Carbon footprint of automotive ignition coil

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Abstract. In recent years, environmental issues, such as climate change and global warming due to the excessive development of industry, have attracted increasing attention of citizens worldwide. It is known that CO₂ accounts for the largest proportion of greenhouse gases. Therefore, how to reduce CO₂ emissions during the life cycle of a product to lessen its impact on environment is an important topic in the industrial society. Furthermore, it is also of great significance to cut down the required energy so as to lower its production costs during the manufacturing process nowadays. This study presents the carbon footprint of an automotive ignition coil and its partial materials are defined to explore their carbon emissions and environmental impact. The model IPCC GWP 100a calculates potential global greenhouse effect by converting them into CO₂ equivalents. In this way, the overall carbon footprint of an ignition coil can be explored. By using IPCC GWP 100a, the results display that the shell has the most carbon emissions. The results can help the industry reduce the carbon emissions of an ignition coil product.

1. Introduction
Carbon footprint can be defined as the carbon dioxide emissions directly or indirectly caused by a product, person or other things. As the international community is increasingly valuing the environmental issues in the modern society, many organizations have been established to monitor the effect of carbon emissions on environment. Regulations on carbon emissions also become clearer and more definite.

As consumers are more concerned about greenhouse gas emissions, this means more cost loading for the industry in terms of a production cost. Therefore, the establishment of carbon footprint of a product can not only save costs, but also do the work for environmental protection.

Sinha and Kutnar [1] conducted life cycle assessment for different window frame materials to explore the environmental impact by using different materials, namely, aluminum, plastic (PVC), and wood for window frames. The result showed that wood window frames has the lowest impact on the environment, as the carbon footprint of aluminum and PVC frames is four times and twice more than...
that of wood frames, respectively. Therefore, wood material is a good selection for low carbon emissions material and thus the environmental selection.

Kim [2] directed a comparison of life cycle assessment of existing and alternative personal computer (PC). The result showed that the greenhouse gas emission of an alternative PC is 15 percent less than an existing computer. However, the existing PCs are still in the usage phase and will generate huge greenhouse gas emissions. How to reduce carbon emissions of the existing PCs is necessary.

Matthews [3] explained the importance of boundary conditions in the analysis of carbon footprint. The study divided carbon emissions into three categories, namely direct emissions, indirect emissions, and emissions in addition to the previous two kinds in the supply chain caused by other industries. Direct emissions of greenhouse gases arise from the industry itself which are the combustion of natural gas and oil during a manufacturing process. Indirect emissions of greenhouse gases are a discussion of carbon emissions generated from the energy purchase process.

Vink et al. [4] performed a life cycle assessment of materials for polylactic acid ester (polylactide, PLA). A PLA material produced by Doyle Company will consume 54 MJ/kg of fossil fuels. The production process was improved by Doyle Company to reduce to 7 MJ/kg of fossil fuels consumption after five to eight years. The greenhouse gas emissions were also reduced from +1.8 to -1.7 carbon dioxide equivalents.

2. Global warming potential

The United Nations Intergovernmental Panel on Climate Change (IPCC) was co-founded by the World Meteorological Organization and the United Nations Environment Program in 1988, specializing in climate change caused by human’s activities. IPCC published four official climate change assessment reports in 1990, 1995, 2001, and 2007, respectively. The SimaPro software referring to Global-warming potential (referred as GWP) IPCC presents the idea that greenhouse gas emissions can be converted into carbon equivalent in order to calculate the carbon footprint.

The GWP_{100a} value of CO_2 is calculated by referring to 100 years from the time of the calculation to reflect the cumulative effects of radiation of CO_2. For example, in 2007, the GWP of methane is 25, which means that one ton of methane after 100 years from the computing time giving the cumulative effects of radiation is equivalent to the cumulative equivalent of 25 tons of CO_2 in the current time [5].

The method of IPCC GWP_{100a} in this study only applied the procedure of characterization. Its characterized factor is the direct global warming potential of air emissions. The considerations are as follows:

- Do not include the indirect emissions of nitrogen caused by the formation of nitrous oxide.
- Do not calculate the radiation effects of nitrogen oxides, water and sulfuric acid emissions arising from the troposphere to the stratosphere.
- Do not consider indirect effects.
- Include the carbon dioxide caused by the CO emissions.
- Consider the offset of bio-absorption of carbon dioxide.

The formulation is as follows:

$$E_{CO2e} = \sum_i M_i \times GWP_i \times \sum_j A^j_i$$

Where, $E_{CO2e}$ is the overall emissions of carbon dioxide equivalent, $M_i$ is for each amount of greenhouse gases, $GWP_i$ is the global warming potential of all greenhouse gases, $EF_i$ refers to the ith greenhouse gas emission, $A^j_i$ refers to the activities information in the manufacturing process.

3. Study procedure

The detailed study procedure is as follows. First, identify this study’s purposes. This study discusses the carbon emissions for the materials that are composed of automotive ignition coil. Ignition coils represent the so-called "power plant" of the ignition process in the petrol engine. As part of the ignition system, they are charged with the task of providing the spark plug with the high voltage
required to generate an ignition spark between the center and earth electrode of the spark plug and ignite the air-fuel mixture.

For this purpose, the ignition coils draw current from the battery through the low-voltage connection and depending on the type, multiply it to up to 45 kilovolts. Then collect and organize data for analysis. The SimaPro software is utilized as the main analytical tool, in different assessment models for analysis and evaluation. The software also can produce a tree diagram to clearly show the environmental impact, as the tree diagram clearly exhibit the branch of respective input energy and the material. In the tree-branch subsystem, the system in a measurable way, based on an expression like a thermometer, quickly determines the materials and the impact of the energy on the environment. The filling material of automotive ignition coil is epoxy resin which is a liquid insulating resin. The elements of an ignition coil will be divided into three parts, i.e. polymer materials, metal materials, and package material. Table 1 lists the material composition, and the weight of an ignition coil (type AS-944).

| Component                  | Packaging Materials | Material composition  | weight  |
|----------------------------|---------------------|-----------------------|---------|
| Terminal Block and cover   | PBT                 | (Polybutylene terephthalate) | 11.0 g  |
| Primary spools             | PBT                 | 7.0 g                 |         |
| Secondary spools           | PPS(Polyphenylene Sulfide) | 29.8 g         |         |
| Shell                      | PBT                 | 30.0 g                |         |
| Insulating resin           | Epoxy resin         | 68.6 g                |         |
| Insulating body            | PBT                 | 110.7 g               |         |
| Terminal                   | copper              | 2.6 g                 |         |
| Coil                       | copper              | 32.8 g                |         |
| Secondary terminal         | copper              | 0.2878 g              |         |
| High-voltage connection    | copper              | 1.5 g                 |         |
| High-voltage terminal      | Iron                | 6.5 g                 |         |
| Core                       | Iron                | 111.5 g               |         |
| Ground sheet               | stainless            | 3.0 g                 |         |
| Waterproof rubber          | rubber              | 2.0 g                 |         |
| Carton                     | paper               | 52.9 g                |         |
| plastic bags               | PE (Polyethylene)   | 4.72 g                |         |

4. Results and discussion
Carbon footprint calculates the amount of greenhouse gas emissions caused by a particular activity or entity, commonly also referred to as global warming potential (GWP). It is measured in kilograms of carbon dioxide equivalent (CO₂eq.). The net diagram analysis was illustrated in figures 1-3. In this study, carbon footprint of different elements was calculated (table 2).

For the categories of polymer materials (figure 1): insulating resin, insulating body, secondary spools, and shell are 0.185 kg, 0.534 kg, 0.164 kg, and 0.145 kg of carbon dioxide equivalent emissions respectively. For the categories of metal materials (figure 2), the biggest emission source is
core (0.102 kg CO$_2$ eq.), followed by coil (0.0619 kg CO$_2$ eq.). For the categories of package materials (figure 3): waterproof rubber, carton, and plastic bags are 0.00386kg, 0.0778kg, and 0.00976kg of carbon dioxide equivalent emissions, respectively.

From the analysis (table 2), it can be known that each production of an AS-944 type ignition coil will generate a total of 1.934 kg carbon dioxide equivalent (kg CO$_2$ eq.). The biggest emission source was Polybutylene terephthalate (54.89%), followed by epoxy resin (13.28%), Polyphenylene Sulfide (11.77%), Iron (8.47%), and paper (5.58%).

The most amount of polybutylene terephthalate is used in insulating body and shell. The paper is packaging material which produces carbon emissions by up to 0.0778 kg CO$_2$ eq.

![Figure 1. The polymer materials net analysis diagram by IPCC GWP.](image1)

![Figure 2. The metal materials net analysis diagram by IPCC GWP.](image2)
5. Conclusion
In the study of carbon footprint, IPCC utilizes global warming as conversion factor to calculate CO₂ equivalent. From the material composition of ignition coil, one can understand that each material used corresponds to how many equivalents of carbon dioxide emissions. It is found that polybutylene terephthalate is used in insulating body and shell produces the most emissions equivalents of carbon dioxide. Therefore, one should pay special attention to the selection and development of the materials. This study presents the carbon footprint and environmental impact of automotive ignition coil. The results can help the industry reduce the emission source carbon footprint in an ignition coil product.
Acknowledgments

The research was supported by Ministry of Science and Technology of the Republic of China. The researchers hereby express the gratitude.

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