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CIRCULAR SOLUTIONS FOR FOOD PACKAGING. INNOVATIVE COATED PAPER PACKAGING AND ITS CARBON FOOTPRINT

Tomasz NITKIEWICZ[1*], Karolina WISZUMIRSKA[2], Marcin RYCHWALSKI[3]

[1] Częstochowa University of Technology, Department of Management and Entrepreneurship; tomasz.nitkiewicz@pcz.pl, ORCID: 0000-0003-2983-9195
[2] Poznań University of Economics, Department of Industrial Products and Packaging Quality; Karolina.wiszumirska@ue.poznan.pl, ORCID: 0000-0002-0381-5032
[3] Cracow University of Economics, Department of Products Technology and Ecology; marcin.rychwalski@uek.krakow.pl, ORCID: 0000-0001-5557-4448
* Correspondence author

Purpose: The strive towards circularity within the packaging sector has been an ever-growing challenge. Regular paper seem to be a good solution due to its natural and renewable origins and relative ease in its end-of-life processing. Food products require defined barrier and mechanical properties and seal functions that cannot be provided by regular paper or cardboard. The underlying objective of the paper is to indicate the best scenarios with regard to circularity challenge. Possibly, the implementation of innovative, highly functional, and recyclable coated paper/cardboard materials for food packaging applications would allow to replace traditional multi-layered plastics.
Design/methodology/approach: The objective of the paper is to verify the environmental performance of selected coated paper material over its counterparts from multi-layered plastics with the use of the Carbon Footprint approach (CF). CF is used to compare the environmental impacts of a chocolate tablet life cycle with the use of different packaging materials: coated paper (CPCS) and oriented polypropylene (oPP). A special focus is on the recyclability issue of the packaging materials and their contribution to overall environmental performance.
Findings: The results show that CPCS packaging has a slightly lower CF. Overall, CPCS packaging is contributing half of CF in comparison to oPP packaging. The difference is higher as far as packaging manufacturing is concerned, but due to the higher weight of CPCS packaging for chocolate tablets, its contribution to CF in whole life cycle rises.
Research limitations/implications: Since the assessment is made during the packaging testing process, its results are not yet final and could be due to change if the composition of CPCS will due to some further changes. Secondly, the shelf life tests are not finished yet and do not impact the life cycle so far.
Originality/value: The study is focused on the assessment of innovative coated paper packaging and investigates its CF in comparison to currently used packaging material for chocolate tablets. Its results could contribute to the selection of more sustainable and circular packaging.

Keywords: coated paper materials, food packaging, carbon footprint (CF), circular economy, life cycle management.

Category of the paper: research paper.

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Introduction

Food packaging is one of the most important actors in the food supply chain, as it protects and preserves the quality and safety of food products and extends their the shelf life (Coles, 2013; Lenartowicz-Klik, 2020). As a consequence, food packaging has a high share of material and energy consumption within the food life cycle, as well as a significant contribution to its emissions, waste generation, and related environmental impacts (Czarnecka-Komorowska, Wiszumirska, 2020; Meng et al., 2023; Xia et al., 2024). Finally, in contrast to most of the other products, the packaging itself has the highest contribution to the impacts that occur in the end-of-life phase, when product has been consumed. It seems that the challenge of sustainability and circularity is putting the food life cycle under high pressure with regard to the recyclability and biodegradability of their packaging materials (Gutierrez, Meleddu, Piga, 2017; Czarnecka-Komorowska, Wiszumirska, 2020; Kan, Miller, 2022; Adibi, Trinh, Mekonnen, 2023; Ferrara et al., 2023; Meng et al., 2023).

The challenge is strongly mainstreamed by new regulations on extended producers responsibility and recycling targets, which are currently being issued in the EU but also in countries and regions across the globe. It is also highly supported by more and more aware consumers who are changing their preferences towards more sustainable packaging materials. Consumer demand and emerging guidelines of the European Commission are driving packages towards circularity by aiming for 100% reusable and/or recyclable packages in 2030 (European Commission, 2019). It seems that the challenge is being approached from many different perspectives and has evidently many paths to follow (Czarnecka-Komorowska, Wiszumirska, 2020; Adibi, Trinh, Mekonnen, 2023; Liang et al., 2023; Meng et al., 2023; Xia et al., 2024). In current paper, we follow one of them that was settled by the REPAC[2] project consortium and is currently being faced by its research and industrial partners. The paper reflects only midway and partial results of the project. The approach is focused on paper/cardboard materials for food packaging, which are one of the key solutions in the food sector. But to achieve the potential increase in its use, together with the improvement of its sustainability and achievement of circularity in its use, it needs transdisciplinary and strategic approach (Wojnarowska, Ćwiklicki, Ingrao, 2022).

The need for a transdisciplinary and strategic approach could be illustrated by the constraints that set the landscape for food packaging development (Lenartowicz-Klik, 2020). The first constrain that should be considered is the specificity of the product itself and the functional and hygiene requirements of the packaging material and its application. The diversity of food products and enormous number of their market variants require packaging that is appropriate for each one of them (Coles, 2013; Mizielińska et al., 2018b, 2018a; Kaszuba, Frydrych, 2021; Wierzchowski, Bartkowiak, 2022). This food product and packaging nexus is itself an area that needs to join several different fields of knowledge and practice. The second constraint comes from the economic and logistic aspects of food supply chains that dominate the decision-making nowadays (Nitkiewicz, 2021, pp. 246-260). The accessibility and costs of materials, their weight and shape options, transportation convenience, storage conditions, or marketing potential define the scope of the second constraint (Mizielińska et al., 2018b, 2018a; Lenartowicz-Klik, 2020; Szumicka, 2022; Wierzchowski, Bartkowiak, 2022). The final constraint is related to the current sustainability and circularity objectives of production and supply chain activities and their consumption counterparts. This final constraint is often the objective of advanced innovation processes in order to be consistent with a first constraint and remains unclear and yet not achievable as far as its expected potential is concerned (Adibi, Trinh, Mekonnen, 2023; Ferrara et al., 2023; Liang et al., 2023; Meng et al., 2023; Xia et al., 2024). This constraint is often in opposition to the second constraint and requires decades of practice and searching for its market-accepted embodiment. The final constraint requires strategic approach and medium- and long-time horizon in order to have all the consequences visible and considered within decision-making process.

In the paper, we focus on paper-based packaging material, which is adjusted to the requirements of food packaging through the application of a coating. The idea comes from the need to replace fossil based plastic packaging with some counterpart that could outperform them with regard to sustainability and circularity performance. The selection of coated paper comes with a certain assumption concerning its manufacturing, use, and recyclability phases.

The White Paper of World Economic Forum recommends the use of the following strategies in order to equip paper-based packing with circularity and sustainability advantages (WEF, 2016): 1) eco-design, 2) eco-management and 3) environmental impact reduction.

The REPAC² project will contribute to achieve the abovementioned results by increasing the fraction recyclable paper-based packaging and potentially decreasing of the fraction unrecyclable plastic packaging. This achievement will be achieved through recycling-oriented eco-design, eco-management through optimization of end-of-life processing from the perspective of packaging and food producers, resulting in a decrease in packaging-related emissions.

According to the CEPI recommendations, when designing alternative barriers, the following aspects should be considered and verified (CEPI, 2020):

- Ensure that paper fraction of the packaging breaks down into single fibers when pulped within a specified time frame.
- Give preference to polymers and other sealing agents that can be removed from the fiber in the conventional screening process.
- Give preference to polymers, sealing agents and application processes that can be dealt with efficiently by the paper mill process and effluent water systems and do not compromise the finished product, the production process or the environment whilst being recycled.
- Metallic and other inorganic coatings applied via vacuum deposition shall not hinder the repulping process and shall be capable of being screened out.

Using coated paper has the potential to meet the functional criteria of food producers and, at the same time, foster the achievement of recycling goals. Unlike paper-plastic laminates and plastic multilayers, coated paper has a potential to fit into existing paper recycling system and outmatch the alternative packaging due to its recycling properties and eco-management of its reverse logistic flows.

Methods and materials

In order to illustrate the challenge of circularity and sustainability by developing the coatings and coated paper packings for the purpose of replacing fossil based, unrecyclable plastic packaging on food market a single research case is presented. The case is based on ongoing process of coated paper packaging development and uses it's up to date evidence to assess the environmental impacts and circularity issues within. The research case is based on solid chocolate tablet (without filling) as a food product. The investigated product is packed within 3-sided sealed pouch with horizontal form-fill-sealer (HFFS). For the purpose of achieving shelf life of 2 years for a chocolate tablet it is important to keep OTR[1] and WVTR[2] parameters below certain levels. Not achieving appropriate barrier protection versus oxygen or water might result in chocolate crystallization and "white skin" appearance as a consequence. Besides, such parameters as seal strength, mechanical resistance, barrier properties or printability issues are also important in developing safety and market ready product. In our study we consider actual packaging of chocolate tablet that is oriented polypropylene (oPP) and its potential alternative – paper coated with cold seal adhesives (CPCS). Both types of packaging are printed.

CPCS packaging is considered as recyclable together with paper fraction of waste. The additive of coating is less than 5% of a total weight of a packing and should not influence the paper recycling process.

The environmental assessment is made with Carbon Footprint method – namely Global Warming Potential (GWP) that was developed by International Panel on Climate Change (IPCC) in 2013 and later updated in 2021. This approach to the assessment of food product packaging is quite common, but the preference is to use more advanced variants of life cycle assessment. It is worth to notice that different approaches take into account a food product within a packaging (Gutierrez, Meleddu, Piga, 2017; Adibi, Trinh, Mekonnen, 2023; Meng et al., 2023), or the packaging only (Ingrao, Gigli, Siracusa, 2017; Xia et al., 2024). The method used for the assessment is denoted as IPCC 2021 GWP100 v. 1.01. The method takes the time horizon of 100 years as a point of reference. The method is based on characterization of impacts,

[1] OTR – oxygen transmission rate [$cm^3/(m^2 \cdot 24h)$].
[2] WVTR – water vapor transmission rate [$g/(m^2 \cdot 24h)$].

which are expressed in single unit of emitted kg of CO_2-eq. Impact factors within GWP100 are referring to the source of generated carbon footprint and include such categories as fossil, biogenic and land transformation sources (PRé Sustainability, 2022). The assessment is made in form of CF screening (European Commission DG Environment, 2010; Fields, Simmons, 2014; ISO, 2018; Liang et al., 2023).

Results of Carbon footprint of a chocolate tablet and its packaging

Goal and scope of the assessment

The major goal of the assessment is to verify whether coated paper packaging could outmatch its plastic based counterpart with regard to circularity and sustainability. Since it is a first part of a wide research on coated paper packaging, we focus here on the Carbon Footprint assessment that could bring out very specific conclusions concerning both concepts.

Functional unit for the assessment is a chocolate tablet of 100 g within two variants of packaging: a) oPP of 22 g or b) CPCS of 30 g. Since the CPCS testing is not yet finished the assumption is that the shelf life of a tablet is 1 year. The following life cycle phases are included in the study: supply of resources for manufacturing, manufacturing, transport to distribution and end of life processing. The phases of distribution itself and use are excluded from the assessment. This is due to lack of CPCS testing results and possibility to model chocolate shelf life in accordance to its storing conditions.

Life Cycle Inventory

Since the functional unit is assessed within two variants the inventory data is collected for both of them. Chocolate tablet remains the same for each one of them while the packing inventory is changing within supply and manufacturing process, transport in distribution and end of life processing. Table 1 presents the primary data for functional unit and its life cycle inventory except for end of life processing. Packaging section is divided for CPCS and oPP packaging while primary resources are concerned.

Table 1.
Life cycle inventory for functional unit

CHOCOLATE TABLET			PACKAGING	
Type of material Volume [kg per kg of the product]				
sugar	0,4860		Paper	0,30003
cocoa mass	0,1202		Inks	0,00062
cocoa butter	0,1874		Heat seal additive	0,00337
whole milk powder	0,0661		Oil barrier additive	0,02100
skimmed milk powder	0,0651		Cold Seal	0,04380
whey powder	0,0501		Food contact varnish	0,02280

Cont. table 1.

milk fat	**0,0200**			
emulsifier lecithin (from soy)	0,0058		oPP	0,022
emulsifier E476	0,0010		Cold Seal	0,04380
vanilla extract	0,0002		Inks	0,00062
Transport (supply) Distance*weight [km*kg]				
Truck, EURO5	303,0000		Truck, EURO5	1093,9250
Reagents and chemicals [kg/kg of the product]				
Cleaning agent	0,000255		Solvents	0,000394
Automatic cleaning agent	0,000027			
Rinse aid agent	0,000002			
Type of energy used, energy source [MJ/kg]				
electricity (country mix)	0,48632301		electricity (country mix)	0,864
Type of fuels used [m3/kg]				
natural gas	0,021657		natural gas	0,0011
	[kg/kg]			
propane butane (for internal transport)	0,000235686			
Water use [m3/kg]				
water	0,000612		water	0,336
Internal transport - Distance*weight [km*kg]				
small truck, EURO5	1		electric forklift truck	1
Distribution packaging [kg/kg]				
display 100g x 20 pcs	0,0275		wooden pallets	0,06
pallets (288 cartons/ pallet)	0,039930556		stretch foil	0,02
strech foil	0,000868056			
foil separator	0,000089583			
carton separators	0,00146875			
carton corners	0,000472222			
Transport (distribution) - Distance*weight [km*kg]				
small truck, EURO5	460			

Source: author's own research calculated in SimaPro software

The end of life phase is included in the assessment with the following assumptions:

1. Chocolate tablets are consumed and present no impact within the use phase of its life cycle.
2. A packaging as a whole is considered to be a waste that is collected separately from consumers (CPCS with paper fraction, oPP with plastic fraction of municipal waste).
3. Recycling scenarios are based on specific share of material actually recycled with accordance to current data on European recycling levels separately for paper and plastics.
4. The fraction of the waste that is not recycled is considered to be processed in accordance to standard procedure for specific fraction and includes incineration and landfill processes.

According to the abovementioned assumptions, the recycling rates are set for European average with regard to the processing technologies, as well as the level of recycling (Haupt et al., 2018).

All the inputs are taken directly from chocolate and coated paper manufacturers being raw data or estimates that are based on total use of media, electricity and resources. The transportation is an external process, as far as supply and distribution is concerned, and its data is estimated on basis of distance, load and averaged type of vehicles used by the third-party logistics operators or suppliers. All the material, energy, transportation and waste flows are modelled with support of Ecoinvent and AgriFootprint databases.

Life cycle carbon footprint assessment

As mentioned before GWP100 method is used to calculate carbon footprint for the functional unit. The assessment is made within SimaPro 9.4 software. Figure 1 shows the total Carbon Footprint for both analyzed variants with regard to contributing manufacturing processes: packaging, chocolate tablet and distribution packaging. The major impacts are related to the manufacturing of a chocolate tablet. The packaging itself contributes to 11,5% of CF in coated paper variant and barely 12% in oPP variant. The impact of distribution packaging is negligible.

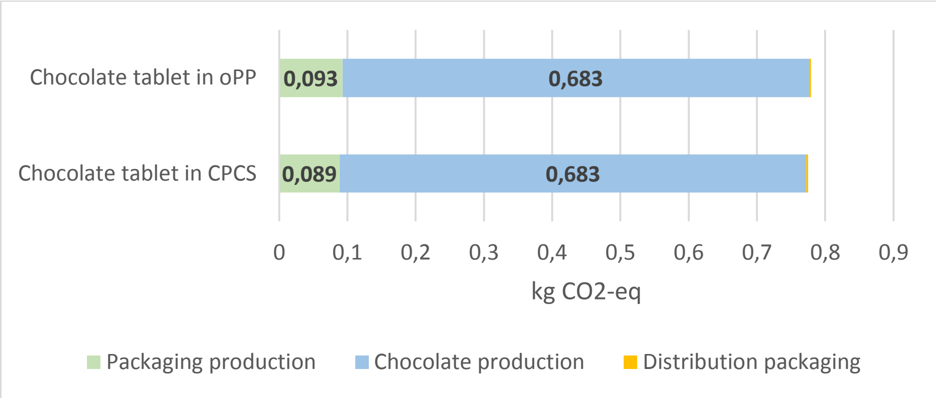

Figure 1. Total CF for both variants of functional unit – contribution of different production processes. Source: author's own research calculated in SimaPro software.

The structure of CF is presented in Figure 2. For both variants the fossil-based sources are the most significant. Land transformation is the second highest source of impact while biogenic sources are responsible for 7% of total impacts.

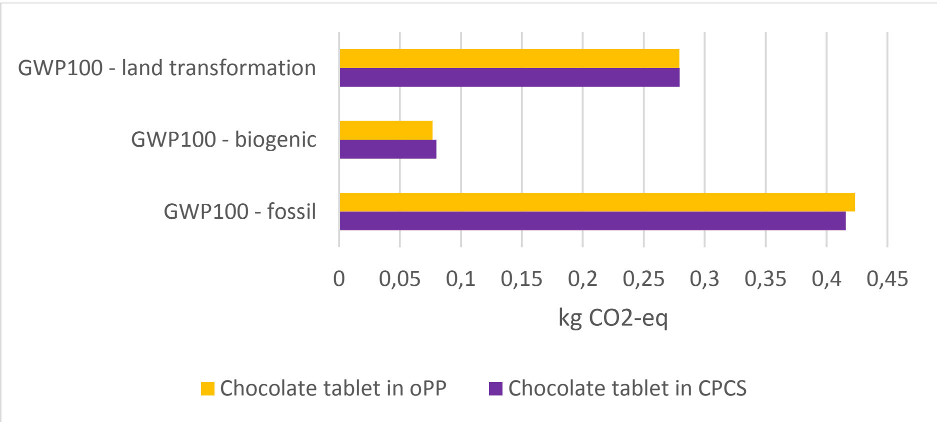

Figure 2. The structure of CF sources for both variant fo functional unit.
Source: author's own research calculated in SimaPro software.

Discussion

In order to investigate the differences between the two variants of packaging, the manufacturing process of packaging production is investigated separately. **Figure 3** presents the contribution of major processes for CF of both investigated packaging. The production process of oPP is more than twice impactful, while CF is concerned. The manufacturing process that includes the supply of resources and its transformation is the most significant contributor to total CF in both cases. The transportation of raw materials, and for some part transportation in distribution is the second highest contributor to CF. Surprisingly, energy use, including electricity and fuels for manufacturing machinery, has only slight contribution to CF. Finally, and surprising again, the recycling processes bring "negative" results for both packaging but with evident dominance of oPP packaging. This is surprising due to the assumed higher recyclability of paper-based packaging.

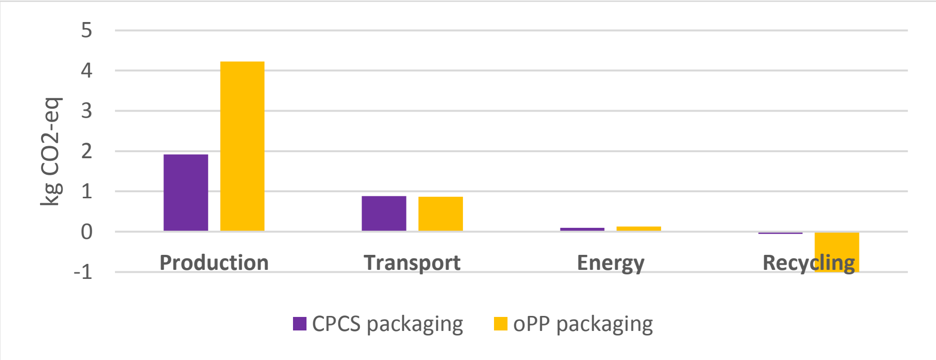

Figure 3. Contribution of selected processes to overall CF for both packaging.
Source: author's own research calculated in SimaPro software.

Closer look at the structure of flows, as shown on **Figure 4** and **Figure 5**, brings out the reasons for that contribution. PP as a secondary material is supplementing more harmful raw PP material, and, therefore, brings much more valued environmental benefit. The assumed recovery of 81,5% of paper for pulp production is contributing in merely 3,8% to decrease of total CF of CSCP packaging, while, recovery of 60% of plastic contributes to 27,5% decrease of total CF for oPP packing.

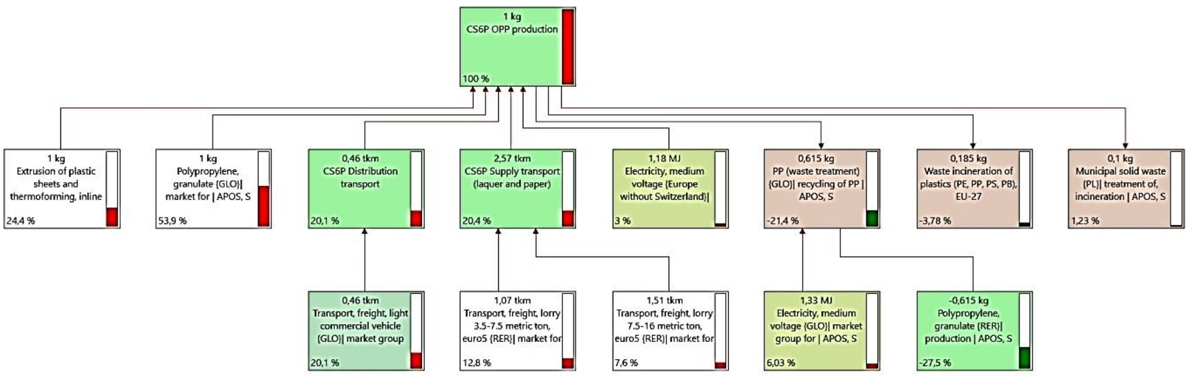

Figure 4. Contribution of processes and material and waste flows to the CF of oPP functional unit.
Source: author's own research calculated in SimaPro software.

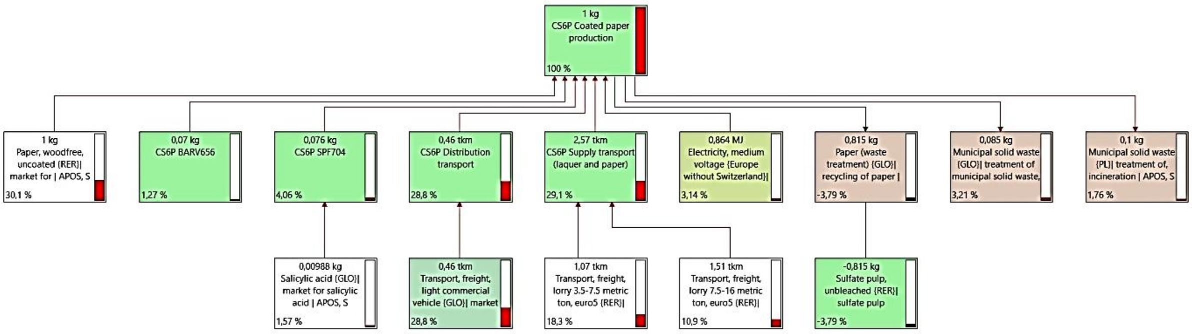

Figure 5. Contribution of processes and material and waste flows to the CF of CPCS functional unit. Source: author's own research calculated in SimaPro software.

Summary

These results do not change the hierarchy of the two packings while total CF is concerned. Overall, CPCS packaging is contributing half of CF in comparison to oPP packaging. But if we consider the holistic view of sustainability and circularity, the conclusions could be a bit more complex. First of all, the life cycle of CPCS packaging has more visible reverse flows, with significantly higher rate of circularity for of major flow of paper. In case of CPCS, the return flow of pulp could be directly used in the same life cycle. The recycling of plastics is more complex process due to the collection of different plastic fraction and common processes of their processing. PP might be partial result of the recycling process, but as the evidence from European data shows, it constitutes relatively smaller share in comparison to PE or PET recovery (Haupt, Kägi, Hellweg, 2018).

As for the sustainability aspects of analyzed packaging, it is important to underline the role of eco-management in its life cycles. Eco-management should take into account the different perspectives of running food product and their packaging life cycles and should support them with valuable decision-making variables. If the waste processing system is well developed, perhaps it is advisable to check the possibilities of oPP packing collection and recycling before the experimental change to CPCS packaging is introduced. On the other hand, less developed recycling systems could handle paper packaging in a more efficient manner and could contribute to sustainable CF performance of its life cycles.

Finally, the eco-design approach is also important for perfecting the match of a food product with sustainable packaging. If the functional requirements are met within innovative CPCS packaging, it is the green light for its implementation. But if the requirements are not yet met or some proofs and experiments are missed, it is better to finalize the development process and avoid a potentially unsatisfied consumer.

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