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MULTIFUNCTIONALITY OF PRODUCT SYSTEMS – A GENERAL INSIGHT FROM THE CIRCULAR ECONOMY'S PERSPECTIVE

Abstract

One of the key and simultaneously the most difficult issues within the methodology of the environmental life cycle assessment (as well as related life cycle-based techniques) is solving the problem of the multifunctionality of product systems, which includes the questions crucial for the circular economy: reuse, recycling, transforming by-products into valuable (in the market aspect) co-products, prolonging durability. The present paper aims at familiarizing the questions of multifunctionality and presenting the Circular Footprint Formula (CFF), which has been developed within the pilot stage of the European Commission project related to the common methods of measurement and communication the life cycle environmental performance of products and organisations. An example of PET bottles has been presented and two scenarios have been analysed: (1) a scenario with no recycling (a recycling content = 0 and a recycling rate = 0) and (2) a scenario with recycling (recycling content = 0.24 and recycling rate = 0.24). Calculations of life cycle emissions of CO2 have been made by using the CFF formula. An idea of division environmental burdens and credits between supplier and user of the recycled material has been shown and explained as well.

Key words

Multifunctionality, product system, life cycle, circular economy, Circular Footprint Formula

Introduction

Within the environmental life cycle assessment [1] and related analyses [2-4] the product system (as opposed to the product itself) is subjected to assessment. The product system is understood as "the collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product". Including the function in the definition of the product system reflects its crucial role within the life cycle techniques. The life cycle assessment (LCA) method (and the abovementioned related tools) is used to assess the potential environmental impact in relation to a specific way for realizing a given function/service. The precise definition of a function and a functional unit is the starting point of each study. Moreover, comparing product systems is possible on condition that their functional equivalence is assured. Despite the fact that it is the condition of each comparative analysis, it is particularly significant in the case of the so-called comparative assertions disclosed to the public ("environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function") [1,5]. In practice it means that answering the seemingly simple questions such as "should an electrical or a traditional toothbrush be used in order to brush teeth?", "what is a more environment-friendly choice – reading a paper book or an e-book?", "should waste be recycled or incinerated with energy recovery?", "should a product be packed into a glass bottle or a multilayer carton?" can be linked with the necessity to solve complex allocation problems. Nowadays, to a large extent due to the technical development, dematerialization and digitalization, the realization of the function itself may often be possible with the use of totally different products/processes (a paper book vs. an e-book; the application of plant protection products vs. the genetic modification of plants; payment transactions realized with the use of traditional methods vs. electronic payment), of different life cycle specificity (a paper book → the use of a renewable wood resource, which is capable of absorbing and accumulating carbon dioxide, the many years' duration of use, a passive product; e-book → an electronic device, the many years' duration of use, it is difficult to dismantle it and dispose of it, an active product powered by electrical energy). It all results in the differences between functionally equivalent product systems referring not only to construction, technological, cost-related and environmental issues but also to a large extent to the social ones (e.g. linked with health, comfort, time of realizing a service, as well as the demand for jobs and requirements on the job market).

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Allocation situations and allocation problem-solving procedures in the life cycle techniques
In the life cycle techniques multifunctionality occurs "if a process or facility provides more than one function, i.e. it delivers several goods and/or services ("co-products")" [2]. In a single product system multifunctionality may occur multiple times, have various background and call for different allocation requirements. From a perspective of LCA practitioner multifunctionality can be analyzed in the context of:

- the background – multifunctionality may be intended (designed) or "spontaneous"**.** In the case of the former multifunctionality results from the construction and way of designing a product (a good, a service) as well as the process (a technology). We may assume that the intended multifunctionality is generated at the stage of production (design) and that the users of these products/technological processes benefit from it. In this case, the multifunctionality can be observed during normal and proper use ("in accordance with the manual"). The "spontaneous" multifunctionality is a certain excess of functionality revealed once a given product or a technological line has been manufactured, which goes beyond the original functionality predicted by designers. It stems from specific and individual decisions of users. It may have a positive impact (prolonging the use due to granting a new application) or a negative impact (premature damage of a product and reducing its durability) on a product system's environmental performance.
- the carrier – the following elements may be the carriers of multifunctionality: a (material, non-material) product, a process, and an organization (which is a set of processes). In the case of products multifunctionality refers to a product's ability to perform specific functions (utility, spectrum of applications), its durability (durability, re-using rate), as well as recyclability and a potential for energy recovery. An example of the designed multifunctionality are smartphones, combined refrigerator-freezers, cosmetics of a varied spectrum of effect (e.g. nutritional values plus a sun protection filter). An example of the process multifunctionality may be processes (individually and a system of them) leading to co-products, e.g. refining of crude oil, incinerating waste with energy recovery, cow husbandry for dairy and meat, sheep husbandry for wool and meat. Hence, the process multifunctionality is a combination of the process and product (material) functionality. It stems not only from the construction and functionality of machinery (a technological line) but the functionality of materials (the anatomical structure of dairy cows and sheep enables the production of meat and milk/wool, the chemical structure of crude oil enables its refinement and obtainment of various final products, the energy stored in the chemical bonds of waste enables the recovery of energy during incineration). Whether a given process amounts to a multifunctional system or not depends on the combination of the two factors and is inextricably connected with specific conditions in a given place at a given time. If the analysis concerns a sheep farm, which is focused on meat production only, it describes a monofunctional system. What is more, even if sheep were actually sheared and the wool were obtained, but treated as waste (a negative or zero economic value), such a system still does not undergo the allocation procedure. However, if within the same farm the machinery for obtaining wool is installed and wool becomes an intended effect of the activity (relevant entities emerge on the market and shape the demand and price, wool reaches a positive economic value with impact on the farm's solvency), then the wool output flow becomes the functional flow and the farm should be considered two-function and be subjected to allocation. This issue is fundamental from the circular economy's perspective, in which the development of technologies for recovering resources from waste/by-products and transforming them into functional flows is prioritized. It means that installing new technological lines, which transform waste and by-products into valuable products, which are desirable on the market, may lead to changing monofunctional product systems into multifunctional ones. It can also result in spreading allocation in the life cycle studies.
- the place of exposure – from a LCA practitioner's perspective multifunctionality may occur in various parts of a product system (upstream processes, core processes, downstream processes) and relate to different places (life cycle stages, unit processes, activity data, elementary flows).
- operability – multifunctionality may relate to the elements of a product system, which are directly run by the practitioner/commissioner of life cycle assessment with the access to specific data (the foreground system). In such a case the practitioner, who gathers inventory data is obliged to identify the potential sources of multifunctionality problems and methods for solving them. However, the allocation situation also occurs in the parts of the system, which are beyond the direct control of the practitioner or/and commissioner. They can indirectly affect the allocation problem solving in the background system. It is possible due to the intense development of databases and data sets modeled according to different allocation solutions (for instance from the third version of the ecoinvent database the data sets are available in three allocation variation: (1) allocation at the point of

substitution, (2) allocation, cut-off, by classification, (3) substitution, consequential, long-term) [6]. Such a choice depends on the goal and scope of research (e.g. attributive vs. consequential) and has impact on the remaining elements of the system.

The functional unit is the pillar and the reference point for analyses realized with the use of the life cycle techniques. It is defined as "quantified performance of a product system for use as a reference unit" [1-4]. Not only does it refer to the product system, the process but also it is related to the organization (in the case of the latter it is usually called a reporting unit) [2,4,7]. The phenomenon of multifunctionality and the questions of allocation in the life cycle techniques is an artificial creation, an artifact [8] and stems from the application of a functional unit as well as the principle of maintaining the functional equality between the compared product systems. In practice it entails the necessity to isolate certain functions of the system or artificially broaden the system boundaries in order to assure this equality. Multifunctionality stems from the product system's ability to generate parallel functional flows. The allocation dilemma consists in answering the question linked with the method for dividing environmental aspects and the relevant potential environmental impact between functional flows. Allocation is understood as "partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" [1, 9]. From allocation's perspective the key element is differentiating between various input/output categories depending on the pertinence of their production/delivery as well as their economic value and contribution to generating income/costs. Thus, the status change from non-functional and functional flows is dynamic and relates to the specificity of the process as well as the technical development and the technological progress. It also results from market mechanisms, the relationship between demand and supply, and the price.

We may distinguish:

- co-products – in compliance with ISO 14040:2006 co-products are defined as "any of two or more products coming from the same unit process or product system" (# 3.10). These products decide about starting the activity, as obtaining (manufacturing) them is the main objective of the economic activity. Their economic value is high enough to have the key impact on the financial results of the activity. An enterprise's infrastructure is created in order to contribute to obtaining co-products. Co-products often result from joint production. Joint products are defined as "two or more outputs generated simultaneously, by a single manufacturing process using common input, and being substantially equal in value. Joint products (such as butter, cheese, and cream from milk, and fuel oil, gasoline, and kerosene from crude oil) are separately unidentifiable, and incur undifferentiated joint costs, until they reach the split-off point" [10]. The following goods amount to examples of co-products: products obtained in the process of crude oil processing (diesel, gasoline, jet fuel, HFO, petroleum coke, refinery hydrogen) [11], electrical energy and heat produced in the heat and power plants [12]. In the context of consequential analyses co-products are determining products ("product output of an activity for which a change in demand will affect the production volume of the activity. Also sometimes called a reference product") [13]. Co-products undergo the allocation procedure [14].
- by-products (dependent products) – products, which do not belong to the group of determining products [13], of less economic importance. The size of production and demand for main products directly determines the demand for by-products. By-products may be reused in the same process and be included in the scope of the Bill of Materials, but are also sometimes used in manufacturing other products (they are embraced by the scope of other product systems). A relevant example is fish processing, within which a cod fillet is the determining product (the main product) and fish mince and codparts (the fish racks including bone, skin, head and offal) are dependent products using as a valuable source of proteins [15]. Another example may be growing and processing corn, in which seeds (the main product) and corn straw (the dependent product) are obtained [16]. The corn straw can be sold for a small price as a valuable fertilizer. By-products can often have little economic value. For this reason, if they are recognized as functional flows, they should be taken into consideration in allocation procedure [8,17].
- waste - waste is no functional flow. It does not have economic value (the price = 0) or generates costs. It does not undergo the allocation procedure [8].

Figure 1 presents some examples of multifunctionality in life cycle analyses. It occurs in the following situations:

- multifunctionality of products (fig. 1 a),
- multifunctionality of output processes (multi-output) (fig. 1 b),
- multifunctionality of input processes (multi-input) (fig. 1 c),

- multifunctionality of input and output processes (input-output), including energy recovery (fig. 1 d), reuse and recycling (with the closed loop fig. 1 e and the open loop fig. 1 f).

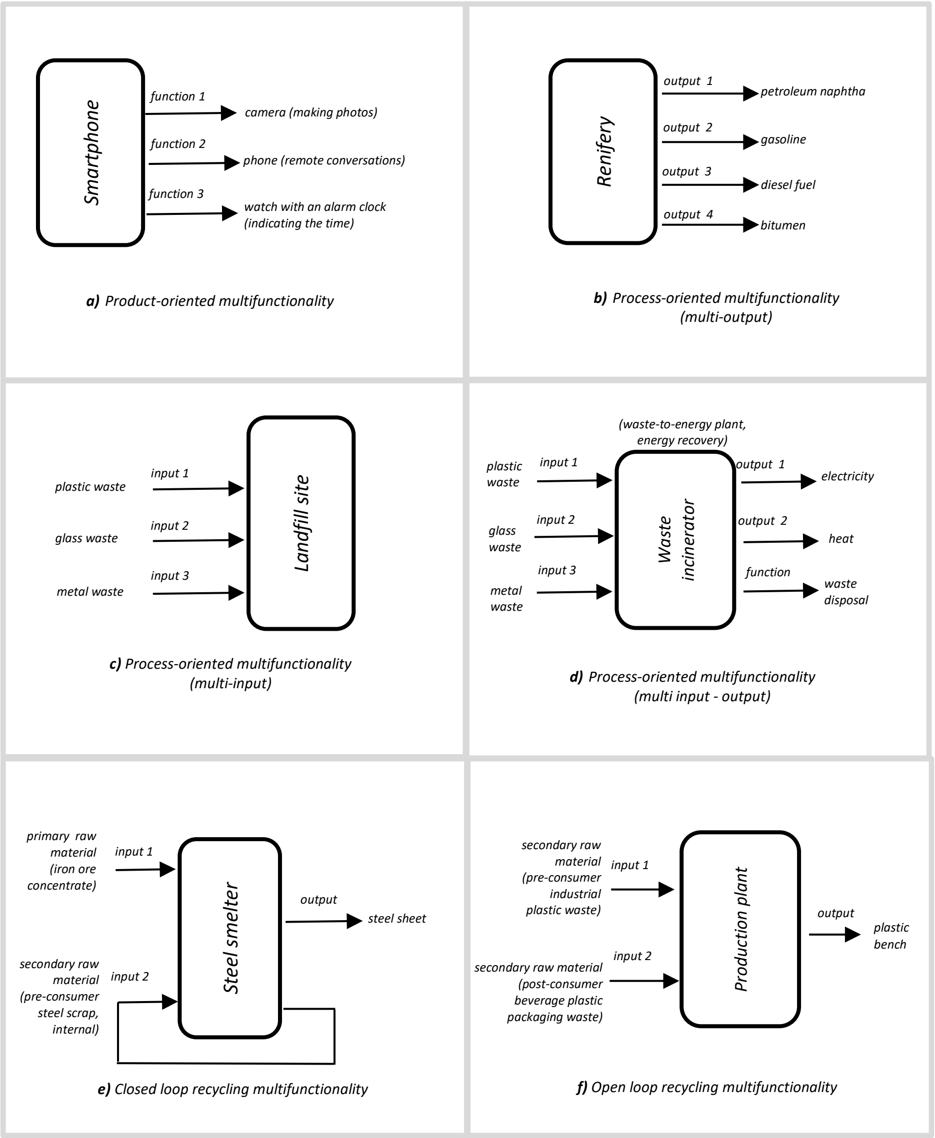


Fig. 1. Examples of multifunctionality in life cycle analyses
Source: Author's

In the life cycle techniques (LCA, carbon footprint, water footprint, environmental footprint of products and organisations) the same general procedure is applied to solve allocation problems. However, specific solutions in given situations may be different for specific tools. The general procedure for dealing with the multifunctionality of product systems is hierarchical and has the following form [3,4,18].

"The study shall identify the processes shared with other product systems and deal with them according to the stepwise procedure presented below.
a) Step 1: Wherever possible, allocation should be avoided by

1) dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or

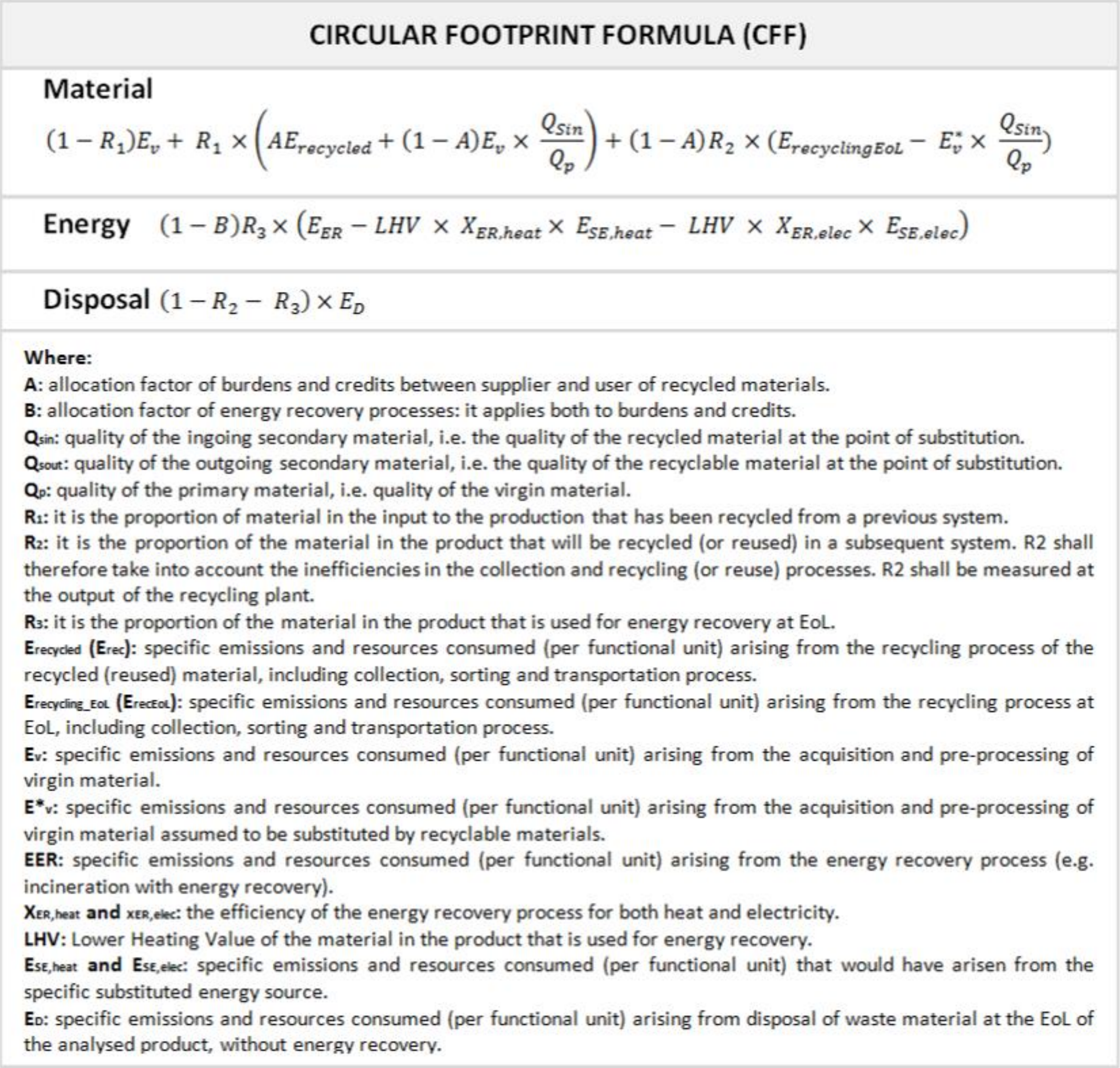
2) expanding the product system to include the additional functions related to the co-products (…).

b) Step 2: Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

c) Step 3: Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products".

Circular Footprint Formula as a solution recommended to use for product systems' multifunctionality in the Environmental Footprint calculations

Within the developmental works of the European Commission on establishing the common methods of measurement and communication the environmental performance in the life cycles of products and organisations [2] an approach to solve multifunctionality problems has been proposed. In the course of the several years' pilot phase the approach evolved and has finally taken the form of the equation called the Circular Footprint Formula (CFF) and presented in Fig. 2 . The CFF has been published in the latest version of PEFCR/OEFSR guidance documents [19, 20] and the detailed rules for specific product or sector categories (PEFCRs, OEFSRs). The CFF mainly solves the multifunctionality problem related to recycling and energy recovery.



CIRCULAR FOOTPRINT FORMULA (CFF)

Material

$$(1-R_1)E_v + R_1 \times \left(AE_{recycled} + (1-A)E_v \times \frac{Q_{Sin}}{Q_p}\right) + (1-A)R_2 \times (E_{recyclingEoL} - E_v^* \times \frac{Q_{Sin}}{Q_p})$$

Energy $(1-B)R_3 \times (E_{ER} - LHV \times X_{ER,heat} \times E_{SE,heat} - LHV \times X_{ER,elec} \times E_{SE,elec})$

Disposal $(1-R_2-R_3) \times E_D$

Where:

A: allocation factor of burdens and credits between supplier and user of recycled materials.

B: allocation factor of energy recovery processes: it applies both to burdens and credits.

Q_{sin}: quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution.

Q_{sout}: quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution.

Q_p: quality of the primary material, i.e. quality of the virgin material.

R_1: it is the proportion of material in the input to the production that has been recycled from a previous system.

R_2: it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system. R2 shall therefore take into account the inefficiencies in the collection and recycling (or reuse) processes. R2 shall be measured at the output of the recycling plant.

R_3: it is the proportion of the material in the product that is used for energy recovery at EoL.

$E_{recycled}$ (E_{rec}): specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.

$E_{recycling\_EoL}$ (E_{recEoL}): specific emissions and resources consumed (per functional unit) arising from the recycling process at EoL, including collection, sorting and transportation process.

E_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material.

E^*_v: specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.

EER: specific emissions and resources consumed (per functional unit) arising from the energy recovery process (e.g. incineration with energy recovery).

$X_{ER,heat}$ and $x_{ER,elec}$: the efficiency of the energy recovery process for both heat and electricity.

LHV: Lower Heating Value of the material in the product that is used for energy recovery.

$E_{SE,heat}$ and $E_{SE,elec}$: specific emissions and resources consumed (per functional unit) that would have arisen from the specific substituted energy source.

E_D: specific emissions and resources consumed (per functional unit) arising from disposal of waste material at the EoL of the analysed product, without energy recovery.

Fig. 2 The Circular Footprint Formula

Source: [18,19]

The characteristic features of the CFF include:

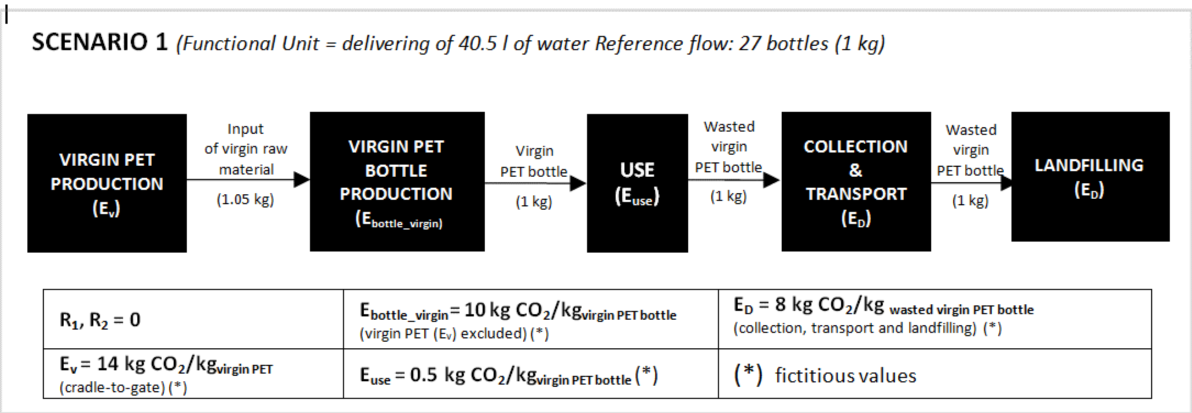
- including the multifunctionality stemming from recycling (open and closed loop) and energy recovery,

- the possibility of applying for life cycle of final products (CFF), intermediate products (CFF) and construction products (CFF-M),
- the application of substitution (avoided burdens) through: crediting the recycling process (which introduces the secondary resource onto the market) with the impacts of the avoided production of the substitution primary resource; crediting the energy recovery process with impacts of the avoided production of energy from the market (only for the amount of energy produced in excess and sold),
- the possibility of taking into account of different substitution points,
- including multifunctionality occurring at different life cycle's stages (production, use and final disposal),
- allocating burdens and environmental credits between two life cycles reflecting the situation on the recycling market (the A allocation factor) and the energy market (the B allocation factor).

The idea of applying the CFF is based on the assumption of the substitutability of primary resources in relation to the functionally equivalent secondary resources. If during a specific technological process wasted products (end-of-life) instead of ending up at the landfill become useful materials, then they replace primary resources while entering the market. That is why the processes, which generate the secondary resources that are desirable on the market, are credited (minus sign) with the burdens linked with the production of the equivalent amount of the primary resource. In other words, the environmental burdens of the recycling processes ($E_{recycling,EoL}$) are less the impact of the avoided production of the substitution primary resource (E^*_v). This crediting is related to the recycling rate (R_2) and is calculated with the use of the right side of the formula in the "material" column according to the following formula: $(1-A)R_2 \times (E_{recyclingEoL} - E^*_v \times \frac{Q_{Sout}}{Qp})$. On the other hand, the use of the secondary resource in the process in order to manufacture a product (the R_1 recycled content) does not cause the avoidance of the use of the primary resource, but leads to the valuable secondary resource's disappearance from the market and its inaccessibility for other applications. In such a situation another producer must use the primary resource in order to fulfill the need to produce other products. Therefore, the process, which uses the secondary resource ($E_{recycled}$) is burdened (debited, plus sign) with the impact of the production of the primary resource, which must be used up as the result of reducing the demand (E_V). The debiting is calculated with the use of the left side of the formula in the "material" column according to the formula: $(1-R_1)E_v + R_1 \times (E_{recycled} + (1-A)\, E_v \times \frac{Q_{Sin}}{Qp})$.

Application of the CFF formula – an example

Below one may find the presentation of two examples of solving the problem of multifunctionality with the use of the CFF (Fig. 3 and Fig. 4). In the examples the default values of parameters A, R_2, Q_{sin}/Q_p and Q_{sout}/Q_p for PET bottles [20] as well as fictional inventory data linked with the emission rate of specific processes have been used (the examples are given only to illustrate the CFF). The examples have been simplified and limited to carbon dioxide emission (in practice environmental profiles embrace hundreds of environmental interventions). In both case the functional unit (FU) has been defined as "delivering of 40.5 l of water", which means that the reference flow is 27 bottles (1 kg of PET). The first example (Fig. 3) illustrates the life cycle of PET bottles manufactured fully from the primary resource (R_1=0), which are not recyclable (R_2=0); thus, 100% of them are stored at a landfill.

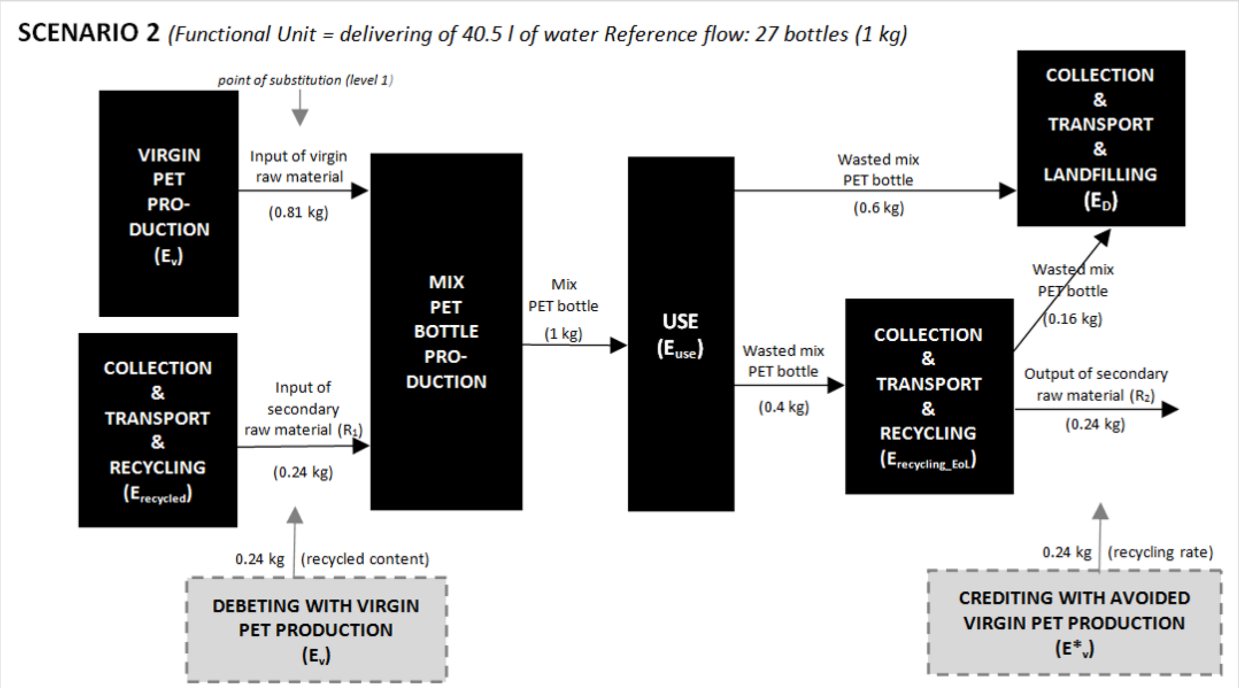


R_1, R_2 = 0	E_{bottle_virgin}= 10 kg $CO_2/kg_{virgin\ PET\ bottle}$ (virgin PET (E_v) excluded) (*)	E_D = 8 kg $CO_2/kg_{wasted\ virgin\ PET\ bottle}$ (collection, transport and landfilling) (*)
E_v = 14 kg $CO_2/kg_{virgin\ PET}$ (cradle-to-gate) (*)	E_{use} = 0.5 kg $CO_2/kg_{virgin\ PET\ bottle}$ (*)	(*) fictitious values

Fig. 3 CFF - scenario 1 – PET bottles with no recycled content (R_1 = 0) and no recycling rate (R_2 = 0)

Source: Author's

In the second scenario (Fig. 4) the life cycle of PET bottles, which are manufactured partly from the secondary resource (R_2 = 0.24 kg/FU) and may be recycled (from 1 kg of bottles within the output flow of a recycling plant we obtain 0.24 kg of the marketable secondary resource, R_2 = 0.24).



R_1 = 0.24 (*)	R_2 = 0.24 (**)	E_D = 8 kg CO_2/kg $_{\text{wasted mix PET bottle}}$ (collection, transport and landfilling) (*)
A = 0.5	E_{bottle_mix} = 8 kg CO_2/kg $_{\text{mix PET bottle}}$ (virgin PET (E_v) and recycling ($E_{recycled}$) excluded) (*)	$E_{recycling\_EoL}$ = 6 kg CO_2/kg $_{\text{secondary raw material}}$ (collection, transport and recycling) (*)
E_v = 14 kg CO_2/kg $_{\text{virgin PET}}$(cradle-to-gate) (*)	E_{use} = 0.5 kg CO_2/kg $_{\text{mix PET bottle}}$ (*)	Q_{sin}/Q_p and Q_{sout}/Q_p = 0.9 (**)
$E_{recycled}$ = 5 kg CO_2/kg $_{\text{secondary raw material}}$ (*)	E^*_v = 14 kg CO2/kg $_{\text{avoided virgin PET}}$ (processes substituted by recyclable material)	(*) fictitious values (**)default values

Fig. 4 CFF - scenario 2 – PET bottles with recycled content (R_1 = 0.24) and recycling rate (R_2 = 0.24)
Source: Author's

The results of life cycle CO_2 emission calculations for both cases have been presented below.

<u>SCENARIO 1 - calculations of CO_2 emissions per FU:</u>

- Virgin material input = 1.05 * 14 = 14.7 kg CO_2
- Virgin bottle production (without E_v) = 1 * 10 = 10 kg CO_2
- Use of virgin PET bottle = 1 * 0.5 = 0.5 kg CO_2
- Collection & transport & landfilling of wasted virgin PET bottle = 1 * 8 = 8 kg CO_2

<u>Life cycle CO_2 emissions per FU:</u>

- Life cycle = 14.7 + 10 + 0.5 + 8 = <u>33.2 kg CO_2</u> per Functional Unit (1 kg of virgin PET bottles).

<u>SCENARIO 2 - calculations of CO_2 emissions per FU:</u>

- Virgin material input = 0.81 * 14 = 11.34 kg CO_2
- Secondary material input, as recycled content debited virgin PEF production = 0.24*((0.5*5 + (1-0.5)*14*0.9)) = 2.11 kg CO_2
- Mix bottle production (without E_v and $E_{recycled}$) = 1 * 8 = 8 kg CO_2
- Use of mix PET bottle = 1 * 0.5 = 0.5 kg CO_2
- Collection & transport & recycling of wasted mix PET bottle, as recycling rate credited with avoided virgin PEF production = (1-0.5)*0.24 *(6 – 14*0.9) = - 0.792 kg CO_2
- Collection & transport & landfilling of wasted mix PET bottle = 0.76 * 8 = 6.08 kg CO_2

<u>Life cycle CO_2 emissions per FU:</u>

- Life cycle = 11.34 + 2.11 + 8 + 0.5 + (-0.792) + 6.08 = <u>27.24 kg CO_2</u> per Functional Unit (1 kg of mix PET bottles).

The life cycle of 1 kg of virgin PER bottles (scenario 1) hypothetically generates CO_2 emission of 33.2 kg. Due to the absence of the secondary resource in production ($R_1 = 0$) and the lack of the final product's recycling ($R_2= 0$) the product system has not been either burdened (debited), or credited with emissions generated during the acquisition and pre-processing of virgin material (E_v and $E*_v$). The emission rate of the system of 33.2 kg stems from the processes of the actual production of the primary resource used fully to manufacture bottles, the bottle production processes, their use and end of life (waste collection, transport and landfilling). In the other case (scenario 2) the abovementioned processes should be complemented with CO_2 emission allocated due to multifunctionality. In analyses the default value of parameter A has been used (A = 0.5), which means the division of the burdens and credits between supplier and user of the recycled material is equal (50:50). In fact the production process of 0.24 kg of recyclate as the result of recycling ($E_{recycled}$) generates the emission of 0.24 kg * 5 kg CO_2 = 1.2 kg CO_2. However, the CFF "punishes" the manufacturer for eliminating the secondary raw material from the market (limiting demand) and burdens the result with additional impact according to the following formula: $R_1 \times (E_{recycled} + (1-A)\ E_v\ \times \frac{Q_{Sin}}{Qp})$, which leads to the following calculation: 0.24*((0.5*5 + (1-0.5)*14*0.9)) = 2.11 kg CO_2. The difference of 0.91 kg of CO_2 is the environmental consequence of eliminating the secondary raw material from the market and the necessity to use the primary resource by a different producer. Within the end of life the used bottles are recycled. From 1 kg of bottles we obtain (as an output from a recycling plant) 0.24 kg of recyclate (R_2 = 0.24). Therefore, in the second scenario 1 kg mix of PET bottles has an "inbuilt" potential to generate 0.24 kg of secondary raw material at the end of its life cycle. The recyclate's entering the market will increase the supply of this resource without further use – and an equivalent amount (after the quality adjustment 0.24 * 0.9 = 0.216 kg) of the primary resource. If we do not apply the CFF we may calculate that the process of acquisition, transport and recycling ($E_{recyclingEoL}$) of 0.4 kg of bottles entails the emission rate of 0.4 * 6 kg CO_2 = 2.4 kg CO_2. However, the CFF "rewards" PET bottles for their recyclability and gives the environmental credit for their potential of replacing the primary resource. The credit is calculated according to the following formula: $(1-A)R_2 \times (E_{recyclingEoL} - E_v^* \times \frac{Q_{Sout}}{Qp})$, which leads to the following calculation: (1-0.5)*0.24 *(6 – 14*0.9) = - 0.792 kg CO_2. Hence, 2.4 kg of CO_2 emission acquires the credited result at the level of 0.792 kg CO_2. Consequently, the difference of the life cycles' emission rate (33.2 – 27.24 = 5.96 kg CO_2) between the two presented examples results from: the recyclability of mix PET bottles (the granted credit), smaller mass of mix PET bottles entering a landfill (scenario 1 = 1 kg, scenario 2 = 0.76 kg) and the use of secondary raw material in production (the granted debit). Furthermore, the CFF enables taking account of the changes of the secondary resource's quality through downcycling (coefficients of quality adjustment - Q), the situation on the secondary resources market (the A coefficient) and the effects of energy recovery (they have not been taken into account in the presented examples).

Final conclusions

In the article the phenomenon of the multifunctionality of product systems as well as the general procedure for allocation situations have been discussed. Moreover, examples of the use of the Circular Footprint Formula (CFF) have been provided. The CFF is an approach recommended by the European Commission to apply in the environmental footprint analyses of products and organisations. The multifunctionality of systems is related to the circular economy key phenomena: recycling, energy recovery and reuse. Therefore, one may expect the significant development of recovery technologies (including recycling). It may also be predicted that product systems will produce more valuable and marketable secondary resources. Consequently, it will lead to the situation in which solving the multifunctionality problems of systems becomes common practice in the life cycle analyses.

Conflict of interest

There are no conflicts to declare.

Acknowledgments

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