Development of an Energy Mix evaluation method of an infrastructure based on a multi-layered territorial approach.

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Abstract

Modern global climate awareness has led governing institutions worldwide to encourage the reduction of CO2 emissions and the development of sustainable production methods, including that of energy. Renewable energy sources are preferred to fossil fuels, and multiple studies have aimed to optimize energy mixes and include more renewable energy sources in them. This paper proposes and describes a methodology to evaluate the available energy mix potential of a territory, centred on an infrastructure. An application of this method to Oise (France) and the Paris Beauvais Airport is proposed.

**Keywords**: Energy Mix, Evaluation, Territorial Approach, Carbon Footprint

* 1. Introduction

The worldwide growing realization of climate change has induced new policies regarding CO2 emissions and environmental impacts, especially concerning energy consumption and generation. Alongside with the increase of energy prices, fossil fuels are being disregarded and renewable energy sources grew massively in current energy mixes (Østergaard and Sperling, 2014). Multiple studies have aimed to model and evaluate renewable energy sources, technologies, and facility locations, trying to develop optimized energy mixes that include more renewable energies (Ilbahar et al., 2019). These studies have been conducted at international, national, and regional scales, each dealing with different challenges and levels of complexity. As the IPCC estimates 75% of ecological and energetic transitions are territorial, it appears suitable to assess the environmental impact of energy mixes at that level, for example by using a carbon footprint evaluation. In this domain, the most common methods are the input-output method and the Life-Cycle Assessment (LCA).

The input–output method works by analyzing each economic activity related to the sector of a product, to be able to economically track it. The LCA analyzes and agglomerates the different carbon footprints of each element and process used to create a final product (Wiedmann and Minx, 2008). The input-output method is used to evaluate the carbon footprint of processes in the LCA. (Von Der Assen et al., 2014). Such methods are effective to calculate the carbon footprint of processes or products.

This study proposes a method to evaluate the carbon footprint of a territory’s energy mix potential centered on an infrastructure, to be used as a base for energy mix optimization.

This is conditioned by a multi-scale inventory of different energy sources in the considered territory, followed by the determination of evaluation criteria, complementary to an LCA evaluation. The sources are first evaluated individually, then results are aggregated in a global evaluation for the territory’s energy mix, centered on a specific infrastructure.

* 1. Method
		1. Method for the inventory of available energy sources

The first step to evaluate the energy mix potential for a territory is to build an inventory of its energy resources. This inventory is done with a multi-scale approach that enables to gather information on multiple energy sources and different energy categories.

* + - 1. Territorial scale

At a territorial scale, a first inventory is done on available gas and electricity resources. In addition to renewable energy sources, fossil fuels are also considered to cover all energy needs, since renewable sources can be insufficient to cover an energy mix. To be considered, the energy sources need to be available, which means they must be connected to the gas or electricity distribution network and produce energy. Electricity sources taken into account include thermal energy (fossil fuel combustion), nuclear energy, onshore and offshore wind turbines, solar photovoltaic panels, hydroelectric power, geothermal power (electricity generation), bioenergy and marine power plants. In the case of gas sources, natural gas extraction stations and biogas generation stations are considered. Other sectors that comply with the inventory requirements may also be included. Therefore, a state of play for electricity and gas resources can be created at a large scale, by using data from the government and/or from the network operators. The spatial perimeter proposed for the regional inventory is based on an administrative division, to facilitate compliance with governments and avoid multiplicity of environmental policies. However, some cases might find a distance-based perimeter definition better suited and could chose to proceed differently.

* + - 1. Infrastructure and city agglomeration scale

A second inventory can be done at smaller scale, namely the infrastructure on which the evaluation is centered, and the city agglomeration eventually surrounding it. The energy sources considered at this scale are heat networks that are already connected to the infrastructure. They can be based on multiple energy types: geothermal, solar, organic matter combustion or fossil fuels. The area of inventory is limited by the uncertainties in heat transfer efficiency (Kavvadias and Quoilin, 2018).

* + 1. Individual Environmental Evaluation of energy sources by criteria development

Once the energy sources available in the studied area have been listed, they can be evaluated according to specific criteria. Their definition is highly dependent of the availability of data. Depending on the facilities, the necessary information is not always available. This study relies on information from public databases, such as the ADEME “Base Carbone” based on an LCA analysis to calculate three criteria that are then combined in a global indicator.

* + - 1. Gross Carbon Footprint by energy sector

The first criterion accounts for the energy sector impact, as addressed by the Lifecycle Assessment. The LCA focuses on the carbon footprint of production processes, from material extraction to marketing, transport of products, production, and packaging. This method also considers the potential of the product to be reused, recycled and how final waste may or may not be recycled. (Von Der Assen et al., 2014). Although this method is widely used to determine à product’s carbon footprint, it does have limitations. In fact, it is easy to double-count hydroelectric dams and electricity supply, as they are not considered as dual function resources in this method (Evans et al., 2009). Some studies recommend adding other criteria to this calculation, such as environmental and social criteria, which are not always linked with carbon footprints (Turconi et al., 2013). In this study, the carbon footprint imputed to the energy sector *CFES* is expressed in gCO2eq/y and calculated as shown in Eq. (1).

|  |  |
| --- | --- |
| $$CF\_{ES}= E\_{ES}\*P\_{y}$$ | (1) |

Where $E\_{ES}$ are the source emissions by kWh produced as indicated in ADEME Base Carbone, in gCO2eq/kWh, and $P\_{y}$ represents the yearly production of the installation (kWh/y), dependent on each source and collected in the inventory.

* + - 1. Urbanization and land use

As forests and green spaces absorb a part of carbon emissions, it is important to evaluate the impact of urbanization and global land use to correctly calculate a territory’s carbon footprint (Harris and Gibbs, 2021). This is calculated from the ground area of the facility and an emission factor, dependent on the biome in which it is implanted (Lal et al., 2018). This emission factor is the opposite of the sequestration factor which comes from the database of the European Environment Agency (EEA). The carbon footprint due to urbanization is calculated as indicated in Eq. (2)

|  |  |
| --- | --- |
| $$CF\_{U}=EF\_{LU}\*A$$ | (2) |

With EFLU the emission factor corresponding to the land use change (gCO2eq/ha/y) and A the ground area of the installation (ha), which depends on the source and is collected in the inventory.

As the installation of solar panels on already urbanized areas (roofs, car parks) does not induce any additional urbanization on the ground, the ground area for these installations is counted as zero.

* + - 1. Distance

The distance between production facilities and consumption areas is considered in evaluation methods for facility-location purposes, in the evaluation of energy projects. Here, it is used to evaluate an energy mix, expressed through the energy losses in transportation and the emissivity of a compensation energy. In France, this compensation is considered equal to 598 gCO2eq per kWh, which is the LCA carbon footprint of imported gas for electricity generation. The distance-related carbon footprint is expressed in Eq. (3)

|  |  |
| --- | --- |
| $$CF\_{D}=P\_{L}\*E\_{CE}\*D$$ | (3) |

Where PL represents the accounted losses during transportation, in kWh/km/y which depends on the study zone, ECE is the emissivity of the compensation energy in gCO2eq/kWh, and D the distance between the energy source and the infrastructure studied in km, collected during the inventory.

* + - 1. Construction of global indicator

As all three criteria are expressed in gCO2eq/kWh, they can be combined to obtain a final value as shown in Eq. (4). It represents the resulting evaluation of every precedent criterion and allows a comparison between different infrastructures.

|  |  |
| --- | --- |
| $$CF\_{S}=CF\_{ES}+ CF\_{U}+ CF\_{D}$$ | (4) |

This value is expressed in gCO2eq/y, to assess the yearly carbon emissions of installation.

* + 1. Energy mix impact evaluation

Once the yearly carbon emissions of each source of energy of the infrastructure studied, they can all be agglomerated to calculate a global carbon footprint, as shown in Eq (5). This global carbon footprint is in fact an evaluation of the energy mix of the infrastructure. This evaluation is an innovation because it becomes a tool for monitoring and comparison over time and with other projects of infrastructures. It also is a decision-support tool as it can help deciding about the source of energy used in an infrastructure and evaluating the interest of a project. As the three main criteria, related to the energy sector, the urbanization, and the distance, are all expressed in the same unit, they can also be compared with values from other infrastructures.

|  |  |
| --- | --- |
| $$CF\_{EM}=\sum\_{}^{}CF\_{S}$$ | (5) |

It is also possible, and even interesting, to compare the carbon emission of each source, within the same infrastructure, with its total energy mix. This allows to study and assess the sustainability of an infrastructure’s energy mix.

* 1. Application of the method to Paris Beauvais Airport and Oise, France

The spatial perimeter on which this method was applied is the French administrative division of Oise, the Hauts-de-France region, with an annual energy consumption of approximately 12 TWh (ODRE, 2023). The evaluation for its energy mix is centered on the Paris Beauvais Airport, for besides plane-related emissions and consumption, these infrastructures have important energy consumption.

* + 1. Energy sources inventory

The inventory of energy sources available in Oise is done with the French public databases from ORE and ODRE agencies, as well as the website data.gouv.fr (ORE, 2023). These databases regroup an important amount of energy-related data, and therefore provide information on gas and electricity-producing installations. From the larger scale of inventory, Oise contains over 4000 solar photovoltaic installations regrouped in aggregations for individual setups, 71 wind turbine fields, 9 bioenergy installations, 9 thermal power plants and 24 biomethane injection points. No nuclear, hydroelectric, marine or geothermal power plants are present. There is also no production of natural gas in Oise. The smaller scale inventory showed that the airport is not connected to a heating network.

* + 1. Criteria evaluation and indicator calculation

For the criteria evaluation, critical values provided for each source by the inventory are annual energy production in kWh, energy sector and position. The latter allowed surrounding biome registration and distance evaluation. For simplification purposes, surface was estimated globally for wind turbines (0.03 ha per wind turbine), bioenergy and biomethane injection points (0.05 ha) and thermal power plants (20 ha per installation). Power losses in transport were imputed for each energy (Gas or Electricity) from national loss ratio, total production and total network length. If it is assumed that these values are not the most precise on exact losses in Oise, they can however be representative of a “national responsibility”.

This allows for the Energy sector, Urbanization and Distance carbon footprints to be calculated and compiled into the global indicator. Table 1 gathers some examples for results, expressed in tCO2eq per year.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **ID** | **Name** | **Energy** | **Sector** | **CFES** | **CFU** | **CFD** | **CFS** |
| 5 | BOISSY BIO | Gas | Biomethane | 878.42 | 0.09 | 1.35 | **879.86** |
| 86 | Confid | Elec | Thermal | 5,080.01 | 36.60 | 165.82 | **5,282.42** |
| 179 | BOUTAVEN | Elec | Wind | 37.38 | 0.18 | 217.80 | **255.36** |
| 308 | Bionerval | Elec | Bioenergy | 167.76 | 0.09 | 391.12 | **558.97** |
| 285 | AGOST | Elec | Solar | 5.54 | 0.00 | 388.87 | **394.41** |

Table 1: Energy sources individual evaluation examples

The impact of distance for gas production facilities is noticeably smaller than for electricity production facilities. This is because losses on the French electricity network (>10,000 kWh/y) are significantly higher than on the gas network (ca. 35 kWh/y).

* + 1. Global territorial energy mix carbon evaluation

Once all energy sources have been individually evaluated, all criteria and the indicator were summed to obtain the carbon evaluation for the territorial energy mix, as well as a compilation each energy sector (Table 2).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Sector** | **Count** | **CFES** | **CFU** | **CFD** | **CFS** |
| Solar | 284 | 3050.11 | 32.94 | 69,912.86 | **72,995.91** |
| Wind | 71 | 13,767.24 | 12.99 | 13,028.07 | **26,808.30** |
| Bioenergy | 9 | 2,157.33 | 0.82 | 2,271.80 | **4,429.96** |
| Thermal | 9 | 48,822.34 | 329.40 | 1,982.83 | **51,134.58** |
| Biomethane | 24 | 12,728.82 | 2.20 | 21.85 | **12,752.87** |
|  |  |  |  |  |  |
| Total | 397 | 80,525.84 | 378.35 | 87,217.41 | **168,121.61** |

Table 2: Criteria compilation for all energy sectors

It can be noted that the global impact of urbanization is significantly lower than the other two criteria. This can be explained by the low surfaces accounted for in the calculation of the urbanization criteria, as well as for the values given in the EEA database.

The total carbon footprint for the territory is 168 ktCO2eq per year, for a total annual production of 2 TWh of energy. Compared to the 2021 energy consumption of 12TWh for Oise, this shows that the territory is not energetically independent. It also enlightens the value of nuclear power in the French energy mix, as the nuclear power plant of Gravelines, in Nord, France, produces over 28 TWh a year.

* 1. Conclusion and prospects

The carbon evaluation method described in this paper is based on a territorial and spatial approach, and the innovative perspective of its centering on a given infrastructure allows to evaluate the situation of an energy mix at territorial scales. The flexibility it offers enables numerous possible variations of parameters, depending on the availability of data, thus allowing for eventual studies more precise than that made in the application. This method also has versatility in the use that can be made of its results. It can be used to monitor temporal evolution of the energy mix, as well as to assess the potential of an energy facility development project. Results of this study highlight the importance of proximity in the energy mix carbon footprint and correlates the IPCC statement that territorial levers are essential to the ecological and energetic transition worldwide.

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