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Research Paper

Energy demand and greenhouse gases emissions in the life cycle of tractors

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Energy supply and global warming are two of the main challenges of 21st century. To produce food to satisfy the increasing world population requires using more assets, more energy and emitting more greenhouse gases. Studies approaching embodied energy into and greenhouse gas emissions from agricultural machinery are rare. This study determined the energy demand and greenhouse gas emissions in the life cycle of tractors. Four tractors with distinct power levels were evaluated: 55 kW (T1); 90 kW (T2); 172 kW (T3) and 246 kW (T4). Life cycles considered were obtained from three different sources. Consumption of the direct inputs used in the assembly phase and of the input used in the maintenance phase were accounted. The results presented higher embodied energy and emissions in life cycle than are found in the literature. The following indicators were determined: T1, 122.7 MJ kg^{-1} and 5.7 kg [CO_2eq.] kg^{-1}; T2, 91.2 MJ kg^{-1} and 4.2 kg [CO_2eq.] kg^{-1}; T3, 85.2 MJ kg^{-1} and 3.8 kg [CO_2eq.] kg^{-1}; and T4, 71.9 MJ kg^{-1} and 3.3 kg [CO_2eq.] kg^{-1}. The hypothesis that more powerful tractors would require less energy and emit less greenhouse gas per functional unit (mass and power) was proved. Tractor (T4) has 313.2% more mass than (T1), but it required 70.6% less energy and 72.7% less GHG per unit mass, or 84.7% less energy and 87.7% less GHG per unit engine power than T1. For further use in modelling, equations were provided to determine energy demand and emission associated with either engine power or tractor mass.

1. Introduction

Energy is vital for the development of economies and societies, being mandatory to transform natural resources into goods and to provide services (Hinrichs & Kleinbach, 2009). Besides, its demand has increased globally (Abubakar & Umar, 2006).

Current energy production chains are insufficient to meet the population's needs (AGECC, 2010). For instance, the growing demand for food and energy production, threatens water availability making ecosystems vulnerable (Jâgerskog et al., 2014). Due to the growing environmental concerns about energy use and greenhouse gas emissions (GHG) in recent years, the global demand for renewable

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materials and alternative energy sources has grown (Lima, 2012, p. 23).

To evaluate a production process, the material flows converging into a product and wastes need to be determined (Dyer & Desjardins, 2006). Energy analysis considers the physical amounts involved in production processes, translating them into energy terms through their energy content (Fluck & Baird, 1980, p. 192). Material flows were used to determine embodied energy of sugarcane harvesters in an environmental evaluation. The carbon steel, forged, ductile iron, lubricants and rubber from repair and maintenance and carbon steel, iron, aluminium, hydraulic oil and rubber from body represented 95.4% of total energy demanded in the life cycle (Mantoam, Milan, Gimenez, & Romanelli, 2014).

Life cycle assessments determining embodied energy in agricultural machinery are rare (Mantoam et al., 2014). Moreover, there are no studies of the greenhouse gas emissions (GHG) associated with agricultural machinery. The existing embodied energy indices for tractors are obsolete and were based on the automotive industry from the late 1960s. Berry and Fels (1972) were pioneers to determine the embodied energy index (81.2 MJ kg^{-1}), when steel and iron components accounted for 94% of car mass. Deleage, Julien, Sauget-Naudin, and Souchon (1979) adapted the index (75.0 MJ kg^{-1}) for tractors, taking account of the different material quantities and proportions compared to the car industry. More recently Mantoam et al. (2014) considered material flows and energy demand to determine indices for sugarcane harvesters. Values found were 2.5–2.7 greater than those determined by Berry and Fels (1972). Sugarcane harvesters are machines with specific applications, and considering the conditions of field working in agriculture, the magnitude of maintenance and repair should not be applied to other machines.

Besides its effect on energy use, production systems contribute globally to GHG emissions, because they require energy and its availability, distribution and use contribute significantly to climate change, representing around 60% of total GHG emissions (AGECC, 2010). This affects global warming (US EPA, 2007), and may cause higher temperatures, water balance changes and rising sea level (Jâgerskog et al., 2014). Edenhofer et al. (2012) suggested reduction of GHG emissions by 50%–85% by 2050, to stabilise the atmospheric concentration of these gases in order to mitigate the effects of the climate change in progress. So, energy systems should provide better incentives to reduce GHG emissions, and increase the energy efficiency to end user (AGECC, 2010). Lee et al. (2000) mentioned that the energy and GHG emissions associated with building a tractor are directly proportional to the material mass.

This study aimed to determine the energy demand and GHG emissions in the life cycle of tractors, because of their importance in world agriculture. The hypothesis of this study is that more powerful tractors present less energy demand and GHG emissions per functional unit (power or mass).

2. Material and methods

To evaluate tractors, this study applied a methodology to determine energy and emissions flows based on material demand of the assembly and maintenance phases of the machine life cycle (Mantoam et al., 2014).

This study determined material flows for tractors, and consequently the embodied energy and GHG emissions, approaching their assembly and maintenance phases. Operational aspects such as fuel consumption and overall work rate were not considered, because they may vary due to management decisions, operator skills, etc. The embodied energy and GHG emissions takes account of the fossil energy and electrical power used in creating the materials that compose the tractors and in assembling them.

Four tractors were evaluated: Tractor 1 (T1) with 4-cylinder 55-kW engine, without cabin and with mass of 2650 kg; Tractor 2 (T2) with 4-cylinder 90-kW engine with cabin and 5100 kg; Tractor 3 (T3) with 4-cylinder 172-kW engine with cabin and 6950 kg; Tractor 4 (T4) with 6-cylinder 246-kW with cabin and 10,950 kg. The selected tractors were assembled by a manufacturer located in Curitiba, Parana state, Brazil.

The required data survey is presented in Figure 1 (numbers in brackets in the text are the numbered steps). To start the data survey (1), two distinct phases were considered: assembly (2) and maintenance (3). Assembly accounts for the directly used inputs (4) with reference to the parts supplied to the assembly plant (6). These parts were identified and quantified (8) and then grouped into material types (10), so that the importance of these materials could be verified in the machinery composition.

Maintenance phase (3) considered the inputs either directly or indirectly used (5), which are necessary according to the manufacturer's recommendations. This assumption was done to avoid discrepancies among farmers and other users, because they may adopt distinct maintenance strategies for their equipment. The frequency of part replacement, labour and material requirements were surveyed (7) and also identified and quantified (9). For instance, tyre replacement is not stated in the owner's manual, so this data was obtained from the post-sale team, dealers and producers and then grouped into material classes (11), for the same reason as stated for item 10.

Indirectly used inputs in the assembly phase, such as electricity, liquefied petroleum gas (LPG), labour and water, were not assessed in this study due to lower embodied energy (Mantoam et al., 2014).

Machinery parts that are made of more than one component, e.g., hydraulic rubber hose (which contains rubber, steel and polypropylene) were stratified in proportion to the composition of the part, using the engineering bill of material from the hose manufacturer.

Material flows were calculated (10, 11) and indices of energy embodiment for each input (12) were obtained from the literature (Appendix A). They were used to determine the input energy flows. After the determination of the embodied energy in direct inputs (13) and embodied energy in maintenance (14), their sum provides the embodied energy of the life cycle of a tractor (15) (Eq. (1)).

$$EE = \sum_{j=1}^{M} \sum_{i=1}^{N} (MF_{ij} * EI_i) \tag{1}$$

where: EE is total embodied energy in the inputs on tractor life cycle (MJ); MF is the material flow directly used in the parts assembled and maintenance into a tractor (kg, L, h); EI is the