Carbon Footprint Calculation and Optimization Approach for CFOOD Project

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***Abstract*—In the paper, the study of carbon footprint optimization process is shown in order to receive low-carbon products. A short description of the Carbon Footprint standards is provided. Basing on the conducting project CFOOD subsided by Polish R&D Agency the optimization boundaries are discussed and presented. In the paper, the methods of carbon footprint are discussed. Basing on life cycle assessment (LCA) the model for carbon footprint is presented and discussed. LCA is then implemented to assess carbon footprint at the manufacturing and transportation stages in the food processing industry.**

Keywords*—carbon footprint; process optimization; expert systems; product life cycle assessment; food processing; global warming potential;

I Introduction

United Nations Framework Convention on Climate Change (UNFCCC) [1], the Kyoto Protocol [2] and the Paris Agreement [3] are well known examples that our world and governments are trying to divert climate changes. The climate changes have taken place several times in the Earth history also in the recent eon e.g. 10000 years in the northern hemisphere.

Nowadays, the climate changes are regarded as one of the greatest environmental, social and economic threats facing our planet. It is a result of the industrial revolution and statistically shows rapid increase in the average global temperature due to the increase in the atmospheric Greenhouse Gas (GHG) concentration, weather changes, draught etc.

The growing population also needs more food especially processed food due to increased urbanization [4][5]. That needs more supplies, raw materials and resources e.g. energy ones. Hence, not only governments or institutions e.g. the EU commission impose higher demands on lowering the usage of the energy resources (coal, fuels, electricity and gas) but also companies e.g. the food processing ones. The companies in their food processes are interested in implementing low-carbon technologies or solutions from economic reasons i.e. the less energy the cheaper product. It must be connected with the keeping-up the food standards [6].

The problem of the process optimization is widely known. In the agricultural and especially food processing industry different techniques are used starting from human-based experience through expert systems to implementing artificial intelligence [6][7][8]. The whole agricultural industry can use the whole variety of standards and good-procedures in their business. The example of such standards might be:

- PAS 2050 [9] - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services ;
- ISO/TS 14067:2018 [10] -Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification;
- ISO14040:2006 [11] - Environmental management-life cycle assessment: principles and framework;
- ISO14064-1:2018 [12] - Greenhouse gases - Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals.

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In our CFOOD project, the research is aimed at estimating carbon footprint (CF) for basic basket of frozen vegetable food by applying developed method and software (CF expert system, called CFexpert) as well as to develop innovative technologies for CF reduction by utilization of vegetable outgrades into valuable products. In the CF calculation task we take into account PAS 2050 and ISO/TS 14067:2018 to calculate/estimate CF and later on in the following optimization task of the food processing.

For individuals that are curious how to evaluate the CF in their common deeds we can recommend using some formulas provided by IBM in [13] as well as some CF calculators that can be found in Internet.

The paper is organized as follows. In Section II carbon footprint calculation and its different definition and approaches are presented widely. Life cycle assessment (LCA) and its stages is discussed in Section III. In the next section carbon footprint formulas for the acquisition of raw materials, manufacturing, transportation, usage, and recycle and disposal LCA stages. CFOOD project is shortly presented in the Section 5 as well as the optimization issues emerging and solutions applied to the project. The conclusions are shown in the final section.

II Carbon Footprint calculation

In the paper, to estimate carbon footprint (CF) for a given product we take into account PAS 2050 [9] and ISO/TS 14067:2018 [10] as mentioned in Sec. I. . The terms carbon emission and carbon footprint are widely used as an indicator of environmental performance, which is derived from ecological footprint. The carbon footprint of a company, a building, land, a structure, or a retail location is measured in tons/kilograms of CO_2 per year, called equivCO_2.

Product carbon footprint refers to the emission of a variety of GHG gases in a product life cycle. All GHGs specified by IPCC 2007 [14]– includes carbon dioxide (CO_2), methane (CH_4), nitrous oxide(N_2O) plus families of gases like hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), fluorinated ethers (see examples in Tab. I).

TABLE I. Direct (Except for CH_4) Global Warming Potentials (GWP) Relative to CO_2

Industrial designation or common name	***Chemical formula***	***GWP for 100-year time horizon***
Carbon dioxide	CO_2	1
• Methane	CH_4	25
• Nitrous oxide	N_2O	298
• CFC-11	CCl_3F	4,750
• CFC-12	CCl_2F_2	10,900
• CFC-13	$CClF_3$	14,400
• Carbon tetrachloride	CCl_4	1400

Carbon footprint is typically calculated by considering carbon emission factors and activity data, which could be evaluated by life cycle assessment (LCA). LCA is based on life cycle inventory (LCI), which is a repository that includes the data of resource and energy consumptions as well as emissions to the environment throughout the global product life cycle, see Fig. 1. What is equally important, the problem of uncertainty associated with all phases in the LCI is important to make LCA-based decisions correctly according to the standards not common sense.

In the Tab. I Global Warming Potentials (GWP) [14] used for the CF calculations are shown. The values of global warming potentials for GHGs to be used in calculations shall be in accordance with Tab. I.

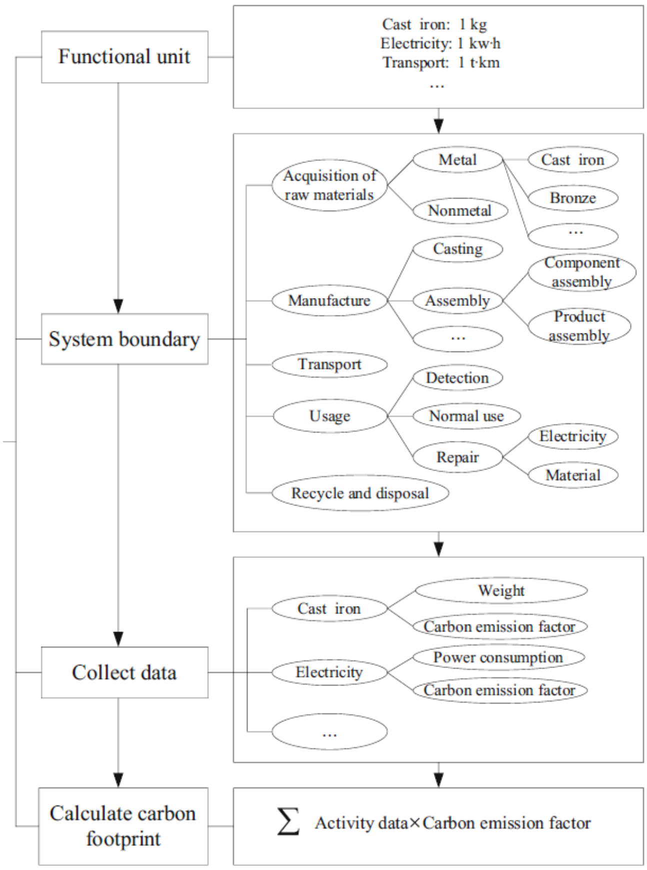

Fig. 1. Life cycle assessment (LCA) in carbon footprint (CF) estimation.

III Life Cycle Assessment in Carbon Footprint Calculation

LCA is a widely used approach to assess the actual environmental impact of a product caused by its production and use. The standards to evaluate the product carbon footprint in the LCA are mainly PAS 2050 and ISO/TS 14067.

The life cycle is defined as a series of consecutive stages of a product by ISO 14040 [12], including acquisition of raw materials (in our case vegetable crops), manufacturing (food processing), transportation, usage, and recycle and disposal. The LCA framework includes the determination of the objective and scope of the evaluation, inventory analysis, life cycle impact assessment, and life cycle interpretation [12]. PAS 2050 uses the LCA framework to evaluate GHG emissions from products, either business-to-consumer or business-to-business. Its main goal is to to minimize carbon footprint. The potential environmental impacts of a production system, either for the entire life cycle of the product or a specific stage, could be effectively assessed through the LCA of the product.

In the paper, a carbon footprint calculation is proposed to quantify the carbon footprint for all stages of production.

The LCA is divided into four stages, see Fig. 1:

1. Functional units selection – their selection should be the same for stages of life cycle.
2. System boundary determination – to indicate the calculation scope; some factors that constitute to less than 1% of total value can be omitted in some cases e.g. input of human and animal power.
3. Data collection - to calculate carbon footprint include activity data and carbon emission factors in the product life cycle as well as their accuracy.
4. Carbon footprint calculation – it is described in the subsection II.B.

IV CARBON FOOTPRINT CALCULATION

According to the definition of product life cycle and the analysis of product carbon footprint given in the PAS 2050 [9], the contribution of carbon footprint is divided into five stages for the entire product life cycle: acquisition of raw materials, manufacturing, transportation, usage, and recycle and disposal. Hence, the total CF for a given product or its unit value can be expressed in following formula:

$$CF = \sum_{i=a}^{r} CF_i \tag{1}$$

where i is each of the stages of product life cycle, $i = a, m, t, u$ and r are for the acquisition of raw materials, manufacturing, transportation, usage, and recycle and disposal stage, respectively.

Carbon footprint of product at the acquisition of raw materials, manufacturing and transportation stage can be calculated with very similar formula that is as follows:

$$CF_i = \sum_{k=1}^{M_i} M_{ik} * C_{ik} + \sum_{m=1}^{G_i} G_{im} * GWP_{im} \tag{2}$$

where M_i, G_i, M_{ik}, C_{ik}, G_{im} and GWP_{im} differ at acquisition of raw materials, manufacturing and transportation stage and have different meaning and they are summed up in Tab. I. Generally speaking:

- M stands for materials, manufacturing or transportation;
- G is the number of direct GHG emissions at each of these stages and the transportation stage this factor as well as the corresponding ones are more sophisticated than in other two stages.

In the transportation stage the generated carbon footprint depends on many other factors. The lorries can have different loads, fuels, as well as during the combustion different GHGs might be present. It might be summarized by the value of activity data at the transportation stage that is estimated for $i=t$ as

$$T_{\tau\kappa} * \Lambda_{\tau\kappa} * EI_{\tau\kappa}, \tag{3}$$

where:

- T_{tj} is the quantity of transportation shipment including materials, parts, products, waste, etc. in the k-th transportation stage;
- L_{tk} is the transportation distance in the k-th transportation;
- EI_{tk} is the energy intensity of the k-th transportation mode. EI_{tk} in other words can be briefed as the energy consumption per unit of energy quantity and per unit of distance in the k-th transportation mode.

TABLE II. COEFFICIENTS INTERPRETATION IN ACQUISITION OF RAW MATERIALS, MANUFACTURING AND TRANSPORTATION STAGE

Coefficients	Stage		
	Acquisition of raw materials	***Manufacturing***	***Transportation***
M_i	the number of raw material types consumed at the acquisition of raw material	the number of manufacturing, processing and assembly activity processes	the number of transportation stages, including road, railway, flight, waterway, etc.;
G_i	the number of direct GHG emissions types at the acquisition of raw materials stage	the number of direct GHG emission types at the manufacturing and processing stage	the number of direct GHG emission types at the transportation stage
M_{ik}	the consumption of the k-th raw material	the consumption of the energy in the k-th manufacturing, processing and assembly activity processes	the consumption of the energy in the k-th transportation chain of the process
C_{ik},	the carbon emission factor of the m-th raw material	the carbon emission factors of the energy consumed in	the carbon emission factor of energy consumption in the

Coefficients	Stage		
	Acquisition of raw materials	***Manufacturing***	***Transportation***
		manufacturing, processing and assembly process	*k*-th transport mode
G_{im}	the emission of the *m*-th type GHG at the acquisition of raw materials stage	the emissions of the *m*-th type GHG at the manufacturing and processing stage	the emission of the *m*-th type GHG at the transportation stage in the whole chain
GWP_{im}	the global warming potential of the *m*-th type GHG	the global warming potential of the *m*-th type GHG	the global warming potential of the *m*-th type GHG in the whole transport chain

Carbon footprint of product at the usage and disposal stages can be also calculated in similar way to the previous ones.

V. CFOOD Project Optimization Approach

One of the aims of the CFOOD project is to use outgraded materials in the production of the new products e.g. vege-burgers. The outgrades can appear at different stages of the production line and they are 100% healthy and usable raw materials that can be used in manufacturing. That is why instead of treating them as the waste/disposal they would be used to develop innovative technologies for CF reduction by utilization of vegetable outgrades into valuable products: frozen vege-burgers, frozen pastes and lyophilized bars (lyobars), enriched in fiber, with improved health and nutritional value.

Different approaches in optimization problem in the measuring CF are used e.g. expert systems, machine learning and artificial intelligence. Well mathematically based approaches sensitivity analysis is used in [16]. The other approach is green supply chain network design is used [16]. Artificial intelligence and computer vision examples are shown in [17]. One of the problems in CF calculations is assessment of water usage named water footprint and it is shown in [18][19]. LCA approach is also shown in [20][21].

Using the sensitivity analysis (SA) in product conceptual design the effect of changing a given input variable or design parameter on a given output of product carbon footprint quantitatively can be measured. Hence, implementing sensitivity analysis can assess and quantify the uncertainty in the product carbon footprint. That can also determine the impacts of design parameters on carbon footprint in a given system [15].

In that way carbon footprint could be reduced effectively by revising those most influential design parameters, this could led to optimization of the each stages of the life cycle. In our model used in the CFOOD project, the sensitivity S_i of carbon footprint function described also in the formulas (1)-(3) $CF_i(p_1, p_2, \dots, p_n)$ with respect to the *i*-th low-carbon design parameter p_i is calculated according to the formula

$$S_i = \frac{\partial CF_i(p_1, p_2, \dots, p_n)}{\partial p_i} \tag{4}$$

In the CFOOD project the measure system for the raw materials and energy resources as well as the transportation are especially prepared. The data from the various elements are united in one information, data acquisition system CFOOD_AS and the knowledge database (KDb). The data about raw materials (vegetables) as well as the usage of some energy resources as coal, gas etc. are inputted by the staff to the KDb system.

The production line elements are connected to the CFOOD_AS and the data from the sensors and meters is stored in KDb in the real time. Some data is also derived from the accountant system as shipment data.

Conclusions

The CFOOD project is at the initial stage. The whole acquisition system is connected and the first real-time tests are conducted. The business partner has started 2019 production campaign and the data for products from the chosen product basket is gathered by the acquisition system and stored in the knowledge database. From the other hand, the expert system and optimization system is tested and tuned on two products from the production line.

In 2019 the developed by the authors CFExpert system is planned to be combine with the data acquisition system. The first process optimization will be done to reduce CF in the products, mainly by lowering the energy resources and water consumption as well as the usage of the outgrades in the new products, that appear during the production in around 5-10%.

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