

Development of Alternative Scenario for Ethiopia's Electricity Sector by LEAP Software

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Abstract

Ethiopia, a country in Africa, is endowed with renewable energy sources such as hydro, solar and wind. These energy sources are economically exploitable and if electrical energy could be produced it could be surplus beyond the country's demand. Exporting electrical energy, Ethiopia could earn more money without disturbing environment as it is a global warming issue now-a-days. But due to lack of technology, the rich renewable resources are not utilized properly, and as a result, only 15

Index terms— ethiopia energy scenario, hydro energy, geothermal energy, energy demand, environmental issue, energy export.

In this paper, as an alternative scenario will be proposed for Ethiopia's electricity sector, let us look through the Ethiopia's baseline scenario. Ethiopia's energy supply is covered mostly by waste and biomass (92%). Oil (6.7%) and hydropower (0.9%) are the other two primary energy sources. The installed capacity of electrical power is about 2060 MW (88% hydro, 11% diesel and 1% thermal). This production is equal to 10% of the demand. For this reason, the country is dependent on the imports of petroleum to meet its requirements. Table ?? : Electricity production sources global-country basis [1][2] With only 15% of the population having access to electricity, there is a significant bias between electricity supply of urban and rural population: 80% of urban areas have access to electricity, whilst only 2% of rural areas habitants have access to electricity [3]. As it can be observed in the Figure 2, the average electrification rate in developing countries is 72%. Therefore, there is a gap of more than 57% to achieve the target for developing countries, specially for Ethiopia. Although there are a number of private, municipal and cooperative owned small scale power producers in areas not served by the utility their combined contribution is estimated not to exceed 2% of EEPCo's capacity.

EEPCO runs two systems; the Interconnected System (ICS) and the Self Contained System (SCS). The ICS, which generates more than 98 percent of total EEPCO supply capacity, is supplied mainly from a set of large hydro systems with some thermal back up. The SCS is a much smaller system of decentralized mini-grid and off-grid systems supplied by small hydro plants and diesel generators. The technologies used by the ICS and SCS are shown in the table 2. [4] The ICS is currently becoming bigger because of the interconnection of SCS to ICS. In 2010, a total of 5, 163 towns were connected by EEPCo. The electricity generation increased 53% from 2005 to 2010. This results in a shortage of electricity, because of a slant between the grid extension and the load of power generated. Transmission and distribution losses are around 20%. This event causes that the users willingness to pay increases significantly in isolated systems.

Nevertheless, Ethiopia's target was to supply 20% of the population with electricity by the year 2012. This is due to the 5 year Growth and Transformation Plan, launched in 2010 which aims to quadruple or even quintuple the country's current capacity and to connect 4 million costumers by 2015. The plan includes the installation of the following new plants:

-8 hydropower plants with 8, 737 MW of total capacity. -7 wind plants with 866 MW of total capacity. -70 MW geothermal power plant of total capacity. Keeping this plan in mind, the alternative scenario is developed. If this scenario is implemented, it will meet Ethiopia's energy demand which will improve the economic growth of the country.

1 a) Hydro Potential

The total hydro potential of Ethiopia is 45,000 MW [6]. Which is the second highest potential in Africa (after Congo). Approximately 30,000 MW hydro power is economically feasible [8-9]. Current production is of only 2.5% of the potential. It is also important to mention that a vast potential is not only given for large hydropower projects, but also for small scale schemes. The potential from micro hydropower schemes is 100 MW, that could be developed on a land area of 200,000 km². Most promising sites can be found in the western part of the country since suitable constant flows are prevailing, figure ???. Though, the drying seasons has to be taken into account because of the lack of water during this period of the year. Hydropower is the main source of electric power in Ethiopia. The exploitable hydro energy potential is estimated to be about 159TWh/year. Nearly 50% of this resource is in the Abay River Basin and 22% is in the Omo-Gibe River Basin. b) Solar Potential Ethiopia's solar potential has been shown in figure ???. The solar potential is 5 kWh/m²day [9]. Ethiopia receives a solar irradiation of 5000-7000 Wh/m² according to region and season. Although the growth rate of the solar PV market has grown (from <5% since the early 1990s to 15 -20% in the last few years) it is still at an early stage. With an installed capacity of approximately 5MW and an estimated PV market potential of 52 MW, not even 10% is exploited.

2 c) Biomass

A total of 30 MW of capacity surplus could be fed in the grid by sugar factories. Power production potential of landfill gas is estimated to be 24 MW.

3 d) Wind

With wind resources with a velocity of 5-6(m/s), Ethiopia's wind potential is estimated to be 10,000 MW [6, ?]. EEPCo is planning to develop seven wind sites that are in close proximity to the ICS by 2015. They will have a capacity between 50 and 300 MW. The installed wind power capacity would be approximately of 720 MW.

In rainy seasons the hydropower potential is high whereas low winds prevail, vice versa hydropower potential is low in the dry season whereas the wind potential is high as can be seen in the figure 6. Based on available scientific information and experiences on the Rift geothermal system both in Kenya and Ethiopia, it is plausible to assume the presence of a huge geothermal energy base in Ethiopia.

For the development of Ethiopia's alternative scenario to meet its energy demand, two technologies, as shown in figure 8, were selected as follows: -Hydropower plants (micro power plants for the SCS system and hydropower plants for the ICS system) -Geothermal power plants. Hydropower Plants : The hydropower plants were chosen because of the highest potential of the country and the current low production as well as the possibility to develop large or small projects. Hydropower is the most abundant energy source of Ethiopia, it is thought to form the backbone of the country's energy sector development. Additionally, hydro is the cheapest potential amongst PV and wind. For this reason, hydro power can be selected as the best technology suitable.

Geothermal Plants : The development of the alternative scenario involves the introduction of geothermal power plants that are feasible because they are located in the Ethiopian geothermal rift.

Other technologies not considered : Despite of this, we were willing to introduce wind, but the wind availability was not sufficient in some areas to produce electricity, and in the areas where we have potential there were already transmission lines, which means that they would be suitable under ICS.

4 b) Description of the Elaborated Systems

Self Contained System : We choose to install 36 hydropower plants with an average capacity of 10 MW distributed along the country where no ICS is available, Figure 9. The selected areas have hydro potential. Additionally, the small projects would offer the opportunity to initially start as SCS and then get connected to the grid. We selected to put this power plants near rivers. The gap to be fulfilled for the self contained system is of around .131 GW. The vast amount of the SCS hydro power plants was located near rivers. Hydro Plant : Additionally we add one big hydropower plant of 900 MW, Figure 10. This plant would be available in the west part of the country, because there is a very big potential for hydropower plant. Gibe IV would be of around 1472 MW. For this reason, our consideration of installing one plant of 900 MW is not by any chance out of analysis. As the new plant will be located near the line that exports electricity to Kenya, we can expect also to export electricity.

5 d) Capacity Installation in ICS

After addition of 4 power plants in ICS, we see that there are no unmet demands in ICS in the year of 2013 and from 2018 to 2026, figure 15. The limitation of the analysis here is that we installed plants in the year of 2011 and 2012 but its effect goes to unmet requirements in the year of 2013 and from the year of 2018 to 2026. We see no change of unmet requirements in the other years. However, our target was not to reduce all the unmet demands in ICS but a little. Also due to increase export energy, we installed that plants in the ICS.

6 e) Unmet Demand in SCS of Ethiopia Moderate Scenario

The figure 16 shows the unmet demands in the SCS area. We see that the unmet demands in the year of 2008 and 2030 are 0.01 million MWh and 4.21 million MWh respectively where the demands are increasing almost exponentially with the year. Our target in the Ethiopia alternative scenario was to meet all the unmet demands in the SCS area. After installing the small hydro plants in the SCS area we see that the unmet demands will be very small in few years. The figure 18 describes the unmet requirements in the Ethiopia alternative scenario. The table 4 explains the small unmet demands in some years. In our alternative scenario, we left these unmet demands, because these are small and sometimes to meet these small demands, the installation of new power plants will not be economically feasible.

7 h) Capacity and Reserve Margin

The figure 19 describes the comparison between two scenarios for Ethiopia's electrical power capacity from the year 2008 to 2030. As we tried to reduce the unmet demands in the alternative scenario, its capacity is higher than the capacity in the moderate scenario.

8 Figure 19 : Capacities in both scenarios

The figure 20 shows the amount of reserve margin in the ICS area. This variable is generally only relevant for electricity generation modules. This variable is only reported if we have specified capacity data for the module.

Reserve margin is defined as follows:

Where, $\text{Module Capacity} = \text{Sum}(\text{Capacity} * \text{Capacity Value})$ for all processes in the module.

Assuming that we have specified certain processes that will be added automatically using the Endogenous Capacity, then the actual reserve margin reported here should be greater than or equal to the planning reserve margin. This is because LEAP automatically adds new plants as needed in order to keep the reserve margin on or above the planning reserve margin. On the other hand, if plants are not being added automatically and if we have not exogenously specified sufficient capacity expansion, then it is possible that the actual reserve margin may fall below the planning reserve margin. From the figure 20, we see that the reserve margin in alternative scenario is always greater than the reserve margin in the moderate scenario.

9 i) Exports

The results in figure 21 explain the exports from ICS area in both scenarios. We see in the bar chart that exports in alternative scenario are greater than moderate scenario one from the year of 2012 to 2017 and 2027 to 2030, also exports are equal in both scenarios from the year of 2018 to 2025. The module balance in figure 22 explains domestic requirements, exports, imports, outputs and unmet demands. The unmet demands are always smaller than module outputs. We see that the exports are gradually decreasing, because in our scenario we selected domestic demands as priority that is why with the increase of domestic demands exports are decreasing.

But if we select exports as priority then the export would be constant all through the years which is shown in figure 23.

But the problem with export as priority that the unmet demands are always larger than the module outputs which may result in load shedding. In the BAU scenario, Ethiopia needs to import secondary fuel namely diesel for both ICS and SCS electricity generation. In the proposed alternative scenario, new plants have been considered based on country's own renewable resources. In case of ICS, the proposed power plants' capacity is more than the existing electricity deficit.

10 Figure 24 : Import -BAU Scenario

As a result, in some cases LEAP has chosen to use the additional electricity from the new power plants instead of diesel based power plants due to less generation cost. Consequently, there is reduction of diesel import from other countries. Diesel import in BAU scenario, figure 24, is compared to diesel import in alternative scenario, figure 25. Because, according to the alternative plan, the additional amount of electricity will be exported to neighbor countries after meeting the domestic demand. Here, this is to be noted that for 'Priority Use of Output' of 'Transformation-Generation ICS-Output Fuel-Electricity' we chose 'Domestic Requirement' instead of 'Export'. So our export quantity didn't remain fixed rather varied.

From 2008 to 2030, Ethiopia's Energy balance for each year reflects the changes in resources and transformations brought within the scenarios. For example, we can consider the energy balance of Ethiopia in 2012 for both the scenarios (please refer to Appendix -Table ?? : Energy Balance for Ethiopia, 2012 -BAU Scenario and Table ?? : Energy Balance for Ethiopia, 2012-Alternative scenario)

In the year 2012, there is considerable amount of increase of production from hydro and geothermal sources in the alternative scenario compared to BAU scenario. Subsequently, import of diesel has reduced from 379 thousand barrel of oil equivalent (BOE) to 156 thousand BOE in the proposed scenario. On the other hand, export has increased from 903 thousand BOE to 1235 thousand BOE. For SCS, electricity generation from hydro has increased and from diesel has decreased. Electricity from coal power plant has reduced from 654 thousand BOE to 0. Total transformation in BAU was 1467 thousand BOE and it has changed to 3805 thousand BOE

157 in the alternative scenario. Total demand for electricity is 3767 thousand BOE in both cases as no change was
 158 done from the moderate scenario. In the year 2012, there was unmet demand of 40 thousand BOE in case of
 159 SCS which has been totally diminished in the alternative scenario. The figures 28 and 29 show the financial
 160 comparison between the moderate and alternative scenarios. It is observed that the involved costs are less and
 161 the negative costs i.e. benefits are more in the alternative scenario. For example, in the year 2030, the benefit
 162 available in the BAU and alternative scenario is around 90 Mill US \$ and 430 Mill US \$ respectively. It means
 163 benefit would be around 5 times more than the BAU scenario. As no change was brought in the demand side,
 164 there is no involvement of cost also. It is seen that the collective benefits from production, import & export
 165 of resources are 309.6, 162.6 & 177.5 Million US \$ respectively. It means though some amount would be spent
 166 for import, it will bring benefit equivalent to 162.6 Million US \$ in the long run. Overall, after considering the
 167 benefits, cumulative cost involved is 1,036.2 Million US \$ (discounted at 5% to the base year). To be mentioned
 168 here, there is no cost involved in environmental externalities for this green scenario, on the other hand, there will
 169 be considerable amount of GHG saving. According to the IPCC's 100 years' integration global warming potential
 170 factors, the total cumulative emissions of all greenhouse gases avoided by the alternative scenario are 0.5 Million
 171 Tonnes of Carbon equivalent.

172 There was a coal power plant called 'Yayu Coal' in the moderate or business-as-usual scenario. In the
 173 alternative scenario, because of the environmental considerations, this plant was replaced by environment friendly
 174 geothermal power plant. The impact of this decision has been clearly illustrated in Figure 30 and 31. In the
 175 year 2012, when the coal power plant would likely be installed, GHG emission would be around 380 thousand
 176 tones CO2 equivalent. On the other hand, there is apparently no emission of global warming potential GHGs in
 177 the alternative scenario. Ethiopia is endowed with renewable energy resources. The alternative scenario focused
 178 on maximum utilization of this resource as a source of clean electricity for the country. There is abundant of
 179 sunshine all through the year in the country. But solar energy was not selected due to its high upfront cost. There
 180 are some potentials of wind energy also in Ethiopia. Unfortunately, that is limited to some areas only and there
 181 are lots of seasonal variations in production around the year. However, the country has many rivers with huge
 182 potentials of hydro energy. That's why, in the proposed scenario, hydro and geothermal were judiciously selected
 183 as the source of energy. In the business-as-usual scenario, there were some unmet demands of ICS electricity.
 184 The alternative scenario has fulfilled the gap and also increased export of electricity to neighboring countries.
 185 In case of SCS, there was unmet demand at every year. These gaps have been almost fulfilled in a conservative
 186 manner as the additional production would be wasted. Besides, there was one coal based plant in the business-
 187 as-usual scenario which has been replaced by geothermal power plant. This change has turned the alternative
 188 scenario a cleaner one compared to BAU with diminishing of global warming potential GHG emissions. Thus,
 189 our proposed alternative scenario is capable enough to meet the electricity demand of Ethiopia in a more reliable
 190 and sustainable way than the business-as-usual scenario.

191 11 ()

192 Year 1 2 3 4

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²F Development of Alternative Scenario for Ethiopia's Electricity Sector by LEAP Software

³F Development of Alternative Scenario for Ethiopia's Electricity Sector by LEAP Software

⁴F Development of Alternative Scenario for Ethiopia's Electricity Sector by LEAP Software



Figure 1: Figure 1 :

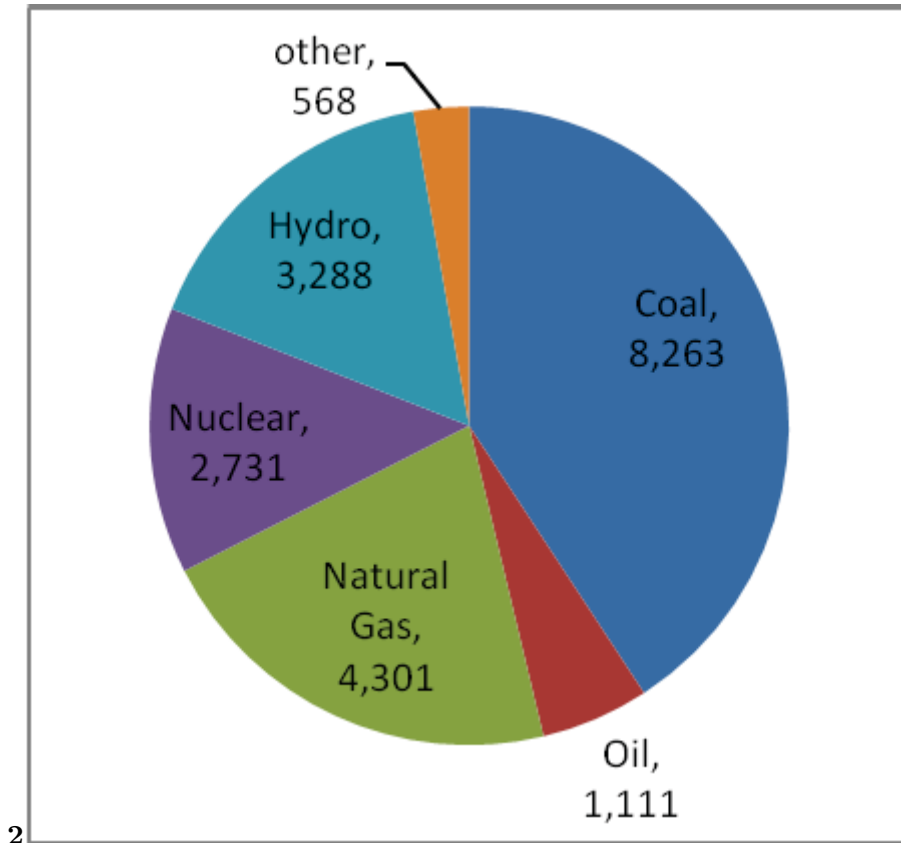
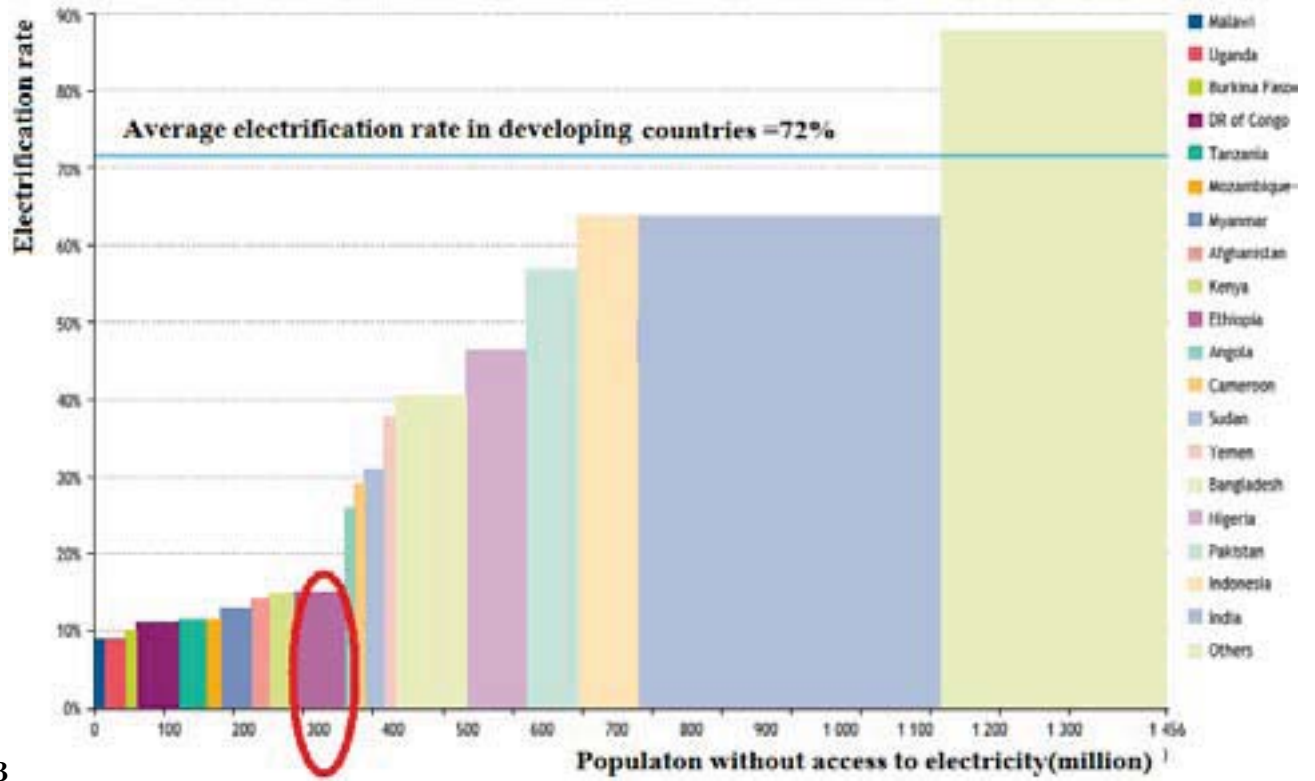
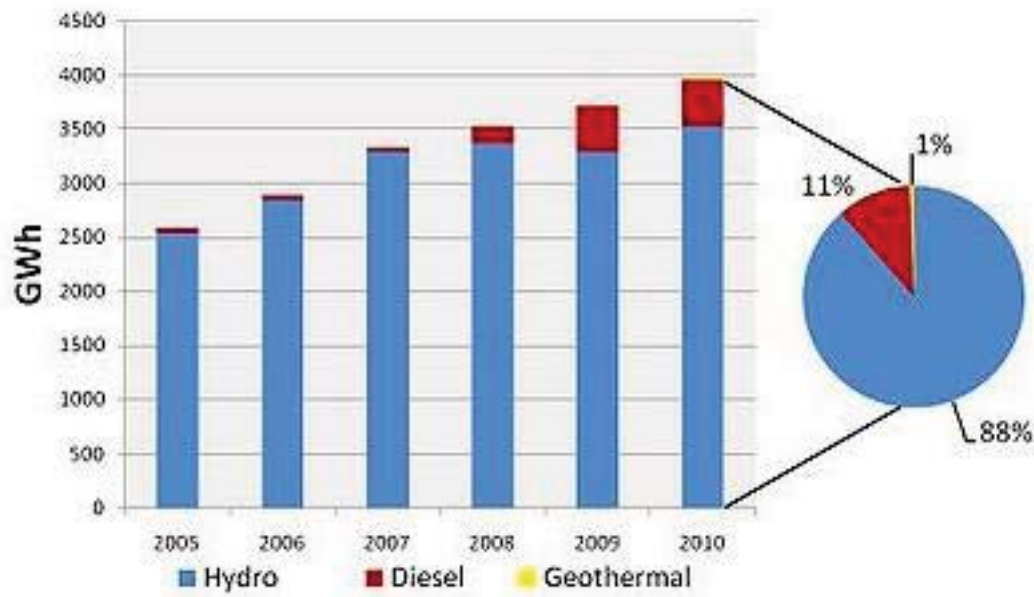


Figure 2: Figure 2 :



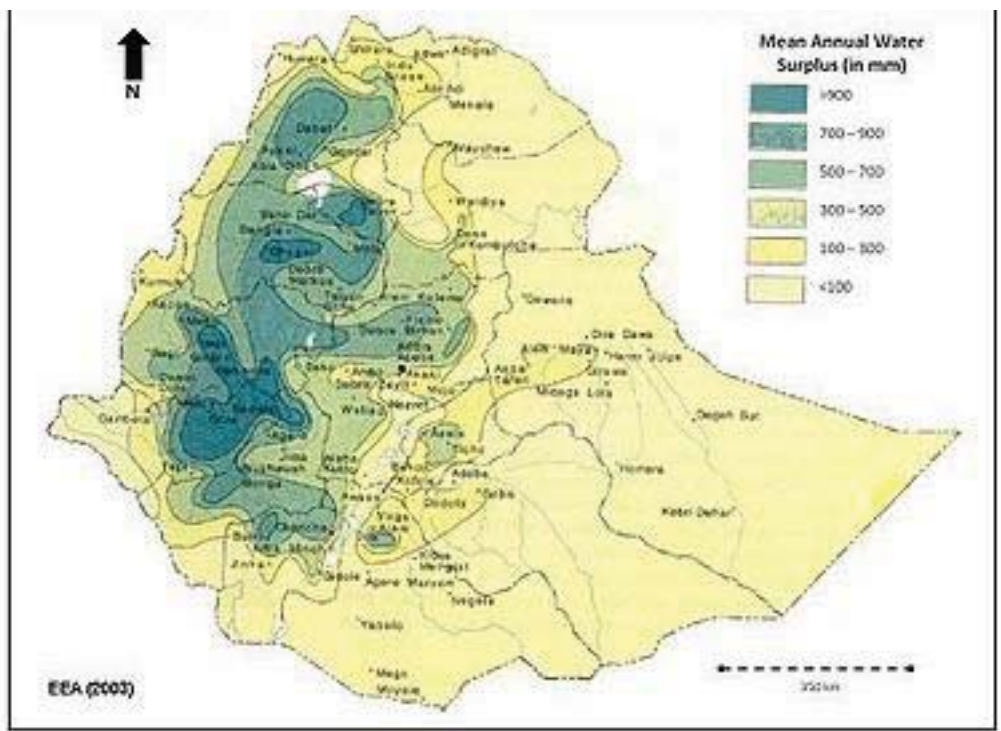
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Figure 3: Figure 3 :



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Figure 4: Figure 4 :Figure 5 :



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Figure 5: Figure 6 :

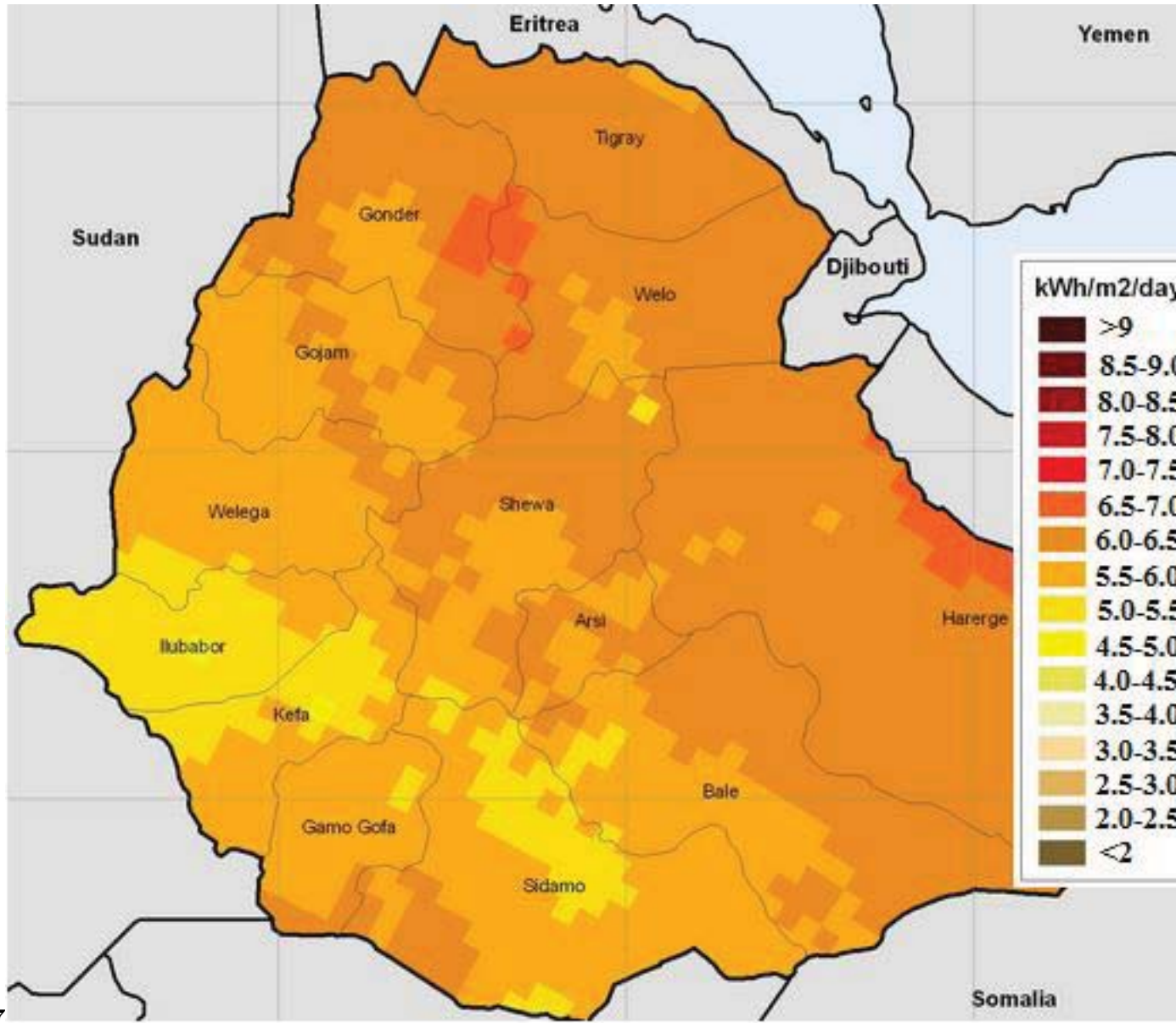
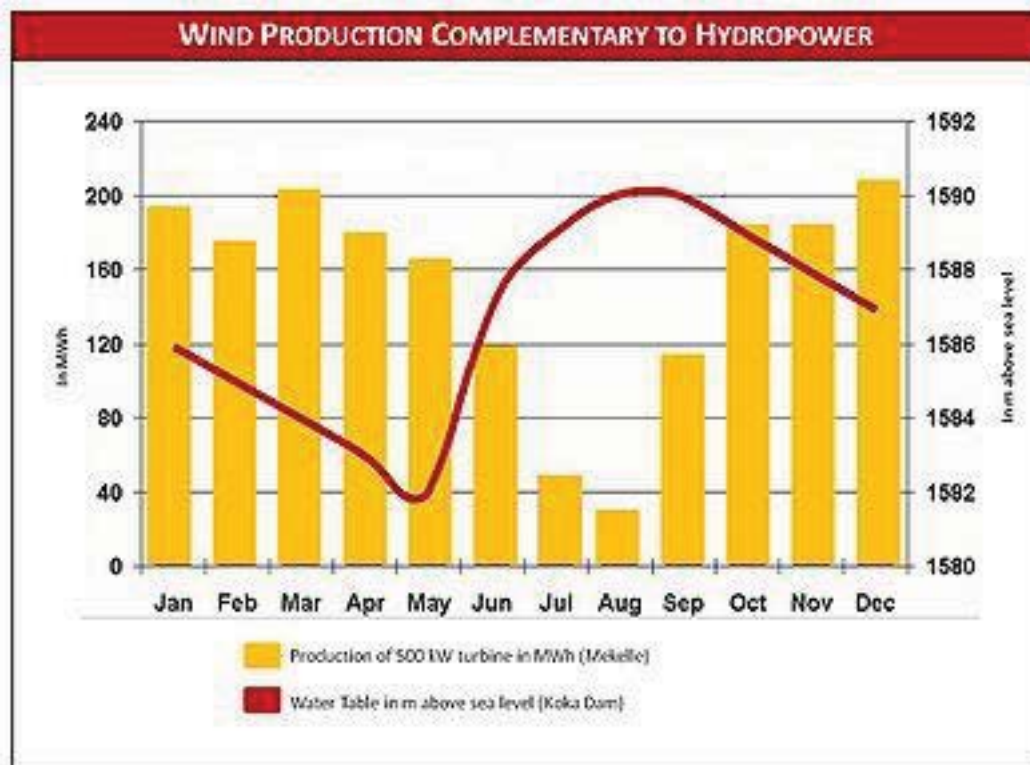


Figure 6: Figure 7 :



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Figure 7: Figure 8 :

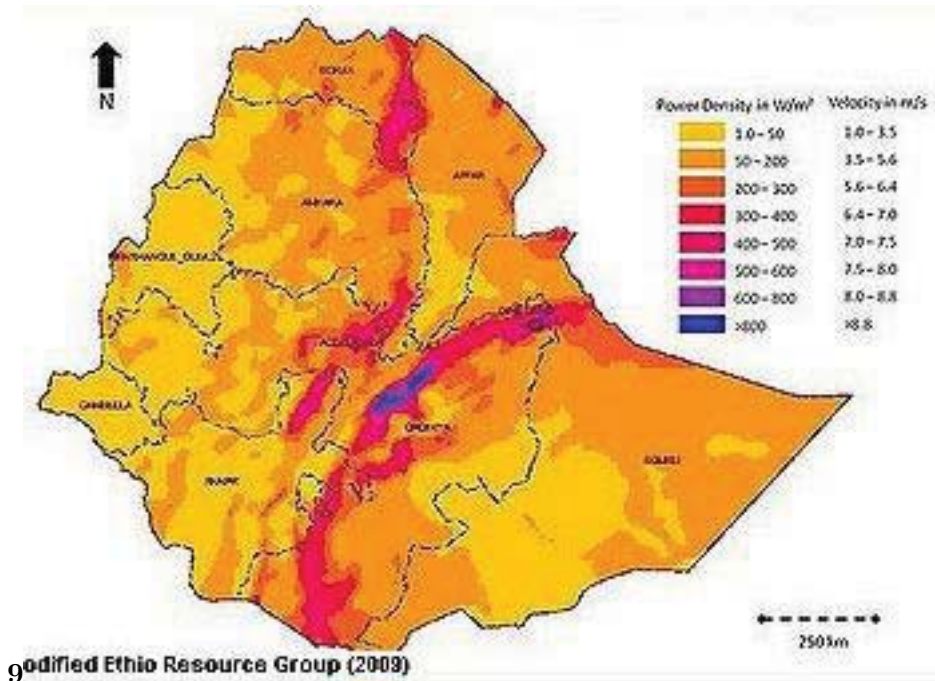


Figure 8: Figure 9 :

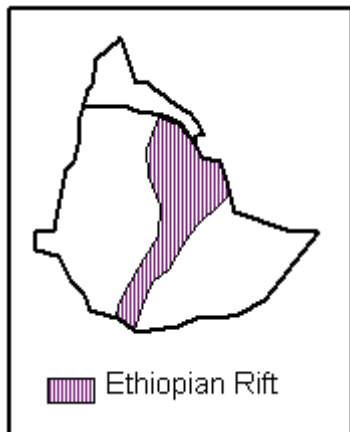
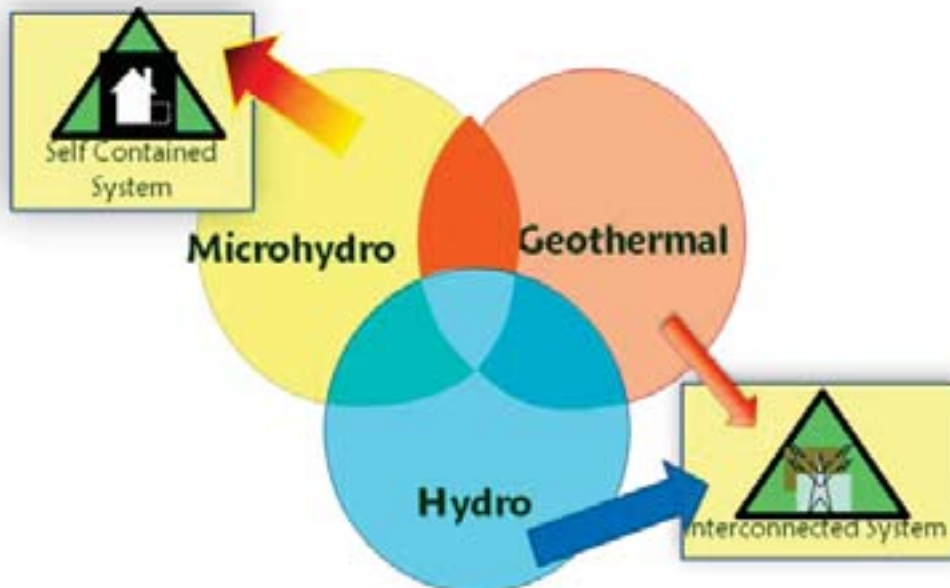
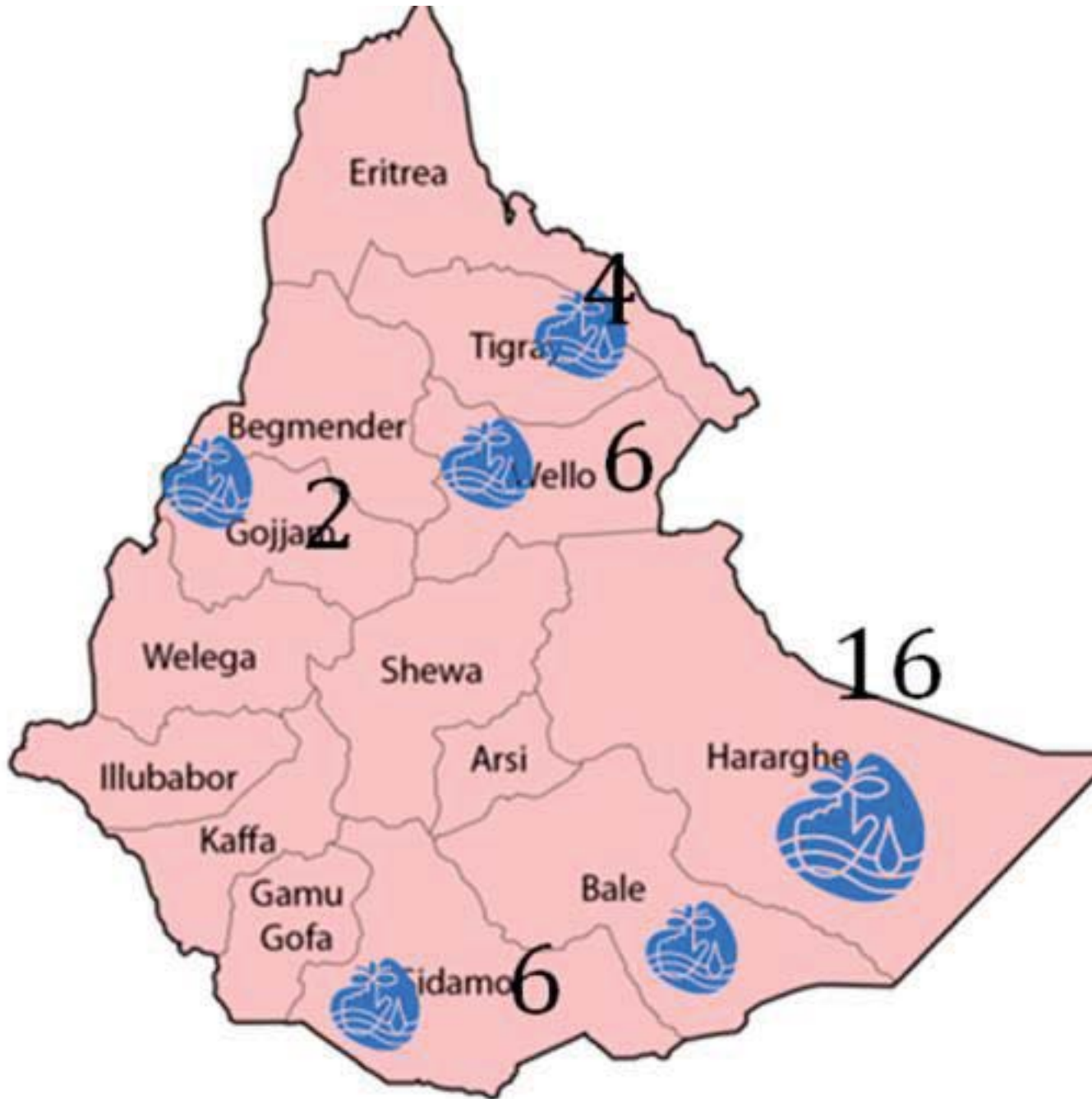


Figure 9:



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Figure 10: Figure 13 :



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Figure 11: Figure 14 :

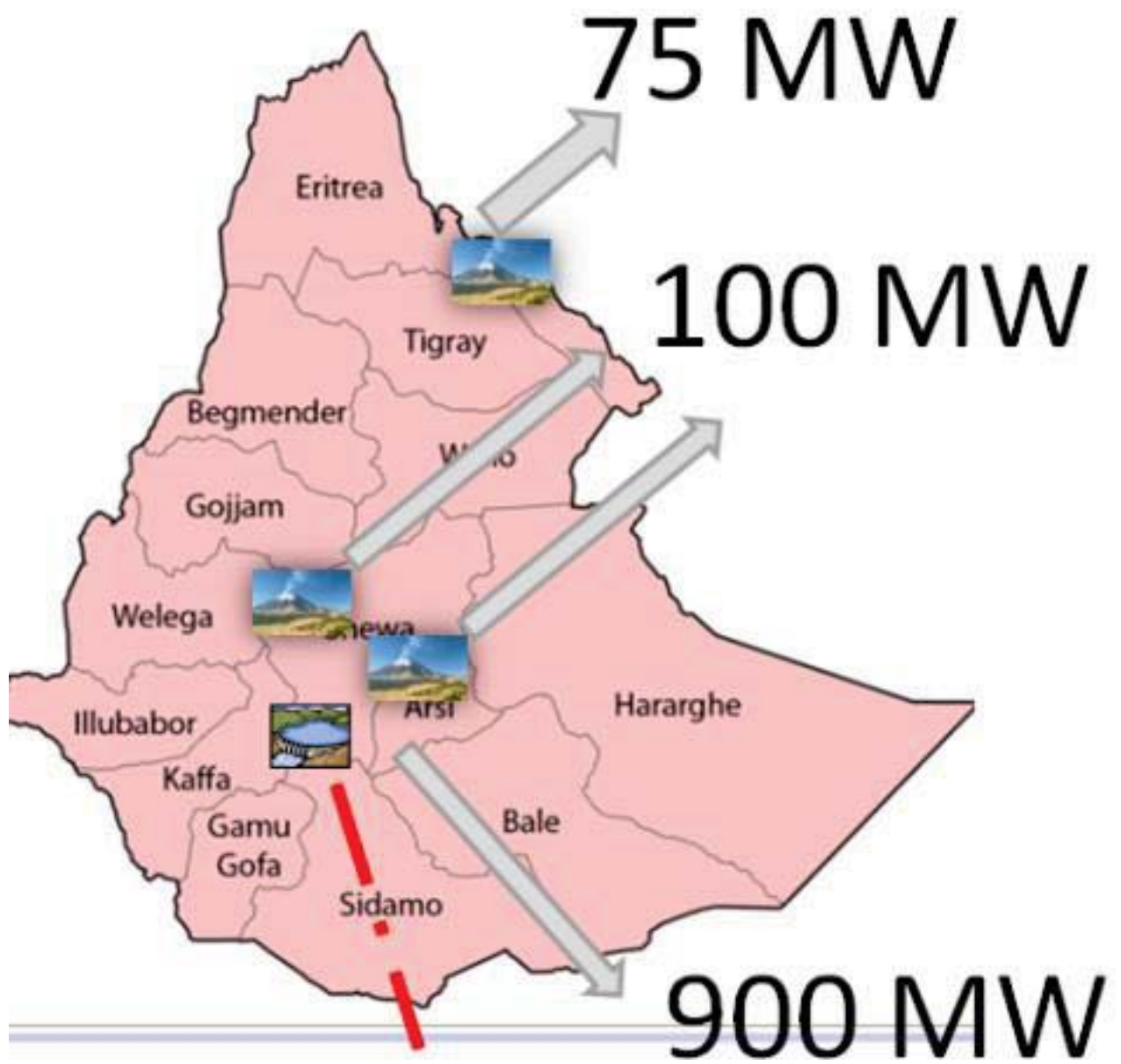
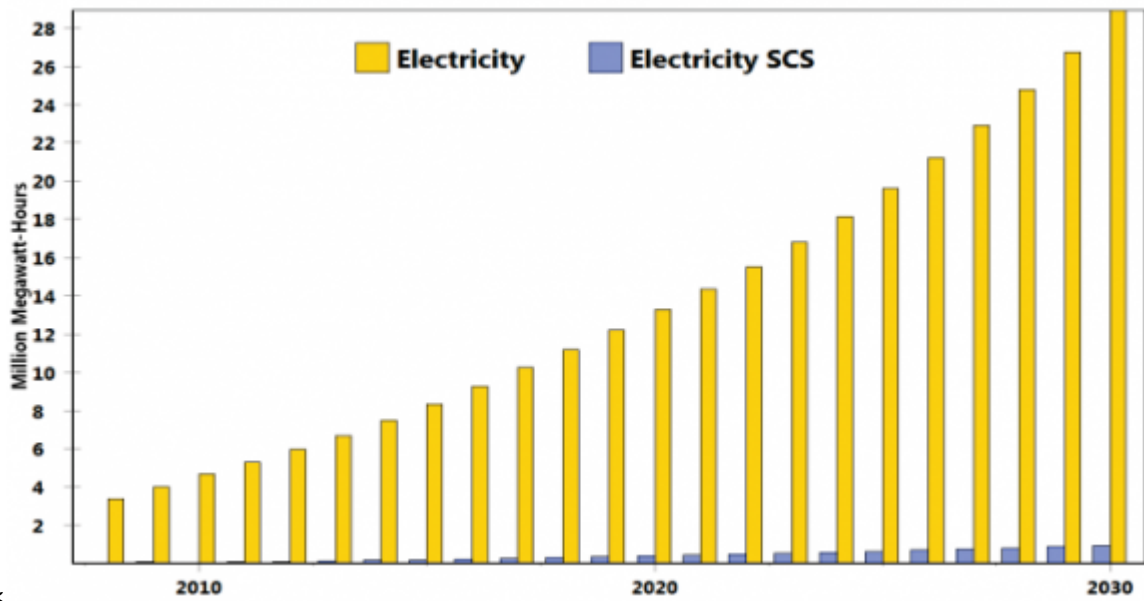
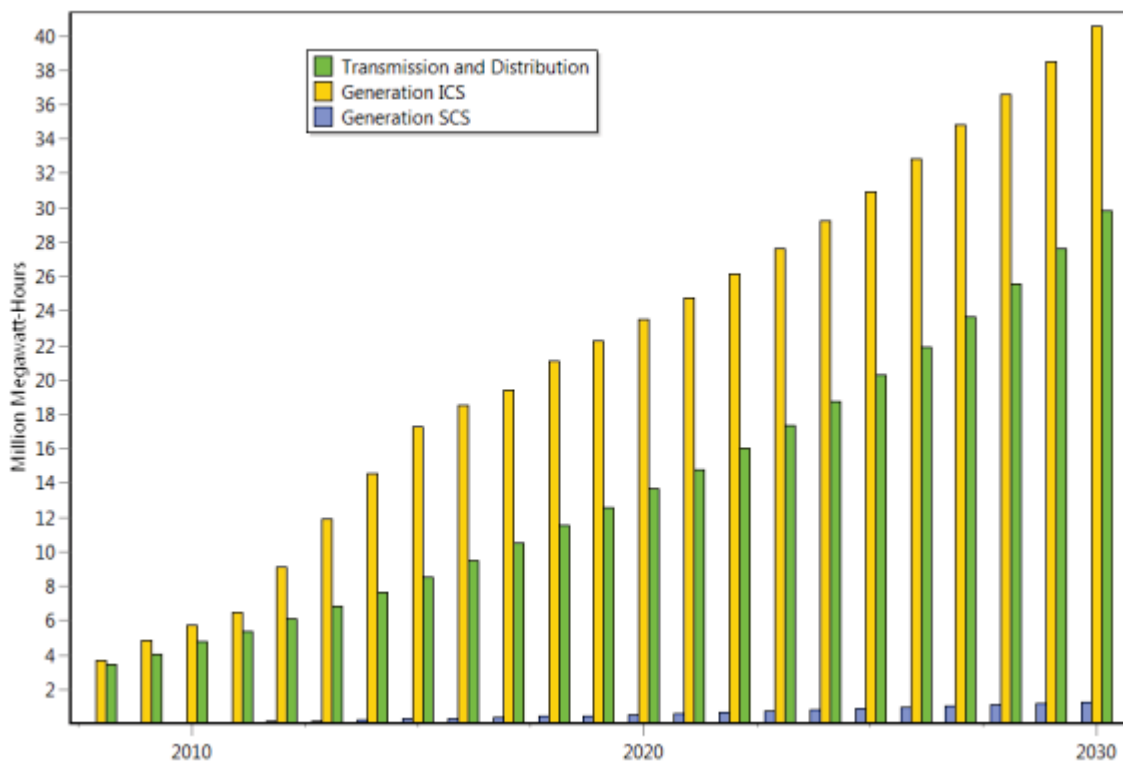


Figure 12: F



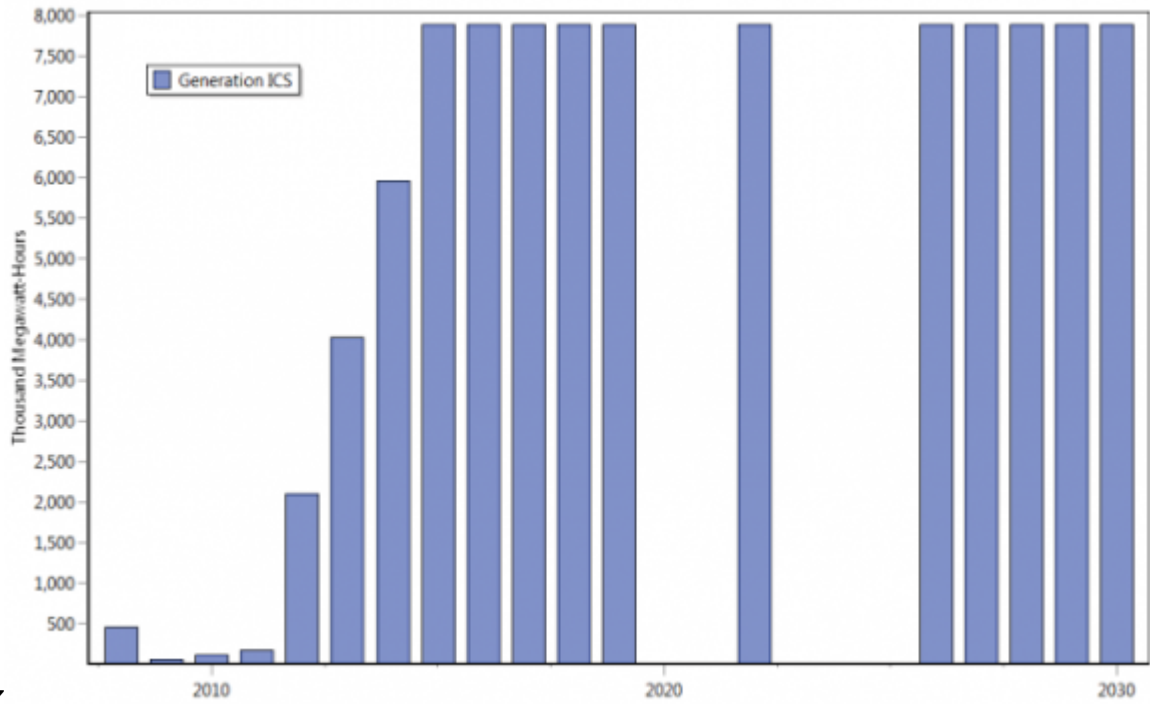
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Figure 13: Figure 12 :Figure 15 :



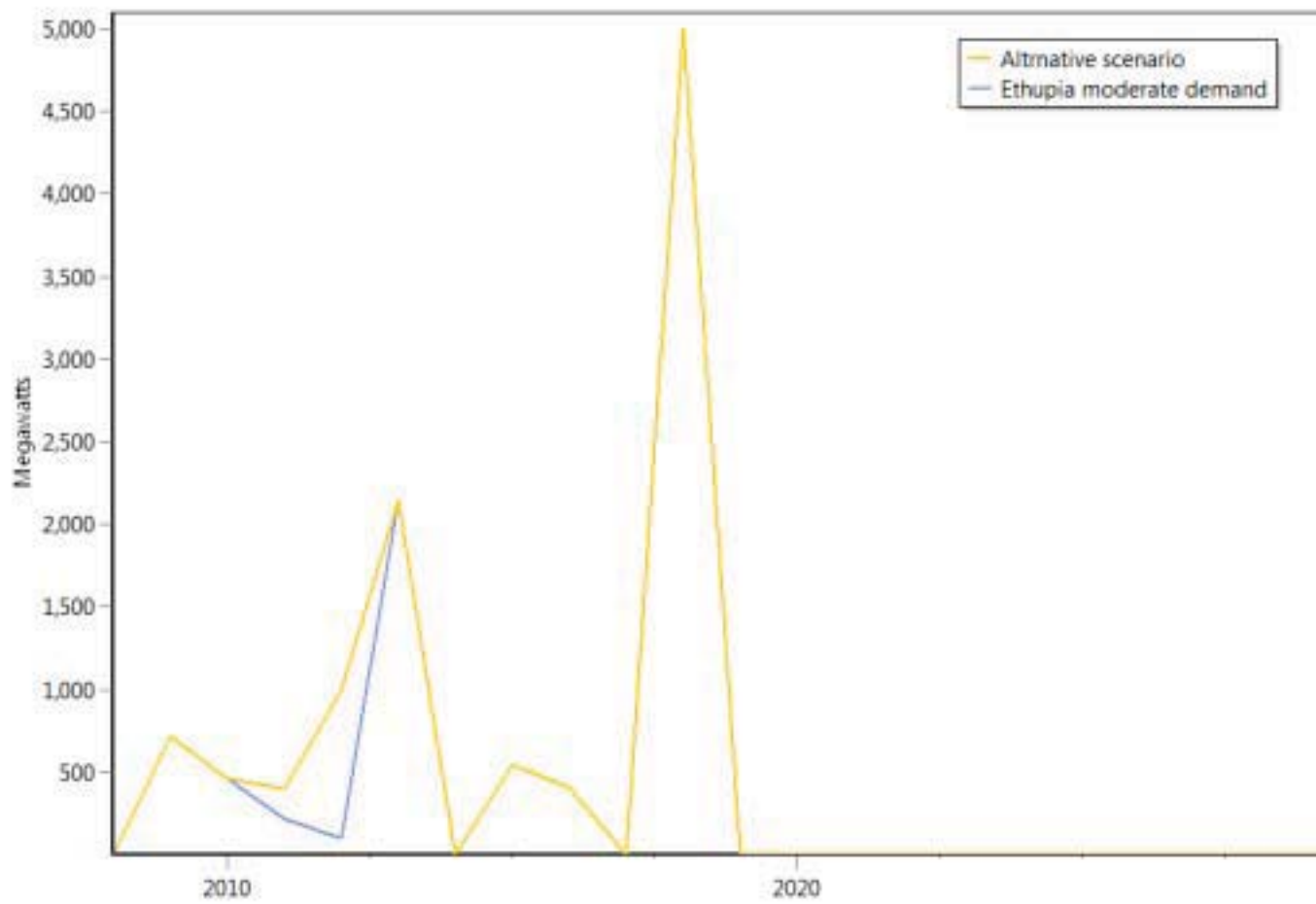
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Figure 14: Figure 16 :



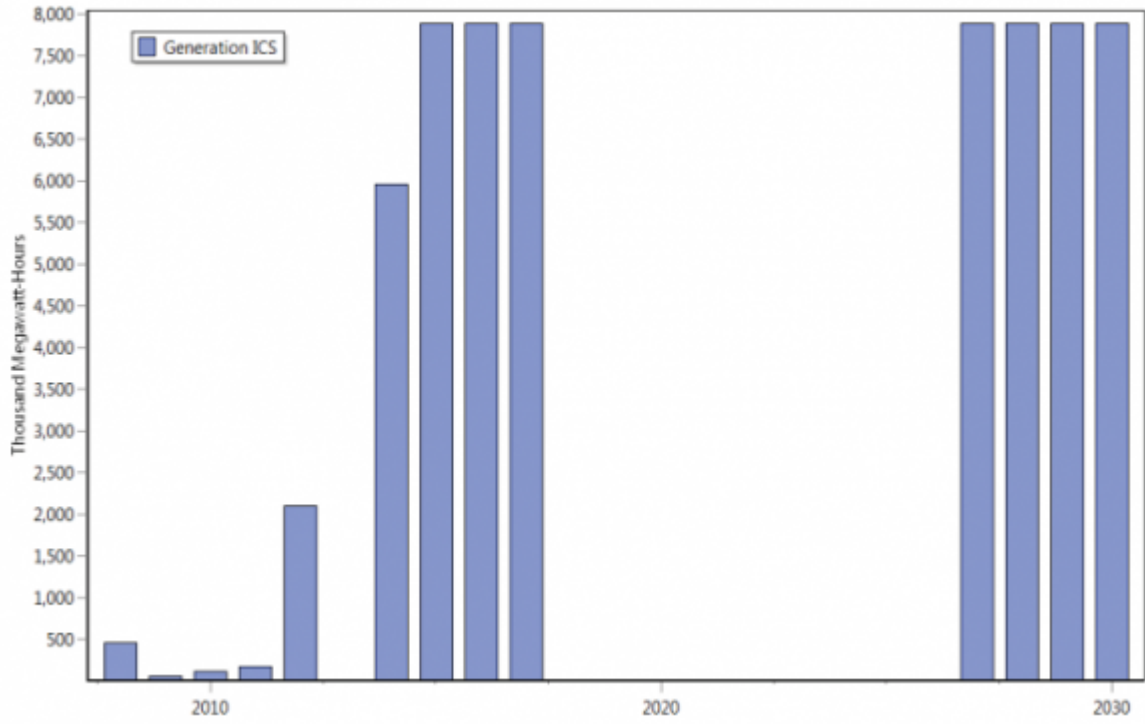
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Figure 15: Figure 17 :



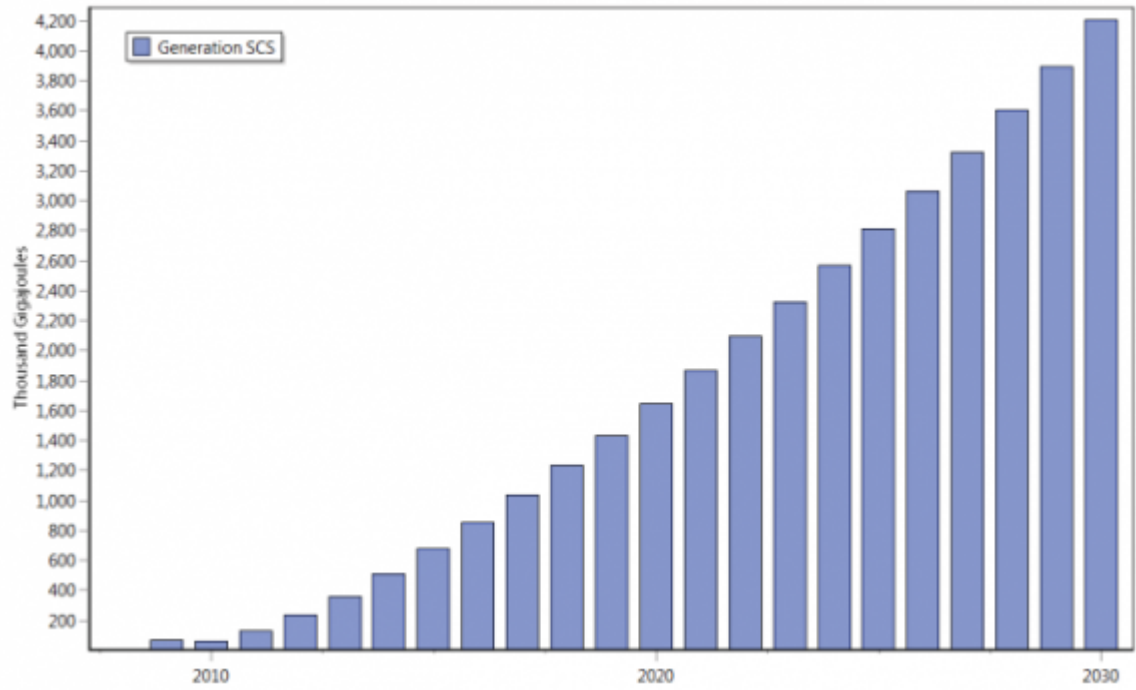
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Figure 16: Figure 18 :



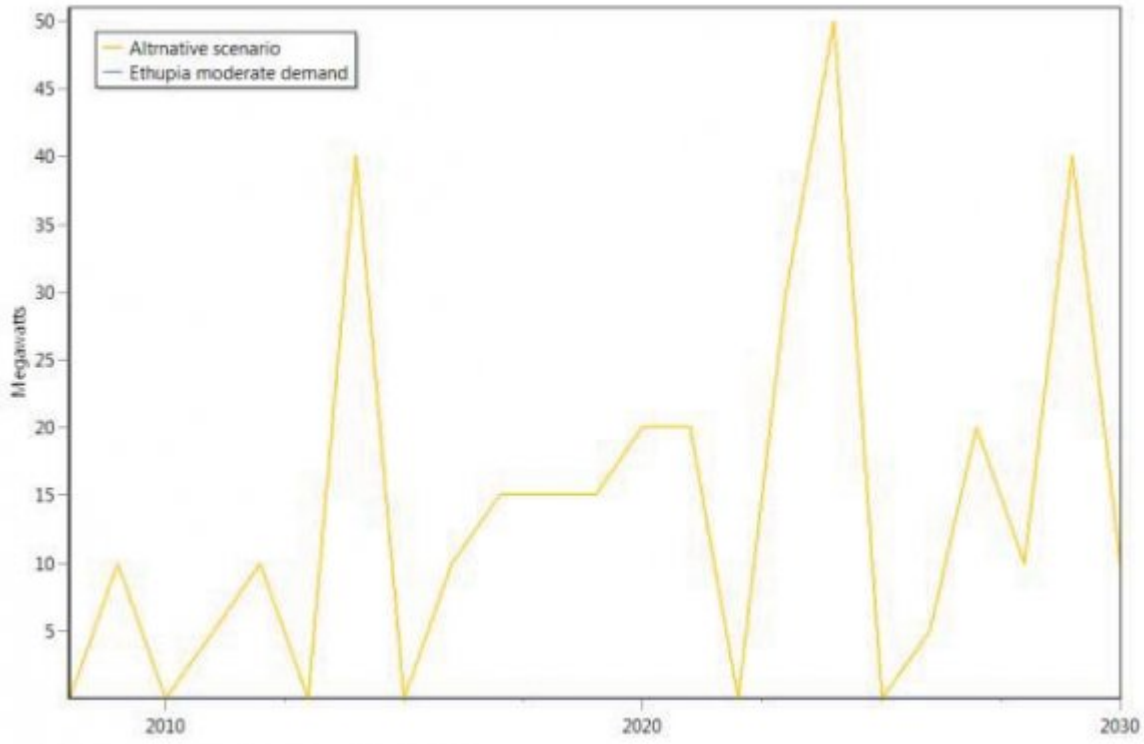
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Figure 17: Figure 20 :



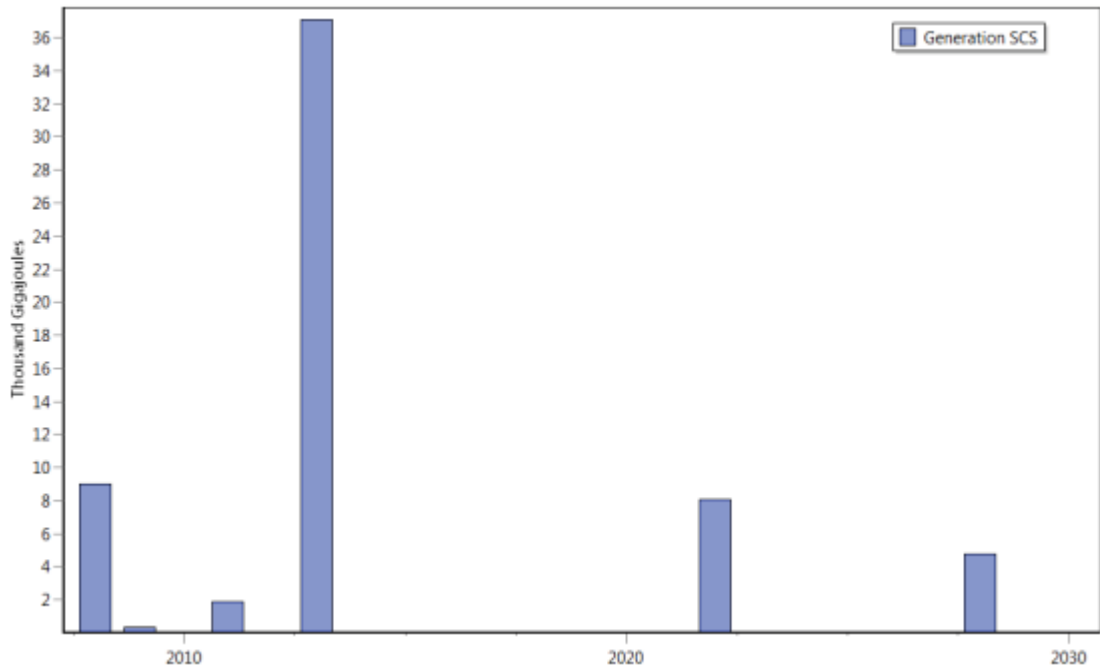
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Figure 18: Figure 21 :



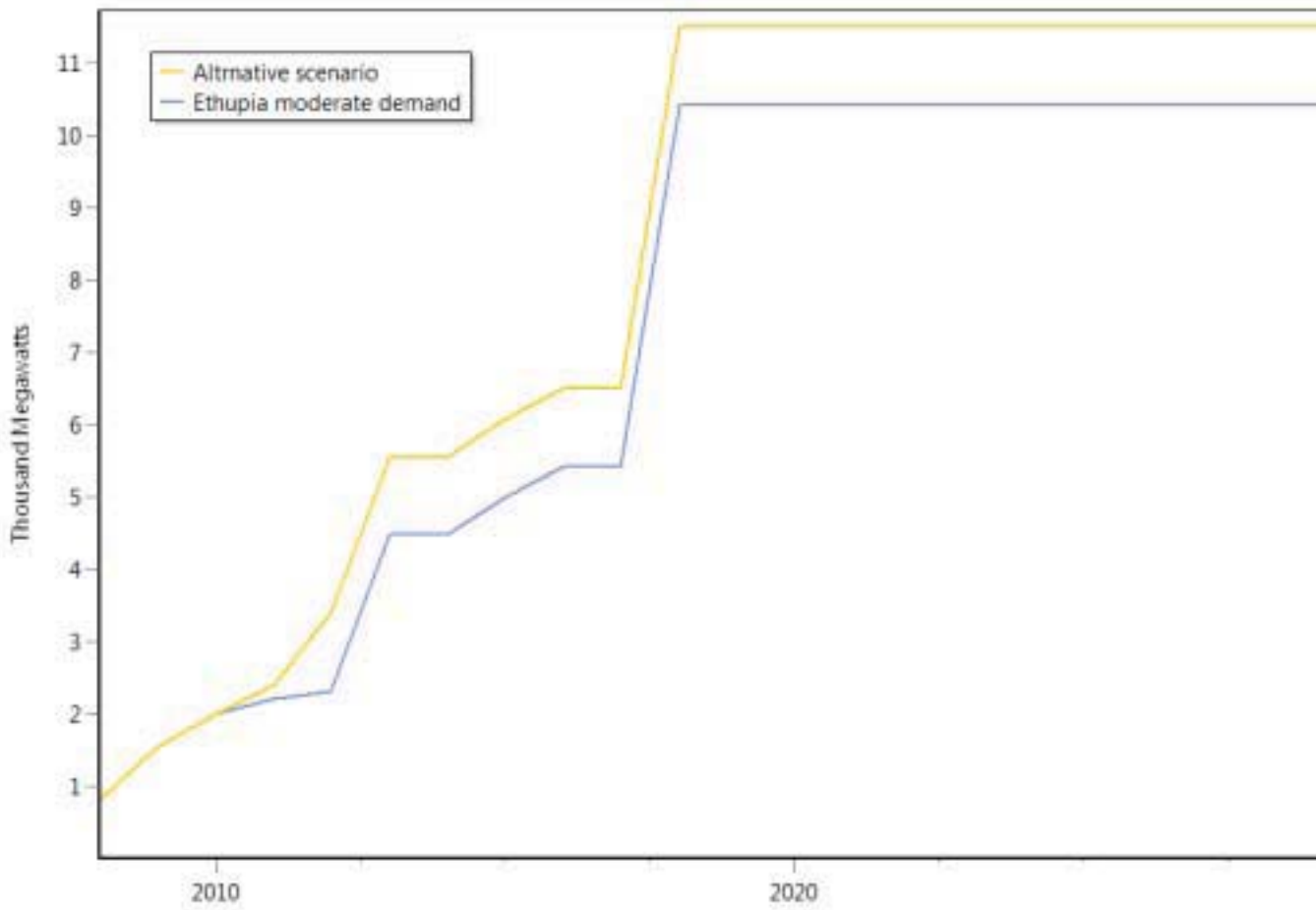
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Figure 19: FFigure 22 :Figure 23 :



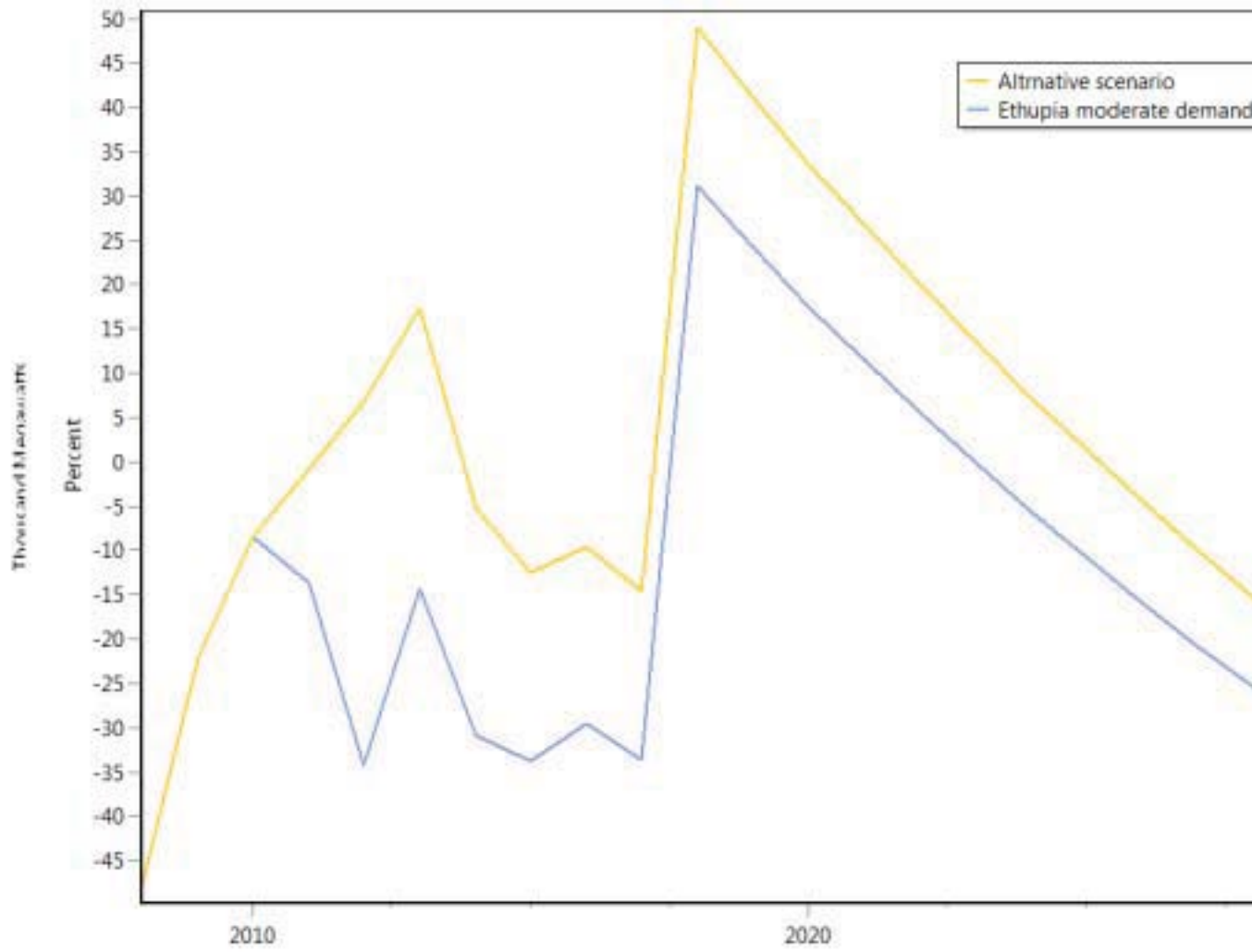
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Figure 20: Figure 25 :



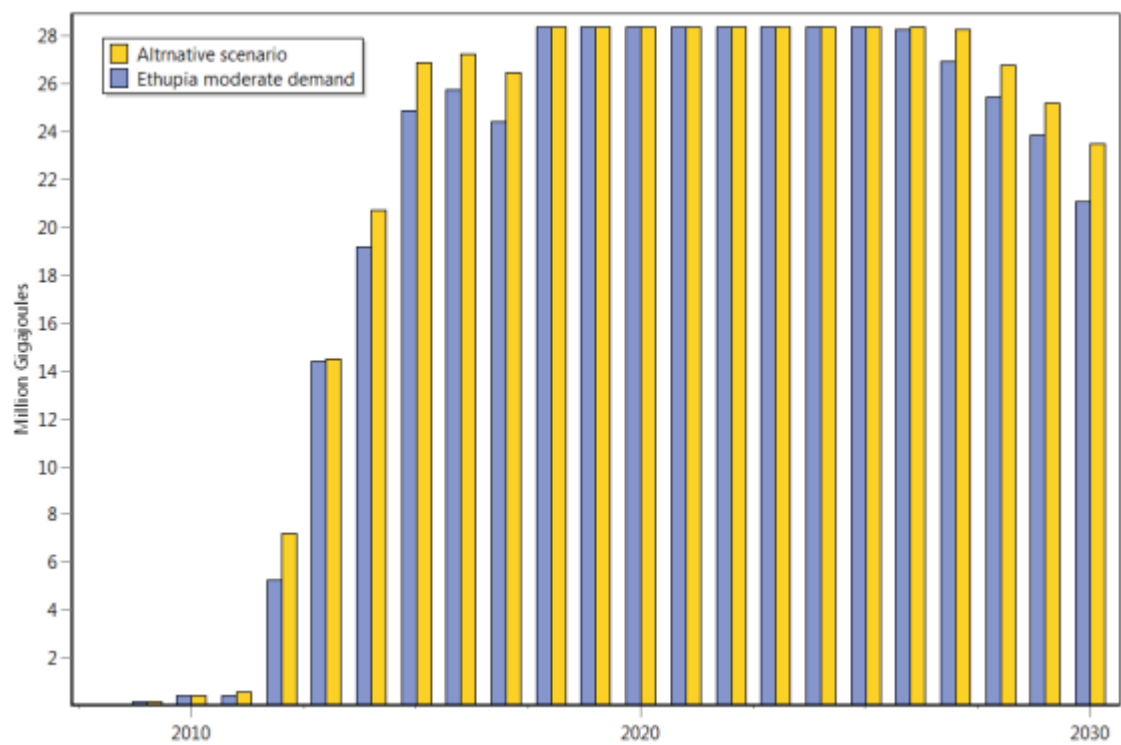
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Figure 21: Figure 26 : 2 F



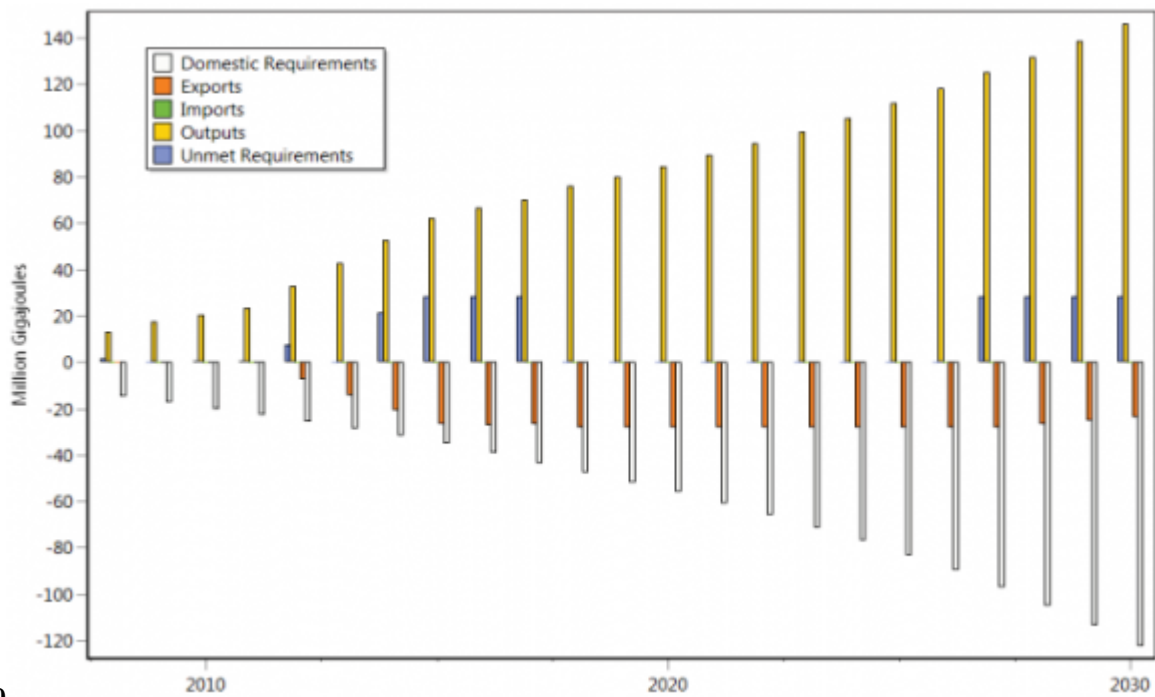
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Figure 22: Figure 28 :



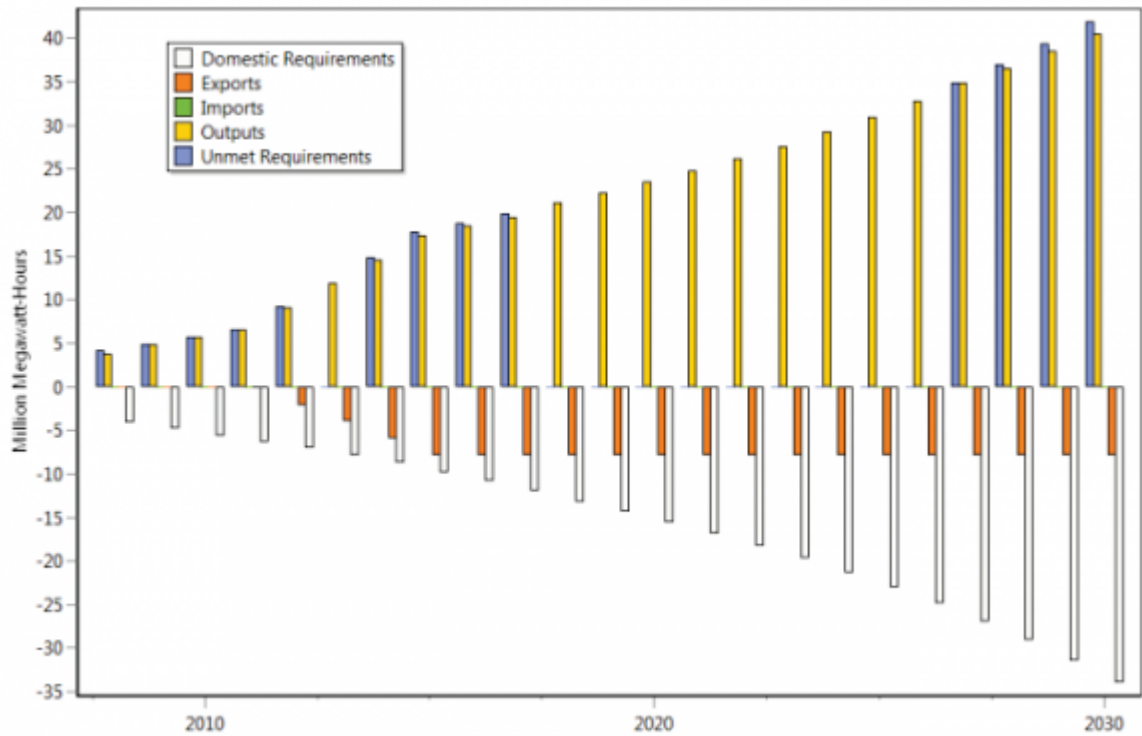
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Figure 23: Figure 29 :



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Figure 24: Figure 30 :



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Figure 25: Figure 31 :

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Figure 26: Table 2 :

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[Note: g) Unmet Demands in SCS of Ethiopia Alternative Scenario]

Figure 27: Table 3 :

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013
2
Year

Figure 28: Table 4 :

Year	Alternative scenario(MW)	Ethiopia Moderate demand(MW)
2009	10	0
2011	5	0
2012	10	0
2014	40	0
2016	10	0
2017	15	0
2018	15	0
2019	15	0
2020	20	0
2021	20	0
2023	30	0
2024	50	0
2026	5	0
2027	20	0
2028	10	0
2029	40	0
2030	10	0

year	Unmet demands in alternative scenario(Thousands MW)	
2008		9.02
2009		0.32
2011		1.87
2013	37.08	
2022		8.04
2028		4.76

Figure 29: F

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013
2
Year

Figure 30: Table 5 :

Figure 31: F

193 [Legros et al. ()] , G Legros , I Havet , N Bruce , S Bonjour . *A Review Focusing on the Least Developed countries*
194 *and Sub-Saharan Africa* 2009.

195 [Ethiopia Current Situation (2011)] , [https://energypedia.info/index.php/Ethiopia_Country_](https://energypedia.info/index.php/Ethiopia_Country_Situation)
196 [Situation](https://energypedia.info/index.php/Ethiopia_Country_Situation) *Ethiopia Current Situation* September 2011.

197 [Energy Balances for International Energy Agency ()] ‘Energy Balances for’. *International Energy Agency* 2010.
198 2010. (Non OECD Countries. Energy)

199 [It is observed that the cost involved in generation ICS is 1,688.5 Million US *.SmallhydropowerplantswereproposedforSCSgener*
200 *It is observed that the cost involved in generation ICS is 1,688.5 Million US \$. Small hydro power plants were*
201 *proposed for SCS generation,* (In the long run, there would be benefits which is equivalent to 2.6 Million US
202 \$)

203 [World Energy Outlook International Energy Agency ()] ‘World Energy Outlook’. *International Energy Agency*
204 2009.