APPLICATION OF THE CIRCULAR FOOTPRINT FORMULA (CFF) IN PRODUCT ENVIRONMENTAL FOOTPRINT (PEF)

Illustrated through a case study on intermediate paper products

October 2020

J. Rickert, A. Ciroth
GreenDelta GmbH, Kaiserdamm 13, 14057 Berlin, Germany

1. Introduction

The European Commission published the ‚Product Environmental Footprint' (PEF) in 2013 in order to create one common European environmental assessment methodology for products and services. PEF is expected to be an important approach in the future.

One challenge of PEF is the application of the so-called Circular Footprint Formula (CFF). The following paper addresses this challenge and uses a simple case study on intermediate paper products to illustrate the application of the CFF. This paper is an additional source of information next to the official PEF guide[1] and the webinar[2] dedicated to the CFF. This paper does not intend to discuss the methodological consistency of the CFF nor methodological challenges of PEF in general.

2. The CFF for intermediate products (modelling recycled content)

The CFF is a specialized allocation rule in the case of product recycling and is a standardized way of sharing environmental burdens and benefits between the supplier and user of recycled materials.

The CFF considers specific emissions and resources consumed stemming from 'Material + Energy + Disposal' (Figure 1[1]).

Material

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

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

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

Figure 1: Original CFF description

[1] https://eplca.jrc.ec.europa.eu//permalink/PEF_method.pdf p.65

[2] https://ec.europa.eu/environment/eussd/pdf/Webinar%20CFF%20Circular%20Footprint%20Formula_final-shown_8Oct2019.pdf (slides) and https://ec.europa.eu/environment/eussd/videos/2019-10-08%2016.01%20The%20Circular%20Footprint%20Formula.mp4 (webinar recording)

For intermediate products and cradle-to-gate PEF studies, parameters $\boldsymbol{R_2}, \boldsymbol{R_3}$ and $\boldsymbol{E_D}$ are set to zero, so that the CFF takes the following form (Equation 1)[3]:

$$\boldsymbol{CFF = (1 - R_1)E_V + R_1 * \left(AE_{recycled} + (1 - A)E_V * \frac{Q_{Sin}}{Q_P}\right)} \qquad (1)$$

The parameters $\boldsymbol{A}, \boldsymbol{R_1}, \frac{\boldsymbol{Q_{Sin}}}{\boldsymbol{Q_P}}$ are dimensionless factors:

- $\boldsymbol{A}$ is an allocation factor for sharing burdens and credits between supplier and user of recycled materials.
- $\boldsymbol{R_1}$ is the proportion of material in the input to the production that has been recycled from a previous system.
- $\frac{\boldsymbol{Q_{Sin}}}{\boldsymbol{Q_P}}$ represents the material quality ratio (ingoing secondary material/primary material).

The parameters $\boldsymbol{E_V}$ and $\boldsymbol{E_{recycled}}$ represent specific emissions and resources consumed:

- $\boldsymbol{E_V}$ represents the specific emissions and resources consumed (per functional unit) arising from the acquisition and pre-processing of virgin material
  (*in this case for example silvicultural, transport or wood processing activities, pulping, … but without final paper production*),
- $\boldsymbol{E_{recycled}}$ represents specific emissions and resources consumed (per functional unit) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process
  (*in this case for example collection, sorting, transportation, deinking, pulping, …, but without final paper production*).

$\boldsymbol{E_V}$ and $\boldsymbol{E_{recycled}}$ are thus vectors[4].

In summary, as the other parameters $\boldsymbol{A}, \boldsymbol{R_1}, \frac{\boldsymbol{Q_{Sin}}}{\boldsymbol{Q_P}}$ are dimensionless, the CFF creates a new vector $\boldsymbol{E_{CFF}}$.

The newly created vector represents the specific emissions and resources consumed caused by the consumption of material and is calculated, via the CFF, from:

- virgin material,
- as well as for the supply of recycled material.

It carries specific emissions and resources consumed from the first life cycle as well as from the second life cycle.

[3] https://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_intermediate_paper_product.pdf p.60

[4] As stated in the webinar recording around minute 30: https://ec.europa.eu/environment/eussd/videos/2019-10-08%2016.01%20The%20Circular%20Footprint%20Formula.mp4

3. Illustrating case study

The following simple case study aims to illustrate the application of the CFF. Accompanying the case study, we developed a MS Excel tool to demonstrate the CFF application procedure. Please note that all vectors, flow quantifications and characterization factors are made up and serve the purpose of illustrating the application of the CFF only.

One common method of life cycle impact assessment calculation (and PEF-compliant impact calculation) is the mathematical approach of matrix modification and multiplication. The use of the CFF will be explained along this computational structure.

The application of the CFF is illustrated based on a case study on intermediate paper products. The simple system (Figure 2) for the production of 1000 kg final paper product, e.g. solid board box, is assessed and the CFF gets applied during the process.

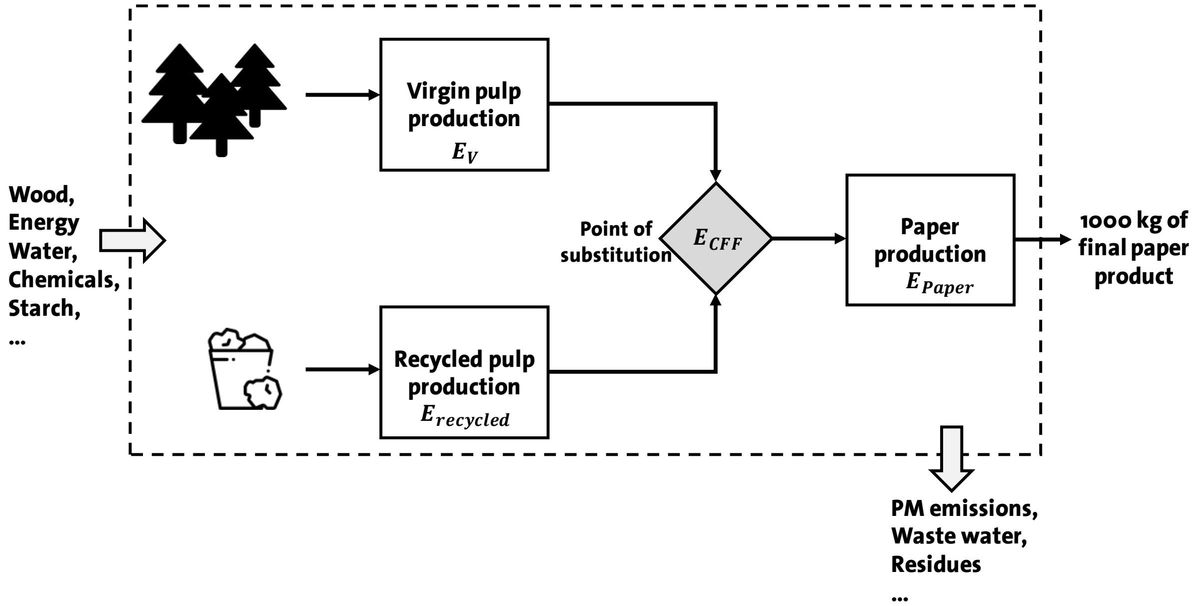

Figure 2: Case study system with point of substitution

The system consists of three foreground processes: two pulp supplying processes, virgin and recycled pulp production, and finally paper production, which takes in the pulp to produce solid board box. These foreground processes additionally take in other resources like wood, electricity or water and emit emissions like PM (Particulate Matter) or waste water.

The point of substitution corresponds to the point where secondary materials substitute primary materials. In this case, where recycled pulp and virgin pulp get mixed for subsequent paper production.

Application of the CFF

In Life Cycle Assessment (LCA), processes are often represented as vectors to describe their inputs and outputs[5]. Inputs are negative and outputs are positive by convention. A simple process which heats water with electric energy can be described like this:

$$E_{example} = \begin{bmatrix} -1 \\ -5 \\ 1 \end{bmatrix} \begin{matrix} liter\ cold\ water \\ kWh\ electricty \\ liter\ hot\ water \end{matrix}$$

For the case study, the following notation for vectors is used:

$$E = \begin{bmatrix} kg\ wood \\ kg\ pulp \\ kg\ recycled\ paper \\ kg\ paper \\ kWh\ energy \\ m^3\ water \\ kg\ chemicals \\ kg\ starch \\ kg\ PM\ emissions \\ kg\ CO_2\ emissions \\ m^3\ waste\ water\ emissions \\ kg\ residues \\ kg\ crude\ oil \\ kg\ biomass \end{bmatrix}$$

The following vectors describe virgin pulp production and recycled pulp production:

E_V = Primary / virgin pulp production	$E_{recycling}$ = Secondary / recycling pulp production	
-3	0	*kg wood*
1	**1**	*kg pulp*
0	-2	*kg recycled paper*
0	0	*kg paper*
-15	-5	*kWh energy*
-20	-10	*m^3 water*
-0.2	-0.1	*kg chemical*
0	0	*kg starch*
0.0008	0.0006	*kg PM emissions*
0.009	0.007	*kg CO_2 emissions to air*
19	9	*m^3 waste water emissions to water*
5	0.5	*kg residues / sludge*
0	0	*kg crude oil*
0	0	*kg biomass*

[5] Heijungs & Suh (2002) The Computational Structure of Life Cycle Assessment (https://doi.org/10.1007/978-94-015-9900-9)

Now the CFF is applied with the corresponding CFF parameter values for solid board box ($\boldsymbol{A} = \mathbf{0.2}$ and $\boldsymbol{R_1} = \mathbf{0.47}$ in accordance with PEF Annex C[6]; and the assumption of $\frac{\boldsymbol{Q_{Sin}}}{\boldsymbol{Q_P}} = \mathbf{1}$) to create the new vector $\boldsymbol{E_{CFF}}$:

E_{CFF} = mixed pulp production	
-2.718	*kg wood*
1	*kg pulp*
-0.188	*kg recycled paper*
0	*kg paper*
-14.06	*kWh energy*
-19.06	*m³ water*
-0.1906	*kg chemical*
0	*kg starch*
0.0007812	*kg PM emissions*
0.008812	*kg CO_2 emissions to air*
18.06	*m³ waste water emissions to water*
4.577	*kg residues / sludge*
0	*kg crude oil*
0	*kg biomass*

This is it; this is the result of the CFF. Note that this procedure can be done with:

a) unit processes (like above, with the process vector notation),
b) or with aggregated system processes (only elementary flows).

This way, the new pulp – which is a mix of virgin and recycled pulp – carries along some of the emissions and consumed resources of the recycled pulp's first life cycle. How much of the emissions and consumed resources from the first life cycle are carried towards the second depend on the parameter A.

How to use the CFF result

Applying the CFF is only an intermediate step during PEF impact calculation. The newly calculated vector $\boldsymbol{E_{CFF}}$ is now going to be used for calculating, in the end, the environmental impact over the life cycle.

Continuing the illustrating case study and adding the main process of paper production as well as the background processes for the production of wood, recycled paper, energy, chemicals and starch, the Technosphere matrix $\underline{A}$ and Biosphere matrix $\underline{B}$ can be described like the following:

E_{CFF} = mixed pulp production	E_{paper} = Final paper production	wood production	recycled paper production	energy production	water production	chemical production	starch production		
-0.3	0	1	0	0	0	0	0	*kg wood*	**Technosphere A**
1	-1.6	0	0	0	0	0	0	*kg pulp*	
-1.8	0	0	1	0	0	0	0	*kg recycled paper*	
0	1	-0.006	0	-0.008	-0.005	-0.003	-0.008	*kg paper*	
-6	-3	-10	-3	10	-0.3	-25	-25	*kWh energy*	
-11	-5	-10	-0.5	-0.5	1	-5	-5	*m³ water*	
-0.11	0	0	0	0	0	1	0	*kg chemical*	
0	-0.5	0	0	0	0	0	1	*kg starch*	
0.00062	0.0005	0.01	0	0.05	0	0	0	*kg PM emissions*	**Biosphere B**
0.0072	0.002	0	0	0.5	0	0	0	*kg CO_2 emissions*	
10	2.5	0	0	0.5	0	5	5	*m³ waste water*	
0.95	5	0	0	0	0	0	0	*kg residues / sludge*	
0	0	0	0	-5	0	-0.5	0	*kg crude oil*	
0	0	-1.3	0	0	0	-0.5	-3	*kg biomass*	

Note that $\boldsymbol{E_{CFF}}$ is part of Technosphere and Biosphere matrix.

[6] https://eplca.jrc.ec.europa.eu//permalink/Annex_C_V2.1_May2020.xlsx

The demand vector f is defined by the user, e.g. 1 ton of paper product.

	0	kg wood
	0	kg pulp
	0	kg recycled paper
demand vector f =	1000	**kg paper product**
	0	kWh energy
	0	m³ water
	0	kg chemical
	0	kg starch

Subsequently, the scaling vector s can be calculated via $s = \underline{A}^{-1} * f$, the inventory vector g can be computed via $g = \underline{B} * s$ and with a given characterization matrix $\underline{Q}$, such as

	PM	*CO_2*	*waste water*	*residues*	*crude oil*	*biomass*	
	0.00043	0.01	0	0	0	0	*Climate change [kg CO2 eq]*
characterization matrix	0.01	0.0001	0.0006	0	0	0	*Human health [DALY]*
Q =	0	0	0	0.00006	-0.00099	-0.0007	*Resource use, fossil [MJ]*
	0	0	1	0	0	0	*Water use [m³]*

the result of the impact assessment can be calculated:

	136.504073	*Climate change [kg CO_2 eq]*
indicator vector	**73.43913398**	*Human health [DALY]*
h = Q x g	**148.0901751**	*Resource use, fossil [MJ]*
	95799.4648	*Water use [m³]*

These environmental impacts can be normalized; otherwise these are the final PEF result.

In practice, the background processes and therefore large parts of the Technosphere and Biosphere as well as the characterization matrix are available via the PEF data sets.

4. For nerds familiar with matrix based LCA computation: Generalized CFF application procedure

The following presents a shortened, generalized application procedure.

1. Choose material under study (e.g. solid board box); set corresponding default parameters for $\boldsymbol{A}, \boldsymbol{R_1}$.
2. Set quality ratio $\frac{\boldsymbol{Q_{Sin}}}{\boldsymbol{Q_P}}$ according to PEF Annex C.
3. Choose the quantity of final product (functional unit).
4. Quantify the vectors for virgin material production $\boldsymbol{E_V}$ and for recycled material production process $\boldsymbol{E_{recycled}}$.

At this point, the CFF gets applied. This can be automated (e.g. by a computational tool or LCA software); the result is a new vector e.g. $\boldsymbol{E_{CFF}}$, which is used for subsequent computations.

This is it; subsequent computational steps are (standard) LCA matrix computations:

- Inverting the Technosphere $\underline{\boldsymbol{A}}^{-1}$ (please note that $\underline{\boldsymbol{A}}$ refers to the Technosphere matrix, and $\boldsymbol{A}$ refers to the parameter of the CFF),
- Calculating the scaling vector $\boldsymbol{s} = \underline{\boldsymbol{A}}^{-1} * \boldsymbol{f}$,
- Calculating the inventory vector $\boldsymbol{g} = \underline{\boldsymbol{B}} * \boldsymbol{s}$,
- Applying a characterization matrix $\underline{\boldsymbol{Q}}$ to get the indicator vector $\boldsymbol{h}$ (i.e. the environmental impacts).

The steps 1-4 are in accordance with the accompanying MS Excel tool.

5. End notes

With this document we aim at illustrating how the CFF may be applied during PEF calculation.

As shown above, the CFF calculates a new vector, which in turn can then be used for subsequent impact computations.

The scope of the case study is an intermediate product or cradle-to-gate PEF as this shortens the CFF considerably. Yet even when applying the full CFF, the message stays the same: the CFF creates a new vector, which can then be used for further calculations.

6. Annex 1

In some special cases, for example in the case of a recycling process for paper, which considers fibre loss, the quality ratio $\frac{Q_{Sin}}{Q_P}$ equals one. Then, the CFF can be further simplified as shown below:

$$(1-R_1)*E_V + R_1*[A*E_{recycled} + (1-A)*E_V*Q_{sin}/Q_P]$$

(rearrange)

$$E_{recycled}*R_1*A \quad + \quad E_V*[(1-R_1)+R_1*(1-A)*\underbrace{Q_{sin}/Q_P}_{=1}]$$

$$E_{recycled}*R_1*A \quad + \quad E_V*(1-R_1*A)$$

7. Annex 2

To understand what the CFF does to the vector, which gets used for impact assessment calculation, we modified the parameters $\boldsymbol{A}$ and $\boldsymbol{R_1}$ without adhering to the PEF default values (Figure 3), but kept everything else as described in the case study above.

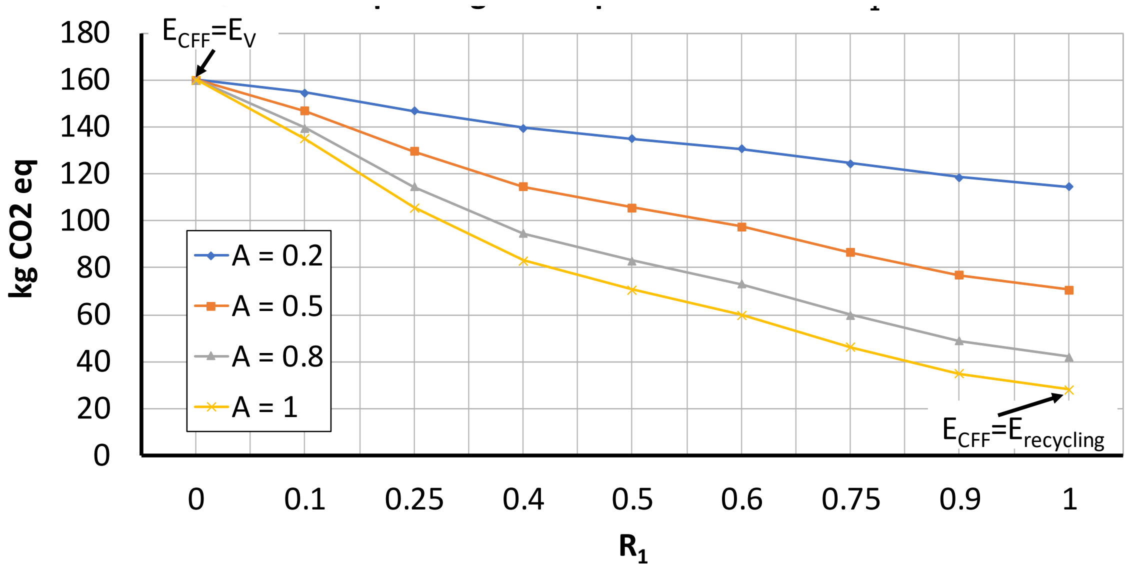

Figure 3: Result of impact assessment for climate change for 1 ton of final product depending on CFF parameters A and R_1

Figure 3 shows that $\boldsymbol{A}$ and $\boldsymbol{R_1}$ steer the resulting vector between two extreme cases:

- $\boldsymbol{R_1 = 0;\ A = [0,1]}$: $\boldsymbol{E_{CFF} = E_V}$ in this case, the environmental impacts are equal to the environmental impacts which would be caused by $\boldsymbol{E_V}$; here ca. 160 kg CO_2 eq.
- $\boldsymbol{R_1 = 1;\ A = 1}$: $\boldsymbol{E_{CFF} = E_{recycling}}$ – in this case, the environmental impacts are equal to the environmental impacts which would be caused by $\boldsymbol{E_{recycling}}$; here ca. 28 kg CO_2 eq.

As can be seen, the modelling parameter $\boldsymbol{A}$ has great influence on the PEF impact assessment result.