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Research paper

Greenhouse gas emission factor for the energy sector in Mauritius

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ABSTRACT

The energy sector, which consists of the power generation, manufacturing and transportation sector, is the biggest emitter of greenhouses gases (GHG) in Mauritius. The different fossil fuels used in this sector are namely sub-bituminous coal, Heavy Fuel Oil (HFO): HFO-180 cSt, HFO-380 cSt, HFO-1500 SSU (324 cSt), kerosene, diesel, gasoline and Liquefied Petroleum Gas (LPG). During the inventory of GHG, the default emission factors from the Intergovernmental Panel on Climate Change (IPCC) are used for the different fuels. In order to have more reliable and better computation of the amount of GHG released from this sector, the emission factor for each of the fuels were determined. The aim of this study was to develop country-specific carbon dioxide (CO_2) emission factors that can be used for future GHG inventory in Mauritius. The emission factors were estimated through fuel analysis whereby the fuels were characterised in terms of their elemental analysis, Net Calorific Value (NCV), ash content and moisture content. Coal fly ash and bottom ash were analysed for their carbon content. The oxidation factor for coal was 0.933 while for the liquid fuels and LPG, it was assumed to be 1. The emission factor for sub-bituminous coal was 90,445 kg/TJ while the emission factors for HFO − 180 cSt, HFO − 380 cSt and HFO − 1500 SSU (324 cSt) were 74,344 kg/TJ, 78,028 kg/TJ and 75,333 kg/TJ respectively. Kerosene had an emission factor of 74,355 kg/TJ while the emission factors for diesel and gasoline was 75,104 kg/TJ and 73,760 kg/TJ.

1. Introduction

The greenhouse effect is a natural process whereby greenhouse gases trap heat energy in the atmosphere, thus causing it to warm. This helps to support the existence of life on Earth [1,2]. However, from 1990 to 2012, the rise in anthropogenic activities has caused the global GHG emissions to increase by almost 47% [3], resulting in global warming [4]. The main GHG responsible for this phenomenon is CO_2 [5] and presently the concentration of CO_2 in the atmosphere stands at 406 ppm [6]. Climate change has several negative repercussions which are namely an increase in global surface temperature [7], shrinking of glaciers, sea level rise [6], extreme weather conditions [8] among others.

Small Island Developing States (SIDS) were responsible altogether for only 1% of the global CO_2 emissions in 2012, but due to their geographical, socio-economic and climate profiles, these islands are the most vulnerable to the effects of climate change [9]. Moreover, many SIDS depend hugely on imported fossil fuels to meet their energy demands [9,10]. Mauritius being a SIDS is also vulnerable to the effects of climate change. The World Risk Report issued for 2016 showed that Mauritius is ranked 13th and 7th in the categories of countries with the highest disaster risk and on the list of nations most exposed to natural hazards respectively [11]. However, Mauritius, which had a GDP growth of 3.5% in 2015 [12], depends heavily on fossil fuels, with a primary energy mix of 84% imported fossil fuels [13]. It is reported that 3,975,600 t of CO_2 were released in 2015 which accounted for 99% of the total GHG emitted in Mauritius during that year [14]. The main anthropogenic sources of CO_2 in Mauritius is the energy sector which consists of power generation, manufacturing industries and transport [14].

Mauritius, being signatory of the Kyoto Protocol since 2001, has an obligation to submit its GHG inventories and national reports to the United Nations Framework Convention on Climate Change (UNFCCC) at regular intervals [15]. The convention works in close collaboration with the IPCC which is the major international body involved in the evaluation of scientific, technical and socio-economic information on climate change and in addressing its causes, possible impacts and response strategies. The IPCC's role in GHG inventories is to prepare Methodology Reports which propose methodologies and guidelines to help countries that are parties to the convention to prepare their national GHG inventories [16]. GHG inventories are tracked by UNFCCC to help stabilise GHG concentrations in the atmosphere such that it does not interfere with the climate system [17]

Presently, Mauritius has already submitted three national

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communications (INC − Initial National Communication, SNC − Second National Communication and TNC − Third National Communication) which all employed the IPCC default CO_2 emission factor to calculate GHG emissions [18–20]. For reliable and accurate GHG emissions inventories, it is very important to have a good reporting mechanism. In line with this, Mauritius, in its TNC, proposed that country-specific emission factors will have to be developed. This will result in more reliable estimates of CO_2 emissions and more consistent GHG inventory reports which will make Mauritius be one of the few SIDS which has developed its own country-specific emission factor [20]. In this context, this study was initiated to determine the country-specific emission factors for fossil fuels in Mauritius.

2. Methodology

2.1. Overview of methodology

The methodology adopted for calculating the CO_2 emission factor in this study is fuel analysis which involved, firstly, the collection of data on the different types and quantities of fossil fuels used in Mauritius in the power generation, manufacturing and transport sectors. Then fuel samples were collected from different power plants. Two different types of HFO are burnt in the oil power plant namely 180 cST and 380 cST. The two types of fuels were collected from the three power plants. In the case of coal, the same coal which is imported from South Africa are used in all the coal fired power plants and therefore samples were collected from two power plants. The transportation fuels namely gasoline and diesel, on the other hand, were bought from a fuel station. All the fuel stations in Mauritius sell the same type of fuel which is imported from India.

Laboratory analyses were then conducted to characterise the fuel samples and the coal ash in order to determine the emission factor. The methodology for the fuel samples was also based entirely on Tier 2 as all the fuel characteristics needed to estimate the CO_2 emission factor were analysed and were thus country-specific. For coal, an additional parameter which is the amount of carbon left unburnt in coal fly ash and bottom ash was also determined. As for LPG, it was difficult to conduct laboratory analyses on it and hence CO_2 emission factor was calculated based entirely on LPG characteristics from literature.

2.2. Fuels data collection

Information on the types of fossil fuel used in each of the three energy sub-sectors were obtained from the Central Statistics Office (CSO) of Mauritius. It was found that the fuels used in the power sector include HFO − 380 cSt, HFO − 180 cSt, sub-bituminous coal, diesel and kerosene. Manufacturing industries use sub-bituminous coal, HFO − 1500 SSU (324 cSt), diesel and LPG while land transportation fuels include gasoline, diesel and LPG. The amount of each fuel burnt annually in each sector was obtained from the CSO. This information was needed to calculate the amount of CO_2 released from each sectors in Mauritius.

2.3. Laboratory analyses

Laboratory analyses namely elemental analysis, Gross Calorific Value (GCV), moisture content and ash content were conducted on the different fossil fuels. On the other hand, the fly ash and bottom ash were subjected to elemental analysis and Loss On Ignition (LOI) tests to determine the unburnt carbon content.

2.3.1. Moisture content

The moisture content of coal was determined as per ASTM D3173–11 "Standard Test Method for Moisture in the Analysis Sample of Coal and Coke" [21] by heating a pulverised coal sample of 0.25 mm at 105 °C in an oven for 3 h. The equation to calculate moisture content is as follows:

$$\boldsymbol{F} = \left[\frac{\boldsymbol{A} - \boldsymbol{B}}{\boldsymbol{A}}\right] \tag{1}$$

Where,
F: Weight fraction of water in sample
A: mass of sample used, g
B: mass of sample after heating, g

2.3.2. Ash content

Dried, pulverised coal was burnt in a furnace as per ASTM D3174–12 "Standard Test Method for Ash in the Analysis Sample of Coal and Coke from Coal" [22] to estimate its ash content. The equation for determining ash percent on a dry basis is as follows:

$$\boldsymbol{AP_{Drybasis}} = \left[\frac{\boldsymbol{B}}{\boldsymbol{A}}\right] \times 100 \tag{2}$$

Where,
AP: Ash percent, %
B: Mass of residue left, g
A: Mass of dried coal sample, g

The ash percent was determined on a dry basis, that is the sample was first dried and then it was burnt. However, in a power plant, the combustibles are burnt the way it is received including its moisture and this is called as-received basis. As-received basis is the condition of the sample as it is and without any pre-treatment, that is including total moisture, ash, volatile matter and fixed carbon [23,24]. Ash percent on a dry basis was then converted to ash percent on an as-received basis using Eq. (3).

$$\boldsymbol{AP_{AsReceived}} = \boldsymbol{AP_{Drybasis}} \times (1 - \boldsymbol{F}) \tag{3}$$

Where,
AP: Ash percent, %
F: Weight fraction of water in fuel

2.3.3. Elemental analysis

Elemental analysis for both coal and the liquid fuels were determined using the Eurovector elemental analyser. For coal, the procedure employed was as per ASTM D5373–16 "Standard Test Methods for Determination of Carbon, Hydrogen and Nitrogen in Analysis Samples of Coal and Carbon in Analysis Samples of Coal and Coke" [25] whereby the coal was first dried and pulverised. Hence its carbon and hydrogen contents were given on a dry basis. Elemental analyses for the liquid fuels were carried out according to ASTM D5291–16 "Standard Test Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants" [26]. For LPG, a mass balance was used to determine its carbon and hydrogen content. LPG consists of butane and propane [27]. 100% propane is used in cold countries while in hot countries it is only 20–30% [28] and in Mauritius which is a tropical country, LPG has a propane/butane mix was assumed to be 25:75 on a mass basis.

2.3.4. Calorific value

The GCV of the fuels were determined using the oxygen bomb calorimeter. The standards applied for this test were as per ASTM D5865–13 "Standard Test Method for Gross Calorific Value of Coal and Coke" [29] for coal and as per ASTM D240–09 "Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter" [30] for liquid fuels. Since IPCC and other research papers reported the values of emission factor on a NCV basis, the GCV obtained from the bomb calorimeter was converted to NCV. For coal, the hydrogen content and the GCV which were both obtained on a dry basis from laboratory analyses were first converted on an as-received basis.

2.3.5. Carbon content in fly ash and bottom ash

Carbon content in fly ash and bottom ash was determined through

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