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Subject:

Potential for green hydrogen production from biomass, solar and wind for the rising of green hydrogen economy in Togo

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by:

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In his book “The Mysterious Island” published in 1875, Jules Verne wrote this: “*water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable*”.

SUMMARY

DEDICATION

To the one by whom I was created, **The Almighty God**, who gives me the chance to be, to my dear parents **Dominique and Elvire KITEGI** who are celebrating their 30th wedding anniversary in September, and to my lovely sisters and brother **Pelagie, Christine** and **Joseph,** I bestow this work.

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- Co-supervisor, **Dr. Yendoubé LARE**, thanks for being more than a professor, a motivator and an inspire. I would like by the deepness of my heart acknowledge you. This work has been done in the right time because of your words and advices. May God bless you day after day, may he fill your life with joy, happiness and unstoppable success.
- To all my Lecturers from Cape Coast University and of the Université joseph KI-ZERBO, and all the partners universities who gave us the best for this degree. May God bless you all, you will never be forgotten.
- Director of WASCAL Togo, **Dr Komi AGBOKA,** this work has been done in a good environment due to your facilities that you have provided me. Thanks for all what you are doing for me since my bachelor degree to now. May God bless you.
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- To you **Dr Youssouphe KIENTEGA** and your spouse **KIENTEGA** born **OUEDRAOGO Talato Maïmouna**. You've hosted me sometimes during my stay in Ouagadougou, you did your best to encourage me. May God bless you, and thanks for all.

To you **all French lectors of the parish Saint Camille of Ouagadougou, Lectors of Parish Mary site of wisdom of Cape Coast**, and the **Pax Choir UCC,** you have accepted me as one of yours. I am really happy to share this part of my life with you. May God rain down upon you all the graces that you need, each of you, to continue brightening in this world.

ABSTRACT

Potential of green hydrogen producing from biomass, solar and wind in Togo has been performed. The availability of all these three resources has been depicted with maps showing them per cantons in Togo, thus, by using the datasets from ESA Biomass Climate Change Initiative, the global solar atlas and the global wind atlas. In order to evaluate the potential of green hydrogen from all these resources these conversions rates were used: for solar resource, 3% of land were allocated for the analysis after removing the exclusions with a conversion rate of 52.5 kWh/kg of hydrogen; for biomass hydrogen, the conversion rate of 13.4 kg BS/kg H_2 was assumed. Wind resources at 50 m above ground were not sufficient to evaluate the potential as it is lower than class 3 winds. QGIS version 3.6.4 and R version 4.0.4 were used. Finally, biomass is the leading resource for producing green hydrogen from renewable energy resource; with good impact in these two cantons: Bassar, Gobe/Eketo/Gbadi N'Kugna. This study has shown that biomass is the lead source of energy but is still decreasing and in some cantons it is null.

Key words: ***Green Hydrogen potential, Solar, wind, Biomass, Climate change***

RESUME

Le potentiel de production de l'hydrogène vert à partir de la biomasse, du solaire et du vent a été analysé. La disponibilité des trois ressources renouvelables a été montrée par cantons à partir de différentes cartes au Togo. Ceci a été effectué par l'usage de la base des données du *ESA Biomass Climate Change Initiative, du global solar atlas* et du *global wind atlas*. Dans le but d'évaluer les différents potentiels de production d'hydrogène vert, différentes formules ont été utilisées. Pour le solaire, 3% des terres ont été allouées au projet par Canton suite à l'exclusions de certaines zones avec un taux de conversion de 52,5 kWh/kg d'hydrogène vert. Pour la biomasse, le taux de conversion fut de 13,4 kg BS/kg H_2. Pour le vent, sa vitesse à 50 m d'altitude était inferieure a la vitesse minimale autorisée pour être classé parmi les vents de classe 3. Sur ce, le potentiel n'a pas pu être évalué. Le logiciel QGIS version 3.6.4 et le logiciel R version 4.0.4 ont été utilisées. Enfin, la biomasse est apparue comme la principale source de production d'hydrogène vert à partir des énergies renouvelables. Les cantons de Bassar, Gobe/Eketo/Gbadi N'Kugna sont les plus prometteurs pour le projet. Cette étude a montré que bien que la biomasse demeure le leader des sources d'énergie et de conversion en hydrogène vert, elle diminue et tend à se réduire dans beaucoup de cantons.
Mots clés : ***potentiel d'Hydrogène vert, Solaire, Vent, Biomasse, Changement climatique***

TABLES

FIGURES

Introduction

Introduction

The United nations have made projections on the world population to 2030, 2050 and 2100[1]. According to findings, the world population is still increasing, even if some countries are experiencing a decrease. Besides, Sub-Saharan Africa will account for most of the growth of the world's population over the coming decades, while several other regions will begin to experience decreasing population numbers. In Togo, Nyoni et al. [2] have made a projection based on 1960 to 2017 population data in Togo and they found that Togo's population can reach 14.2 million in 2050. This growing population will certainly insinuate the increase of needs. Among these needs, energy is one of the essentials. The Togolese Agency for Rural Electrification and Renewable Energies [3] has stated that the rate of electricity access was around 45% in 2018 and 8% in rural areas. Compare to the previous population estimated data, we can conclude that there is an urgent need to find sustainable and climate smart ways of generating energy for the growing population. The seventh sustainable development goals were built to ensure access to affordable, reliable and modern energy for all by 2030. Vijay [4] explore how green energy is useful for the future aspect of the world. She found that sources of green energy such as solar, wind, geothermal and hydro energy, developed and promoted as alternative source will make a little or no contribution to climate change. Most known form of renewable energy comes from solar energy. Anyone can install, where sunlight is available, in its space's solar panels. Other areas where wind is plenty can be full of wind turbines to produce wind energy. To the previous, we can add the marine energy which is also an important renewable energy resource. Biomass is another source of renewable energy. It can be used as a transportation fuel and to produce electricity. There is a problem of energy storage when it comes in the using of renewable energies. How to maximize the storage of the energy? To solve it, the conversion of renewable energy electricity to hydrogen became the best way. So many researchers have worked on the subject. The primitive designation of green hydrogen was renewable hydrogen. It was used for the first time in 1995 by the Hydrogen Technical Advisory Panel (HTAP) of the U.S. Department of Energy's (DOE) as hydrogen produced from renewable energies. Furthermore, in 2020 IRENA has distinguished 4 different shades of hydrogen[5]: the grey hydrogen, the blue, the turquoise hydrogen and finally, the green hydrogen. In 1992, Veziroglu and Barbir [6] had compared conventional and unconventional fuels with the green hydrogen through these criteria: transportation fuel, versatility, utilization efficiency, environmental compatibility, safety and Economics (effective cost). At the end of the study, green hydrogen was selected as the best transportation fuel, the most versatile fuel, the most efficient fuel, the environmentally most compatible fuel, the safest fuel, and the most cost-effective fuel to society and the paper was named the Hydrogen, the wonder fuel. In 2008, Veziroglu and Sumer[7] has confirmed the previous result and they had named it green hydrogen, the 21st century fuel. But to make further studies on the implementation of green hydrogen technology, it is important to know the potential for green hydrogen of the area. The United States have assessed their potential in 2007[8], Argentina in 2014[9] from their key renewable resources. These studies have helped them to visualize the potential in any cantons of the country and enable other researches and investments to establish green hydrogen economy in these countries at the appropriate areas. To date, there is no study to know the potential of green hydrogen production from renewable energy resources in Togo. This study intends to fill this void for Togo, by assessing the potential for green hydrogen production from wind, solar and biomass.

The general objective of this research is:

- To assess the potential of green hydrogen production from wind, solar and biomass in Togo.

The specific objectives are to:

- assess the wind, solar, and Biomass energy resource available by cantons and globally for the whole country;
- evaluate the green hydrogen potential from wind, solar, and Biomass by cantons and for the whole country
- determine the total amount of hydrogen that could be produced from wind, solar, and Biomass by canton in Togo

The document will be structures in five chapters. The first will explore the literature review on green hydrogen, the second, the third and the fourth will evaluate respectively the potential of green hydrogen production from biomass, solar and wind. The last chapter will focus on the total amount of green hydrogen producible in Togo.

Chapter 1:

Literature review on green hydrogen

Chapter 1: **Literature review on green hydrogen**

Introduction

IRENA[10] has stated that green hydrogen is the most suitable one for a fully sustainable energy transition. In this chapter we will cover the definition of the concept, an attempt answers of the question: why green hydrogen?

1.1 What is green hydrogen?

In 1766, Henry Cavendish [11] have discovered a gas that he had name *hydrogen*. This name hydrogen came from two Greek words 'hydro' and 'genes' meaning water forming. Its combustion release only water. We can remember this simple equation.

$$2H_2 + 0_2 \rightarrow 2H_20$$

Dihydrogen is the form in which we can find hydrogen, the first element in the periodic table, in the nature. It is a gas colorless, odorless but very inflammable diatomic molecule. Indeed, hydrogen is present in anybody which contain a little water such as water, hydrocarbons and carbohydrates.

The primitive designation of green hydrogen was *renewable hydrogen*. It was used the first time[12] in 1995 by the Hydrogen Technical Advisory Panel (HTAP) of the U.S. Department of Energy's (DOE) as hydrogen produced from renewable energies. Furthermore, IRENA [10] has distinguished 4 different shades of hydrogen. The Fig. 1 depicts these four different shades. The ***grey hydrogen*** which is produced by steam methane reforming or gasification, ***blue hydrogen*** produced by steam methane reforming or gasification with a carbon capture between 85 to 95%, ***turquoise hydrogen*** produced by pyrolysis, and the ***green hydrogen*** produced from renewable energy through electrolysis.

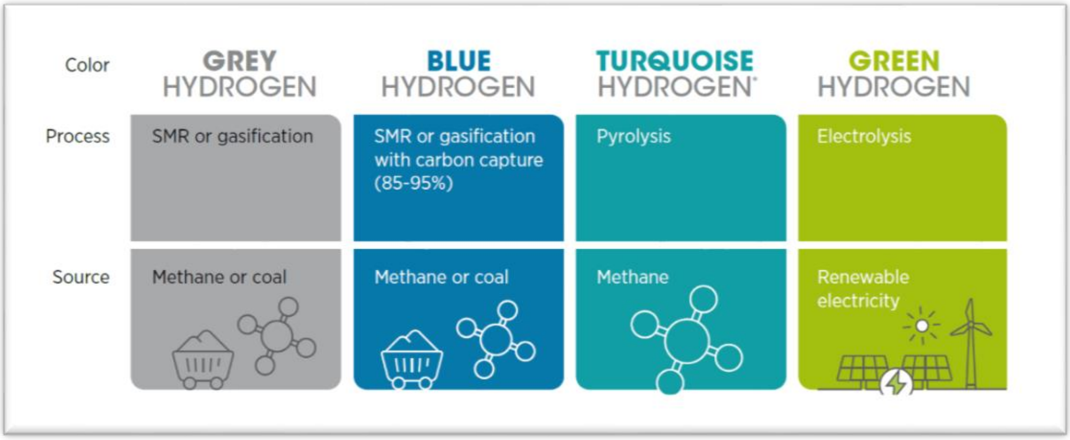

Fig. 1. *Shades of hydrogen* [10]

SMR = steam methane reforming

1.2. Why green hydrogen?

The industrial revolution was stamped by the discovery of fossil fuel. The humankind is still dependent on them until today. This new source of energy seemed to bring a sustainable future for the world, but unfortunately, they've brought many damages to the world. Nejat and Sumer[13] in 2008 has listed some of these damages presented in TABLE I. First, the depletion of fossil fuels due to the rise of demand for energy because of two main reasons: (a) the continuing increase in world population, and (b) the growing demand by the developing countries in order to improve their living standards. Secondly, environmental damages that we can resume in Table 1. It depicts the results for each type of damage, in 1998, in US dollars. It can be seen that the environmental damage for coal is $14.51 per GJ of coal consumed, for petroleum $12.52 per GJ of petroleum consumed, for natural gas $8.26 per GJ of natural gas consumed, and the weighted mean damage in the world is $12.05 per GJ of fossil fuel consumption. These damage costs are not included in the prices of fossil fuels, but they are paid for by the people directly or indirectly through taxes, health expenditures, insurance premiums, and through a reduced quality of life. In other words, today fossil fuels are heavily subsidized.

TABLE I. ENVIRONMENTAL DAMAGE CAUSED BY EACH OF FOSSIL FUELS IN 1998[13]

Type of damage (n)	Environmental damage 1998 $ per GJ					
	Coal		Petroleum		Natural gas	
	Itemized damage	Sub-totals	Itemized damage	Sub-totals	Itemized damage	Sub-totals
Effect on humans		5.16		4.19		3.09
Premature deaths	1.75		1.42		1.05	
Medical expenses	1.75		1.42		1.05	
Loss of working efficiency	1.66		1.35		0.99	
Effect on animals		0.75		0.63		0.45
Loss of domestic live stock	0.25		0.21		0.15	
Loss of wildlife	0.20		0.42		0.30	
Effect on plants and forests		1.99		1.61		1.20
Crop yield reduction – ozone	0.25		0.21		0.15	
Crop yield reduction – acid rains	0.13		0.10		0.07	
Effect on wild flora (plants)	0.77		0.62		0.46	
Forest decline (economic value)	0.27		0.22		0.16	
Forest decline (effect on biological diversity)	0.53		0.43		0.33	
Loss of recreational value	0.04		0.03		0.03	
Effect on aquatic ecosystems		0.26		1.55		0.16
Oil spills	–		0.44		–	
Underwater tanks leakages	–		0.90		–	
Liming lakes	0.04		0.03		0.03	
Loss of fish population	0.04		0.03		0.03	
Effect on biological diversity	0.18		0.15		0.10	
Effect on man-made structures		1.66		1.34		0.98
Historical buildings and monuments degradation	0.18		0.15		0.10	
Buildings and houses' detriment	0.37		0.30		0.22	
Steel constructions corrosion	0.99		0.80		0.59	
Soiling of clothes, cars, etc.	0.12		0.09		0.07	
Other air pollution costs		1.45			1.16	
Visibility reduction	0.30			0.23		0.18
Air pollution abatement costs	1.15			0.93		0.70
Effect of strip mining		0.73		–		–
Effect of climactic changes		2.04		1.66		1.22
Heat waves – effects on humans	0.27		0.22		0.16	
Droughts						
Agricultural losses	0.16		0.13		0.10	
Livestock losses	0.13		0.10		0.07	
Forests losses	0.16		0.13		0.10	
Wild flora and fauna losses	0.93		0.75		0.56	
Water shortage and power production problems	0.25		0.21		0.15	
Floods	0.07		0.06		0.04	
Storms, hurricanes, tornadoes	0.07		0.06		0.04	
Effect of sea level rise		0.47		0.38		0.28
Totals		14.51		12.52		8.26

From the TABLE I. , the use of fossil fuel has effect on the climate, on man-made structures, aquatics ecosystems, plants and forests, animals and humans. There is a need to find a solution to that problem. In 1992, Vezirocjlu and Barbir[14] had compared conventional and unconventional fuels with the hydrogen through these criteria: transportation fuel, versatility, utilization efficiency, environmental compatibility, safety and Economics (effective cost). At the end of the study, green hydrogen was selected as the *best* *transportation fuel*, the *most versatile fuel*, the *most efficient fuel*, the *environmentally most compatible fuel*, the *safest fuel*, and the *most cost-effective fuel to society* and the paper was named the Hydrogen, the wonder fuel. In 2008, Veziroglu and Sumer[13] has confirmed the previous result and they had named it "green hydrogen, the 21st century fuel".

The green hydrogen can be store higher than the other resources. It helps to break the wall of storage large amount of energy supplied for extended periods. Green hydrogen can be stored at pounds to pounds, higher than the other resources and for long time. It could be produced wherever there is electricity and water or biomass.[1]

Added to these advantages, hydrogen has many uses. Green hydrogen can be used also in industry and be stored in pipelines to power household appliances. [2]

Hydrogen could also be used as a replacement of power to anything that uses electricity, such as electric vehicles, and devices. Besides, unlike batteries, hydrogen fuel cells don't need to be recharged and won't run down as long as they have the hydrogen fuel[3].

1.3. How to get green hydrogen?

As wonder as hydrogen is, there are different techniques to get it as it cannot be found purely in the nature. It could be getting from the conversion of renewable energy resources. This part will be focused on the production of biomass from biomass, solar and wind.

1.3.1. from biomass

Green hydrogen could be gotten from biomass through many processes but the gasification process will be developed here.

Gasification is a chemical process that help to converts carbon-containing materials such as biomass into valuable gaseous fuels and chemicals[15]. There are three different reactions during the biomass gasification process. The first is the gas solid reaction, the second the gas phase reaction and the last the synthesis gas[15].

The gas solid reaction

The gas solid reaction is also composed by 4 different reactions (TABLE II.). The carbon-oxygen reaction delivers thermal energy to binding reaction and carbon-water reactions,

[1] https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/
[2] https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/
[3] https://news.climate.columbia.edu/2021/01/07/need-green-hydrogen/

which are important for gasification of charcoal to CO and H_2. The hydrogeneration reaction provides energy to the endothermic reaction of hydrogen production process.

TABLE II. SOLID GAS REACTIONS [15]

Carbon-oxygen reaction	$C + 1/2O_2 \leftrightarrow CO$	ΔHR = - 110.5 MJ kmol-1
Binding reaction	$C + CO_2 \leftrightarrow 2CO$	ΔHR = 172 MJ kmol-1
Carbon-water reaction	$C + H_2O \leftrightarrow H_2+CO$	ΔHR = 131.3 MJ kmol-1
Hydrogenation reaction	$C +2H_2 \leftrightarrow CH_4$	ΔHR = -74.8 MJ kmol-1

The gas phase reaction

It is composed on two main reactions.

- The Water-gas displacement reaction:

$CO + H_2O \leftrightarrow CO_2 + H_2$ ΔHR = -41.1MJ kmol-1 (1)

- Methane formation reaction:

CO + 3H2 ↔ CH4 + H2O ΔHR = -206,1 MJ kmol-1 (2)

Although the water-gas binding reactions increase the H2 content in the synthesis gas, the methane formation reaction increases the amount of methane in the synthesis gas and contributes to the production of synthetic natural gas. [15]

Synthesis gas

The mixture of carbon monoxide (CO) and hydrogen (H_2) is named the synthesis gas. This is the result of the final reaction of the four ones during the gasification process for hydrogen production process.

1.3.2 from wind and solar

From wind and solar, green hydrogen could be get by the electrolysis technology.

Electrolysis is a technological process which intends to use electricity to split ionic compounds of any liquid.

The electrolysis process

Green hydrogen and oxygen can be produced from water using electricity with an electrolyzer. This electricity could come from solar or wind.

The Fig. 2 present an overview of the electrolyzer system. The power supplies and electrical controls are on the far left. Purification equipment is to the right of the power controls. The electrolyte reservoir and hydrogen and oxygen float valves with pressure gauges are to the right of the purification equipment. The caustic electrolyte storage tank is on the ground below the float valve.[16]

The same process could be used for wind energy supplied from the wind turbine to produce hydrogen.

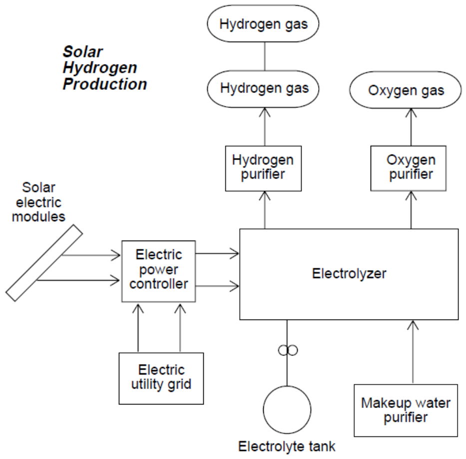

Fig. 2. *Diagram of green hydrogen production from solar electrolysis*[16]

Conclusion

Green hydrogen is seen to be promising as a wonder fuel for the future centuries. It can be produced from different techniques. This chapter attempt to explore why do we need to produce green hydrogen, how to get it. As appreciated as it is, green hydrogen production has many challenges that science is addressing. The storage principles, the efficiency of its production, the complexity of the green hydrogen system. We could have solar, and wind but without water it could not be possible to produce green hydrogen. These are some of the challenges regarding the production of green hydrogen. The next part of our work will be focusing on the methodology that we will use to perform the assessment of the potential of green hydrogen in Togo.

Chapter 2:

Green Hydrogen potential from above ground biomass in Togo

Chapter 2:

Green Hydrogen potential from Biomass data in Togo

Introduction

In this chapter we assess the potential for green hydrogen production from biomass in Togo. It is composed on three parts. The first describe the dataset use for the study and the second present the methodology used to obtain the results that we discussed.

2.1 Study area

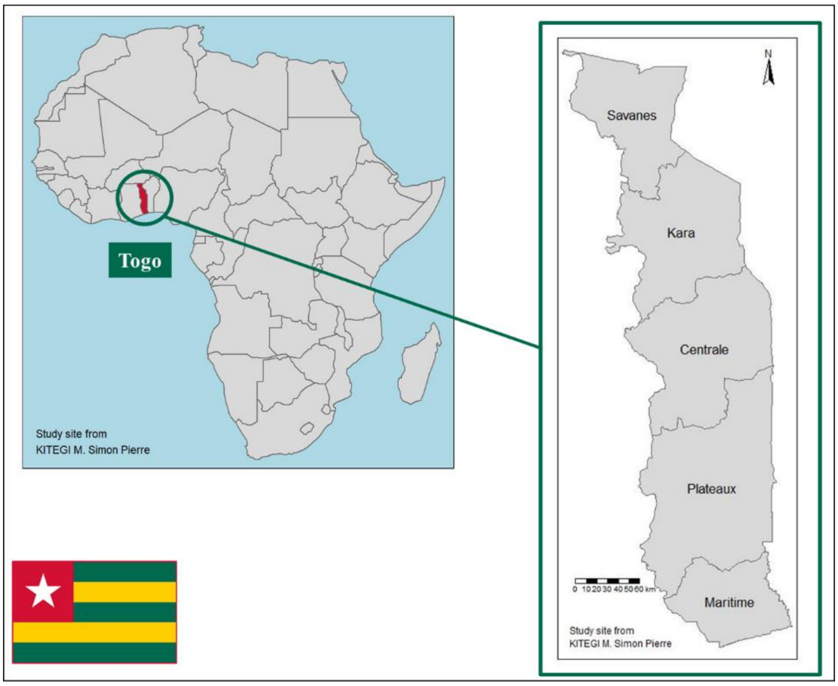

Fig. 3. *Study area, position of Togo on the map*

Togo is located in West Africa. It has 5 differents economic regions. They are : region des savanes, regions de la kara, regions centrale, region des plateaux and region maaritime.

2.1 Biomass datasets

The dataset used is from the ESA Biomass Climate Change Initiative[17]. The data consist of the forest above ground biomass for the year 2018. The data was obtained from a grouping of Earth observation data, the Copernicus Sentinel-1 mission, Envisat's ASAR instrument and JAXA's Advanced Land Observing Satellite (ALOS-1 and ALOS-2), along with additional information from Earth observation sources. It is expressed in Megagram per hectare. They have defined the above ground biomass as the mass of the oven-dry weight of the woody parts such as stem, bark, branches and twig of all living trees excluding stums and roots. The processing of the biomass resources data per cantons in Togo helps to roll out the map of the available biomass in Togo depicted in Fig. 4.

2.2 Analysis Methodology for potential of green hydrogen production assessment from biomass

To estimate the green hydrogen potential from biomass, we used the model used in the same past study in USA[18], a conversion rate of 13.8 kg bone dry weight (BDW)/kg hydrogen was applied. This rate is based on the conversion of lignocellulosic plant material to hydrogen via gasification analyzed by the U.S. Department of Energy's Hydrogen Analysis (H2A) Group. In Argentina, to calculate the potential for hydrogen production[19] per unit area from the dry biomass supply available, a conversion rate of 13 kg Biomass Supply /kg H_2 was assumed. This value is based on the conversion rate of lignocellulosic plant material to hydrogen via gasification. Our data is about all the above ground biomass available, so we chose to apply the mean of these two values, 13.4 BS/kg H_2 to estimate the potential in Togo. QGIS version 3.6.04 was used added to R version 4.0.4 was used for the analysis.

2.3. Results and Discussion

- **Available above ground biomass**

The available biomass resources are concentrated in the "region centrale" and "region des plateaux". Most of cantons in these regions have over than millions of kilograms of biomass per hectare (fig. 5). This leads to the green hydrogen potential map illustrated on Fig. 5, as the green hydrogen presence is related directly, without any restriction, to the biomass available.

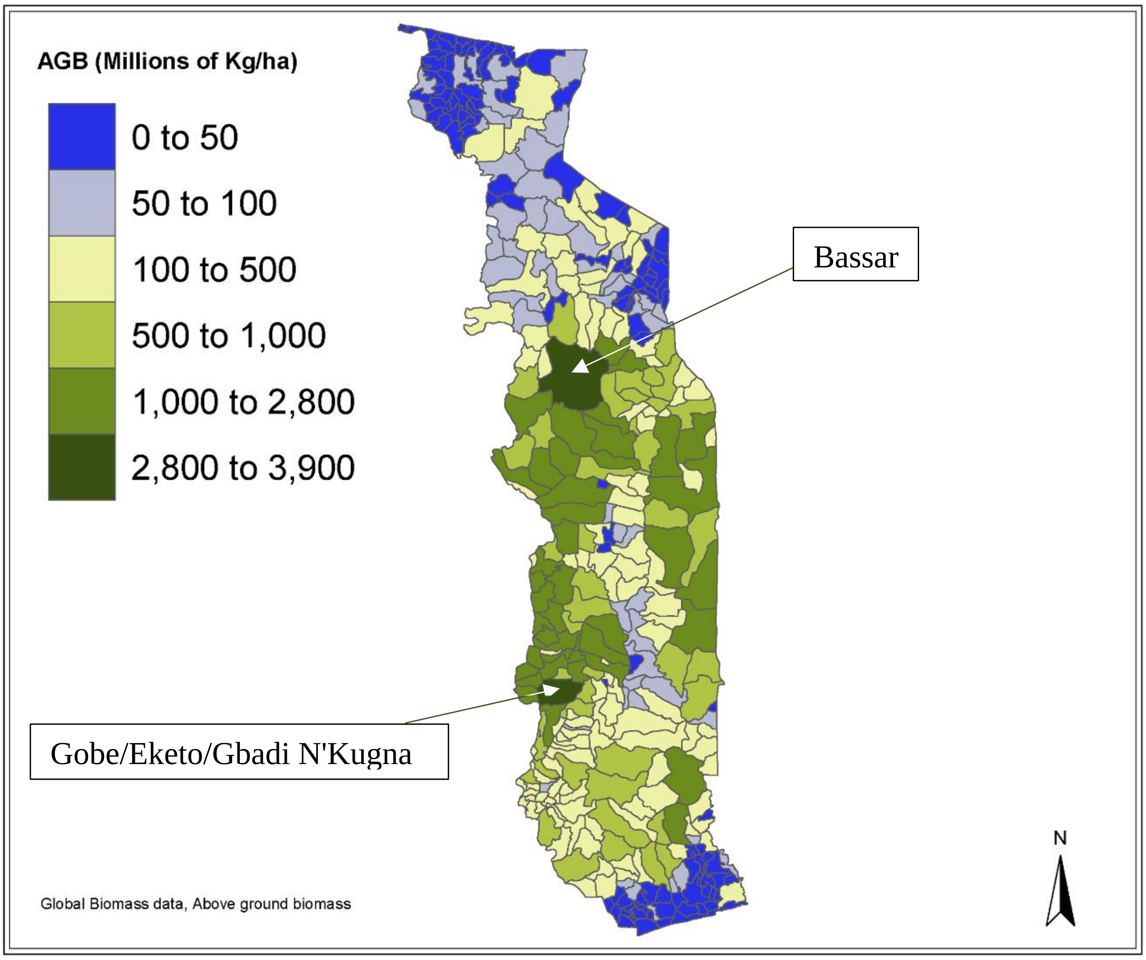

Fig. 4. *Available biomass(Above Ground Biomass) in Togo in millions of kilogram per hectare*

- **Green hydrogen potential from biomass**

Fig. 5 shows that Bassar, Gobe/Eketo/Gbadi N'Kugna are the cantons with the highest potential of green hydrogen production from biomass. They can produce respectively 2975.732 and 3896.426 million of kilogram per hectare. The second highest cantons account are Alibi, Aouda, Atchintse, Badou, Boulohou, Diguengue, Djon, Elavagnon/Atigba, Fazao, Gbende, Kaboli, Kessibo, Klabe Efoukpa, Koussountou, Kpete Bena, Lama-Tessi, M'Poti, Otadi, Seregbene,Sotouboua.Tchebebe, Tintchro,Tomegbe, ,Yalla, Yegue. They can produce between 1000 and 2800 million of kilogram per hectare. The results of this analysis show clearly that Togo has a potential to produce green hydrogen from biomass gasification.

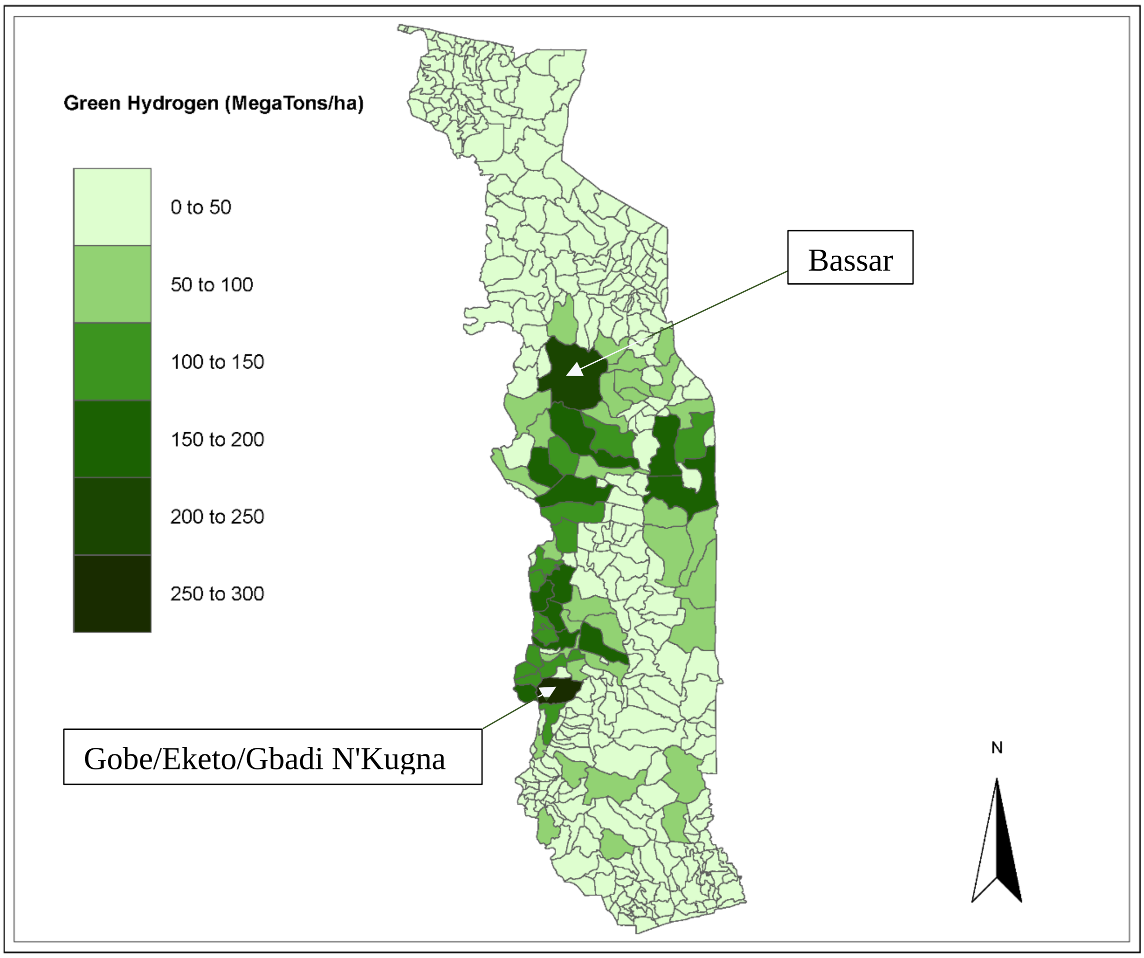

Fig. 5. *Green hydrogen potential from biomass in Togo, in megatons per hectare*

The study has been limited on the overall biomass available in the country because of the lack of data on the available biomass supplied per canton. Further studies need to be done to explore the amount of biomass that can be used for green hydrogen production.

Conclusion

Togo has a potential to produce green hydrogen from gasification. This will be an important contribution to energy transition for the country. Bassar, Gobe/Eketo/Gbadi N'Kugna are the top one cantons in which further studies of gasification plants can be made. The "region centrale" seems to be the best producer of green hydrogen from biomass through its highest potential. Finally, climate change might impact negatively or positively the evolution of the biomass, so climate change impacts on biomass should be evaluated in further studies. These contributions will help to increase the potential of green hydrogen production from biomass in the country

Chapter 3:

Green Hydrogen potential from solar in Togo

Chapter 3:

Green Hydrogen potential from solar in Togo

Introduction

In this chapter, we assess the potential for green hydrogen production from solar in Togo. It is composed on four parts. The first describes the dataset used for the study, the second presents the exclusions and the last, the methodology used to obtain the results that we discussed.

3.1. Solar datasets

The datasets consist of long-term yearly average of global horizontal irradiation (GHI) in kWh/m^2 /day. This data layer represents an output from the Solaris global solar model. It has been delivered for the Global Solar Atlas[20] ,an online platform funded by the Energy Sector Management Assistance Program (ESMAP), a multi-donor trust fund administered by The World Bank, under a global initiative on Renewable Energy Resource Mapping covering the period 1994-2018. The software R version 4.0.4 was used for the analysis.

3.2.Exclusions

The exclusions are land used where solar projects cannot be installed. The data [21]consists of National Park (4), Forest Reserve (65), Faunal Reserve (4), Community Forest (3), Natural resource management area (4), Habitat and species management reserve (1), UNESCO-MAB Biosphere Reserve (2), Ramsar Site, Wetland of International Importance (4) added to inlands water areas.

3.3.Analysis methodology for potential of green hydrogen production assessment from solar

The evaluation of the potential of solar hydrogen from the solar resources depicted in Fig. 6 used the electrolysis conversion rate with the same efficiency as that considered in the past studies in Argentina [9]; that is, 52.5 kWh/kg of hydrogen. We consider also the same photovoltaic panels of 222 W rated power, with a surface of 1.63 m^2 and an efficiency of 13.6%. We took into account that the effective area for panels could be 3 % of the total land suitable for solar ventures. The disproportion of our population with the high numbers in urban than rural areas, the decentralization plans and the growing population suggest that the 3 % per canton can be suitable for this analysis. This value is somewhat lower than the 4.5% assumed by Sigal in Argentina [9] due to the lowness of the population density of Argentina than USA who used 3%.

3.4.Results and discussion

- **Available Solar resources in Togo**

The processing of the solar resources data per cantons in Togo help to roll out the map of the available solar resource in Togo depicted in Fig.7.

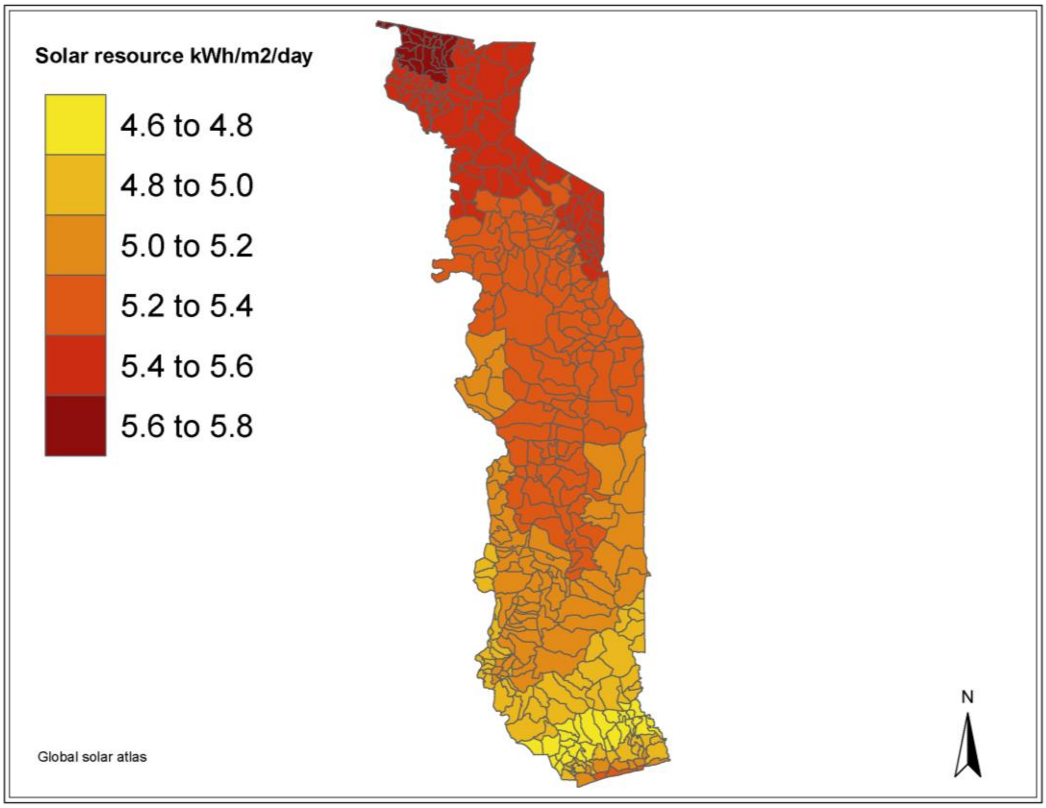

Fig. 6. *Available Solar ressource in Togo in kilowatt hour per meter square per day.*

Fig. 7 depicts the green hydrogen potential from solar in Togo. The “region des savanes” and “region de la kara” will be the best producers as they can produce over 155 tons hydrogen per kilometer square. It will be good to start green hydrogen solar projects pilots in these regions, particularly in “region des savanes”. The development of the pilots demonstration projects in these two regions could be based on the same process as done in other countries for instance in Pakistan [22] and Germany[23] where these facilities were used: The Photovoltaic farm to gather the sun energy, the electrolyser for helping to split water into hydrogen and oxygen, using the electricity produced by the photovoltaic cells, the Compression and storage tools to store the hydrogen produced, the Desalination plant to help producing fresh water to feed the electrolyser, the gas filling unit, the power unit and data acquisition and storage unit. The project could start for a few region and being promoted and developed in the whole country.This could help to assure the independence of energy in the canton, create jobs, force decentralization, help to manage public water storage for a good purpose and limit the propagation of malaria through these water in the canton.

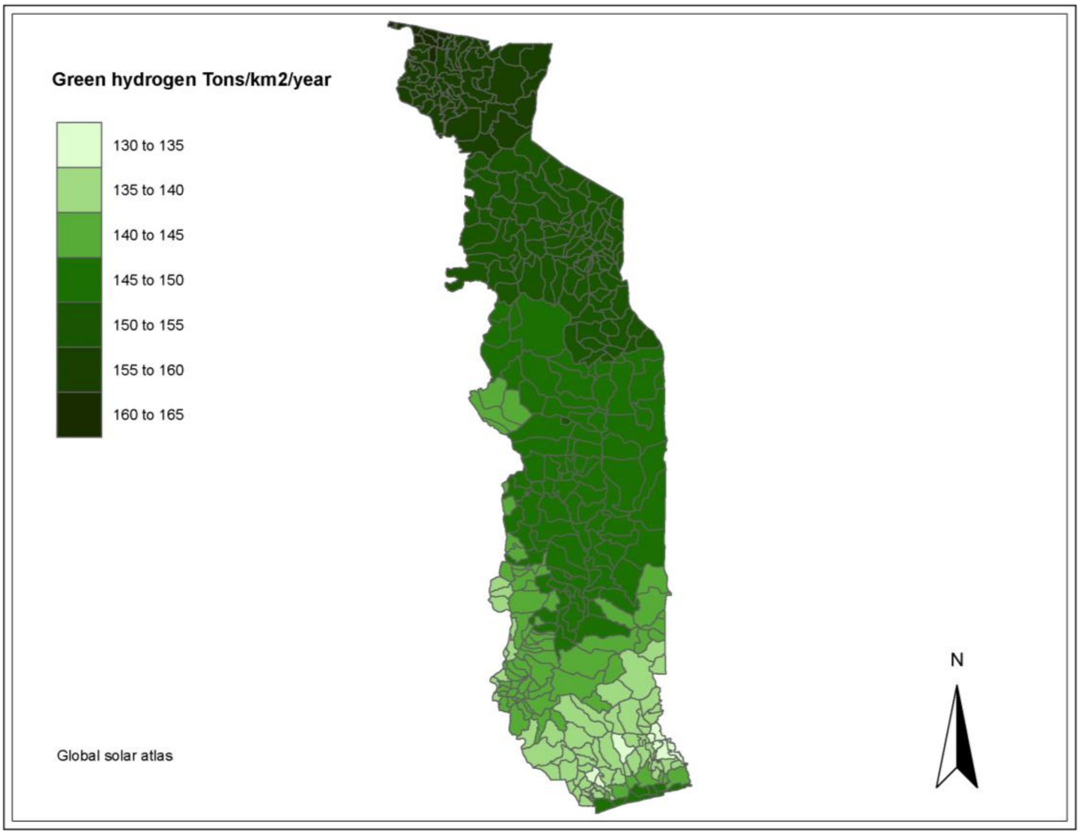

Fig. 7. *Green hydrogen potential from solar in Togo in tons per kilometer square per year*

4. Conclusion

Togo has a potential to produce green hydrogen from solar. We saw that the top regions from the northern part of the country “region des savanes” and “region de la kara” are the one who show the highest potential. So, further studies are needed to assess the future impact of climate change on the irradiation, to be able to predict the real trends of this exploitation.

Chapter 4: **Green Hydrogen potential from wind in Togo**

Chapiter 4:

Green Hydrogen potential from wind in Togo

Introduction

In this chapter we assess the potential for green hydrogen production from wind in Togo. It is composed on two parts. The first describes the dataset used for the study, the second presents the methodology used to obtain the results that we discussed.

4.1.Wind datasets

For the assessment, we used the global wind atlas data[24]. It has been developed through the partnership of the Department of Wind Energy at the Technical University of Denmark and the World Bank Group. The purpose of this dataset is to support wind power development during the exploration and preliminary wind resource assessment phases before the installation of meteorology measurement stations on site. The data downloaded is from 50m above ground as done by Mann and Milbrandt[18] and Sigal [9].

4.2.Analysis methodology

The processing of the data helps to create the wind resource map depicted in Fig. 8.

4.3.Results and discussion

The highest wind speed at 50 meters above ground is 5m/s. it is lower than the one considered by Mann and Milbrandt[18] and Sigal [9]. They have all made the analysis with wind power class 3 which is between 6.4 to 7.0 m/s. So, the analysis of green hydrogen from wind cannot be done in Togo as the wind power is low. The software R version 4.0.4 was used for the analysis.

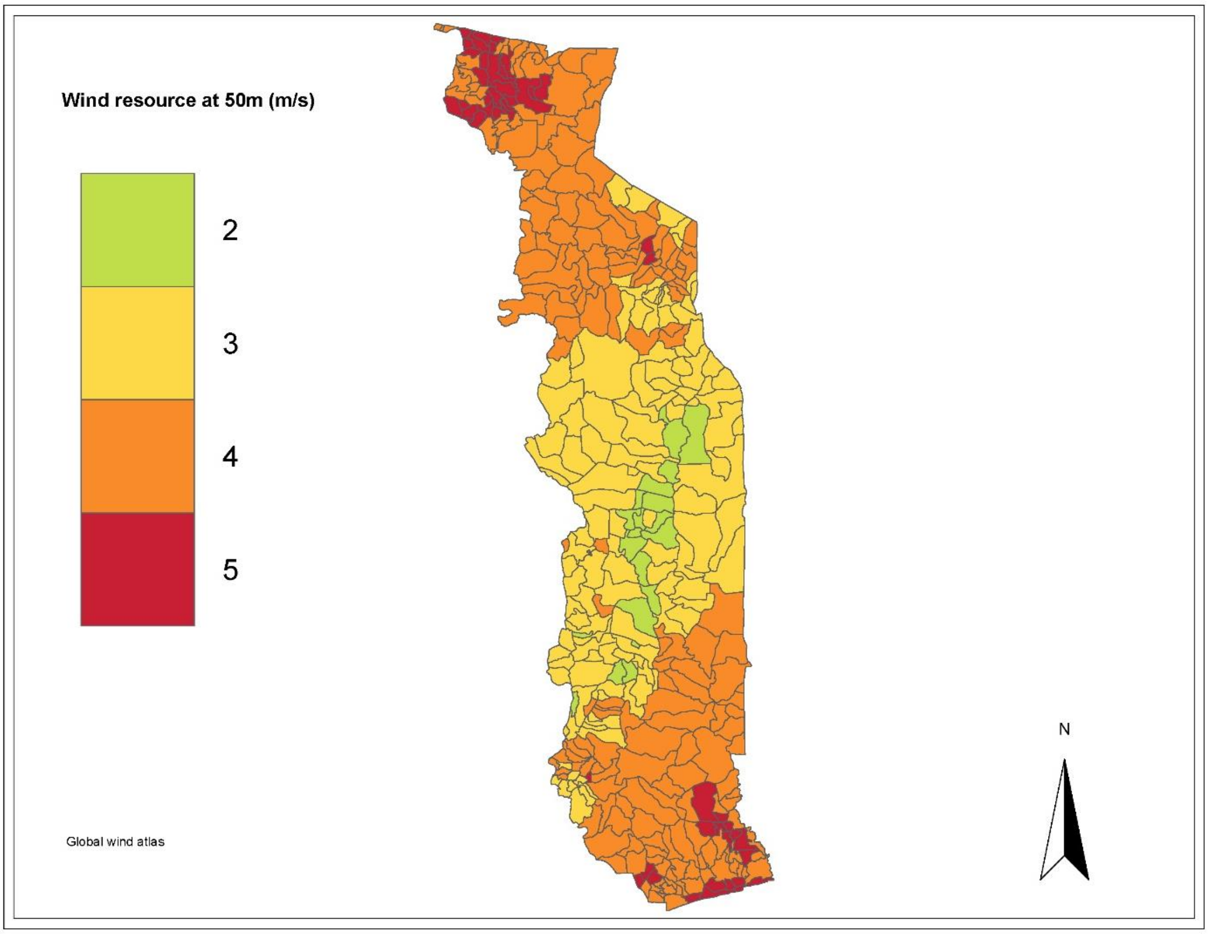

Fig. 8. *Available wind speed at 50 m above ground in Togo*

This result shows that we could not produce green hydrogen from wind in Togo as the highest speed is lower than wind power class 3 classification which is between 6.4 to 7.0 m/s[18]. For the moment we do not have the wind speed above 30 m and above 50 m in Togo. The data used is a raster dataset due to the lack of in situ data.

Conclusion

From the analysis, with power in Togo is lower than wind power class 3 classification which is between 6.4 to 7.0 m/s[18]. Togo has a lower potential to produce green hydrogen from wind energy according to the analysis and the previous analysis done in the literature review [18].

Chapter 5:

Potential for Green Hydrogen from Biomass and Solar in Togo

Chapter 5:

Potential for Green Hydrogen from Biomass and Solar in Togo

Introduction

In this chapter, we compute the overall green hydrogen potential in Togo, consisting of potential from solar and biomass

5.1. Analysis methodology

To compute the total potential for green hydrogen from biomass and solar, we compute the sum of the potentials from biomass and solar.

5.2. Results and Discussion

The total amount of hydrogen that could be produced from renewable energy resources (biomass and solar) by canton in Togo (Fig. 9). The potential from biomass being largely dominant compared to that of solar, the map is quietly as same as the map of green hydrogen producing from biomass. The same cantons with the best biomass potential show the top global potentials. From this we can say that biomass is the highest resource to produce green hydrogen in Togo. But the concentration of this resource is in “region centrale” and “region des plateaux”. These are parts of Togo where the pilots’ projects can start. The other parts of the country need reforestation projects.

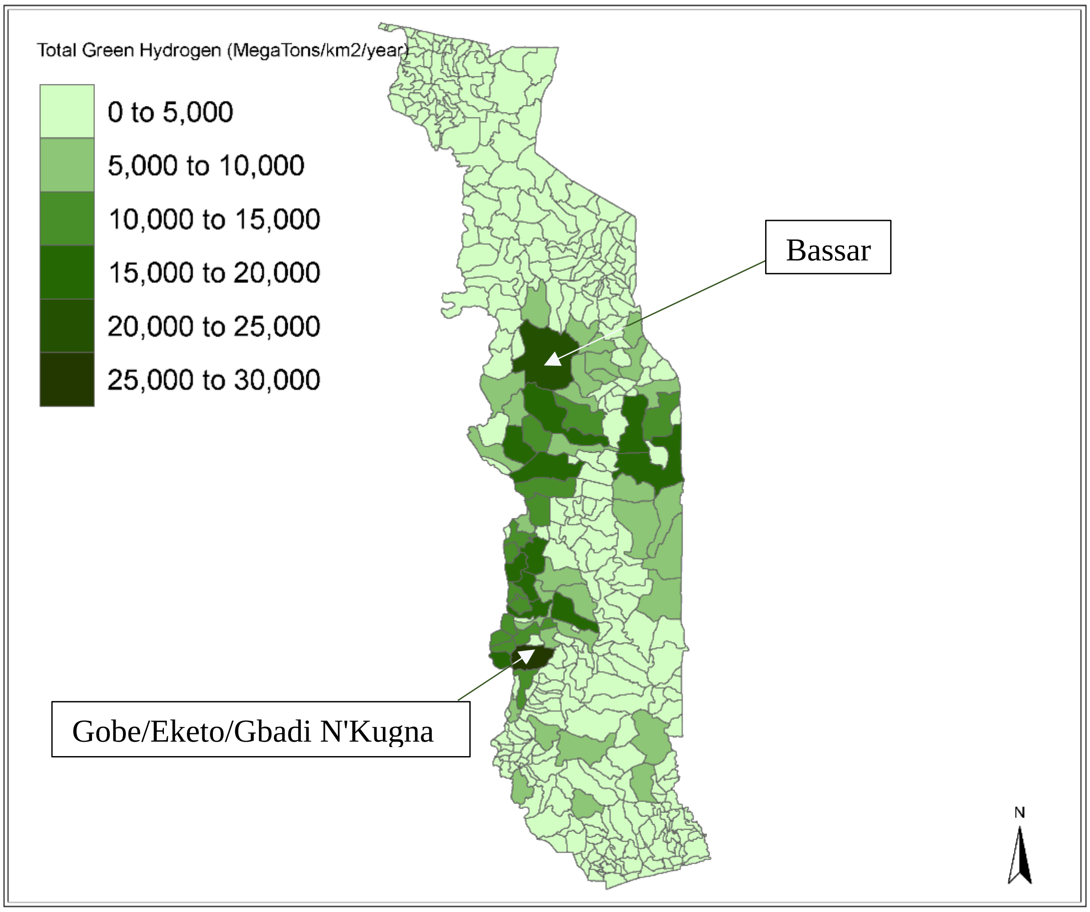

Fig. 9. *Total green hydrogen producible per cantons in Togo*

The results show that biomass is the highest resource for producing green hydrogen in Togo. This is similar to the report of West African Economic and Monetary Union[25] on available energy resources in Togo. The report stated the flowing situations:

The energy sector is dominated by biomass which represent 100% of the national energy balance in 2018 [25].

The producing of electricity remains from fossil fuel: 55% from natural gas, 46% from oil products and the rest from hydrology. There is a huge decreasing from 2017 to 2018

Comparing the consumption of energy in Togo from 2010 to 2018, it can be seen that the lead is still biomass from 64% to 75%. The consumption of biomass in Togo is higher than the producing. Its main purpose is for carbonization.

Togo is consuming biomass highly than other sources of energy but is producing less biomass.

This is drawing a problem at the horizon where human is using the natural resources but is producing it less[25]. It could be good to start the process of the conversion of biomass in green hydrogen to meet the energy need of the population with a good plan of reforestation. The biomass gasification project will force the production of biomass and reduce its consumption. This will help to limit the consumption of biomass and limit also the contribution of energy sector to climate change by finding a clean source of energy to the public and an independence of energy to the local region. This require the education to the population on the use of new source of energy, for human behaviour is difficult to change. The development of energy policy to facilitate the development of green hydrogen in local areas, the development of a favourite economic environment for innovations for smart green hydrogen energy grids.

Conclusion

Biomass is the leading resource for hydrogen producing in many of the cantons in Togo. The highest values are in “region centrale” and “region des plateaux”. Biomass as lead as it is, is also the one who is contributing to climate change in Togo by its use for carbonization. There is an urgent need of developing a reforestation plan and for transformation of biomass in green hydrogen to preserve the nature.

Conclusion

Conclusion and perspectives

For the first time in Africa, precisely in Togo, an analysis of the potential for green hydrogen producing from wind, solar and biomass has been performed.

Green hydrogen can be produced in Togo from Biomass and solar. The study has shown that biomass is the leading resource. Togo can produce a maximum of 100,000 Megatons of green hydrogen from solar and biomass. The study has shown that biomass is currently used in the country but for other purpose which is contributing to climate change. Green hydrogen transition will be good for reinforcing the decentralization process, the reforestation in places where the biomass is decreasing, the adaptation to climate change and to meet the growing demand of energy in the population.

The perspectives of this research are as follows:

- Climate change impact on biomass in Togo;
- Climate change impact on Solar and Wind in Togo;
- Evaluate the energy consumption per cantons in Togo for further comparison;
- Evaluate the policy on the developing of green hydrogen economy in Togo;
- Evaluate the investment opportunity per cantons where the potential of producing green hydrogen is the best;
- Evaluate the willingness of the population to change its behaviour by using directly the green hydrogen than the biomass as source of energy.
- Amount of biomass available in each canton to produce green hydrogen
- Define the conversion rate of local biomass to green hydrogen
- Further studies need to be done to explore the amount of biomass that can be used for green hydrogen production.

Bibliography

[1]"United Nations et al. - 2019 - World population prospects Highlights, 2019 revisi.pdf." Accessed: May 14, 2021. [Online]. Available: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf[1] "United Nations et al. - 2019 - World population prospects Highlights, 2019 revisi.pdf." Accessed: May 14, 2021. [Online]. Available: https://population.un.org/wpp/Publications/Files/WPP2019_Highlights.pdf

[2] "Full Text PDF." Accessed: May 14, 2021. [Online]. Available: https://www.researchgate.net/profile/Thabani-Nyoni/publication/336995049_Prediction_of_total_population_in_Togo_using_ARIMA_models_PREDICTION_OF_TOTAL_POPUALTION_IN_TOGO_USING_ARIMA_MODELS/links/5dbe9db7299bf1a47b0f3740/Prediction-of-total-population-in-Togo-using-ARIMA-models-PREDICTION-OF-TOTAL-POPUALTION-IN-TOGO-USING-ARIMA-MODELS.pdf

[3] "AT2ER." https://at2er.tg/ (accessed Jun. 09, 2021).

[4] "(PDF) GREEN ENERGY: The NEED of the WORLD." https://www.researchgate.net/publication/283482870_GREEN_ENERGY_The_NEED_of_the_WORLD (accessed May 14, 2021).

[5] "Global Renewables Outlook Energy Transformation 2.pdf." Accessed: May 14, 2021. [Online]. Available: https://www.sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/IRENA_Global_Renewables_Outlook_2020.pdf

[6] F. Barbir and T. N. Veziroğlu, "Effective costs of the future energy systems," *International Journal of Hydrogen Energy*, vol. 17, no. 4, pp. 299–308, Apr. 1992, doi: 10.1016/0360-3199(92)90006-I.

[7] "21st Century's energy: Hydrogen energy system|INIS." https://inis.iaea.org/Search/search.aspx?orig_q=RN:40016371 (accessed May 14, 2021).

[8] "Potential for Hydrogen Production from Key Renewable Resources in the United States | Request PDF." https://www.researchgate.net/publication/237735832_Potential_for_Hydrogen_Productio

n_from_Key_Renewable_Resources_in_the_United_States (accessed May 14, 2021).
[9] A. Sigal, E. Leiva, and C. R. Rodríguez, "Assessment of the potential for hydrogen production from renewable resources in Argentina," *International Journal of Hydrogen Energy*, vol. 39, May 2014, doi: 10.1016/j.ijhydene.2014.03.157.
[10] "Renewable Energy Statistics 2020.pdf." Accessed: May 17, 2021. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Jul/IRENA_Renewable_Energy_Statistics_2020.pdf
[11] J. Wisniak, "Henry Cavendish," *Educación Química*, vol. 15, pp. 60–70, Jan. 2004, doi: 10.22201/fq.18708404e.2004.1.66217.
[12] National Renewable Energy Lab., Golden, CO (United States), "The green hydrogen report. The 1995 progress report of the Secretary of Energy`s Hydrogen Technical Advisory Panel," DOE/GO--10095-179, 81032, Jul. 1995. doi: 10.2172/81032.
[13] T. N. Veziroğlu and S. Şahi˙n, "21st Century's energy: Hydrogen energy system," *Energy Conversion and Management*, vol. 49, no. 7, pp. 1820–1831, Jul. 2008, doi: 10.1016/j.enconman.2007.08.015.
[14] T. Vezirolu and F. Barbir, "Hydrogen: the wonder fuel," *International Journal of Hydrogen Energy*, vol. 17, no. 6, pp. 391–404, Jun. 1992, doi: 10.1016/0360-3199(92)90183-W.
[15] Z. Fang, R. L. Smith, Jr, and X. Qi (Eds.), *Production of hydrogen from renewable resources.*, 1st ed. Springer Netherlands, 2015. Accessed: May 17, 2021. [Online]. Available: http://gen.lib.rus.ec/book/index.php?md5=fb64a394810929c177242987a4172aa3
[16] W. Pyle, "Solar Hydrogen Production by Electrolysis," *Home Power*, vol. 39, Feb. 1994.
[17] M. Santoro and O. Cartus, "ESA Biomass Climate Change Initiative (Biomass_cci): Global datasets of forest above-ground biomass for the years 2010, 2017 and 2018, v2." Centre for Environmental Data Analysis (CEDA), 2021. doi: 10.5285/84403D09CEF3485883158F4DF2989B0C.
[18] A. Milbrandt and M. Mann, "Potential for Producing Hydrogen from Key Renewable Resources in the United States," National Renewable Energy Lab. (NREL), Golden, CO (United States), NREL/TP-640-41134, Feb. 2006. doi: 10.2172/899141.
[19] A. Sigal, E. P. M. Leiva, and C. R. Rodríguez, "Assessment of the potential for hydrogen production from renewable resources in Argentina," *International Journal of*

Hydrogen Energy, vol. 39, no. 16, pp. 8204–8214, May 2014, doi: 10.1016/j.ijhydene.2014.03.157.

[20] "Global Solar Atlas." https://globalsolaratlas.info/download/togo (accessed May 19, 2021).

[21] "Protected Planet | Togo," *Protected Planet*. https://www.protectedplanet.net/country/TGO (accessed May 19, 2021).

[22] N. Lutfi and T. Veziroglu, "Solar-hydrogen demonstration project for Pakistan," *International Journal of Hydrogen Energy*, vol. 17, no. 5, pp. 339–344, May 1992, doi: 10.1016/0360-3199(92)90170-2.

[23] A. Szyszka, "Ten years of solar hydrogen demonstration project at Neunburg vorm Wald, Germany," *International Journal of Hydrogen Energy*, vol. 23, no. 10, pp. 849–860, Oct. 1998, doi: 10.1016/S0360-3199(97)00172-9.

[24] "Global Wind Atlas." https://globalwindatlas.info (accessed May 21, 2021).

[25] "Atlas de l'énergie dans l'espace UEMOA - Rapport 2020," p. 156.

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ANNEXES

TABLE III.. Data per canton

TABLE III. represents the data of the analysis. From the availability of resources to the potential of green hydrogen per canton.

Cantons	Biomass (Millions of Kg/Ha)	Biomass Hydrogen (MegaTons/Ha)	Solar (Kmh/m2/day)	Solar hydrogen (Tons/Km2/year)	Wind (m/s)	Total(MegaTons/km2/year)
Abobo	45.66	340753.73	5.02	141.84	4.43	340895.57
Adeta	493.95	3686156.72	5.07	143.99	3.47	3686300.71
Adetikope	21.42	159813.43	4.77	134.99	4.10	159948.42
Adiva	31.94	238388.06	5.12	145.10	2.63	238533.16
Adjahun Fiagbe	205.44	1533156.72	4.99	141.55	3.21	1533298.27
Adjengere	683.53	5100962.69	5.28	149.82	2.82	5101112.50
Adogbenou	1294.35	9659305.97	5.12	145.22	3.65	9659451.19
Adzakpa	153.66	1146723.88	4.92	139.53	3.68	1146863.41
Afagnan / Afagnagan	41.89	312641.79	4.76	134.91	4.63	312776.70
Affem	334.43	2495761.19	5.32	150.80	3.09	2495911.99
Aflao Gakli	0.01	44.78	4.94	140.02	3.93	184.80
Agbandi	228.12	1702350.75	5.24	148.63	2.47	1702499.38
Agbandi-Yaka	83.56	623552.24	5.39	152.97	3.57	623705.21
Agbelouve	605.52	4518768.66	4.93	139.83	4.35	4518908.49
Agbodrafo	4.84	36134.33	5.23	148.86	5.13	36283.19
Agoenyive	4.25	31723.88	4.92	139.55	3.95	31863.43
Agome	202.91	1514246.27	4.93	140.38	3.48	1514386.65

Agome-Tomegbe	348.15	2598134.33	4.85	137.59	3.75	2598271.92
Agome Glozou/Agbetiko	72.11	538097.01	4.71	133.69	4.15	538230.70
Agotime Nord	786.13	5866656.72	4.97	140.91	3.15	5866797.63
Agou-Akplolo	128.70	960432.84	5.07	143.88	3.67	960576.72
Agou Agbetiko/Agou Dzidjole	221.64	1654059.70	5.06	143.57	4.08	1654203.27
Agou Atigbe	163.69	1221559.70	5.00	141.77	3.33	1221701.47
Agou Gadzepe	225.80	1685082.09	5.01	142.21	3.21	1685224.30
Agou Kebo	178.74	1333880.60	4.99	141.64	4.96	1334022.23
Agou Yiboe/Kati	302.20	2255194.03	5.07	143.80	4.18	2255337.83
Agouegan	15.11	112746.27	5.15	146.17	4.75	112892.44
Agoulou	999.68	7460268.66	5.33	151.15	2.82	7460419.80
Ahassome	191.01	1425425.37	4.97	141.07	3.63	1425566.44
Ahepe	328.57	2451992.54	4.79	135.80	4.69	2452128.34
Ahlon	580.11	4329186.57	4.86	137.84	2.46	4329324.40
Akata	407.87	3043768.66	5.04	142.97	3.81	3043911.63
Akepe	9.36	69850.75	4.77	135.41	4.43	69986.15
Aklakou	130.73	975626.87	4.97	141.86	4.42	975768.73
Akoumape	68.64	512246.27	4.79	135.68	4.34	512381.95
Akpare	72.85	543641.79	5.15	146.03	4.02	543787.82
Akponte	104.37	778910.45	5.41	153.64	3.38	779064.08
Aledjo	1152.77	8602761.19	5.32	150.99	3.46	8602912.18
Aleheride/Amaide	988.36	7375798.51	5.32	150.85	2.85	7375949.36
Alibi	2168.60	16183544.78	5.25	149.27	2.48	16183694.05
Aloum	175.47	1309485.08	5.36	151.94	3.76	1309637.01
Amou-Oblo	619.84	4625641.79	5.12	145.18	3.09	4625786.97

Amoussime	53.53	399440.30	4.80	136.11	4.74	399576.41
Amoussou Kope	146.73	1095029.85	4.95	140.31	3.88	1095170.16
Amoutive	43.40	323858.21	5.02	142.81	3.93	324001.02
Aneho	1.35	10044.78	5.21	147.89	5.21	10192.67
Anfoin	4.60	34343.28	4.97	141.04	4.36	34484.32
Anie	99.45	742194.03	5.25	148.93	2.82	742342.96
Anyron Kope	2.47	18425.37	5.17	146.84	4.66	18572.21
Aouda	2239.44	16712261.19	5.26	149.82	2.76	16712411.01
Assahoun/Ando Peme	515.37	3846074.63	4.86	137.92	4.31	3846212.55
Assrama	1212.74	9050298.51	4.91	139.61	4.09	9050438.11
Atalote	98.59	735768.66	5.40	153.03	3.62	735921.69
Atchangbade	145.79	1087955.22	5.38	152.55	3.22	1088107.77
Atchinedji	511.52	3817320.90	5.18	147.01	3.91	3817467.91
Atchintse	2433.42	18159873.13	5.12	146.01	2.95	18160019.14
Atsave	329.11	2456059.70	4.92	139.60	4.34	2456199.30
Attitogon	10.00	74634.33	4.83	137.35	4.55	74771.68
Avedje	83.53	623320.90	5.18	146.80	3.13	623467.69
Awandjelo	44.72	333761.19	5.40	153.08	3.35	333914.27
Badin	942.76	7035514.93	5.14	145.69	2.90	7035660.61
Badja	227.17	1695305.97	4.77	135.30	4.49	1695441.27
Badou	1422.73	10617417.91	4.91	139.41	2.63	10617557.32
Bafilo	439.64	3280917.91	5.37	152.30	3.74	3281070.21
Baga	18.34	136835.82	5.45	154.49	4.55	136990.31
Baghan	1223.79	9132753.73	5.18	146.84	3.12	9132900.57
Bago	678.14	5060731.34	5.21	147.84	2.60	5060879.18
Bagou	27.40	204447.76	5.58	158.34	4.88	204606.10
Baguida	47.96	357925.37	5.21	148.79	4.60	358074.16
Balanka	221.82	1655335.82	5.25	148.78	2.99	1655484.60
Bangeli	199.09	1485708.96	5.31	150.49	3.82	1485859.45
Bapure	81.68	609522.39	5.32	150.89	3.82	609673.28
Barkoissi	51.15	381746.27	5.54	157.22	4.30	381903.49

Bassar	2975.73	22206955.22	5.28	149.84	3.02	22207105.06
Biankouri	16.92	126231.34	5.64	160.03	4.74	126391.37
Bidjenga	5.78	43156.72	5.58	158.24	4.76	43314.96
Bitchabe	284.53	2123335.82	5.28	149.75	3.59	2123485.57
Blitta-Gare	189.67	1415417.91	5.26	149.30	2.21	1415567.21
Blitta Village	40.68	303574.63	5.28	149.86	2.48	303724.48
Boade	0.47	3477.61	5.65	160.34	4.46	3637.95
Bodjonde	78.54	586082.09	5.28	149.86	2.43	586231.95
Bogou	21.76	162380.60	5.58	158.23	4.91	162538.83
Bohou	21.19	158141.79	5.37	152.27	3.11	158294.06
Bolou Kpeta	108.71	811246.27	4.78	135.50	4.20	811381.77
Bombouaka	31.74	236828.36	5.59	158.49	4.81	236986.85
Borgou	293.78	2192417.91	5.54	157.43	4.27	2192575.34
Boufale	32.68	243895.52	5.43	153.98	3.75	244049.50
Boulade	43.59	325283.58	5.39	152.83	3.74	325436.41
Boulogou	19.97	149037.31	5.57	157.90	4.57	149195.22
Boulohou	2189.46	16339276.12	5.09	142.21	3.48	16339418.33
Cinkasse	4.58	34156.72	5.66	160.58	4.91	34317.29
Dagbati	35.64	265955.22	4.77	135.38	4.48	266090.61
Dako/Daoude	1009.73	7535298.51	5.35	151.86	3.69	7535450.37
Dalave	49.15	366776.12	4.78	135.58	4.43	366911.70
Dalia	281.86	2103440.30	4.93	140.19	4.10	2103580.49
Danyi-Kakpa	848.84	6334589.55	4.92	139.62	3.24	6334729.18
Danyi Kpeto-Evita	315.85	2357097.02	5.08	144.15	3.53	2357241.16
Dapaong	68.99	514828.36	5.62	159.49	4.74	514987.85
Datcha	72.61	541835.82	5.16	146.39	3.53	541982.21
Davie	66.89	499141.79	4.74	134.82	4.24	499276.61
Defale	72.22	538932.84	5.42	153.62	4.67	539086.45
Diguengue	1360.04	10149574.63	5.08	144.99	3.04	10149719.62
Dikpeleou	323.86	2416835.82	5.06	143.66	3.54	2416979.49
Dimori	656.15	4896641.79	5.22	148.12	3.39	4896789.92
Djagble	58.70	438022.39	4.99	139.91	4.17	438162.30

Djamde	341.97	2551992.54	5.36	152.32	3.40	2552144.86
Djarkpanga	655.23	4889746.27	5.08	144.17	3.19	4889890.44
Djemegni	114.47	854283.58	4.98	141.38	4.44	854424.96
Djon	2099.07	15664664.18	5.11	145.03	2.76	15664809.21
Doufouli	572.03	4268850.75	5.23	148.36	2.64	4268999.11
Doukpergou	40.32	300895.52	5.59	158.53	5.14	301054.05
Doume	646.86	4827313.43	5.05	143.24	2.53	4827456.67
Dzolo	211.82	1580761.19	4.79	135.99	4.45	1580897.19
Dzrekpo	11.21	83664.18	4.82	136.87	4.41	83801.05
Ekpegnon	258.00	1925365.67	5.16	146.39	3.46	1925512.06
Elavagnon	198.44	1480865.67	5.20	147.08	3.18	1481012.75
Elavagnon/Atigba	1585.24	11830156.72	5.00	141.99	3.18	11830298.71
Esse Godjin	117.19	874582.09	4.80	136.18	4.10	874718.27
Evou	121.38	905813.43	5.13	145.44	2.76	905958.87
Fare	2.07	15462.69	5.45	154.53	3.76	15617.22
Fazao	1365.07	10187104.48	5.25	149.18	3.43	10187253.66
Gadja	441.30	3293246.27	5.02	142.45	3.88	3293388.72
Galangashie	283.65	2116805.97	5.49	156.03	4.03	2116962.00
Game	363.19	2710365.67	4.91	139.14	4.25	2710504.81
Game	1140.75	8513022.39	5.22	148.19	2.22	8513170.58
Ganave/Fiata	1.19	8910.45	5.01	142.05	4.42	9052.49
Gando	44.85	334686.57	5.46	154.79	3.95	334841.36
Gape-Centre	681.37	5084858.21	4.87	138.47	4.22	5084996.68
Gape Kpodji	246.23	1837514.93	4.94	140.11	3.95	1837655.04
Gbadjahe	158.73	1184552.24	5.18	146.93	3.39	1184699.17
Gbaladze	176.70	1318671.64	5.02	142.27	3.07	1318813.92
Gbalave	176.58	1317783.58	4.98	141.17	3.72	1317924.76
Gbatope	518.27	3867671.64	4.77	135.24	4.32	3867806.89
Gbende	1622.51	12108313.43	5.10	144.63	2.69	12108458.06
Gblainvie	286.68	2139365.67	4.80	136.23	4.31	2139501.90
Gboto	144.07	1075119.40	4.81	136.33	4.47	1075255.73
Glei	365.94	2730895.52	5.11	145.05	3.96	2731040.57

Glidji	4.23	31589.55	5.13	145.67	4.58	31735.22
Glitto	638.29	4763380.60	5.07	143.70	3.92	4763524.30
Gnagna	79.22	591186.57	5.20	147.62	3.79	591334.19
Gnoaga	0.14	1052.24	5.65	160.36	4.35	1212.59
Gobe/Eketo/ Gbadi N'Kugna	3896.43	29077805.97	5.03	142.81	3.03	29077948.78
Goubi	412.37	3077395.52	5.20	147.59	2.57	3077543.12
Gouloungoussi	0.14	1029.85	5.65	160.38	4.35	1190.23
Goundoga	21.67	161716.42	5.57	158.06	4.65	161874.48
Govie	149.49	1115559.70	5.04	143.21	3.28	1115702.91
Guerin-Kouka	128.76	960925.37	5.37	152.24	3.97	961077.62
Hahotoe	72.12	538171.64	4.78	137.35	4.12	538308.99
Hanyigba	267.78	1998335.82	4.95	140.46	3.81	1998476.28
Helota	142.19	1061126.87	5.38	152.67	3.59	1061279.54
Hiheatro	1242.58	9273014.93	5.15	145.98	2.67	9273160.91
Hompou	30.11	224716.42	4.81	137.28	4.38	224853.70
Houdou	31.71	236604.48	5.22	148.03	3.88	236752.51
Imle	348.22	2598671.64	5.13	145.44	2.27	2598817.08
Kaboli	2679.64	19997283.58	5.20	147.44	2.68	19997431.02
Kabou	704.69	5258858.21	5.33	151.22	3.80	5259009.43
Kadambara	505.54	3772671.64	5.27	149.42	2.45	3772821.07
Kadjalla	79.51	593358.21	5.37	152.30	3.55	593510.51
Kagnigbara	844.83	6304701.49	5.12	145.13	3.40	6304846.62
Kalanga	159.50	1190298.51	5.26	149.32	3.39	1190447.83
Kame	192.68	1437932.84	5.09	144.36	3.50	1438077.20
Kamina	1256.42	9376246.27	5.12	145.17	3.15	9376391.44
Kamina	964.88	7200597.02	5.24	148.75	2.74	7200745.76
Kande	102.17	762470.15	5.40	153.13	3.56	762623.28
Kaniamboua	21.17	157977.61	5.30	150.30	2.74	158127.91
Kantindi	55.92	417343.28	5.63	159.60	4.64	417502.89

Katchamba	62.47	466194.03	5.40	153.22	3.99	466347.25
Katchenke	961.39	7174574.63	5.18	147.06	3.24	7174721.69
Katome	29.91	223179.10	4.97	140.88	4.38	223319.99
Katore	141.67	1057238.81	5.10	144.57	3.65	1057383.38
Kazaboua	203.86	1521313.43	5.25	148.98	2.35	1521462.41
Kemeni	608.65	4542134.33	5.35	151.80	3.08	4542286.13
Kemerida	2.18	16261.19	5.43	154.10	3.42	16415.29
Kessibo	1620.24	12091358.21	4.96	140.81	3.05	12091499.02
Ketao	3.45	25746.27	5.43	154.03	3.36	25900.30
Keve	181.99	1358111.94	4.82	136.74	4.38	1358248.68
Kidjaboun	79.47	593074.63	5.38	152.65	3.91	593227.27
Kini-Kondji	14.18	105835.82	4.75	134.77	4.50	105970.59
Klabe Efoukpa	1983.87	14805029.85	5.05	143.38	2.70	14805173.23
Koffiti	126.81	946305.97	5.24	148.77	2.52	946454.74
Koka	8.31	62029.85	5.45	154.63	4.32	62184.49
Kolina	749.75	5595156.72	5.32	150.82	3.15	5595307.54
Kolokope	114.43	853977.61	5.22	148.07	3.37	854125.68
Komah	333.04	2485343.28	5.30	150.43	2.91	2485493.71
Korbongou	47.60	355231.34	5.61	159.20	4.37	355390.55
Kougnohou	1014.83	7573343.28	5.08	144.07	2.72	7573487.35
Koulfiekou	55.00	410447.76	5.41	153.44	3.84	410601.21
Kouma	661.22	4934500.00	4.89	138.63	3.93	4934638.63
Koumea	40.08	299089.55	5.43	154.17	4.29	299243.72
Koumonde	367.16	2740029.85	5.36	151.96	3.43	2740181.82
Koumongou	20.60	153694.03	5.45	154.67	3.95	153848.70
Koundjoare	46.69	348425.37	5.58	158.28	4.42	348583.65
Kountoire	56.76	423611.94	5.43	153.84	3.98	423765.78
Kourientre	30.98	231179.10	5.63	159.80	4.40	231338.91
Koussountou	1658.92	12379970.15	5.25	148.96	2.86	12380119.11
Koutchitcheou	29.17	217664.18	5.35	151.69	3.81	217815.87
Koutougou	349.80	2610432.84	5.43	154.17	3.47	2610587.01

Kouve	1119.00	8350768.66	4.82	136.80	4.54	8350905.46
Kovie	29.75	222037.31	4.78	135.52	4.55	222172.83
Kpadape	407.35	3039932.84	4.99	141.53	2.98	3040074.37
Kpaha	195.07	1455716.42	5.43	154.17	4.28	1455870.58
Kpalave	723.29	5397664.18	5.21	147.80	3.54	5397811.98
Kpangalam	834.67	6228865.67	5.30	150.28	2.65	6229015.95
Kparatao	266.29	1987246.27	5.29	149.94	2.65	1987396.21
Kpassouade	534.39	3987947.76	5.30	150.41	2.92	3988098.17
Kpategan	345.24	2576447.76	5.17	146.60	3.36	2576594.37
Kpedome	618.65	4616783.58	5.07	143.84	4.29	4616927.42
Kpegnon/Haito	355.77	2655014.93	5.14	145.72	3.99	2655160.65
Kpekpleme	98.33	733798.51	4.97	140.93	4.18	733939.44
Kpele-Centre	415.29	3099149.25	5.08	144.08	3.43	3099293.34
Kpele-Dawlotou	705.48	5264783.58	5.08	143.97	3.73	5264927.55
Kpele-Dutoe	83.34	621910.45	5.11	144.78	3.57	622055.22
Kpele-Nord	183.65	1370552.24	5.12	145.22	3.57	1370697.46
Kpendjaga / Papri	21.13	157694.03	5.60	158.76	4.07	157852.79
Kpessi	202.40	1510462.69	5.20	147.52	2.85	1510610.21
Kpete Bena	2042.23	15240500.00	4.87	138.08	2.59	15240638.08
Kpetsou	35.78	267037.31	4.74	134.56	4.67	267171.87
Kpime	455.94	3402552.24	4.97	140.96	3.81	3402693.20
Kpome	47.90	357455.22	4.82	137.57	4.30	357592.79
Kri-Kri	396.65	2960089.55	5.34	151.39	2.87	2960240.94
Lama	85.72	639694.03	5.39	152.79	3.32	639846.82
Lama-Dessi	18.17	135611.94	5.44	154.22	4.02	135766.16
Lama-Tessi	1601.54	11951776.12	5.28	149.78	2.76	11951925.90
Landa	4.85	36216.42	5.43	153.92	3.60	36370.33
Landa-Pozenda/Kpinzinde	77.53	578567.16	5.40	153.25	3.05	578720.41

Langabou	116.66	870626.87	5.24	148.75	2.62	870775.62
Larni	114.81	856783.58	5.31	150.55	2.87	856934.14
Lassa	94.39	704380.60	5.42	153.85	3.87	704534.45
Lavie/ Apedome	523.28	3905089.55	4.99	141.53	3.81	3905231.08
Legbassito	2.77	20671.64	4.81	136.69	4.45	20808.33
Leon	112.13	836768.66	5.32	151.07	3.21	836919.73
Loko	35.54	265231.34	5.53	156.75	4.19	265388.09
Loko	3.38	25208.96	5.55	157.45	4.48	25366.41
Lokpano	19.63	146522.39	5.57	157.95	4.85	146680.34
Lome Commune	4.52	33761.19	5.15	146.09	4.28	33907.28
Lotogou/War kambou	57.08	425962.69	5.60	158.83	4.07	426121.51
Louanga	24.69	184261.19	5.61	159.07	4.49	184420.27
M'Poti	1798.97	13425141.79	5.23	148.24	3.37	13425290.03
Mamproug	69.99	522276.12	5.58	158.26	4.95	522434.38
Mandouri	62.36	465358.21	5.56	157.87	4.20	465516.08
Manga	40.53	302477.61	5.34	151.49	4.00	302629.10
Mango	72.73	542731.34	5.47	155.19	3.91	542886.53
Massedena	71.29	532014.93	5.42	153.88	3.42	532168.80
Mission-Tove	16.12	120305.97	4.77	135.53	4.61	120441.50
Mogou	61.42	458380.60	5.49	155.56	4.06	458536.15
Mome- Hounkpati	17.69	131977.61	4.76	135.03	4.63	132112.64
Moretan	1063.89	7939440.30	5.18	146.99	2.85	7939587.29
Nadjoundi	9.12	68059.70	5.65	160.17	4.70	68219.87
Nadoba	23.75	177208.96	5.41	153.35	3.27	177362.31
Nagbeni	57.80	431365.67	5.54	157.21	4.36	431522.88
Naki-Est	88.62	661328.36	5.58	158.14	4.64	661486.50
Naki-Ouest	20.39	152126.87	5.63	159.60	4.46	152286.46
Nali	71.76	535522.39	5.43	153.90	3.76	535676.28
Namare	9.03	67365.67	5.64	159.97	4.68	67525.65

Namon	111.06	828798.51	5.36	151.94	3.60	828950.45
Namoundjoga	87.85	655619.40	5.59	158.52	4.29	655777.93
Nampoch	72.79	543201.49	5.39	152.75	3.93	543354.25
Nandoga	7.34	54768.66	5.56	157.85	4.72	54926.50
Nandouta	186.69	1393223.88	5.32	150.92	3.53	1393374.80
Nanergou	19.50	145500.00	5.64	160.07	4.87	145660.07
Nano	38.41	286656.72	5.57	158.12	4.47	286814.84
Natchibore	107.26	800440.30	5.37	152.28	3.56	800592.58
Natchitikpi	66.11	493320.90	5.36	152.17	3.86	493473.07
Natigou	16.28	121455.22	5.63	159.70	4.48	121614.92
Naware	72.39	540246.27	5.34	151.41	3.72	540397.68
Nayega	4.21	31432.84	5.58	158.37	4.71	31591.20
Niamtougou	98.17	732589.55	5.40	153.22	4.02	732742.77
Nioukpourma	41.94	313014.93	5.62	159.46	4.70	313174.38
Noepe	30.28	225977.61	4.76	135.05	4.60	226112.66
Notse	895.75	6684723.88	5.03	142.68	4.15	6684866.56
Nyamassila	53.52	399373.13	5.24	148.40	2.64	399521.54
Ogaro	42.62	318059.70	5.57	158.06	4.51	318217.77
Ogou	96.38	719246.27	5.22	148.15	3.68	719394.42
Okou	1139.13	8500992.54	5.13	145.57	2.88	8501138.11
Okpahoe	105.43	786791.04	5.13	145.65	2.24	786936.70
Ossacre	94.66	706388.06	5.42	153.64	3.97	706541.70
Otadi	2534.75	18916007.46	5.17	146.75	3.36	18916154.21
Ouma-Amlame	504.52	3765059.70	5.09	144.52	2.33	3765204.22
Ounabe	578.82	4319582.09	5.18	147.07	2.93	4319729.16
Ountivou	655.79	4893955.22	5.02	142.29	3.92	4894097.52
Pagala Gare	199.92	1491940.30	5.26	149.35	2.37	1492089.65
Pagala Village	363.35	2711559.70	5.25	148.91	2.82	2711708.61
Pagouda	24.46	182544.78	5.43	154.13	3.60	182698.90
Pallakoko	74.54	556253.73	5.25	148.98	2.17	556402.71
Pana	45.04	336082.09	5.60	158.98	4.90	336241.06

Pessare	25.65	191432.84	5.44	154.36	3.93	191587.19
Pesside	180.08	1343865.67	5.41	153.60	3.60	1344019.28
Pitikita	18.09	135029.85	5.45	154.58	4.38	135184.43
Pligou	8.21	61291.04	5.58	158.26	4.89	61449.30
Pogno	22.07	164664.18	5.58	158.40	4.07	164822.58
Poissongui	28.18	210313.43	5.65	160.32	4.63	210473.75
Pouda	32.73	244238.81	5.41	153.56	3.50	244392.36
Pya	34.97	261000.00	5.38	152.72	3.37	261152.72
Sadori	11.02	82261.19	5.46	154.78	3.82	82415.97
Sagbado	2.23	16656.72	4.88	138.48	4.35	16795.20
Sagbiebou	57.11	426156.72	5.44	154.61	3.85	426311.32
Saiboude	315.32	2353111.94	5.04	143.01	3.14	2353254.96
Saligbe	115.88	864761.19	4.95	140.36	4.05	864901.56
Sam-Naba	18.86	140723.88	5.66	160.68	5.06	140884.56
Sanda-Afohou	407.16	3038522.39	5.34	151.60	3.43	3038673.99
Sanda-Kagbanda	312.45	2331708.96	5.34	151.55	3.56	2331860.50
Sanfatoute	23.03	171888.06	5.62	159.38	4.34	172047.44
Sangou	1.38	10276.12	5.58	158.17	4.90	10434.29
Sarakawa	76.87	573686.57	5.35	151.76	2.80	573838.33
Sedome	45.49	339470.15	4.82	136.83	4.15	339606.98
Seregbene	2182.92	16290477.61	5.16	146.44	2.76	16290624.05
Sessaro	161.64	1206246.27	5.25	148.89	2.35	1206395.16
Sevagan	3.47	25902.99	4.95	140.62	4.49	26043.61
Siou	107.95	805619.40	5.45	154.46	3.93	805773.87
Sirka	63.01	470194.03	5.41	153.36	3.17	470347.39
Sissiak	22.79	170074.63	5.58	158.34	4.23	170232.97
Sodo	207.43	1548000.00	5.11	144.84	3.46	1548144.84
Sola	46.49	346947.76	5.45	154.63	4.13	347102.39
Somdina	34.15	254858.21	5.43	154.10	3.91	255012.31
Sotouboua	2030.78	15155097.01	5.26	149.83	2.87	15155246.84
Soudou	830.84	6200313.43	5.38	152.55	3.47	6200465.99

Tabinde	249.40	1861201.49	5.26	149.25	2.41	1861350.74
Tabligbo	38.32	285970.15	4.77	135.44	4.61	286105.59
Tado	401.79	2998462.69	4.92	139.58	4.02	2998602.27
Takpamba	150.49	1123059.70	5.39	152.99	3.66	1123212.69
Tambigou	30.76	229529.85	5.53	156.63	4.14	229686.48
Tambonga	16.78	125253.73	5.60	158.79	4.18	125412.52
Tami	48.53	362126.87	5.62	159.31	4.37	362286.18
Tamongue	20.29	151440.30	5.53	156.76	4.26	151597.06
Tampialime	27.98	208783.58	5.58	158.22	4.18	208941.81
Tchalo	1009.58	7534201.49	5.28	149.78	2.75	7534351.28
Tchaloude	90.18	672977.61	5.25	148.96	2.49	673126.57
Tchamba	710.05	5298858.21	5.28	149.88	2.90	5299008.09
Tchamonga	52.36	390776.12	5.50	155.88	4.09	390932.00
Tchanaga	109.59	817828.36	5.50	156.00	4.08	817984.36
Tchare	14.64	109223.88	5.41	153.36	4.11	109377.24
Tchare-Baou	106.49	794723.88	5.26	149.27	2.47	794873.15
Tchebebe	1760.35	13136917.91	5.24	149.32	2.72	13137067.23
Tchekpo	536.88	4006537.31	4.75	134.96	4.14	4006672.27
Tchifama	331.02	2470291.05	5.27	149.52	3.61	2470440.56
Tchitchao	39.18	292388.06	5.37	152.24	2.81	292540.30
Tchore	36.97	275902.99	5.37	152.46	3.69	276055.44
Temedja	184.97	1380388.06	5.17	146.54	2.65	1380534.60
Tenega	6.12	45701.49	5.46	154.99	4.27	45856.48
Timbou	14.87	110977.61	5.65	160.40	4.99	111138.01
Tindjassi	1114.00	8313417.91	5.07	143.77	3.28	8313561.68
Tintchro	2585.40	19294059.70	5.23	148.49	3.47	19294208.19
Titigbe	153.85	1148149.25	5.27	149.62	2.54	1148298.87
Toaga	15.63	116641.79	5.63	159.67	4.79	116801.46
Togblekope	23.85	178000.00	4.85	138.10	3.98	178138.10
Togoville	8.50	63462.69	5.16	146.34	4.84	63609.03
Tohoun	190.80	1423902.99	4.89	138.85	4.15	1424041.83
Tokpli	109.27	815410.45	4.74	134.39	4.25	815544.84
Tome	194.74	1453268.66	5.02	142.48	3.15	1453411.14

Tomegbe	1469.77	10968462.69	4.89	138.78	3.02	10968601.47
Tomety-Kondji	454.74	3393611.94	4.82	137.07	4.07	3393749.01
Tove	212.04	1582388.06	5.05	143.19	3.36	1582531.25
Tovegan	324.61	2422432.84	4.90	138.92	4.05	2422571.75
Tsevie	182.07	1358753.73	4.78	135.67	4.48	1358889.40
Vakpossito	0.00	0.00	4.90	139.11	3.88	139.11
Veh	437.36	3263910.45	5.06	143.63	2.43	3264054.08
Vo-Koutime	20.80	155231.34	4.88	138.43	4.35	155369.77
Vogan	35.10	261970.15	4.95	140.22	4.46	262110.37
Wahala	350.01	2612000.00	5.04	143.61	3.90	2612143.61
Waragni	43.83	327111.94	5.27	149.56	2.32	327261.50
Warengo	41.46	309380.60	5.39	153.07	3.52	309533.67
Wassarabo	209.65	1564522.39	5.29	150.10	2.83	1564672.49
Welly	529.72	3953141.79	5.25	148.85	2.57	3953290.65
Wli	78.31	584410.45	4.76	135.08	4.15	584545.53
Wome	285.55	2130970.15	4.90	139.02	3.08	2131109.17
Yade	21.62	161328.36	5.36	152.13	3.12	161480.49
Yalla	1450.43	10824082.09	5.10	144.67	3.36	10824226.76
Yaloumbe	55.18	411776.12	5.27	149.62	2.57	411925.74
Yegue	1914.70	14288828.36	5.14	145.97	3.21	14288974.33
Yikpa	219.08	1634955.22	4.82	136.65	2.78	1635091.88
Yokele	92.63	691238.81	5.05	143.35	3.84	691382.16
Zafi	600.17	4478858.21	4.82	136.84	4.15	4478995.05
Zanguera	1.71	12761.19	4.82	136.86	4.35	12898.05

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