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Allowance of the Emission Quota Using Life Cycle Assessment for the Creation of a National Carbon Market: Framework Developed for Hydroelectric Projects in Cameroon

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Abstract

The lack of synergy between infrastructure financing mechanisms and mechanisms for combating climate change does not favor the definition of sustainable infrastructure in Cameroon. The definition of a sustainable infrastructure could meet the requirements of these mechanisms, thanks to the control of Greenhouse Gas (GHG) emissions during its installation, in relation to a predefined value. However, the promotion of efforts to reduce emissions from new infrastructures is not subject to a local market. This situation is a limit in the implementation of the policies defined in the Nationally Determined Contribution (NDC). This article proposes a framework for promoting reduction efforts for a national carbon market, in favor of hydroelectric infrastructures. Thanks to the Life Cycle Assessment (LCA) environmental assessment tool, we are going to determine the carbon quota for a specific power. The study carried out on the hydroelectric power station of Mekin (HydroMekin) leads us to a reduction effort of 68.2% compared to the threshold defined at 14.057 gCO_{2eq}/kWh_e. The framework, developed, contributes to defining the environmental parameters in the decarbonation strategy during the implementation of new hydroelectric infrastructures and the market carbon design elements special to the construction phase of these infrastructures.

Keywords

Carbon Market, Sustainable Infrastructure, Reference Value, Emission, Hydroelectricity

1. Introduction

Actions to limit climate change have existed since the Kyoto Protocol in 1997. At that time, the objective was to reduce the emissions of industrialized countries to 5% compared to their 1990 level on their emissions during the period 2008-2012 (Kyoto, 1997). Its mechanism called clean development mechanism (CDM), in its article 12 defines the carbon valuation mechanism. Most recently, the Paris Agreement in 2015 made it possible to obtain Nationally Determined Contributions (NDCs), which describe the decarbonation strategies, not only for industrialized countries but also for developing countries. Its article 6 defines the mechanism to ensure environmental integrity (Paris, 2015). The unit of exchange guaranteeing it in the international systems is based on the emissions reduced on the basis of each Business as Usual (BaU) (Michaelowa, Herwille, Obergassel, & Butzengeiger, 2019). The first instrument (Kyoto protocol) is not successful in the Sub-Saharan African (SSA) zone in the energy industry domain (Karamoko, 2018). The second occurs in an environment where needs for the implementation of new production capacities are estimated at about 73.44% in the various NDCs (Noah, Tom, & Hamandjoda, 2021). The Kyoto Protocol and the Paris Agreement coexist in the context of the fight against climate change in the sectors of agriculture, energy, industry and waste management. They propose financing mechanisms to support the targeted objectives of the various stakeholders. Other "private" mechanisms for climate change mitigation are also in operation, such as the China South-South Climate Cooperation Fund for Climate Change (Chirambo, 2018).

In addition, the SSA zone has other funding programs that aim at improving electrification or the installation of new energy production capacity, such as Power Africa from the United States government initiative, Sustainable Energy For All (SE4All) from the World Bank but also from banking institutions such as the African Development Bank. The existence of these different types of financing can weaken the achievement of the objective of sustainable electrification (Chirambo, 2018), in the sense that the SSA countries do not have instruments that will help regulate the coexistence of several modes of financing. Indeed, international agreements (Kyoto, 1997; Paris, 2015) aim at achieving carbon neutrality through an emissions transfer system, by promoting efforts to reduce emissions. These efforts are not a requirement in the other mechanisms. Although the sustainability of infrastructure requires reforms leading to the harmonization of climate fund and energy access mechanisms, through the reformulation of the carbon market in this part of the globe at the macroeconomic level, it is also necessary to set up pilot projects for the valuation of emissions inside the country (Assefa & Ramjeawon, 2019).

The carbon market defined by the Paris Agreement targets all levels of a country (macro (entire economy, NDC), meso (sector of the economy, region of the country) and micro (projects)). On the basis of different NDCs, the market is being implemented at the macro level of the different SSA countries. At the end of the first national inventories, the meso level will be able to be defined. However at the micro level, in the case of Cameroon, many infrastructures are defined in its National Development Strategy by 2030 (NDS 30), but do not appear in its NDC, and will contribute to the improvement of rural electrification estimated at 20% (MINEPAT, 2020), including hydroelectricity. These hydroelectric infrastructures will not be subject to efforts to limit GHG, yet their construction phases are the most polluting over the entire life cycle (Motuziene, Ciuprinska, Rogoza, & Lapinskiene, 2022). Moreover, the development of the hydroelectric potential of SSA countries will be linked to their industrial ambitions (Kpewoan II & Elkiran, 2022), thus the definition of a national carbon market intended for hydroelectric projects arises. It will strengthen the decarbonation strategies taken at the macro level, for the control of carbon emissions of all the sectors which contribute to its realization on one hand, it could also become a future development of local climate governance, its interconnection on a certain scale can inspire participants' enthusiasm and even promote liquidity and activities (Hua & Dong, 2019); (Zhang, Fan, & Dou, 2014) on the other hand, and finally for weak economies, it can serve as a synergy for the development of sustainable infrastructure. However, it follows the international classification of a market, namely mandatory and voluntary approach (Lehmann, Finkbeiner, Broadbent, & Balzer, 2015). In these two approaches to the carbon market, the regulatory authority defines the annual emission reduction quotas of participating companies with adjustments if excesses are observable (Hua & Dong, 2019). The methods for allocating carbon quotas are grandfathering, the auction mechanism and a combination of the two (Han, Yu, Tang, Liao, & Wei, 2017). For the electrical energy industry sector, allocation methods of the grandfathering type can be done by the history of emissions, or by the industry benchmark (Hua & Dong, 2019); (Li, Zhang, & Lu, 2018); (Liu, Chen, Zhao, & Zhao, 2015); (Alberola & Chevalier, 2009); (Chang, Chen, & Chevalier, 2018); (Flachsland, Marschinski, & Edenhofer, 2009); (Xiong, Shen, Qi, Price, & Ye, 2017). Thus, it is therefore possible to define a carbon market by a mechanism allowing the emissions resulting from an activity to be maintained at a pre-defined level. However, the new electrical energy production capacities foreseen, following the example of Cameroon, cannot benefit from an annual history of the emissions of the whole, but rather from the history of pollution of the manufacture of the inputs. The possible method for defining quotas is therefore that of the industry benchmark.

Moreover, the adoption of the practice of sustainability has already been planned or is already used in some organizations, this through the appropriation of life cycle theory (Olin, 2018), thanks to the Life Cycle Assessment (LCA) tool. It is one of the reliable methods for assessing the environmental impacts of products (Minkov et al., 2020). In the literature, the LCA method is used to assess the environmental impacts of human activity. It is presented according to three approaches: the bottom approach or Process Chain Analysis (PCA), the top-down approach or Input Output Analysis (IOA) and the hybrid approach (Turconi, Boldrin, & Astrup, 2013). The PCA makes use of data from the construction of the structure, generally at the end of the execution of the works. It is energy-intensive but the results obtained are generally accurate (Finnveden et al., 2009). The IOA approach is based on the financial data of each sector that contributed to the realization of the work. It provides results only depending on the cases and more complete, moreover it is less precise than the PCA approach (Hendrickson, Arpad, Joshi, & Lave, 1998); (Joshi, 1999). Indeed, the IOA evaluates a large number of impacts that the PCA approach causes because the limits are extended and no process limits are applied (Meier, Wilson, Kulcinski, & Denholm, 2005). The last, the hybrid approach is the combination of the two previous ones. In the case of hydroelectric infrastructure, it contributes to the assessment of the impact on global warming. Environmental sobriety or its durability is demonstrated either through an intra-sector study (technology having the same process for obtaining the product (e.g. electricity)) or inter-sector study (different technologies having the same product) (Varun, Prakash, & Bhat, 2010); (Suwanit & Gheewala, 2011); (Zhang et al., 2007). This involves comparing the global warming potential of the infrastructure studied with other infrastructures. Either by the position of its global warming potential compared to the results of the literature; as an example in the case of a run-of-river hydroelectric infrastructure, the values are between 2 - 5 $kgCO_{2eq}/MWh_e$ (Turconi, Boldrin, & Astrup, 2013), or less than 15 gCO_{2eq}/kWh_e (Motuziene, Ciuprinska, Rogoza, & Lapinskiene, 2022). Both approaches refer to GHG emissions per functional unit of infrastructure in the same sector or different electricity production sectors other than the one studied. It is a benchmark of the environmental behavior of infrastructures and its global warming potential compared to others. Thus, the appropriate carbon allowance method for new energy infrastructures would be that of the industry benchmark.

The environmental sustainability of an energy infrastructure is done in comparison (benchmarking) with other infrastructures. However, how can we define the GHG emissions quota for a specific power of a hydroelectric infrastructure? How can it be used when defining a carbon market in Cameroon? These two questions define the points developed in this work.

The definition of a reference value of emissions for a given power will be based on the hypothesis of the interdependence between the installed power of the infrastructure and its emissions over the life cycle (Pascale, Urmee, Humpenoder, & Moore, 2011); (Vattenfall, 2008); (Gagnon & van de Vate, 1997); (Dones, Heck, & Hirschberg, 2004). With regard to carbon markets (Kyoto, 1997) and (Paris, 2015) and the Chinese carbon market (Hua & Dong, 2019), reduction efforts are defined in relation to a reference (BaU). The reduction effort will promote the establishment of sustainable infrastructures (Chirambo, 2018); (Michaja et al., 2017). In Section 2, we are going to present the methodology for valuation of GHG reduction efforts by functional unit; it puts in relationship the tools for assessing environmental impacts, and the strategy defined at the macro level of the country. In Section 3, the obtained results will allow us to quantify the reduction effort in a context of operationalization of the NDC at the project level, and the discussion allows us to show the contribution of the use of LCA for the allowance of quotas on one hand, and elements necessary for the implementation of a carbon market based on LCA on the other hand. In the section 4 we are going to conclude our study.

2. Tools and Methods

This paper aims to define a baseline of GHG emissions per functional unit of a given power of the hydroelectric infrastructure, through the use of LCA. It will serve as a reference when evaluating reduction efforts, as part of the implementation of a decarbonation strategy. This reference will be defined on the basis of LCA studies contained in the literature, on the basis of the hypothesis of interdependence between power and GHG emissions per functional unit (Pascale, Urmee, Humpenoder, & Moore, 2011); (Vattenfall, 2008); (Gagnon & van de Vate, 1997), (Dones, Heck, & Hirschberg, 2004). The promotion of this effort on one hand, and Cameroon's decarbonation strategy through its NDC on the other hand, constitute two elements of the methodological framework for the creation of sustainable value defined in (Harbi, Margni, Loerincik, & Dettling, 2015). Its use, in our work, applies to the incentive of a voluntary and specific carbon market to hydroelectricity infrastructure.

The different stages of sustainable value creation are summarized in **Figure 1**.

2.1. Toolbox

The impact of the plant will be assessed using the LCA tools according to the ISO 14040 standard (ISO 14040, 2006). The different phases of LCA are as follows:

- Objective and framework of the study;
- System modeling and inventory calculation;
- Impact assessment using the open source LCA software tools;
- Analysis of life cycle impacts and comparison of results.

1) Choice of hydroelectric plant

The Mekin hydroelectric power station is located at about 1.5 km downstream

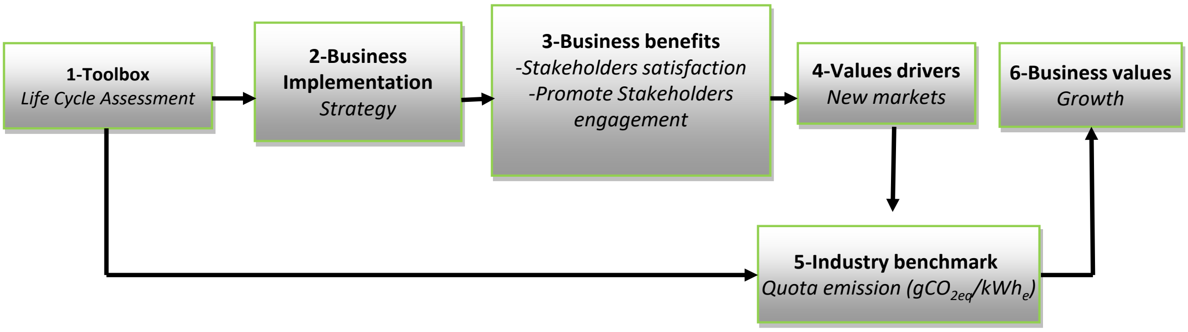

Figure 1. Methodological framework for creating the sustainable value of a hydroelectric infrastructure.

from the confluence of three rivers: Dja, Lobo and Sabe. The project site is approximately 200 km from Yaoundé the political capital of Cameroon. It is a plant at the foot of the dam which has an installed capacity of 15,000 kW. It is equipped with three turbo-alternator groups of 5 MW each. The equipment flow rate is 180 m^3/s with a unit value per group of 60 m^3/s. The annual operating time of the plant will be 5839 hours, i.e. approximately 16 hours per day. The application of the new methodological framework makes it possible to assess its environmental sustainability in relation to its impact on climate change. The different "inputs" of the project come from different geographical areas, subject to different environmental standards, or even different environmental product declarations; but aggregation is not enough to justify the sustainability of the infrastructure.

2) Objectives and functional unit

The study carried out on the HydroMekin plant aims to determine its life cycle carbon emissions on one hand and to assess its sustainability (comparison of results) on the other. Finally, in an international context of ecological transition, this is a prospective study which aims at encouraging the control of GHG emissions in a case of aggregation of potentially polluting sectors of activity and whose environmental policies incoming flows do not really rely on the host country of the infrastructure (Cameroon). The functional unit is 1 kWh of electricity produced.

3) Borders system

The documentation of the project allowed us to have the various elements that were useful during its realization. They have been summarized in the opposite Table 1.

4) Inventory modeling and calculation

The appropriate LCA approach is IO-LCA with regard to the reliable information available on one hand and the need to have the environmental status of the infrastructure before its construction on the other. In addition, the Inputs data are expressed in economic value, which leads us to use the Economic Input Output LCA (EIO-LCA) approach. Then, we considered the year of the EIO-LCA model. The HydroMekin project was carried out according to the Engineering

Table 1. Components of the studied system.

Component	Cost in RMB (Yuan)
Secondary dam	9,730,763
Main dam	26,745,007
Main plant engineering	88,312,099
Flood discharge	15,283,713
Overflow dam	25,803,062
Gravity dam and gat chalber section	8,377,865
Hydro generator and installation	53,038,208

Procurement and Construction (EPC) model by a Chinese company. As a result, the monetary unit adopted in our work is the RMB. In the absence of data available on steel production in Cameroon, we considered, after investigation, that the amount of energy needed to manufacture 1000 kg of steel and that the cost of a ton of steel in 2015 were fixed at 21,074.81 RMB. In order to verify the applicability of U.S EIO-LCA software developed by the Carnegie Mellon University for the HydroMekin plant in Cameroon, this value was converted using the Purchasing Parity Price (PPP) and the inflation index for the United States. The value of \$3686.6, obtained from formula (1) below, is used as an input value for the EIO-LCA software model 1997, and we get 22 GJ for manufacturing 1000 kg of steel. The value obtained is compared with the order of magnitude used for steel production in China for the same year. That is a value in the range of 17.5 - 22.5 GJ/1000kg admitted for the path of the basic oxygen furnace of the blast furnace (He, Wang, & Li, 2020).

Thus, the 1997 model of the EIO LCA software is valid for the evaluation of the energy consumed and the greenhouse gas emissions released for the construction of 1 kWh of the HydroMekin plant.

$$\text{Equivalent cost in}\left(\text{U.S\$}\right)=\frac{\text{Costin RMB}}{\text{PPP}}\times\frac{\text{Inflation index for year 1997}}{\text{Inflation index for year 2015}}\quad(1)$$

The values of the inflation indexes of the United States for the years 1997 and 2015 respectively are contained in Table A1 of the **Appendix A**.

5) Analysis of life cycle impacts and comparison with other hydroelectric projects

Civil works

Civil engineering activities are limited to secondary dam, main dam, main plant engineering, flood discharge and over flow dam activities. The resulting technical operations are excavation, concrete production, treatment and installation of steel bars, etc. whose costs are contained in the price sub-detail, 2015. Table 2 summarizes the inventories resulting from civil engineering activities. The total energy consumption and GHG emissions related to civil works is obtained from the EIO-LCA software. Related inputs from raw material extraction to material and equipment manufacturing are included in this EIO-LCA software.

Electromechanical equipment

The activities of manufacture and installation of electromechanical equipment are summarized in the installation of the hydro generator, the auxiliaries of the hydraulic machines, the installation of electrical equipment. The inputs associated with all the processes included in the extraction of the raw material until the manufacture of materials and equipment are included in the EIO-LCA software. Table 3 presents the inventory of activities for obtaining and installing the various electromechanical equipments.

Operation and maintenance (O&M)

General estimations of energy consumption and GHG emissions for O&M of

Table 2. Inventory of HydroMekin project civil works activities.

S.n.o	Component	Cost in RMB **2015**
1	Secondary dam	9,730,763
2	Main dam	26,745,007
3	Main plant engineering	88,312,099
4	Flood discharge/scouring sluice engineering	15,283,713
5	Overflow dam	25,803,062
6	Gravity dam and gate chamber section	8,377,865
	Total	174,252,509

Table 3. Inventory of E&M equipment of HydroMekin project.

S.n.o	Component	Cost in RMB **2015**
1	Hydro-generator and installation	42,418,642
2	Auxiliary hydraulic machinery and installation	319,253
3	Electrical equipment and installation	10,300,313
	Total	53,038,208

the plant are taken from 3% of the total costs of civil works and 3% of the cost of equipment. The annual electricity consumption of the factory is estimated at 5% from the annual electricity produced.

Decommissioning

The main machinery and equipment installed in a hydropower plant should last between 15 to 30 years at least compared to the life of the main elements of the dam construction, concrete foundation, etc. Energy consumption and GHG emissions for the replacement and recycling of machinery and equipment have been averaged and included here in the annual maintenance costs.

GHG emissions by functional unit

GHG emissions (gCO_{2eq}/kWh_e) have generally been estimated based on the full operational life cycle of each renewable energy system, from commissioning to full system operation (cradle to grave). These emissions vary considerably within each technology for the estimation of GHG emissions. The life of the projects is considered to be 30 years. The estimation of GHG emissions is obtained by the following formula (2).

$$\text{GHG emissions} = \frac{\text{Total CO}_2 \text{ emissions throughout its life cycle}\left(\text{gCO}_{2\text{eq}}\right)}{\text{Annual power generation}\left(\dfrac{\text{kWh}_\text{e}}{\text{year}}\right)\times\text{lifetime}\left(\text{year}\right)} \quad (2)$$

6) Sustainability study

This study was conducted using an intra-sector comparison. To do this, a database was built on the assumption of interdependence between installed power and life cycle GHG emissions.

7) Determination of the level of correlation

The evaluation of this interdependence was made thanks to the Pearson correlation coefficient through the formula (3).

$$\rho(E;P)=\frac{\sum_i^N\left(E_i-\bar{E}\right)\times\left(P_i-\bar{P}\right)}{\sqrt{\sum_i^N\left(E_i-\bar{E}\right)^2}\times\sqrt{\sum_i^N\left(P_i-\bar{P}\right)^2}} \tag{3}$$

where the parameters P_i: represent the power (kW) of the dam i, and $\bar{P}$ its mean value;

E_i: the quantity of gCO_{2eq}/kWh_e emissions from the dam i, and $\bar{E}$ its mean value; and N: the number of hydroelectric dams in the database.

The coefficient will be negative, because in the literature it appears that the greater the power of the installation is, the less it has an impact on global warming and when its power is low, the greater the impact.

Moreover, if $\rho(E; P) = -1$, we will have a perfect negative correlation, then the database expresses a strong interdependence between its parameters;

If $-1 < \rho(E; P) \leq -0.5$, we will have a strong negative correlation, then the database expresses an interdependence between its parameters;

If $-0.5 < \rho(E; P) \leq -0$, we will have a weak negative correlation, then the database there is no interdependence between its parameters.

2.2. Business Implementation

The NDS 30, adopted by the State of Cameroon in its "energy industry" section, has retained three orientations, including the development of the significant national hydroelectric potential. As for the environmental component, one of the actions will aim to further integrate concerns related to climate change into sectorial strategies and policies to adapt to climate change. Thus, all sectorial actions should take into account the requirements related to sustainable development. In particular, the energy infrastructure development strategy should respect the reduction quota for the energy sector estimated at 13,369.85 Ggeq CO_2 (NDC, 2021) by 2030. In the absence of national regulations defining the limitation of emissions during constructions, the approach proposed in the context of our study will enable decision-makers in Cameroon to show to the other parties of the Paris Agreement, their willingness to implement a sustainable development policy defined in its NDC; through the use of the environmental sustainability of infrastructures. In this context, the strategy adopted by the decision-makers would be an environmental innovation with the aim of controlling the carbon footprint of infrastructure on the one hand and a model of synergy between infrastructure needs and the fight against climate change resulting from human activity on the other hand.

2.3. Business Benefits

The method proposed in our work and implemented in the case of HydroMekin aims to satisfy the requirements for limiting GHG emissions of each country that can be considered as the expression of the sustainable development strategy.

Since the reduction quotas are defined by sector in Cameroon's NDC, the approach illustrates the strategy for limiting emissions of a component of the sector (sub-sector). This action may be the subject of specific internal communication within the framework of policies to popularize efforts to respect the objectives of the NDC.

2.4. Values Drivers

The priority needs defined by the various NDCs, in SSA, are those of the implementation of sustainable energy infrastructures. Their implementation comes up against funding problems. This is the case of the implementation of Cameroon's energy policy for 2030. However, Post-CoP 21 energy infrastructures are defined by a desire to develop sustainable infrastructures due to climate change, but they are hampered by a lack of synergy between traditional funding mechanisms and so-called climate funding mechanisms (Chirambo, 2018). Thus, a mechanism valuing efforts to control GHG emissions below a predefined sustainability threshold induces the creation of a new market. The creation of a market based on the enhancement of the environmental sustainability of infrastructures will make it possible to ensure a better energy transition and to popularize the strategy of adaptation to climate change among endogenous populations thanks to the specialization of the new market.

2.5. Industry Benchmarks

The definition of the reference value within the framework of a hydroelectric infrastructure for a precise power will be done using the affine regression line (BaU baseline). It will be obtained by the following formula (4).

$$E-\bar{E}=\frac{\sum_{1}^{N}P_i\times E_i-\bar{P}\times\bar{E}}{\sqrt{\sum_{1}^{N}P_i^2-\bar{P}^2}}\left(P-\bar{P}\right) \tag{4}$$

2.6. Business Value

Following the Paris Agreement, the needs expressed in the electricity production sector, in the SSA countries, represented approximately 73.44% of the needs for new infrastructures that would improve the country's capacity (Noah, Tom, & Hamandjoda, 2021). However, the relationship between these needs, identified in electrification programs and the limitation of emissions, in the context of climate change, allows us to define the essential element of a new local carbon market. This is the allowable emission potential for a given power. It will make it possible to assess the efforts to control emissions from the new infrastructures. The new market, created, is defined by the following mechanism: firstly, the definition of the BaU baseline, using the results of various LCA studies of the hydroelectric sector (step 1). Secondly, the GHG emissions quota allowed to the project, according to its power, is compared to the emissions quota defined by the BaU baseline (step 5). After validation of the quota, the project is executed.

Thirdly, at the end of the construction phase, an emission assessment is carried out to check whether the allowed quota has not been exceeded. In the event of excess, regulatory measured could be applied by the competent authority.

3. Results and Discussion

3.1. Results

Global warning potential

Based on the inventories of Table 2 and Table 3 we obtain the GHG emissions. Table 4 below presents the results obtained from formula (1) and (2).

By integrating the emissions from operations and maintenance we obtain the emissions and energy over the life cycle of the HydroMekin plant. They are summarized in the following Table 5.

Construction-related activities are those that emit more GHGs and use more energy. It includes the analysis of material (extraction, processing, and transportation) and energy (extraction/generation, processing, transportation) inputs,

Table 4. Energy consumed and GHG emissions for Civil works and electromechanical equipment of the project.

S.n.o	Component	GHG emissions (Mt CO_{2eq})	Energy used (TJ)
	Civil works		
1	Secondary dam	1357.92	19.17
2	Main dam	3828.31	54.79
3	Main plant engineering	3839.32	63.07
4	Flood discharge/scouring sluice engineering	773.40	11.60
5	Overflow dam	775.18	13.88
6	Gravity dam and gate chamber section	271.62	5.00
	Total	10,845.77	167.54
	Electromechanical equipment		
1	Hydro-generator and installation	398	8.56
2	Auxiliary hydraulic machinery and installation	3.3	0.067
3	Electrical equipment and installation	169	3.35
	Total	570.3	11.977

Table 5. Energy consumed and GHG emissions for the project.

Component	Cost in US $ **1997**	GHG emissions (Mt CO_{2eq})	Energy used (TJ)
Civil works	30,491,673.61	10,845.77	167.54
E&M equipment	9,281,686.4	570.3	11.97
O&M	1,193,200.8	342.48	5.38
Total	40,966,560.81	15,711.81	184.90

and equipment used in construction processes (combustion of fuel) (Horvath, 2005). This result is in accordance with the point of view of (Motuziene, Ciuprinska, Rogoza, & Lapinskiene, 2022). **Figure 2** below shows the distribution in terms of GHG emissions of all the activities that compose it. Activities related to main dam and main plant engineering each represent 35% of emissions from construction.

To sum up, the GHG emissions from the HydroMekin plant over 30 years of operation led us to 4.47 gCO_{2eq} /kWh_e. The value of the emissions emitted over the life cycle is included in the recommended range for studies from the hydroelectric power plants run over the river, i.e. 2 - 5 $kgCO_{2eq}$ /MWh_e (Turconi, Boldrin, & Astrup, 2013) and less than 15 gCO_{2eq}/kWh_e (Motuziene, Ciuprinska, Rogoza, & Lapinskiene, 2022). The total energy that will be consumed is 184.9 TJ.

Determination of the level of correlation and study of sustainability

From research in the literature, through the various search engines, we have created a database. It is summarized in the following **Table 6**.

The Pearson coefficient of this database is calculated from Equation (3) and gives us an interdependence coefficient of −0.55. This is a strong correlation and this result justifies the relevance of the hypothesis of the dependence between installed power and GHG emissions per functional unit. The approach also consisted in retaining, in the database, the installations whose powers are close to that of the study and those of very low powers on one hand, and we did not make a sorting on the type of construction (run of river, dam toe, and canal).

The database created allowed us to assess the environmental sustainability of the plant. From **Figure 3** below, we observe that the HydroMekin plant records a low life cycle emissions rate compared to the majority of the plants in the database except the Simalungun plant and Switzerland. From this, we conclude that the plant is environmentally friendly.

Business value

The reference value for HydroMekin is obtained from Equation (4). It gives us

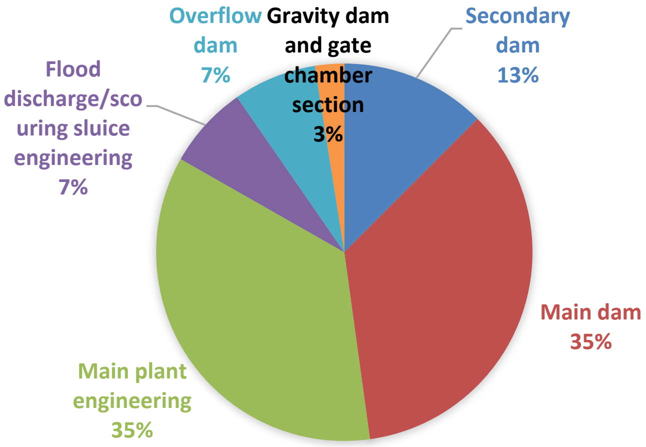

Figure 2. Distribution of GHG emissions from different stage of Civil Works.

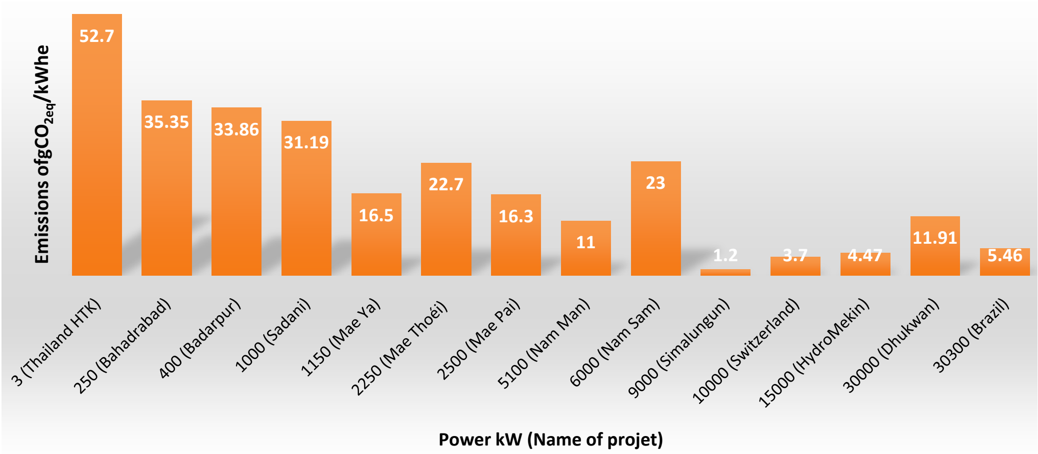

Figure 3. Analysis of the environmental sustainability on HydroMekin.

Table 6. Database for HydroMekin environmental sustainability study.

Name of project	Power (kW)	GHG emissions gCO_{2eq}/kWhe	Type	Source
Thailand HTK	3	52.7	Run of river	(Pascale, Urmee, Humpenoder, & Moore, 2011)
Bahadrabad	250	35.35	Canal	(Varun, Prakash, & Bhat, 2010)
Badarpur	400	33.86	Canal	
Sadani	1000	31.19	Dam-toe	
Mae Ya	1150	16.5	Run of river	(Suwanit & Gheewala, 2011)
Mae Thoei	2250	22.7	Run of river	
Mae Pai	2500	16.3	Run of river	
Nam Man	5100	11	Run of river	
Nam San	6000	23	Run of river	
Simalungun	9000	1.2	Run of river	(Hanafi & Riman, 2015)
Switzerland	10,000	3.7	Run of river	(ETDEWEB, 2023)
Dhukwan	30,000	11.91	Dam-toe	(Varun, Prakash, & Bhat, 2010)
Brazil	30,300	5.46	Dam-toe	(Suwanit & Gheewala, 2011)

$$E = -0.0008 \times P + 26.057 \tag{5}$$

The admissible threshold for a power of 15,000 kW, based on the linear model of the previous equation, is 14.057 gCO_{2eq}/kWh_e. Thus the carbon reduction effort is 9.587 gCO_{2eq}/kWh_e. It represents a 68.2% reduction effort. Therefore, the HydroMekin project is executable due to the position of its GHG emissions per functional unit compared to the predefined threshold. A reassessment at the end of its construction is the next step, to ensure that the quota allowed this phase has been respected.

3.2. Discussion

The use of the EIO approach and the errors of "hot air"

The LCA study of the HydroMekin plant leads us to emissions of 4.47 gCO_{2eq}/kWh_e for a period of 30 years. This value is used to promote efforts to combat climate change, by situating it in relation to the reference carbon quota. However, the IOA approach in LCA, in general, is a source of overvaluation of impacts (Noburu, Inaba, & Tonooka, 2001). The overvaluation of BaU is qualified as "hot air" (Schneider & Theuer, 2019), in the context of the international carbon market. Thus, although GHG emissions per functional unit are between 2 - 5 gCO_{2eq}/kWh_e (Turconi, Boldrin, & Astrup, 2013) for run-of-river power plants, it would be important to estimate the error that would arise when using LCA for allowances.

The Database in Environmental Sustainability

The database constituted to evaluate the durability of HydroMekin is made on an interdependence of −0.55. This approach makes it possible to choose the elements of comparison objectively. The 13 LCA studies make it possible to constitute it, and to evaluate the environmental sustainability of HydroMekin. In the literature, the evaluations of this do not justify the choice of the elements of the database (Varun, Prakash, & Bhat, 2010); (Suwanit & Gheewala, 2011); (Zhang, Fan, & Dou, 2014); (Pascale, Urmee, Humpenoder, & Moore, 2011); (Vattenfall, 2008); (Gagnon & van de Vate, 1997); (Dones, Heck, & Hirschberg, 2004). In a context of the fight against climate change which has a global impact, the sustainability of infrastructures should be made on an empirical basis (Industry benchmark). Indeed, in the literature, the evolution of GHG emissions per functional unit, of a hydroelectric power station, are decreasing in relation to the evolution of the installed capacities. In addition, in these studies, the various infrastructures are considered to be environmentally friendly. Thus, the various results constitute a relevant basis for leveling emissions (quota allowances). However, in the constitution of our database, a sorting was not carried out for the type of infrastructure and the year of implementation. An analysis of the sensitivity of the quotas in relation to these parameters would be recommended.

The definition of the reference base to control the emissions of the aggregation of different inputs

The synergy between financing mechanisms for electrification and the fight against climate change in SSA requires a definition of infrastructure sustainability. According to the carbon markets defined in the Kyoto Protocol and the Paris Agreement, a baseline must be defined. In Cameroon's NDC, the BaU is 119,084.45 Ggeq $C0_2$ with a target of 76,825.72 Ggeq $C0_2$, i.e. a 35% reduction in its emissions (NDC, 2021). Our study develops a baseline to limit GHG emissions for hydroelectric projects. It reinforces the strategy defined at the micro level (Chirambo, 2018) on the one hand, and provides the elements for the creation of a local carbon market on the other. The use of the reference base gives rise to two possible interpretations: "immediate" durability, the gCO_{2eq}/kWh_e

emissions of the infrastructure can reach the reference value or "deferred" durability, in this case modifications of the components of the projects are called upon to give it durability. Electromechanical equipment is not manufactured in SSA countries. The manufacturing countries are subject to different environmental standards or environmental declarations. Their aggregations do not confer sustainability without an emissions baseline. Furthermore, the use of an emissions quota to control the emissions resulting from the aggregation of the various products contributes to the collection and measurement of basic values for the measurement of performance and the reporting of environmental performance indices (Olin, 2018). However, its implementation requires the availability of data relating to environmental impacts different inputs (Adrianto et al., 2021) on the one hand, and it would be recommended to set up inventories to facilitate exploitation by decision-makers on the other hand.

Incentive of a specific carbon market

The evaluation of the reduction efforts of the HydroMekin plant is estimated at 9.587 gCO_{2eq}/kWh_e. That is a reduction effort of 68.2% compared to the reference value, **Figure 4** below. This value quantifies the consideration of the environmental aspect in relation to the quota that has been defined. Its valuation contributes to encouraging the specialization of the market for a better appropriation by the populations on the one hand, to serve as a national lever for the achievement of the objectives of the NDC.

One of the important elements, for the market, is the database. It makes it possible to define the quota to be allocated and therefore allows the evaluation of the effort to reduce emissions. However, a database constituted so the Pearson coefficient would be close to −1 would be recommended. A study of the sensitivity of the evolution of the Pearson coefficient and the percentage reduction for is recommended.

Legislative reform

Valuing efforts to reduce GHG emissions by functional unit requires taking into account the quantification of emissions. According to Cameroonian legislation, the environmental and social impact assessment is defined as a systematic examination aimed at determining the favorable and unfavorable effects likely to be caused by a project on the environment. It makes it possible to mitigate, avoid, eliminate or compensate for harmful effects on the environment (MINEPDED, 2013). Thus, the quantification of emissions is not required in the environmental assessment. However, the Post CoP 21 era places an emphasis on controlling emissions from human activity through the definition of targets in NDCs. In current practice, this is done by an annual evaluation of the country's emissions using the reference approach (IPPC, 2006), which does not provide the possibility of evaluating the efforts to reduce emissions that the establishment of a new infrastructure. Thus, legislative reform is needed to align with the issue of controlling GHG emissions. **Figure 5** below illustrates the connection between the division of hydroelectric power Cameroon's legislation

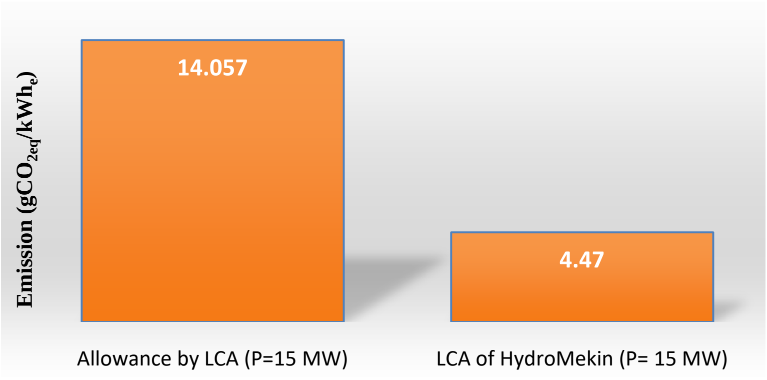

Figure 4. Carbon reduction effort.

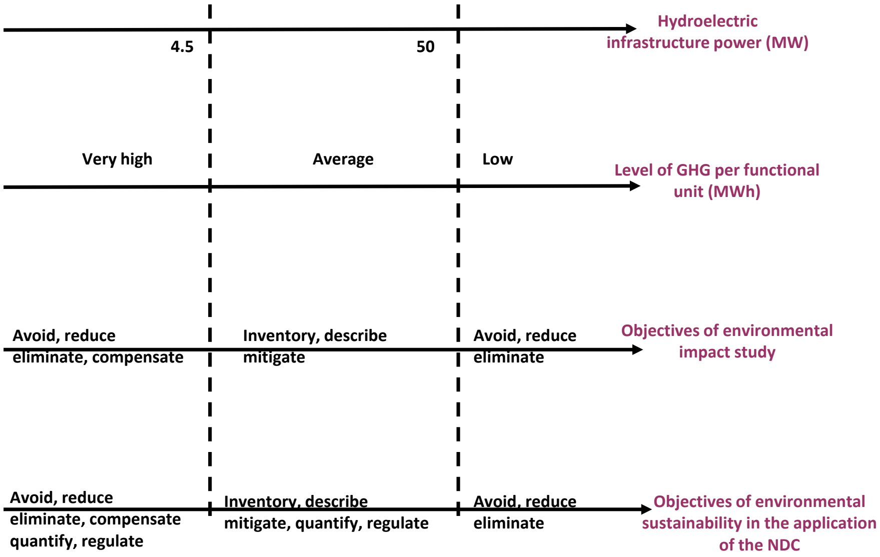

Figure 5. Comparison of methodologies in the Post CoP 21 era, Case of Cameroon.

on the one hand, the evolution of the level of GHG emissions per functional unit (Pascale, Urmee, Humpenoder, & Moore, 2011); (Vattenfall, 2008); (Gagnon & van de Vate, 1997); (Dones, Heck, & Hirschberg, 2004), on the other hand, and finally the objectives defined in the environmental impact studies of hydroelectric projects (MINEPDED, 2013).

The quantification requirement must be specified for a certain infrastructure power range. Thus for 50,000 kW infrastructures, quantification within the framework of the carbon market would not be necessary in view of the low level of emissions. It would therefore be more advisable to require quantization for lower powers.

Relevance of the temporality of needs in the definition of the carbon market

Based on the carbon market methodologies of the CDM and the Paris Agreement (Article 6), the temporality factor on the life cycle is important for the success of the mechanism defined within the framework of the synergy. Indeed, it is a question of placing the application of the methodology on the basic life cycle of

Table 7. Applicability over the life cycle of the methodologies proposed by the international carbon markets for renewable energy.

Mechanism	Methodology Designation	Mitigation actions	Temporality of methodology	Source
CDM	AM0007; AM0019 AM0026; AM0052 AM0100; ACM0002 ACM0006; ACM0018 ACM0020; ACM0022 AMS-I.A; AMS-I.C. AMS-I.D; AMS-I.F. AMS-I.G; AMS-I.H. AMS-I.M.	Displacement of more intensive production GHG	Exploitation	(UNFCCC, 2021)
	AM013	Displacement of more intensive production GHG	Construction, exploitation	
Paris Agreement	Article 6.2 et 6.4	BaU reduction	exploitation	(Paris, 2015)

the infrastructure (implementation (new construction), operation (improvement of the existing) and end of life (recycling). The analysis of the temporality of the methodologies proposed within the framework of the projects of production and supply of electricity of the renewable energy type of the CDM through the methodologies Approved Methodology (AM), Approved Consolidated Methodology (ACM) and (Approved Methodology for Small-scale (AMS) on the one hand and the Paris Agreement through the NDCs on the other hand, are summarized in **Table 7**.

The interpretation of **Table 7** shows that the efforts to reduce GHGs are mainly in favor of existing infrastructures. While the establishment of new production capacities concerns areas without infrastructure for which it is impossible to have the baseline for emissions reduction efforts. Thus, on the temporality of the life cycle of the infrastructure, it appears that the carbon markets (Kyoto, 1997; Paris, 2015) cover the existing infrastructures. The definition of the market resulting from the synergy should integrate the specification on the temporality of the need over the life cycle of an infrastructure, in order to guarantee its effectiveness.

4. Conclusion

No less than 3700 hydroelectric power plants with a capacity of at least 1000 kW are planned or under construction in several countries of emerging economies (Zarfl et al., 2015), some of which are defined in the NDCs, with the aim of combating climate change. SSA countries are covered by different mechanisms for building new power generation capacity and mitigating climate change (Chirambo, 2018). The lack of synergy between these mechanisms could be a cause of the delay of the objective of sustainable electrification. It involves defining the concept of sustainable infrastructure. LCA makes it possible to study the environmental sustainability of infrastructures. However, the practice of environmental sustainability does not impose a life cycle GHG emissions benchmark for a specific power. Our study proposes its definition and its valuation within the framework of a local carbon market in Cameroon. The model applied to the HydroMekin plant, with an installed capacity of 15,000 kW, lead to a reduction of 68.2% compared to the reference of 14.057 gCO_{2eq}/kWh_e. The valuation is made, within the framework of the creation of a voluntary carbon market, by integrating the determination of the quota of allowance of the GHG emissions for a given power. The mechanism of the new market is as follows: firstly, the definition of the BaU baseline, using the results of various LCA studies of the hydroelectric sector (step 1). Secondly, the GHG emissions quota allowed to the project, according to its power, is compared to the emissions quota defined by the BaU baseline (step 5). After validation of the quota, the project is executed. Thirdly, at the end of the construction phase, an emissions assessment is carried out to check whether the allowed quota has not been exceeded. In the event of excess, regulatory measured could be applied by the competent authority.

The existence of "hot air" due to the use of the IOA approach is recognized (Noburu, Inaba, & Tonooka, 2001), the evaluation of the level of impact remains to be determined. Setting up this market requires:

- Taking into account the temporality of the market mechanism, it makes it possible to specify the type of needs that it covers over the basic life cycle of an infrastructure;
- Legislative reform, the quantification of emissions is essential for the fight against climate change, the authority of Cameroon should consider its integration into the procedures for studying environmental impacts.

Data Availability Statement

The data relating to the plant construction project are available from the HydroMekin Company. Energy used and Ghg emissions calculation by sectors are based on eiolca software develop by Carnegie Mellon University. (http://www.eiolca.net (Accessed November 13, 2021)). The results are available on https://doi.org/10.5281/zenodo.7852195.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A

The total costs in RMB (Yuan) are converted into the equivalent total cost in US dollar for the year of the model (1997) using PPP. The PPP conversion factor for the year 1997 is given in **Table A1** below. Afterwards, convert that equivalent total cost in US dollar for the year of model by using the inflation index.

Table A1. Economic data for 1997 and 2015 (OECD, 2021).

Designation	Value
PPP of China (1997)	3.871
Inflation Index for year 1997 USA	160.5
Inflation Index for year 2015 USA	237.02