Assessing the impact of large-scale community investments in Developing Countries: application of a Multi-regional Input-Output model to a case study in Congo

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Abstract

The interest of the international community for sustainable development and the multiple interconnections among energy, environment and society has widely increased. As highlighted by interlinkages of the 17 SDG’s of the 2030 Agenda, energy has started to be considered as a key means for assuring sustainable and equitable access to basic needs and for supporting local enterprises and creating new jobs opportunities. Within this framework, the private sector may initiate effective actions of technological cooperation with an impact on the different dimensions of development: environmental, social and economic. This calls for a proper evaluation approach able to capture the complexity of current challenges.

In this paper, the application of a Multi-Regional Input-Output (MRIO) model coupled with an econometric production function is proposed to assess the prospected economic and environmental impact caused by community investments in the energy field. This approach provides a multi-dimensional complexity of results: economic and environmental impact can be distinguished by country, sector and type. More specifically, Open and Closed Multi-Regional Input-Output models have been jointly adopted to distinguish between direct, indirect and induced impact.

The model is applied to a case study in Congo, consisting in the deployment and operation of a large-scale power plant, which contributes to the generation of about 70% of the electricity production in the country. Macroeconomic and environmental data are retrieved from the EORA Multi Regional Input-Output database, while data required to calibrate the econometric production function are retrieved from World Bank database. Results shows that almost 50% of the economic impact is generated in Congo of which 28% is directly and 72% is indirectly caused by the Energy Project. The induced impact in Congo is negligible while counts for the 85% of the impact generated abroad. Same kind of results but different in magnitude are obtained for environmental indicators.

Keywords: Impact Assessment, Input-Output analysis, Energy Access, Energy-Development nexus.
1. Introduction

Over the last decades, the interest of the international community for sustainable development and the multiple interconnections among energy, environment and society has widely increased. Several initiatives have been launched with the common feature of overcoming the fragmentation of different competences and disciplines, aiming at the integration of economic, environmental, and social aspects across sectors, territories, and generations. This comprehensive paradigm of sustainable development, embracing complex systems such as global economy, social interactions, environmental preservation, governance regulation, has been clearly highlighted in the 2030 Agenda recently launched, where interlinkages are embedded within the new framework of the 17 Sustainable Development Goals [1]. Energy has started to be considered as a key means for unleashing development, to assure sustainable and equitable access to basic needs, for supporting local enterprises and creating new jobs, improving health and education [2].

From 2000 to 2016, the proportion of the global population with access to electricity increased from 78% to 87% Despite these promising developments, the outlook for electrification shows that the world is not yet on track to achieve universal access by 2030. Some countries have met the target since 2010; other 98 countries will need to intensify their efforts to do so. Among all Sub-Saharan countries of Africa are the ones very far from achieving the goal of universal access. In this region the power generation capacity is expected to more than double by 2030 with an increase of yearly energy investments by 46% [3].

Within this paradigm, multi-stakeholder partnerships become essential and act under a new asset, where differences between donors and recipients are overcome. While civil society has a direct knowledge of the local community and the public sector oversees the management of the local resources and services, the private sector may initiate effective actions of technological cooperation with an impact on the different dimensions of development: environmental, social, financial.

Given this energy scenario, the adoption of an ex-ante evaluation metric able to address the complexity of current challenges and the interconnection among the environmental, social and economic dimensions, has become necessary.

1.1. Brief Literature review

The relevance of the energy access issue is remarked by the increasing number of studies that in the last decades faced the problem of how to spread the availability of electricity to those remote area that still lack of it. The issue is particularly exacerbated in those rural areas that are generally scattered populated, isolated and characterized by low levels of livelihoods standards. In dealing with this phenomenon several aspects have to be properly taken under consideration. There isn’t a unique recipe for all the electrification projects. Accurate analysis has to be performed case by case to find the most suitable solution for spreading electricity connections. This is a theme widely debated in the scientific literature. Mandelli et al. in a comprehensive literature review [4] proposed a detailed classifications of electrification options alternative to grid extension that rank from stand-alone systems to Micro-Grids. In most of the cases strategy selection for electrification projects are driven by techno-economic criteria. Roo et al. proposed spatially detailed model able to select the best electrification strategy for each area of Sub-Saharan Africa [5]. This model selects
either to go for conventional grid extension or decentralized solution using LCOE as optimization parameter. Economic variables are driving parameters of many other studies devoted to analyze electrification pathways for developing countries [6–8]. This kind of studies, as explicitly stated by Moncada et al. [9], have the limitation to not directly considered other fundamental aspects to achieve sustainable development such as land use, environmental impact and public support among others. Few studies include also GHG emission in their analysis for the selection of the most suitable strategy for electrification projects. Anyway, whenever environmental impact is taken into consideration are accounted only the direct emissions related to each electrification options without considering any indirect impact. This is the case of the analysis conducted by Deshmukh et al. [10] in which they evaluate possible renewables alternatives to a big hydropower plant that may serve the southern region of Africa.

Enlarging the analysis to studies not strictly related to system optimization purpose can be seen that Life Cycle Analysis (LCA) is suitable for the evaluation of different electrification strategies since it allows to compute the potential environmental impacts generated by natural resource exploitation and the release of pollutants emissions at each stage of the life cycle of a given product or service [11]. Only in more recent studies the LCA methodology has been applied to evaluate the life cycle environmental performance of microgrid systems. The novelty of these applications is to have the focus on the system as a whole while most of the pertinent previous LCA researches was focused only on single components [12]. The study performed by Smith et al. [13] underly the need to holistically assess the environmental impact of a hybrid microgrid to better understand its environmental sustainability even if compared with the grid extension option. Das et al. [14] performing an LCA study for a PV battery system in India highlight the appropriateness of this approach for quantifying indicators, such as the Energy Pay Back Time and the Net Energy Ratio, that characterize the performances of the technical solutions under study. Pascale et al. [15] in addressing the comparison of a community size hydropower system with other power generation options find in the LCA a suitable methodology to address the global concern about environmental implication that may not be considered if shaping the appropriateness of a technical solution for electrification only by considerations driven by local concern. Limitations of such analyses without considerations about socio-economics aspects, is that are unable to comment the overall sustainability of the systems [12,13].

The importance of considering such socio-economic aspects is remarked by Riva et al. [16]. Reviewing several studies about the energy-development nexus they come to the conclusion that the success of different electrification process is subject to the complex interactions of different dynamics such as improved productivity, growth, poverty alleviation, household income, employment, new enterprise development and enhanced enterprises’ productivity. Bhattacharyya [17] in proposing a framework for analyzing the sustainability of energy access programmes accordingly to five dimensions (namely technical, economic, social/ethic and environmental dimensions) comes to the conclusion that so far the link between energy access, economic development and consequent environmental impact has not received adequate attention at the project and programme level. Also other studies evaluating electrification projects focus their analysis on multiple indicators that covers different dimensions of sustainable development [18–20]. Anyway, their results are obtained by conducing ex-post qualitative document analysis complemented by semi-structured interviews. Ex-post impact assessment analysis can bring only qualitative information about best practice that have to be followed in the planning phase of new energy access project while only ex-ante analysis can
provide decision makers with quantitative information about economic and environmental performances of projects at the planning stage.

Regarding ex-ante impact assessment studies are available few recent examples of consequential analysis performed through the application of Input-Output models. The strength of this approach is to combine the environmental analysis with economic performance indicators [21]. These studies although belonging to the energy field do not strictly relate to access to energy projects. One of the most interesting contributions is the distinction they make between different type of impact. Fan et al. [22] in analyzing the economic structure of China where able to distinguish between the direct and indirect energy requirements and water use embedded in product and services available to final consumption. Almost the same characterization of the impact is given by Varela-Vazquez and Sanchez-Carreira [23] that use a Input-Output model to evaluate the potential benefits for the Spain economy of the off-shore wind technology. In those cases, two different impact are defined. Direct impact is the one triggered by the initial stimulus in the final demand. (i.e. the wind turbine installation); indirect impact is the one due to all the recursive inputs needed by sectors directly involved. (i.e. all the material inputs needed for wind turbine construction). Anyway, other studies present an additional category of the impacts. This is the case of Kecek et al. [21] that quantify the economic and environmental impact of Renewable Energy Technologies (RET in the following) deployment in the Croatian economy. The additional impact category is defined as Induced impact that include the economic benefits generated by the producers of goods and services intended for household consumption fostered by the increase of employment and income generated in the sectors directly and indirectly supplying the material for RET deployment.

In addition to that it is widely recognized that a relationship exists between final consumption of goods and services (increase in Final Demand) and electricity consumption. In particular, literature findings reveal a bidirectional causal relationship between electrical energy consumption and final consumption in the long-run, but only a unidirectional causal relationship from energy to economic output in the short run [24–27]. This complex issue of coupling economic models with environmental assessment is widely discussed by Beaussier et al. [28]. According to their analysis to date there are no relevant studies that couple econometric functions with impact assessment analysis anyway this can be an option to have a more comprehensive analysis that include also one of the effects that additional electricity availability has on the community.

1.2. Aim of the work

Based on the outcomes of the literature review, it can be inferred that none of the reviewed researches have been able to ex-ante assess jointly the economic and environmental consequences due to the implementation of electrification projects in developing countries through a standardized, fully integrated and holistic approach, able to include the indirect and induced effects of changes in the national and international economic system.

Based on the background information and the research needs emerged from the literature review, the objectives of this study are:
• First, to propose a model-based approach for the assessment of the economic and environmental impacts of future electrification project in a holistic perspective. The proposed approach is based on Input-Output Analysis (IOA in the following), that is widely recognized as the computational structure of consequential analysis [29,30].

• Secondly, the proposed IOA method is employed to assess the economic and environmental impact related to the implementation of a large-scale energy access project in Congo. The project consists in the deployment of a 300 MW natural gas fueled power plant. The economic impact is evaluated as the expected changes in national value-added, while the environmental impact as the change of energy related CO2 emissions.

• Finally, is presented a multidimensional way to aggregate results from IOA to obtain a comprehensive picture of the impact generated by the project.

The developed IOA model aims at filling the gaps emerged from the literature review, providing an ex-ante evaluation of the economic and environmental effects that the Energy Project will provide both to the economy of Congo and to the worldwide economy. Nevertheless, in the approach here used, the increase in national electricity production due to the project implementation causes an increase of final consumption of product from domestic production or import assessed by means of a linear econometric production function estimated ad hoc.

The rest of the paper is organized as follows: section 2 describes the proposed IOA model-based approach and proposes a possible way for results aggregation. Section 3 sets the case study application and describes how the IOA model is adapted to the real-world application. In section 3, results obtained for the case study are presented and discussed accordingly with the impact assessment framework previously detailed. Concluding remarks and future research directions are collected in section 4.

2. Materials and Models

This section introduces and explains the proposed IOA model-based approach, and the results aggregation procedure.

2.1. Input-Output analysis

To the purpose of this analysis a Top-down Input-Output based approach is chosen according to the following reasons:

• Relies on freely available and constantly updated data sources (i.e the Multi-regional Input-Output Tables).

• It enables to comprehensively include more dimension of the economic and environmental impact [31].

• Provides a detail richness about national and international economies [32].

The IOA model can be either used for Attributional and Consequential applications. Notably, Consequential applications is strongly debated in literature, and it includes a variety of modeling approaches [33]. For the
definition of Both Attributional and Consequential approaches Authors refer to the previous study in which the two approach are widely described [32]. To the purpose of this study a Consequential approach is followed.

First, the national economy in a time frame before the Energy Project implementation is selected and IOA model characterized in accordance macroeconomic and environmental accountings. With reference to Figure 1, the economy is represented as composed by several production activities (industry and services sectors) that produce goods and services (including electricity) for the households. Trades with other economies (Rest of the World, RoW) are also represented, as well as the linkages with the environment due to resources consumption and emissions. This economy constitutes the baseline for the subsequent impact assessment, and for this reason it will be named Baseline Economy (A) in the following.

The Energy Project is then characterized based on its technical and economic features, and it is numerically introduced into the Economy Baseline IOA model, hence defining the Shocked Economy (B) in which have to be considered three overlapping effects with reference to Figure 1:

I. Changes in production and consumption structures of the economy: each sector of the economy support the operation of the Energy Project through a flow of products, and consume energy produced by a national technology mix altered by the project (orange box “Energy Project”).

II. Change in industrial goods and services production yields, stimulated by the increase in energy availability. This quantity is estimated based on historical data regression between energy availability and national gross domestic product (orange box “Increased products demand”).

III. The project is supported by a flow of yearly investments compared to the baseline (orange box “Investments”).

Figure 1. Baseline Economy (A) and Shocked Economy (B), before and after the implementation of a relatively large Energy Project connected to the national power sector.

The Baseline and Shocked Economies need to be numerically characterized based on national economic and environmental accountings and on detailed Energy Project data (section 3). While the fundamental mathematics required to apply the IOA model are here briefly introduced and described. The application of
The different types of impacts that can be considered as the decomposition of the total impact as described by equation (4) and are graphically represented by Figure 2.

\[ \Delta R_{\text{total}} = \Delta R_{\text{direct}} + \Delta R_{\text{indirect}} + \Delta R_{\text{induced}} \]

\[ \text{(4)} \]
2.2.1. Direct impact

Direct impact is the portion of the overall impact which is directly caused by the operation of the Energy Project. This includes economic and environmental flows that cross the boundaries of the project, and therefore this impact can only occur in the sector and in the economy where the Energy Project is owned and operated. Consequently $\Delta R_{\text{direct}}(s \times n)$ contains non-zero values only in the row corresponding to the electricity sector and is computed as the total production of CO2 emissions and total value-added generation related to the functioning of the power plant (see orange features of Figure 2).

2.2.2. Indirect impact

The indirect impact $\Delta R_{\text{direct}}(s \times n)$ origins since the Baseline Economy (A) undergoes a Shock caused by the implementation of the project. The application of equations (5) and (6) to the IOA model with project implemented (B) allows to account for the total production $\Delta x_{\text{indirect}}(n \times 1)$ and consumption/production of exogenous factor $\Delta R_{\text{indirect}}(s \times n)$.

$$\Delta x_{\text{indirect}} = L \cdot (\Delta f_{\text{inv,o&m}} + \Delta f_{\text{add}})$$ \hspace{1cm} (5)

$$\Delta R_{\text{indirect}} = B \cdot \Delta x_{\text{indirect}}$$ \hspace{1cm} (6)

The characterization of the Shocked Economy (B) is given by the expected increase in households’ final demand $\Delta f_{\text{add}}(n \times 1)$ stimulated in the short-run by the increase in electric energy production of the new power plant that has to be added to the final demand consumption related to investment and O&M $\Delta f_{\text{inv,o&m}}(n \times 1)$ needed to implement the project itself. The increase in households’ final demand is estimated based on a linear econometric production function like the one in equation

Errore. L’origine riferimento non è stata trovata., where coefficients $c$ and $d$ are retrieved by deriving the best-fit relation between the national final consumption expenditures and the total electricity production ($EE_{\text{prod}}$).

$$\Delta f_{\text{add}} (EE_{\text{prod}}) = c \cdot (EE_{\text{prod}}) + d$$ \hspace{1cm} (7)

This change in industrial productivity causes economic and environmental burdens that may occur in every sector and country worldwide (see blue features of Figure 2).

2.2.3. Induced impact

The change in production yields caused by the operation of the Energy Project causes an increase in households’ income. This increased households’ economic availability ultimately results in a subsequent re-expenditure which causes further economic and environmental impact (see green features of Figure 1).
Such induced impact \( \Delta R_{\text{induced}}(s \times n) \) can be computed as the complementary part of direct and indirect impact to the total. The total impact \( \Delta R_{\text{total}}(s \times n) \) is defined considering also the re-spending power of households.

To compute the additional production related to households’ re-expenditures a semi-closed IOA model is applied. The semi-closure of the model implies the introduction in the production system of a new sector that correspond to household. To this purpose the original transaction matrix \( Z_{\text{open}}(n \times n) \) is edged with an additional column corresponding to total households’ final demand and an additional row corresponding to compensation of employees. So, households are considered as a productive sector that need income as input to sustain their consumption (considered as output). The new transaction matrix is defined in equation (7) as \( Z_{\text{closed}}((n + 1) \times (n + 1)) \).

\[
Z_{\text{closed}} = \begin{pmatrix}
Z_{\text{open}} & f_{\text{HH}} \\
V_{\text{aHH}} & 0
\end{pmatrix}
\]  

(8)

In particular, \( f_{\text{HH}}(n \times 1) \) is the sum of final consumption by household of all the countries while \( V_{\text{aHH}}(1 \times n) \) corresponds to the component of value-added that refers to compensation of employees. \( f_{\text{closed}}(n \times 1) \) corresponds to remaining component of final consumption (government and no profit expenditures, investments, acquisition/disposal and change in inventories). The new transaction matrix is then used to compute the matrixes of closed model \( A_{\text{closed}}((n + 1) \times (n + 1)) \), \( L_{\text{closed}}((n + 1) \times (n + 1)) \) and \( B_{\text{closed}}(s \times (n + 1)) \) following the same matrix algebra afore mentioned (equations (1), (2) and (3)). Once defined the closed system IOA model is applied, imposing the same increase of final demand to obtain the total impact in terms of production \( \Delta x_{\text{total}}((n + 1) \times 1) \) and exogenous factors \( \Delta R_{\text{total}}((n + 1) \times 1) \) as detailed in equations (9) and(10).

\[
\Delta x_{\text{total}} = L_{\text{closed}} \cdot (\Delta f_{\text{inv,okm}} + \Delta f_{\text{add}})
\]

(9)

\[
\Delta R_{\text{total}} = B_{\text{closed}} \cdot \Delta x_{\text{total}}
\]

(10)

Now having the total amount of the impact, it is possible to rise by difference to the induced part as follow:

\[
\Delta R_{\text{induced}} = \Delta R_{\text{total}} - \Delta R_{\text{direct}} - \Delta R_{\text{indirect}}
\]

(11)

2.2.4. Impact disaggregation

Impact indicators based on three dimensions can be further disaggregate as described in the following.

Disaggregation by sector. Impact may occur in every sector of the economy, depending on the techno-economic features of the project. The national accountings upon which the IOA model is grounded classify the economic sectors according to an international agreed standard (ISIC rev.2). Results can be aggregated or disaggregated by sector groups in order to ease the results inspection.

Disaggregation by country. Due to the international trades of goods and services, the overall impact may occur both in the country in which the project takes place and in foreign countries. Results can be aggregated or disaggregated by country groups in order to ease the results inspection.
A close inspection of the sector, country and type disaggregation may provide useful strategic insights, revealing the nature and the location of the impact hotspots on which focus efforts and improvement interventions.

The innovative features of this approach, with respect to previous studies are summarized and justified in the following

- Direct impact refers only to the operations of the project under study. So it can be unambiguously related to the efficiency of the project and its efficacy in generating value-added.
- CAPEX are annualized through the expected lifetime of the plant and accounted together with OPEX as a change in final demand. So, the results obtained from the analysis are harmonized with the standard national accountability.
- The coupling of the Input-Output model with an linear econometric production function is a first attempt of dealing with dynamical changes that access to energy projects brings into the economy in which are implemented.

3. Case study: definition and analysis of large-scale energy access project in Congo

In this section, the analyzed Energy Project and the related assumptions are introduced and justified. Then, the project is introduced as a Shock in the Input-Output model based on the approaches described in subsection 2.1, and the economic and environmental impacts are consequently assessed.

3.1. Case study definition and input data

Following the theoretical description of the IOA model presented in section 2, the purpose of this section is to assess the expected impact due to the construction and operation of the Independent Power Producer (IPP) in Congo Brazzaville.

The IPP Central Electrique du Congo (CEC) is situated near Matève, about 15 km from Point Noir. The CEC is equipped with 2 turbines by ANSALDO (AE 94.2 type), of 150 MW ISO of power each, for a total installed capacity of 300 MW. Natural gas supply is in charge of Eni Congo, and it comes from Litchendjili off-shore camp. The power plant from its starting in 2010 took several years to reach its nominal operativity conditions. Yearly values of energy efficiency show that the plant reached a stable operating condition after 2013 with a yearly average energy efficiency of 33%, which remains almost constant during the following years.

As far as the first coupling to the national grid is occurred in 2010, year 2009 is taken as reference for the definition of the Baseline Economy (A). Year 2015 is chosen as reference condition for the fully operative power plant that characterize the Shocked Economy (B): this assumption is motivated by the availability of background macroeconomic and energy statistics data.
Model inputs can be distinguished in between technical and economic data. Table 1 presents Plant specifications data for the reference year: while CAPEX and OPEX are summarize in Table 2, where the breakdown basket of expenditures is reported.

### Table 1: Summary of plant specification data

<table>
<thead>
<tr>
<th></th>
<th>value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal capacity</td>
<td>300</td>
<td>MW</td>
</tr>
<tr>
<td>Electricity production</td>
<td>1435</td>
<td>GWh/y</td>
</tr>
<tr>
<td>Average efficiency</td>
<td>0.33</td>
<td>-</td>
</tr>
<tr>
<td>Fuel type</td>
<td>NG</td>
<td></td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>421</td>
<td>MSm3/y</td>
</tr>
<tr>
<td>CO2 emissions</td>
<td>937</td>
<td>kton/y</td>
</tr>
<tr>
<td>NOx emissions</td>
<td>2.06</td>
<td>kton/y</td>
</tr>
</tbody>
</table>

### Table 2. CAPEX & OPEX by country and sector.

<table>
<thead>
<tr>
<th>sector</th>
<th>country</th>
<th>Basket share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAPEX = 606 [MUSD]</td>
<td></td>
</tr>
<tr>
<td>Mining and Quarrying</td>
<td>France</td>
<td>0.1%</td>
</tr>
<tr>
<td>Electrical and Machineries</td>
<td>Switzerland</td>
<td>70.8%</td>
</tr>
<tr>
<td></td>
<td>Canada</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>3.6%</td>
</tr>
<tr>
<td>Construction</td>
<td>Italy</td>
<td>1.6%</td>
</tr>
<tr>
<td></td>
<td>Congo</td>
<td>5.1%</td>
</tr>
<tr>
<td>Financial Intermediation and Business Activities</td>
<td>Italy</td>
<td>6.4%</td>
</tr>
<tr>
<td></td>
<td>Congo</td>
<td>11.4%</td>
</tr>
<tr>
<td>Others</td>
<td>Switzerland</td>
<td>0.0%</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>0.1%</td>
</tr>
<tr>
<td></td>
<td>Congo</td>
<td>0.8%</td>
</tr>
<tr>
<td></td>
<td>OPEX = 12 [MUSD]</td>
<td></td>
</tr>
<tr>
<td>Petroleum, Chemical and Non-Metallic Mineral Products</td>
<td>Congo</td>
<td>0.1%</td>
</tr>
<tr>
<td>Electrical and Machineries</td>
<td>Congo</td>
<td>7.3%</td>
</tr>
<tr>
<td>Maintenance and Repair</td>
<td>Congo</td>
<td>50.7%</td>
</tr>
<tr>
<td>Transport</td>
<td>Congo</td>
<td>0.7%</td>
</tr>
<tr>
<td>Post and telecommunication</td>
<td>Congo</td>
<td>0.3%</td>
</tr>
<tr>
<td>Financial Intermediation and Business Activities</td>
<td>Congo</td>
<td>20.9%</td>
</tr>
<tr>
<td>Education, Health and Other services</td>
<td>Congo</td>
<td>6.3%</td>
</tr>
<tr>
<td>Others</td>
<td>Congo</td>
<td>13.8%</td>
</tr>
</tbody>
</table>

Beside the project specific data three are the main sources of data needed for setting up the model:
• **EORA Input-Output Database** ([http://worldmrio.com/](http://worldmrio.com/)). It provides essential macroeconomic and environmental background data. It provides Multi-Regional Input-Output tables (MRIO) for the world economy, collected for years 1990-2015, covering 189 countries with 26 industries and 7 final demand types for each country. Moreover, it includes several extensions: 6 value-added categories and several types of environmental impacts (including non-renewable energy usage, GHG emissions, pollutants emissions, raw material production, water and land use). In this case study, the 2009 EORA MRIO has been assumed as the Baseline Economy (A).

• **IEA statistics database** ([https://www.iea.org/](https://www.iea.org/)). It provides essential national electric energy statistics of Congo in 2009 that are required to calibrate the IOA model.

• **World bank database** ([http://data.worldbank.org/](http://data.worldbank.org/)). It provides historical economic data required to calibrate the econometric production function that is adopted to assess the increase in national productivity stimulated by the electricity produced by the CEC in Congo. In this case study, this function has been derived as the best-fit linear relation between the national Final Consumption Expenditures and the total electricity production in years 1995-2005. The choice of the dataset for the econometric regression was subject to the need of reproducing data availability in an ex-ante evaluation.

### 3.2. Main assumptions

Beside the theoretical assumptions of the IOA model widely discussed in the reference bibliography related to Input-Outputs analysis [30], other practical assumptions have been adopted based on the data availability and the characteristics of the analysed economic context:

• Yearly goods and services requirements by the project are produced within the economy where each supplier company has its own headquarter (The upstream production processes are automatically tracked and accounted by the IOA model);

• The natural gas supplied to the CEC is assumed to be recovered from natural gas that was previously flared;

• Use of recovered flared gas do not contribute to additional CO2 emissions, according to the official CO2 emissions accountability rules (IEA statistics, [34]);

• It is assumed that the production technologies of all the sectors of world economies are kept constant and equal to the Baseline Economy (A);

• The increase in final demand of goods and services is distributed among sectors and countries accordingly with the distribution of 2009, assuming that households in Congo increase their endogenous consumptions and their imports with the same basket of products.

### 3.3. Results of the IOA

In this section is presented what results from the comparative application of the IOA model on the Shocked and on the Baseline Economies. In this way is possible to quantify how and how much the Energy Project...
contributes (or is expected to contribute) to the global economic and environmental impact, considering the effects and the backward and forward linkages that the project has with the national and global economy. For this case study it is chosen the total CO2 emissions and the value-added generation as representative indicators of the two dimensions of the impact (environmental and economic).

3.3.1. Impact by type and sector

Considering the overall impact, the CEC produces an increase of value-added of 5.6 Billion US Dollars (BUSD), (corresponding to the 51% of the Congo GDP in 2009), accompanied by 1.8 Mton of CO2 emissions (equal to 114% of Congo’s emissions in 2009).

With reference to Figure 3, the overall value-added and CO2 emissions are distinguished by type (direct, indirect, induced) and by sector (Primary, Energy related, Manufacturing, Services, Transport). The following considerations can be made:

- Direct CO2 emissions of the power system are equal to zero: this occurs because the plant is consuming natural gas previously flared, hence it does not contribute to additional CO2 emissions;
- Indirect and Induced CO2 emissions are non-negligible, and they are mainly caused by Energy Related (about 50%) and Transport (about 30%) activities. Other sectors (i.e. Manufacturing, Primary and Services) cause only a minor part of the overall CO2 emissions;
- A different picture emerges looking at value-added generation: indeed, the power system contributes by 15% to the overall economic impact, while the rest is equally shared among the indirect and induced components;
- Differently with respect to CO2 emissions, most of the value-added generation is due to the Service sector (about 60%), followed by energy related activities (about 20%, mainly due to the power system itself);

![Figure 3. Global results aggregated by type and sectors.](image-url)
3.3.2. Impact by region

Another possible way to visualize the obtained results is by distinguishing the regions where the impact is generated. Value-added generation and CO2 emissions distinguished by impact type, by sector and by region are reported in Figure 4. The analysis of numerical values enables some considerations.

Considering a reference year of operation of the Energy Project at its average capacity it is estimated that 241 kton/y of CO2 emissions are generated in Congo (about 13% of the total). Almost the totality of this amount of emissions are indirectly caused by CEC. On the other hand 1553 kton of CO2 emissions are generated abroad of which 19% are indirectly caused by the CEC, mainly in those regions that provide the machineries for the CEC or have strong commercial relationship with Congo. The remaining part of these emissions (about 81%) is induced and it is located especially in those regions like Asia and North America where purchasing capacity and carbon footprint of industries are relevant.

A different situation is depicted by the map that presents results for value-added generation. An economic value of 2.73 BUSD/y is generated in Congo (about 50% of the total) of which the 28% is directly and the 72% is indirectly caused by CEC. Induced impact is negligible in Congo due to households low spending capacity. The remaining part of yearly value-added generation that count for 2.91 BUSD/y is generated abroad. The 14% of this economic value is indirectly caused by CEC, mainly in those regions that provide the machineries for the CEC or have strong commercial relationship with Congo. The induced part is mostly generated in those regions, like North America or Europe, where households have a strong purchasing power.

What can be inferred from the regional aggregation of results is that, apart from Congo, a very little impact, both economic and environmental, is generated in Sub Saharian Africa. This is because Congo and other countries of Africa region haven’t strong commercial relationships among each other while are subject to importation intermediate productive inputs from outside their continent. Two are the characteristics of countries that mostly benefits from the increased economic condition of Congo: they contribute to intermediate inputs for Congo national economy and show a great consumer re-spending power. This is the case of Europe, North America and Asia from where a great portion of the impact comes.
Figure 4. Value-added generation and CO2 emissions aggregated by region.
3.3.3. Focus at national level

A more specific focus on Congo allows to have a quantitative information about the magnitude of the impact generated by the Energy Project within the country in which it is implemented. The indicators analyzed, namely value-added generation and CO2 emissions, give the information about how much economic value is generated by the project and at which expense in terms of environmental burden. Notably results may be affected by the accountability assumption: IEA official statistics account only for the emissions that refers to fuel burning for the production of marketable product. So official accountability does not take into account all the emissions related to gas flaring. This may cause a bias if we want to measure the positive effect of using in the new plant natural gas that previously was flared. For this reason Table 3 and Errore. L'origine riferimento non è stata trovata. presents as results only the effective increase of natural gas consumption and CO2 emissions so excluding the direct emissions of the CEC. Implicitly, emissions that previously was related to gas flaring are not considered neither in the Baseline Economy nor in the Shocked Economy. To quantify with a single indicator the performance of Congo national economic system before and after the project implementation the CO2 intensity ($i_{CO2}$) is computed as detailed in equation (12). Results are summarized in Table 3.

$$i_{CO2} = \frac{CO2 \text{ emissions}}{GDP}$$  \hspace{1cm} (12)

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Unit</th>
<th>Baseline Economy (A)</th>
<th>Shocked Economy (B)</th>
<th>(\Delta)</th>
<th>(\Delta)%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value-Added (GDP)</td>
<td>M$</td>
<td>11040</td>
<td>13815</td>
<td>2775</td>
<td>25%</td>
</tr>
<tr>
<td>CO2 Emissions</td>
<td>kton</td>
<td>1570</td>
<td>1827</td>
<td>257</td>
<td>16%</td>
</tr>
<tr>
<td>$i_{CO2}$ – CO2 Intensity</td>
<td>g/$</td>
<td>142</td>
<td>132</td>
<td>-10</td>
<td>-7%</td>
</tr>
</tbody>
</table>

The advantages of using natural gas that previously was flared are straightforward: CO2 intensity is reduced with respect to the Baseline Economy. This means that the Energy Project using a by-product of oil industry generates economic development at less environmental cost with respect to what occurred before the implementation of the project.

4. Conclusions and future works

From the literature analysis emerges the importance of ex-ante impact evaluation, the case study application shows how the IOA approach can be adopted also for access to energy projects in developing countries. In these countries the need of a comprehensive economic and environmental evaluation has a greater importance since in the following decades more and more investment will be addressed to achieve the energy access for all. The approach presented in this study can be indiscriminately applied to case study already implemented, like the one presented, or to project still on planning phase. In the former case the results of the model can be used for attributing responsibilities of the occurred economic and environmental
impact, while in the latter case the results of the model can be used for comparing different electrification strategies to select the one with better economic and environmental performances.

The proposed impact assessment methodology allows for a three-dimensional characterization of the impact bringing some insight about which are the process that are mostly responsible for either the economic benefits and the environmental damages related to the Energy Project. In this case the picture that arises from results analysis is that countries of Sub-Saharan Africa are very little commercially interrelated among each other; this characteristic, coupled to the fact that household have low re-spending power, makes any kind of economical push strictly located to the country where the intervention occurs. The side effect of the intervention has its echo only in faraway countries. In facts households with the highest re-spending power live in those developed countries that have also strong commercial relation for final or intermediate goods supply to developing countries.

As far as concern the economy of Congo, it is valuable the result that shows how the intervention enables an economic development at less environmental cost with respect of what occurred before the project implementation. This confirm, form a multidimensional perspective, that ensuring access to modern energy facilities through to the exploitation of natural gas from flaring is a good performing option from an economic and environmental point of view.

Efforts for future work will be developed to a deeper analysis of the energy-development nexus. Because of the purpose of this study it was necessary to consider the effect that electricity availability has on economic activities but the adopted econometric approach presents some limitations since it reduces a complex dynamic to the correlation of only two variables. To achieve further improvement Authors are working on the adoption and integration with Input-Output analysis of complex models based on System Dynamics.
Nomenclature, Subscripts

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Quantity</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Technical coefficients matrix</td>
<td>k$/k$</td>
</tr>
<tr>
<td>L</td>
<td>Leontief inverse matrix</td>
<td>k$/k$</td>
</tr>
<tr>
<td>B</td>
<td>Exogenous transaction coefficient matrix</td>
<td>kton/k$ and k$/k$</td>
</tr>
<tr>
<td>Z</td>
<td>Transaction matrix</td>
<td>k$</td>
</tr>
<tr>
<td>( \hat{x} )</td>
<td>Total production diagonal matrix</td>
<td>k$</td>
</tr>
<tr>
<td>x</td>
<td>Total production vector</td>
<td>k$</td>
</tr>
<tr>
<td>I</td>
<td>Identity matrix</td>
<td>dmnl</td>
</tr>
<tr>
<td>R</td>
<td>Exogenous transaction matrix</td>
<td>kton and k$</td>
</tr>
<tr>
<td>f</td>
<td>Final demand vector</td>
<td>k$</td>
</tr>
<tr>
<td>( EE_{prod} )</td>
<td>Total electricity production</td>
<td></td>
</tr>
<tr>
<td>HH</td>
<td>Households</td>
<td></td>
</tr>
</tbody>
</table>

Acronyms

LCOE | Levelized Cost Of Electricity
GHG | Green House Gases
LCA | Life Cycle Assessment
PV | PhotoVoltaic
RET | Renewable Energy Technologies
IOA | Input-Output Analysis
RoW | Rest of the World
IPP | Independent Power Producer
CEC | Centrale Electrique du Congo
MRIO | Multi Regional Input-Output tables
GDP | Gross Domestic Product
IEA | International Energy Agency
ISIC | International Standard Industrial Classification
References


