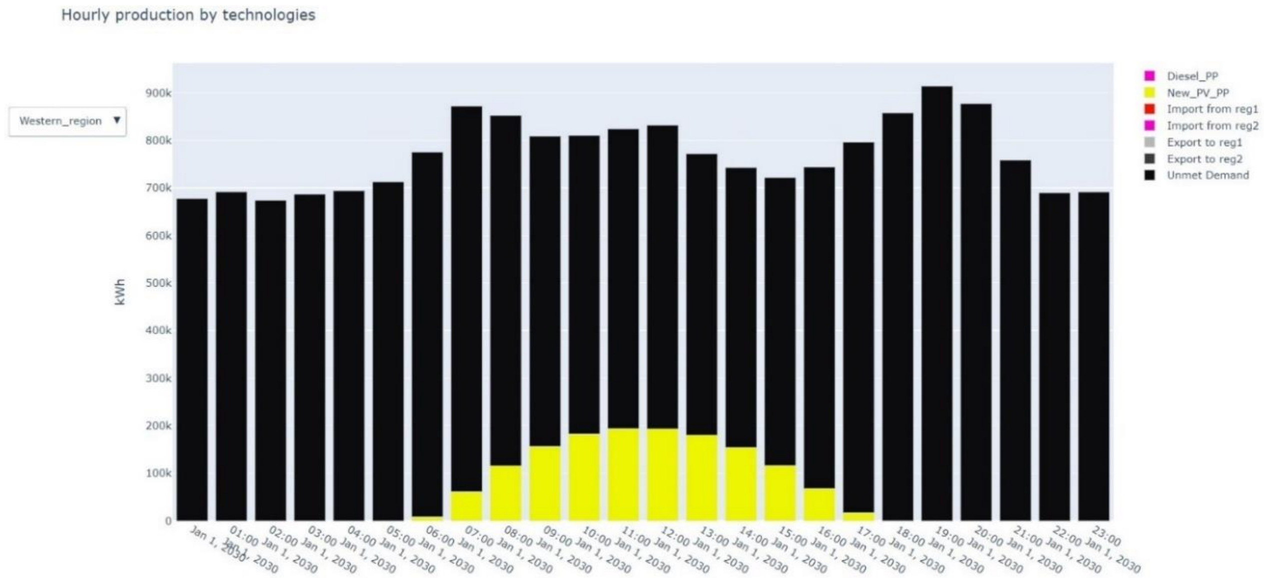


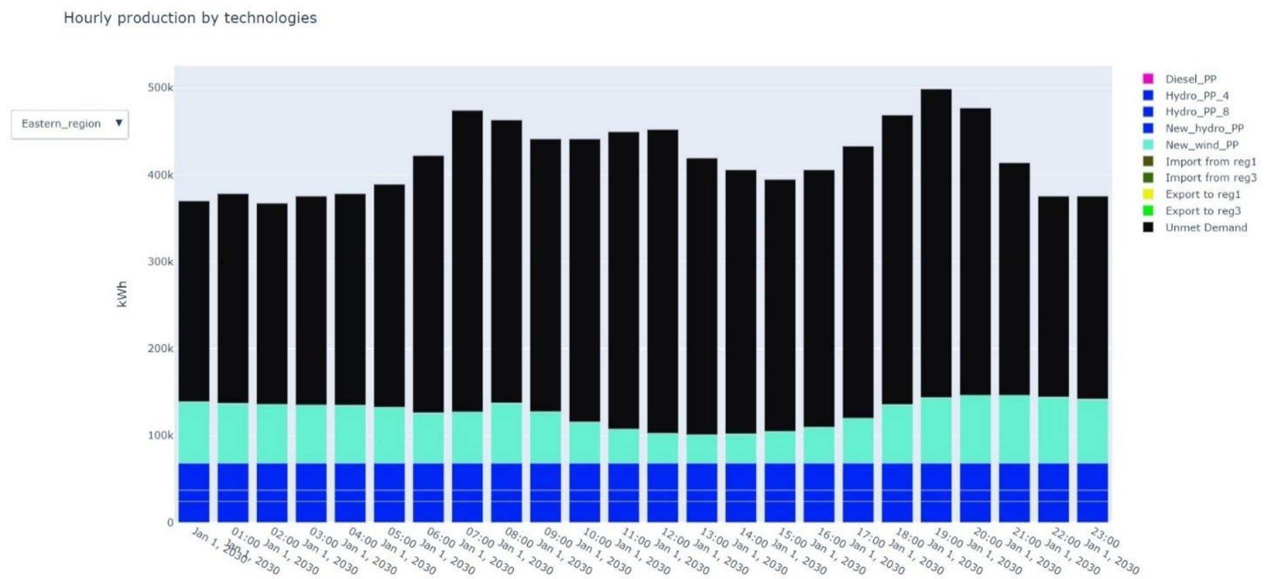



New Capacity
Western_region
Diesel_PP
New_PV_PP
kW
200k
150k
100k
50k
0
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11


CO2 emission
Kg
1.4B
1.2B
1B
0.8B
0.6B
0.4B
0.2B
0
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11


Hourly production by technologies
Central_region
kWh
2M
1.5M
1M
0.5M
0
Coal_PP
Diesel_PP
HFO_PP
Bio_PP
Hydro_PP_1
Hydro_PP_2
Hydro_PP_3
Hydro_PP_5
Hydro_PP_6
Hydro_PP_7
Hydro_PP_9
Hydro_PP_10
PV_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP
Import from reg2
Import from reg3
Export to reg2
Export to reg3
Unmet Demand

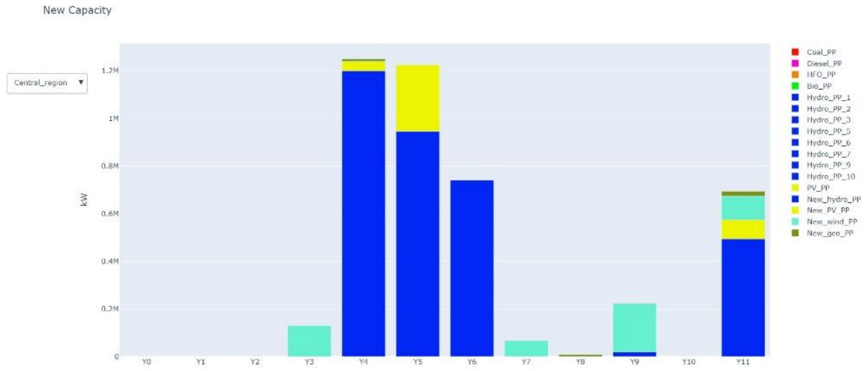

Hourly production by technologies
Western_region
kWh
900k
800k
700k
600k
500k
400k
300k
200k
100k
0
Diesel_PP
New_PV_PP
Import from reg1
Import from reg2
Export to reg1
Export to reg2
Unmet Demand

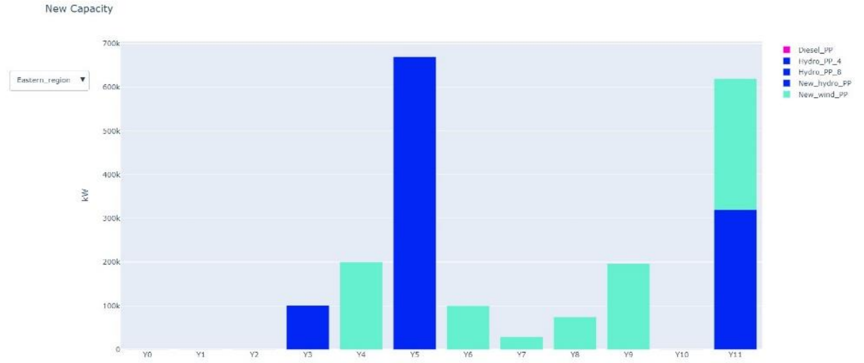

Hourly production by technologies
Eastern_region
kWh
500k
400k
300k
200k
100k
0
Diesel_PP
Hydro_PP_4
Hydro_PP_8
New_hydro_PP
New_wind_PP
Import from reg1
Import from reg3
Export to reg1
Export to reg3
Unmet Demand

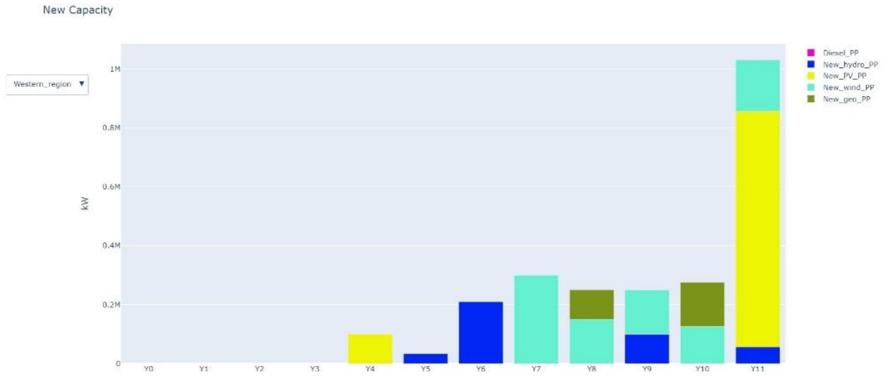
3) Announced Pledges

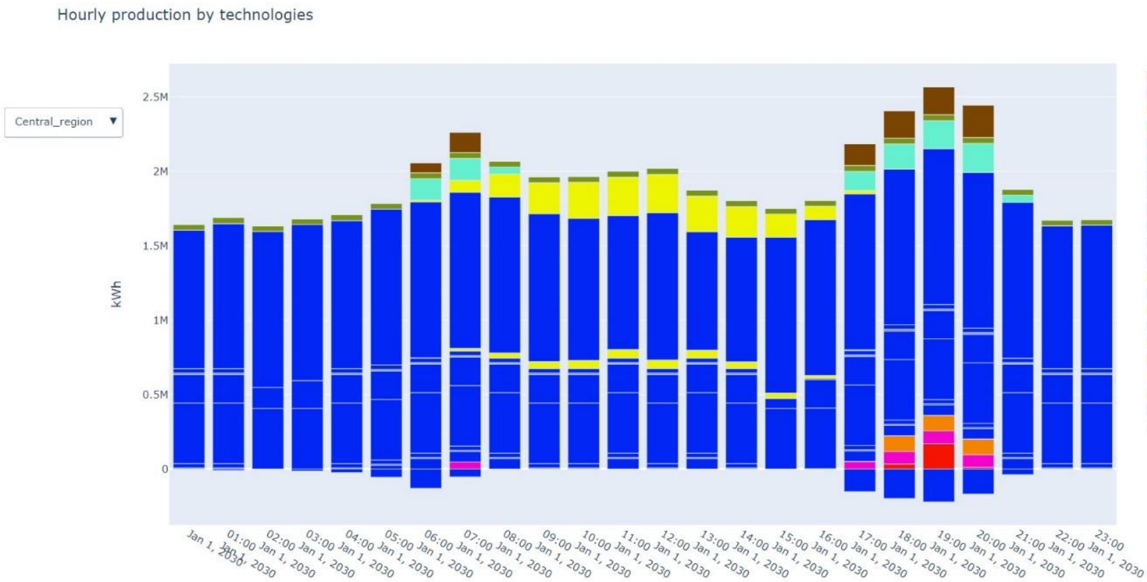
As predicted, this optimistic scenario makes the challenging goal of "meeting the national demand by 2030" possible. To meet the increasing demand, additional wind and hydro power plants are introduced after 2027. Although Zambia has a lot of biofuel resources, caution is exercised not to abuse this source in the country. A comprehensive sensitivity analysis has been conducted to determine the optimal capacity additions for wind and bioenergy sources in order to meet the entire demand of the country without the need for import from the neighbouring countries. All these implementations, lead to an unrealistic add of new capacity to the power sector (in comparison to the current trend of Zambia), resulting in meeting the national demand in all three regions, while keeping the emissions below the maximum cap. However, the high penetration of renewables poses reliability challenges in the electricity production system with the hydroelectric power continuing to dominate the energy mix, while wind and photovoltaic power experience a moderate growth.

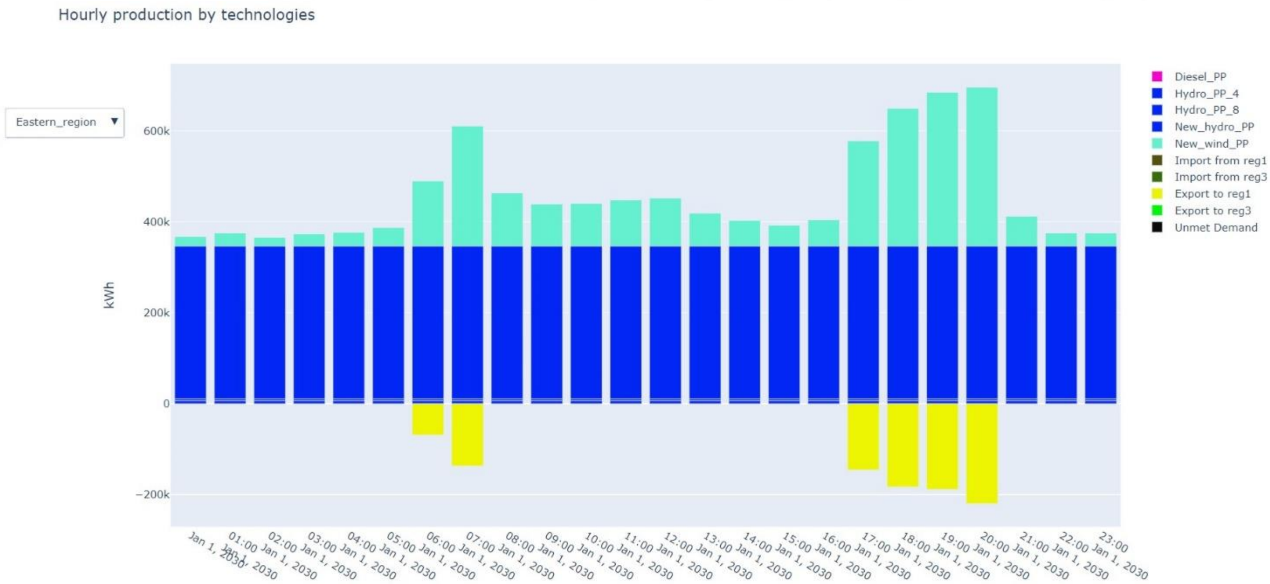
Net Present Cost	
28832689605	$
28.8326896	billion$

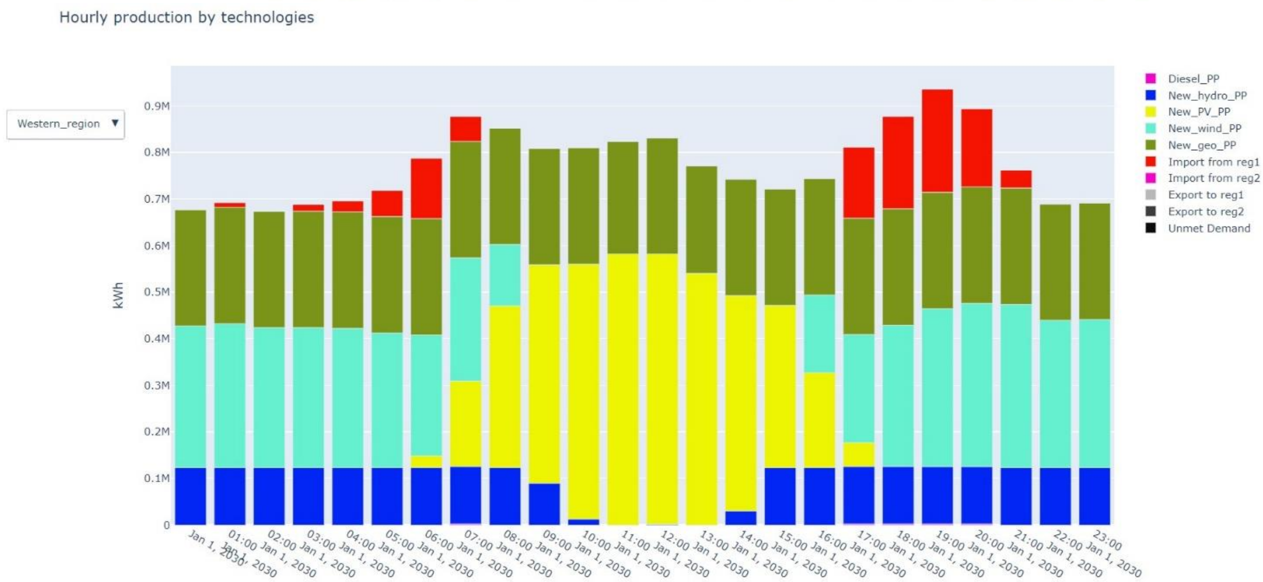


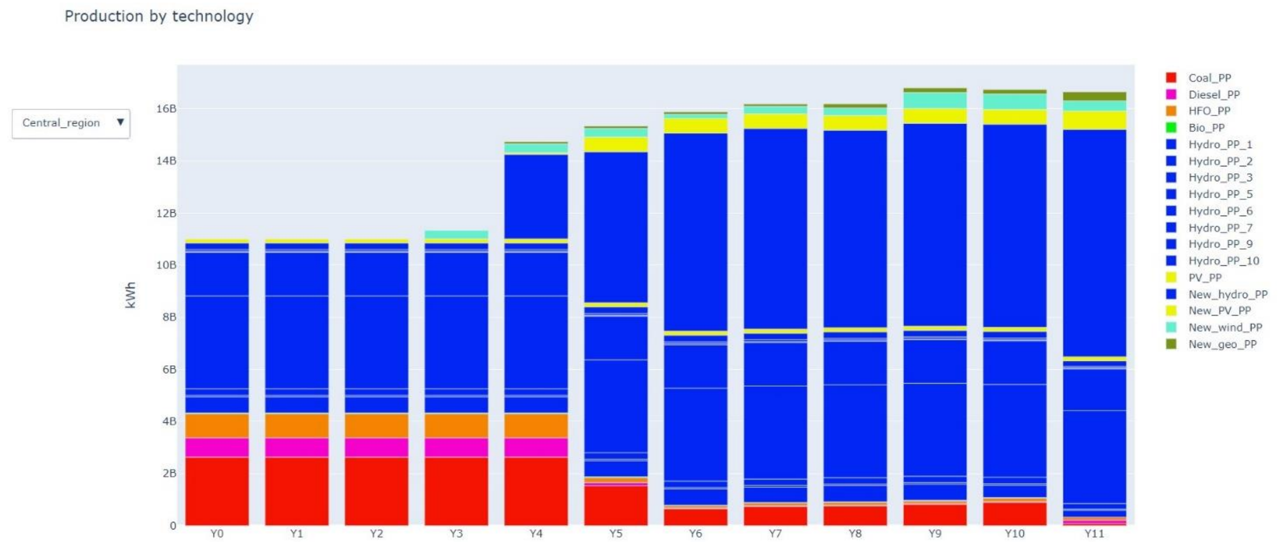


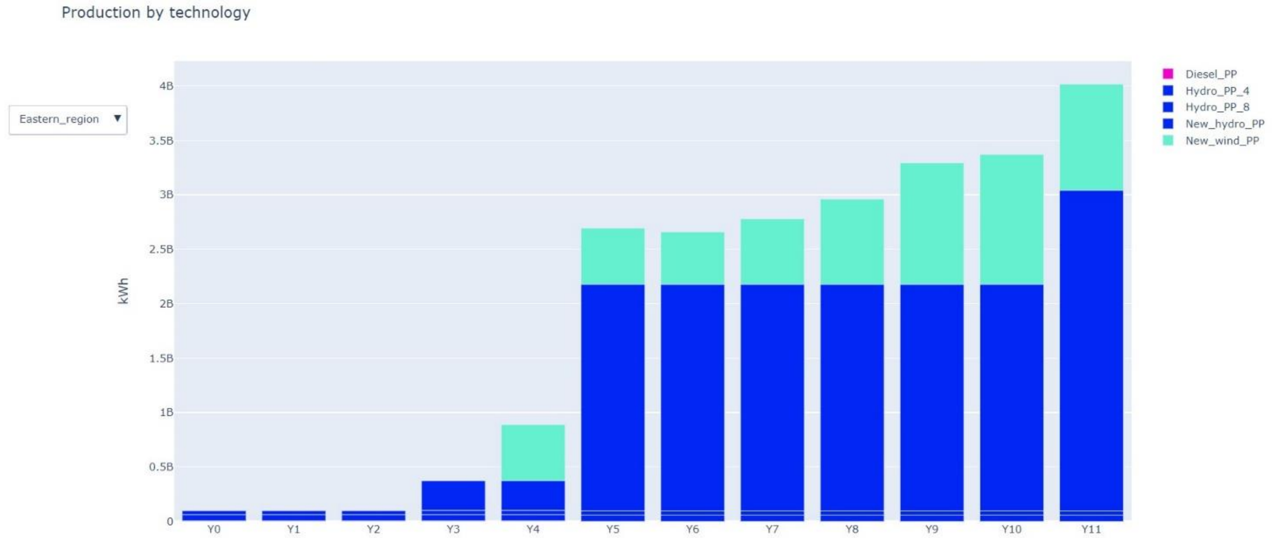


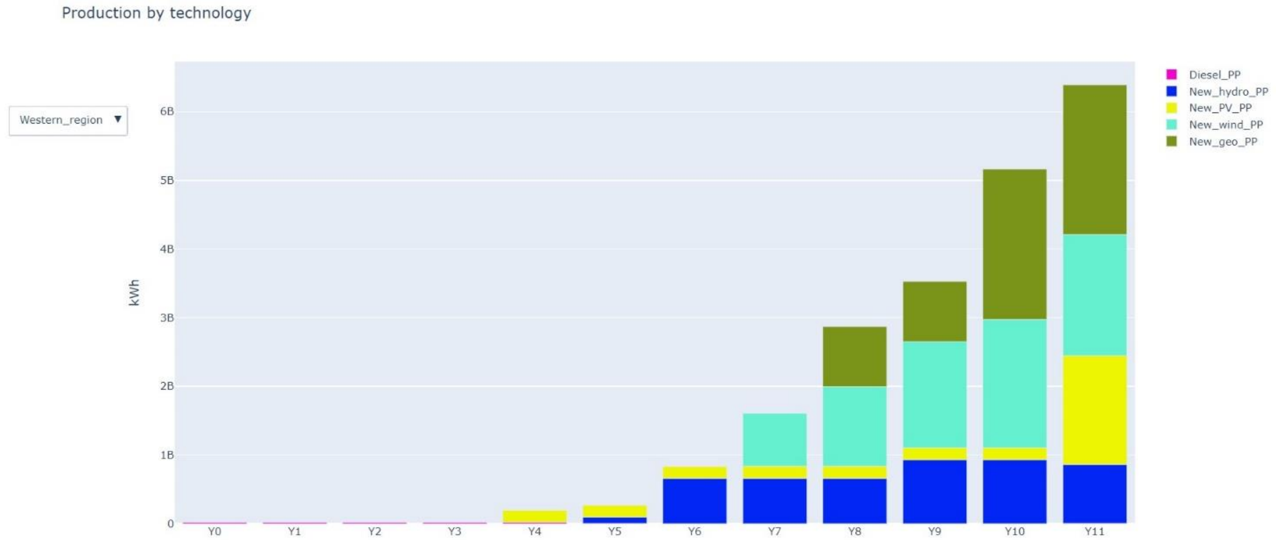

Hourly production by technologies
Central_region
kWh
Coal_PP
Diesel_PP
HFO_PP
Bio_PP
Hydro_PP_1
Hydro_PP_2
Hydro_PP_3
Hydro_PP_5
Hydro_PP_6
Hydro_PP_7
Hydro_PP_9
Hydro_PP_10
PV_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP
Import from reg2
Import from reg3
Export to reg2
Export to reg3
Unmet Demand


Hourly production by technologies
Eastern_region
kWh
Diesel_PP
Hydro_PP_4
Hydro_PP_8
New_hydro_PP
New_wind_PP
Import from reg1
Import from reg3
Export to reg1
Export to reg3
Unmet Demand


Hourly production by technologies
Western_region
kWh
Diesel_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP
Import from reg1
Import from reg2
Export to reg1
Export to reg2
Unmet Demand


Production by technology
Central_region
kWh
0
2B
4B
6B
8B
10B
12B
14B
16B
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11
Coal_PP
Diesel_PP
HFO_PP
Bio_PP
Hydro_PP_1
Hydro_PP_2
Hydro_PP_3
Hydro_PP_5
Hydro_PP_6
Hydro_PP_7
Hydro_PP_9
Hydro_PP_10
PV_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP

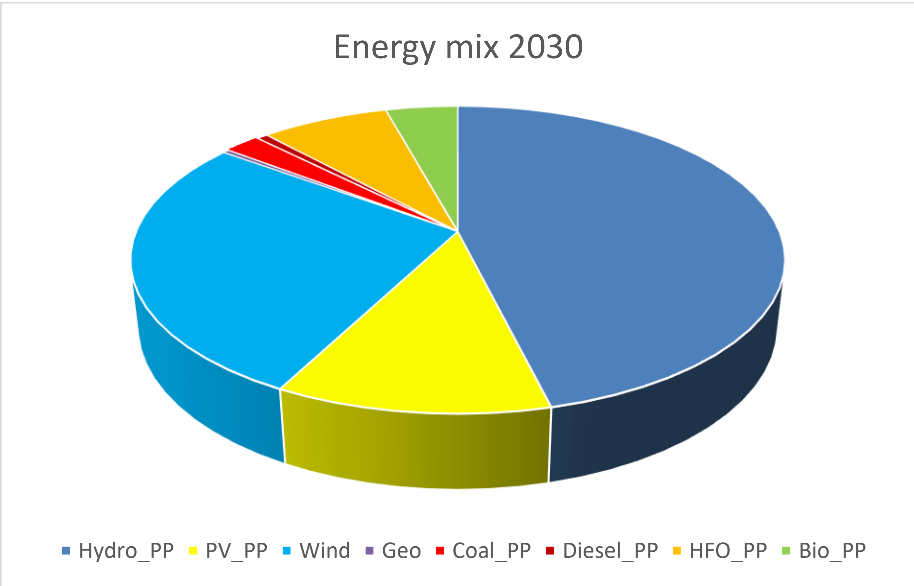

Production by technology
Eastern_region
kWh
0
0.5B
1B
1.5B
2B
2.5B
3B
3.5B
4B
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11
Diesel_PP
Hydro_PP_4
Hydro_PP_8
New_hydro_PP
New_wind_PP


Production by technology
Western_region
kWh
0
1B
2B
3B
4B
5B
6B
Y0
Y1
Y2
Y3
Y4
Y5
Y6
Y7
Y8
Y9
Y10
Y11
Diesel_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP

4) Diversification

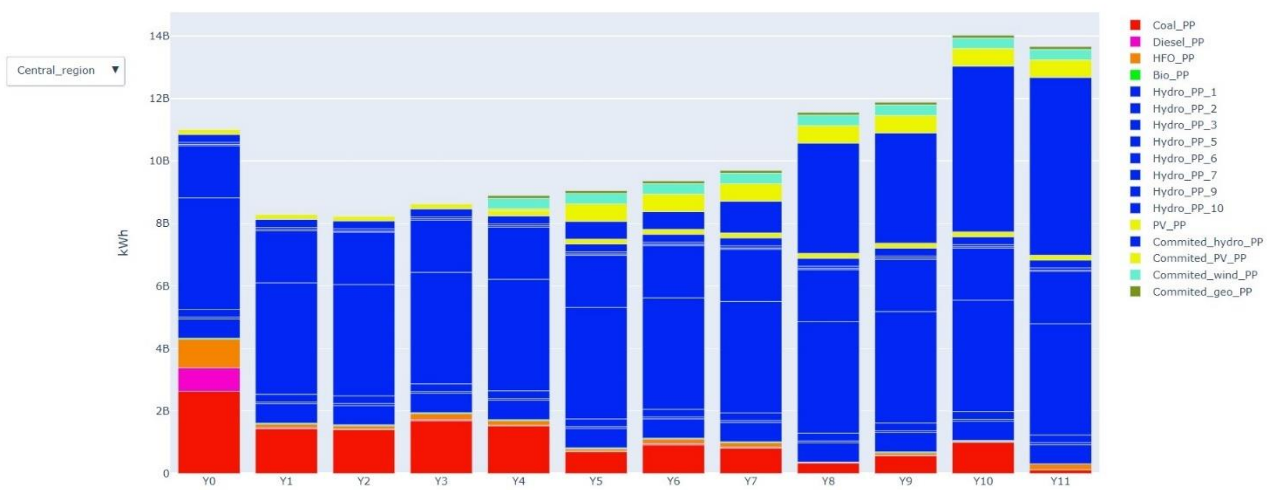
As a result of the newly installed renewable energy sources in the eastern and western regions, region one becomes an electricity importer from an electricity provider during certain periods. Over time, the energy production profile shifts from relying predominantly on bioenergy and hydro to a greater emphasis on wind and solar power generation in regions 2 and 3. Overall, the energy demand in each region is adequately met, and region 3 transforms into a net exporter of electricity. All of this happens while maintaining the ultimate goal of having less than 50% of electricity production share by hydro power by 2030. As a result, in 2030 we have a much more reliable mix of energy, that also respects the CO2 emissions and meets the national demand in all three regions.
We see that the addition of wind power plants plays a huge role in this transition from hydro power plants, as based on their capacity factor and costs, they seem to be the obvious choice of Hypatia. Other big player is PV power plants.
Obviously, this set of suggested policies requires a lot of infrastructure and planning that is very hard to achieve now. However, this model shows that things could have gone different for Zambia's energy sector if the right policies were implanted at the right time. Not only Zambia could have had a reliable source of electricity, while keeping its CO2 emissions to an acceptable limit, it could have also exported its excess of electricity in winter (when the capacity factor of hydro is higher), and economically improve as a country, leading to improvements in other aspects of society.

Net Present Cost	
27431459806	$
27.43145981	billion$

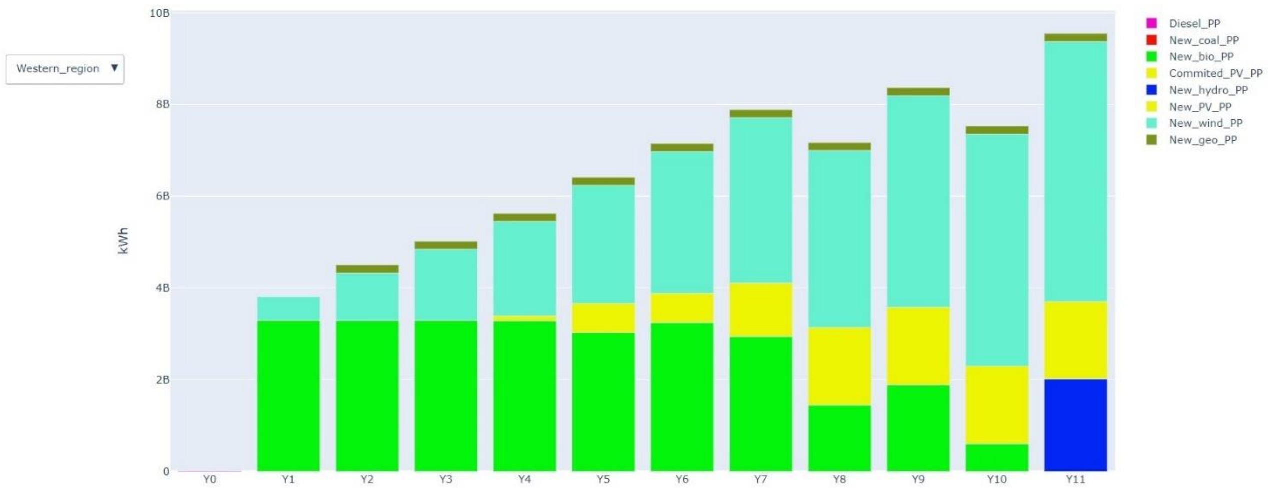


Year	TES [TJ]	TES - No Hydro - SHARE	TES - Only RES - SHARE
2019	68971.34	65.4%	35.6%
2025	96139.11	73.1%	67.5%
2030	101607.91	49.4%	97.0%

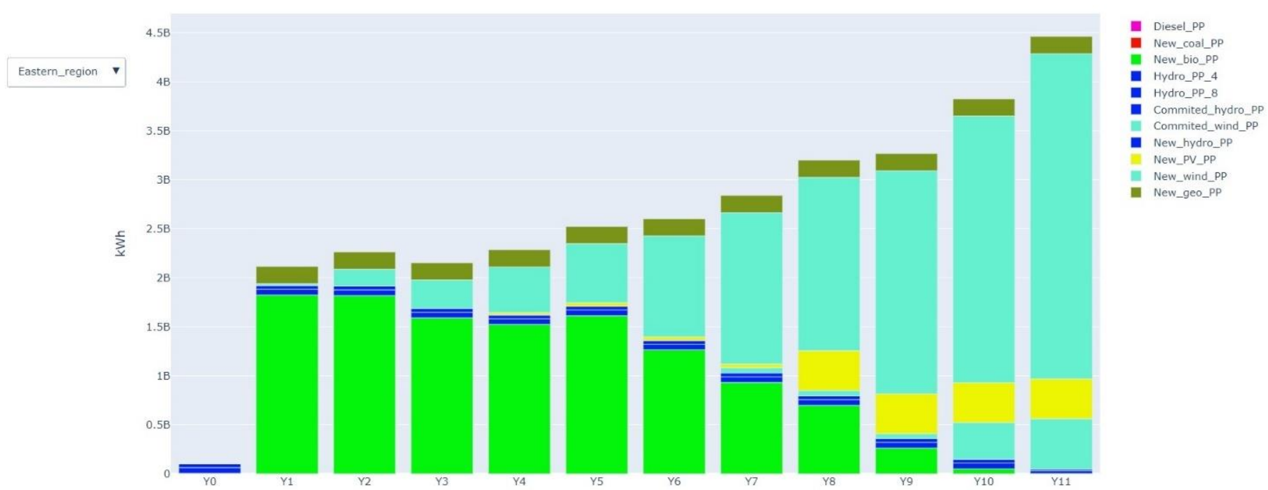
Production by technology

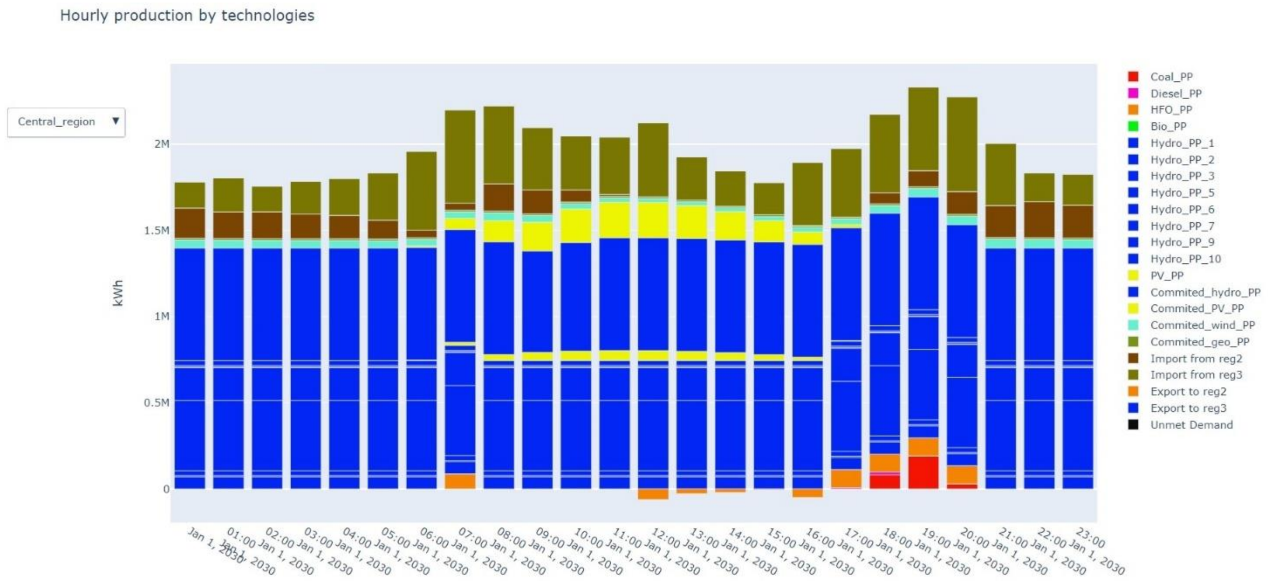


Production by technology

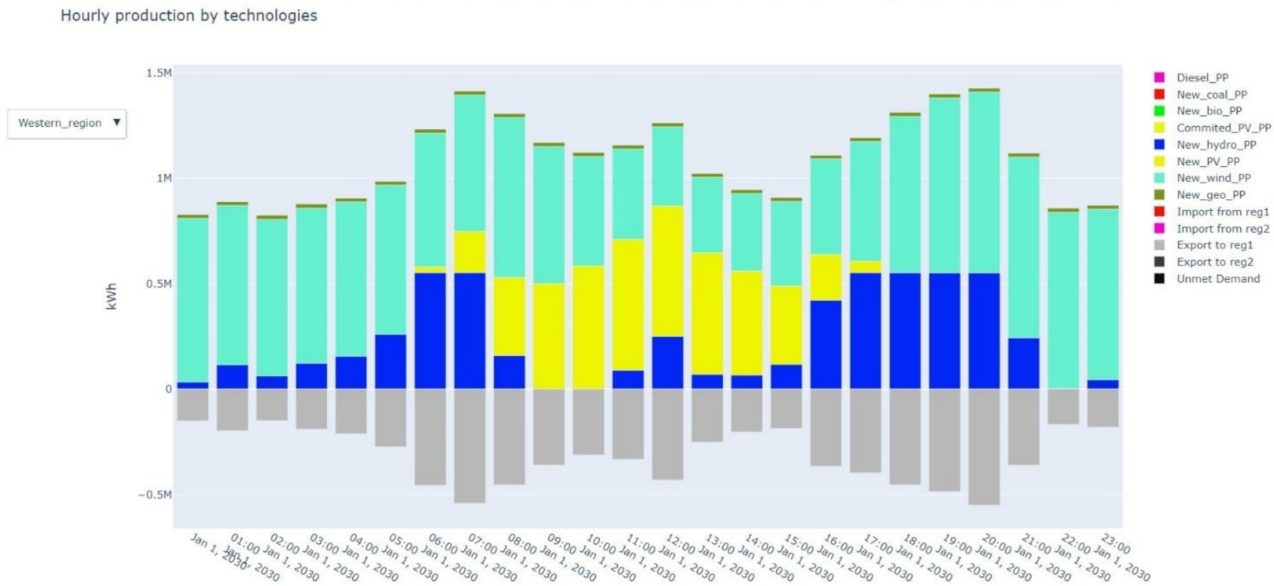


Production by technology




Hourly production by technologies
Central_region
kWh
Coal_PP
Diesel_PP
HFO_PP
Bio_PP
Hydro_PP_1
Hydro_PP_2
Hydro_PP_3
Hydro_PP_5
Hydro_PP_6
Hydro_PP_7
Hydro_PP_9
Hydro_PP_10
PV_PP
Commited_hydro_PP
Commited_PV_PP
Commited_wind_PP
Commited_geo_PP
Import from reg2
Import from reg3
Export to reg2
Export to reg3
Unmet Demand

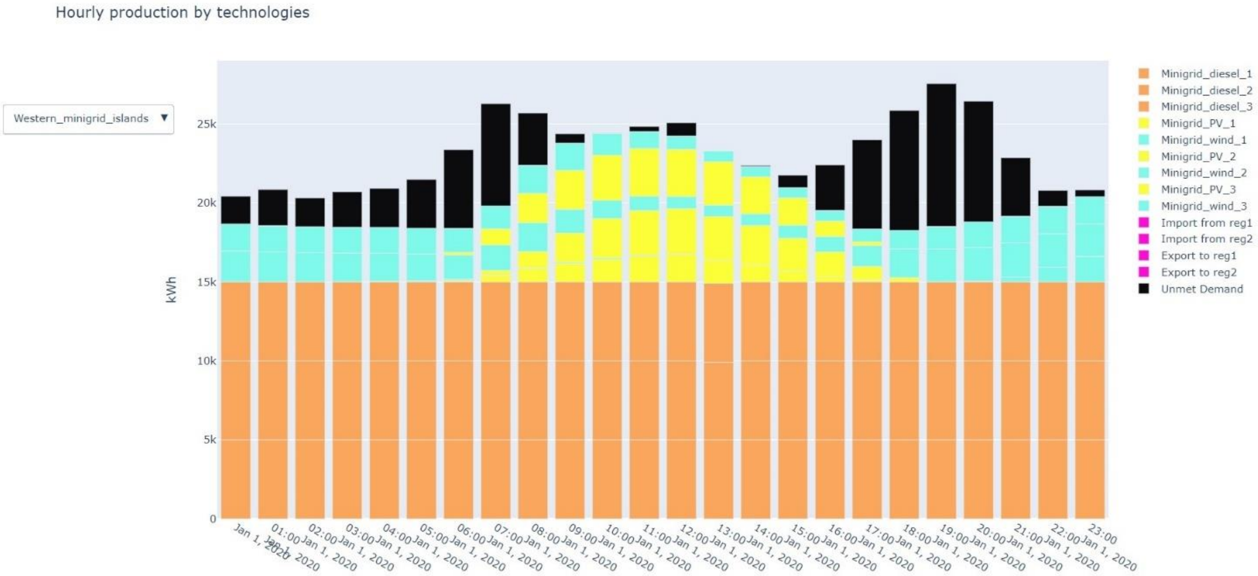

Hourly production by technologies
Eastern_region
kWh
Diesel_PP
New_coal_PP
New_bio_PP
Hydro_PP_4
Hydro_PP_8
Commited_hydro_PP
Commited_wind_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP
Import from reg1
Import from reg3
Export to reg1
Export to reg3
Unmet Demand

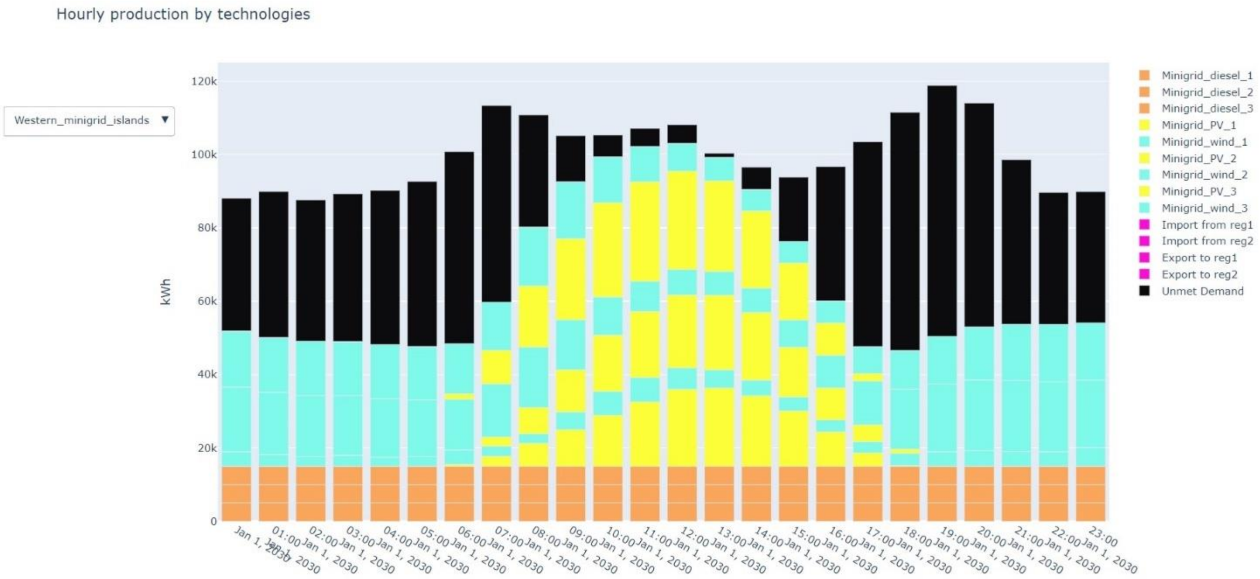

Hourly production by technologies
Western_region
kWh
Diesel_PP
New_coal_PP
New_bio_PP
Commited_PV_PP
New_hydro_PP
New_PV_PP
New_wind_PP
New_geo_PP
Import from reg1
Import from reg2
Export to reg1
Export to reg2
Unmet Demand

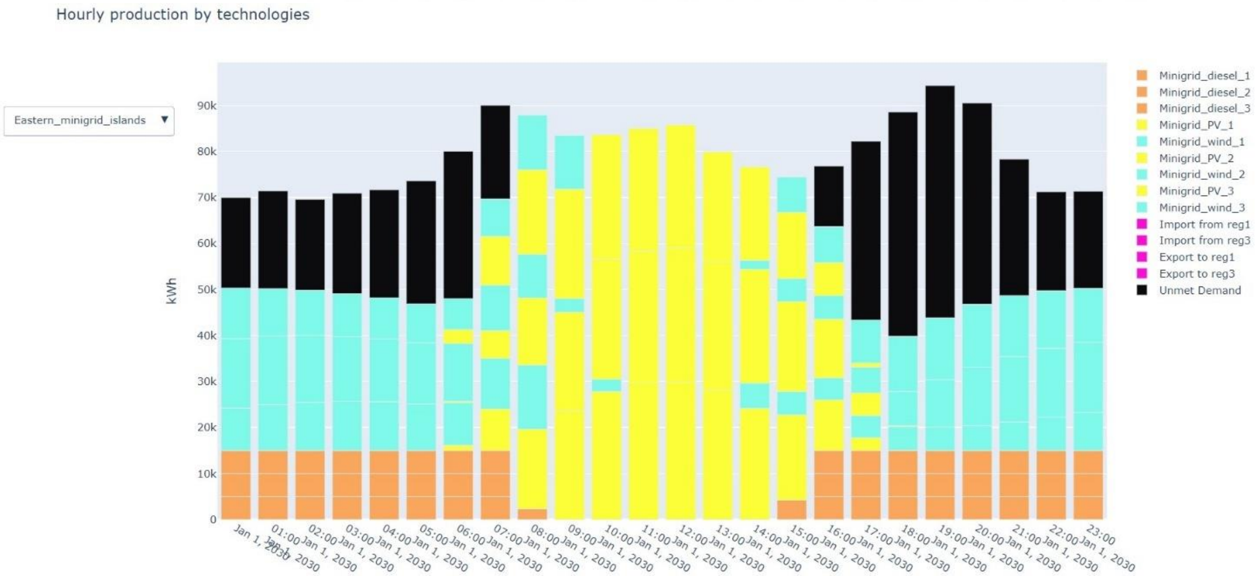
5) Mini Grid

This scenario takes a step further, and while keeping the diversification scenario for On-grid demand, improves the access to electricity to the wanted value of 51%. We can see, that after installation of these islands in Y1, the unmet demand decreases significantly (but not completely). This margin does increases year by year due to the fact of higher rate of increasing demand.

Net Present Cost	
33584593833	$
33.58459383	billion$







However, by connecting these islands to the main grid and allowing the transmission, the unmet demand of these regions almost disappear, and we reach the 51% of added demand for access to electricity.

Conclusion

Zambia is a country with a high potential in many sources of energy, from already used hydro power, to almost untouched potentials of wind and solar power. However, the current energy situation of country is obviously lacking, main problems being an unmet demand almost in every month, unreliable consistency of electricity due to the dependency on hydro power, and last but not least, the low access to electricity.
In each of our 6 scenarios we tried to tackle these problems one by one. We started from projecting the future of energy sector based on their actions (BAU scenario), and then their committed actions (STEPS). We also analyzed the unprobeable possibility of reaching all their sayings (Announced pledges).
After all, we tried to suggest better policies ourselves to solve these problems. In the 4th scenario (Diversification) we made sure that the electricity is reliable (by cutting the hydro power share to around 50%), while meeting the whole national demand and keeping the CO2 emissions under control. Then, we tried to solve an even bigger problem, by suggesting Mini grid islands in rural areas to improve the access to electricity. Finally, we planned an even better Mini grid island with net-zero emission that would solve the problem without producing any CO2.

References

I. Demand and general data, land usage, co2 emission

https://www.iea.org/data-and-statistics/charts/average-age-of-existing-coal-power-plants-in-selected-regions-in-2020

https://data.worldbank.org/

https://energydata.info/dataset -

http://globalenergyobservatory.org/geoid/46611

II. Emission, fuel costs, investments, efficiency, capacity factor

https://doi.org/10.1016/j.dib.2022.108021

https://www.engineeringtoolbox.com/fuels-higher-calorific-values-d_169.html

<4D6963726F736F667420576F7264202D203030328140955C8E86816094E0814093B193FC959495AA81698DC58F4994C5
(ecfa.or.jp)

Renewable Ninja

Committed and candidate power plants

https://cdn.slrconsulting.com/uploads/2022-03/Annex%20C%20-%20Mphepo%20Power%20Unika%20I%20Wind%20Farm%20Zambia_Scoping%20Report_Final%20complete.pdf

Planning and Prospects for Renewable Power: Eastern and Southern Africa (irena.org)

https://assets.researchsquare.com/files/rs-480042/v1/06b1e5d3-53e8-496d-b0b6-074e6a26ea48.pdf?c=1631881954

III. Grid estension

https://offgrid.energydata.info/#/explore?_k=e0c50a

https://offgrid.energydata.info/#/explore?_k=e0c50a

http://www.geo-ref.net/ph/zmb.htm

IV. Minigrid data

134326-ESMAP-P154383-PUBLIC-4-2-2019-15-30-28-ESMAPMiniGridsArrivalofMainGrid

Annual-Report-GET-FIT-ZAMBIA-2019_FINAL-2

Beyene YB et al., On the design and optimization of distributed energy resources for sustainable grid-integrated
microgrid in Ethiopia, International Journal of Hydrogen Energy,
https://doi.org/10.1016/j.ijhydene.2023.04.192

https://offgrid.energydata.info/#/explore?_k=e0c50a

ENEL Zambia VRES Integration Executive Summary1

V. Policies

RENEWABLE ENERGY FEED IN TARIFF STRATEGY , Published by Ministry of Energy,Zambia 2017

Ministry-of-Energy-Strategic-Plan-2018-2021 Published by Ministry of Energy,Zambia

Zambia profile, IRENA website

Zambia-Energy-Efficiency-Strategy-and-Action-Plan-2022 Published by Ministry of Energy,Zambia

Zambia-Power-Development-Framework Published by Ministry of Energy,Zambia

VI. Situation , Energy sector actual situation

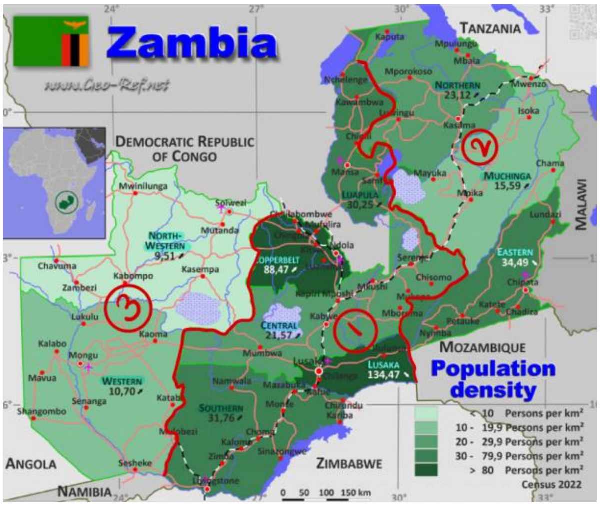
ENEL Zambia VRES Integration Executive Summary1

esr2021 , report of Minister of Energy ; Zambia Ministry of Energy – MOE

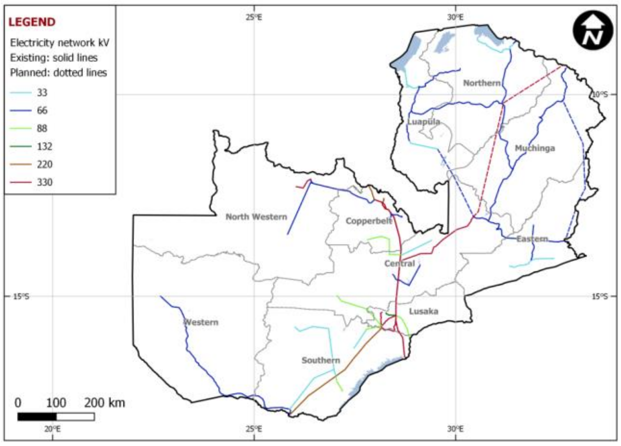
IRENA_Planning_Prospects_Africa_2021

Appendices

APPENDIX 1 – DIVISION OF REGIONS and GRID LENGTH (8)



Province	Region	Population			
Central	1	2382699			
Copperbelt	1	2757539			
Luapala	1	1514011			
Lusaka	1	3158744			
Southern	1	2172732			
Total Region 1		11985725		**Portion (%)**	61,11808
Western	2	1363520			
North-western	2	1325783			
Total Region 2		2689303		**Portion (%)**	13,7134
Eastern	3	2539361			
Muchinga	3	862541			
Northern	3	1533839			
Total Region 3		4935741		**Portion (%)**	25,16852
Total		19610769			



Tot Area	752614				
5km area from grid	675997				
	76617				
conversion in length	7661,7				
Residual capacity	5,00E+05				
efficiency	0,864				
V_OM	0,0001315				
1 to 3	73,82221226	km			
1 to 2	786,6959996	km			
	km hv line	share	lenght	new	new/y
3	536,7	0,14	73,82221	200,1080306	40,02161
1	1613,17	0,41	666,936	601,468738	
2	1752,03	0,45	786,696	653,242543	130,6485

APPENDIX 2- PROJECTION OF DEMAND ON GRID AND OFF GRID (9)

To calculate the additional demand arising from the connection of the Mini grid to the national grid, we followed this procedure: initially, we estimated the number of households in the area by dividing the rural population by the average number of individuals in a Zambian household, which is approximately 5. Subsequently, we multiplied this value by the access to electricity of rural areas. Furthermore, we considered the minimum household consumption threshold, provided by the IEA, which is 0.00125GWh. This minimum consumption value is the minimum value for which it is possible to be considered as having electricity access. Once obtained the additional demand we added it on top of the already existing grid one.

APPENDIX 3- CO2 CAP EMISSION CALCULATION

Based on the "Nationally Determined Contribution" of Zambia, the target for their CO2 emissions by the year 2030 is set to be a reduction of one-fourth compared to the emissions in 2010. To determine the specific values, we referred to the IEA website, where we found the recorded CO2 emissions for the years 2019 and 2020. Using these three data points, we employed cubic interpolation to estimate the CO2 emissions for the period spanning from 2021 to 2030.

APPENDIX 4- HYDRO SHARE<50%

In the Parameters_global excel file, we have a couple of sheets dedicated to renewables shares of electricity production. The function is to give user the ability to set a minimum share limit for the power plants using renewable sources of energy. (For example, setting the limit in a way that we have 75% of out electricity production from renewable sources of energy in 2050.)
The approach is that we must firstly select which technologies are counted as renewables (1 for renewables and 0 for non-renewables), and then we can set a percentage minimum share limit for their production.
We, however, has used this function in another way to our advantage. As we wanted to make the energy sector of Zambia more reliable, we had to put some kind of limitation for the electricity share of hydro power. So, we chose the renewables tech selection in a way, that everything but the hydro power plants are counted as Renewables (1), and all hydro power plants counted as non-renewables (0). Our share of fossil fuel power plants is already under control because of the CO2 emission cap. In this way, we were able to cut the hydro share year by year, and achieve the 50% share by 2030, which is much more reliable than the currently 85% share.

APPENDIX 5- SPECIFIC & MAXIMUM LAND USAGE

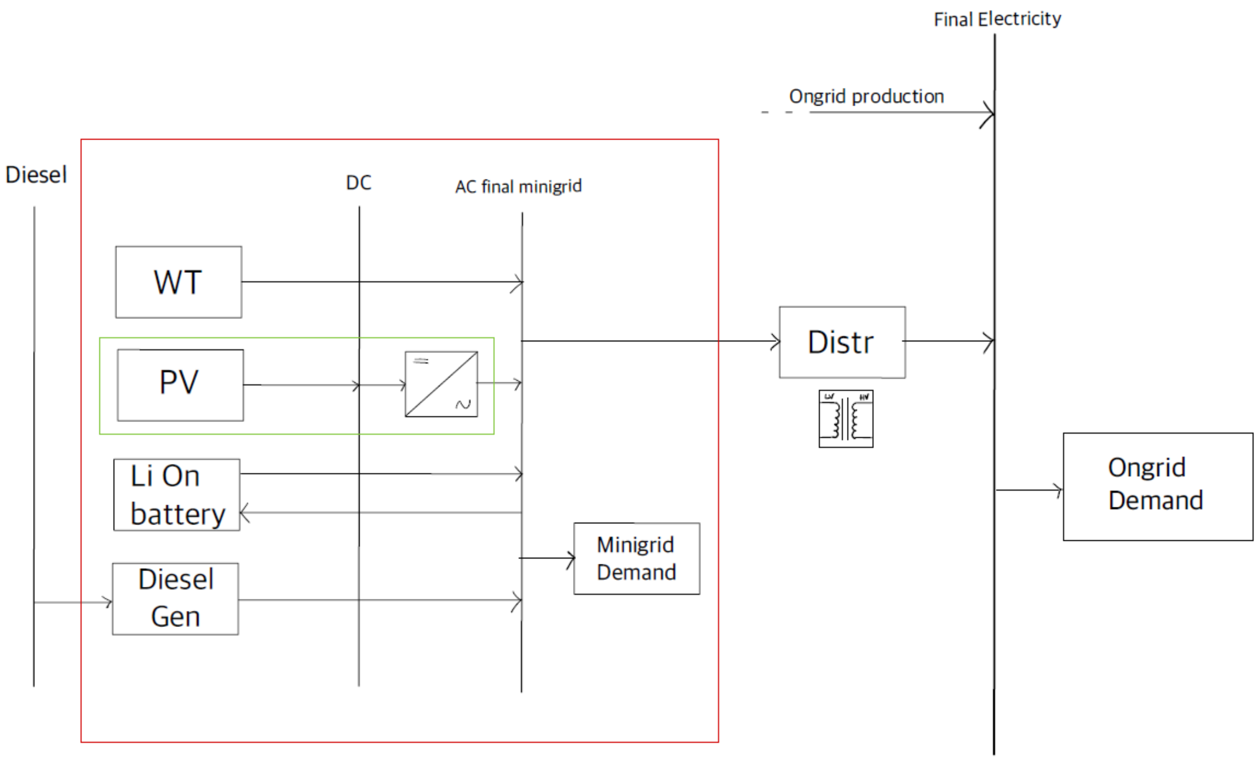
For the value of the specific land usage of the PV panel, we had to find the optimal angle for each panel based on Zambia's latitude. Doing so, we were able to calculate how the shadow of one panel may create an area that cannot be used for another panel. After some calculations, we reached a value for the specific land usage. For maximum land usage, we had to find the area for each of our designated regions, and then subtract the areas that are protected or occupied from that value. Zambia is one of the biggest natural habitats for many rare animals in Africa and therefor, has a lot of protected areas and national parks.

Country Name	Country Code	Series Name	2019 [YR2019]		km2 converted		km2 usable		**region2 km2**	**region3 km2**	
Zambia	ZMB	Permanent cropland (% of land area)	0.000484268		360		435,912		139471.429	195309	
Zambia	ZMB	Land area (sq. km)	743390		743390						
Zambia	ZMB	Terrestrial protected areas (% of total land area)	0.412594		306718.2537				334780.429		
Zambia	ZMB	Forest area (sq. km)	450022.4		450022.4						
Zambia	ZMB	Surface area (sq. km)	752610						0.416605682	0.583394318	
		lusaka			400						
								All	181603.3104	254308.4359	
					specific land use			**Capacity**	0	300000	
Data from database: World Development Indicators					4.04686E-05	Km2/kW		**Commited use**	0	12.14058	
Last Updated: 05/10/2023								**left for new**	181603.3104	254296.2953	435899.6

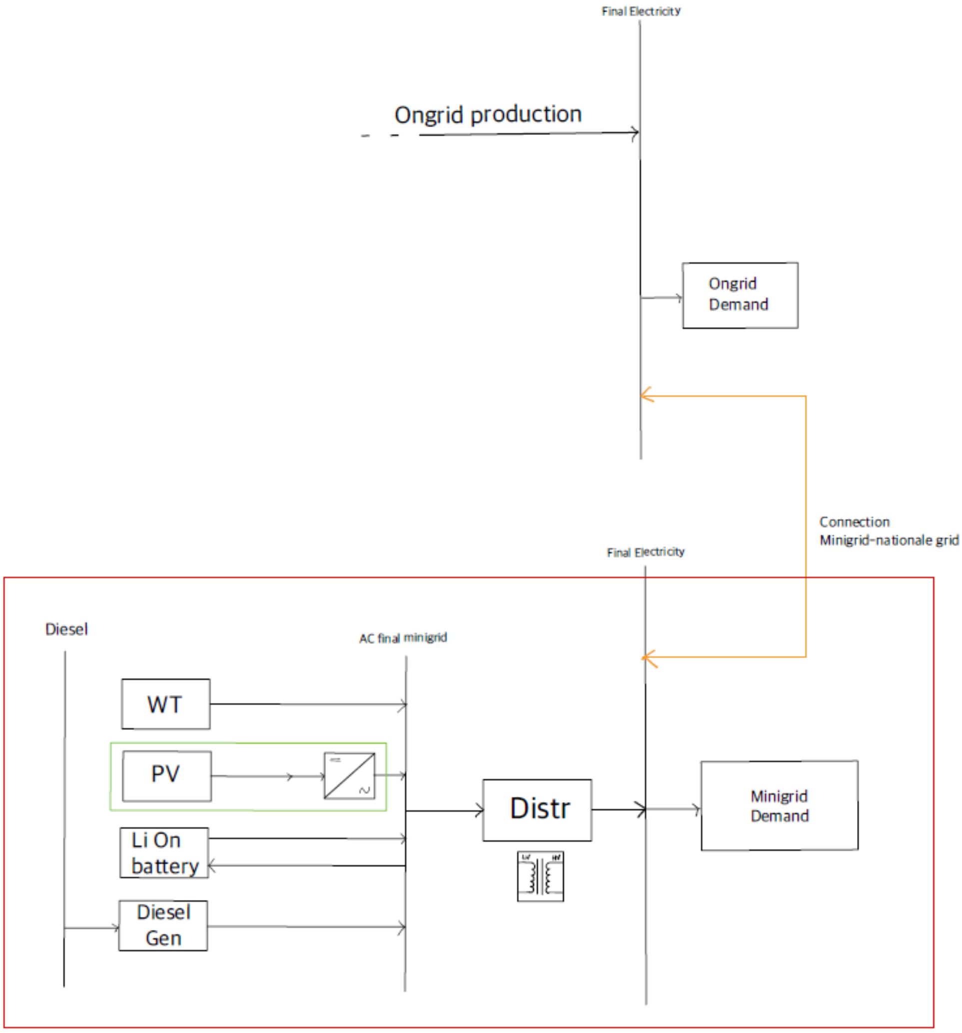
APPENDIX 6- MINIGRID IMPLEMENTATION AND MAIN SCHEMES

For the mini grid implementation, the scheme of the mini grid island energy system is drawn. The implementation of them in the national scenario should be evaluated as an internal production-demand in both the regions, with a second demand attached to a new final carrier, and a transmission that can exchange the excess of production with the on-grid system.
The system will include PV panels, a wind turbine, a diesel generator (to guarantee a minimum of power always available) and a Li-on battery devoted to the storage. Due to existing PV system, the electrical scheme needs to include two main electrical carriers, one of AC and one of DC, connected by an inverter. The overall connection of On-grid should also take into account the transformer due to LV-HV.
In order to obtain the same result with Hypatia, some hypotheses were considered:
PV panels has been considered inverter-integrated (existing type available on the market), and the conversion of the LV-HV grid has been included in transmission.
The structure of the two islanded Mini grids has been designed as new connected regions. Doing so, the demand of the sub-region will be concise with the off-grid demand, while the carrier dedicated to the exchange of electricity between the on and off grid will be represented by the line connection between regions.

“Mini grids real RES”

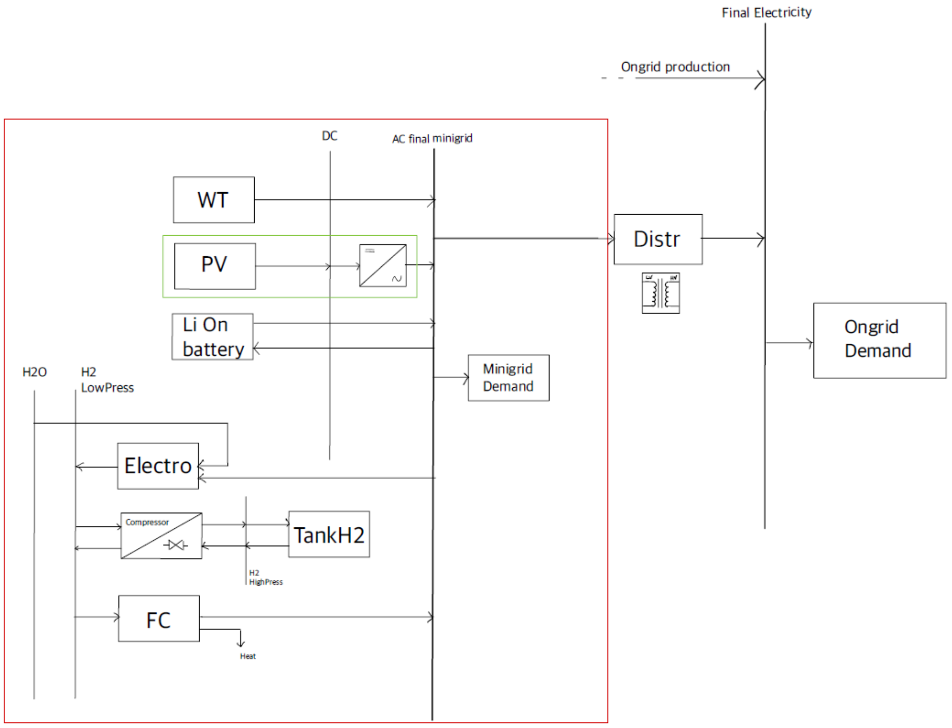


"Mini grids implemented RES"



APPENDIX 7- HRES MINIGRID IMPLEMENTATION AND MAIN SCHEMES

“HRES Mini grids real RES”



“HRES Mini grids implemented RES” (avoiding the loop)