TRANSITIONING FROM CONVENTIONAL PLASTIC TO MORE SUSTAINABLE ALTERNATIVE MATERIALS: EVIDENCE FROM SOUTH AFRICA

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ABSTRACT

The Council for Scientific and Industrial Research in partnership with UNIDO and the University of the Witwatersrand, with funding from the Japanese government, undertook research to identify and implement opportunities for sustainable alternative materials, including biodegradable plastic in South Africa. The project aims are twofold: 1) to develop an action plan to support sustainable transition to alternative materials and 2) to strengthen plastic recycling through encouraging waste separation at source and integration of informal waste collectors in a circular economy.

This paper reports on the findings from research activities to determine the most appropriate alternative materials for consideration when transitioning to more sustainable alternatives. The results include that of the LCA study, availability of end-of-life treatment options for alternative materials, demonstration of the identified technologies/materials, the potential to produce alternative materials locally, and the Action Plan for South Africa to make the transition.

KEYWORDS

Biodegradable plastic, LCA, sustainable development

INTRODUCTION

With an increase in plastic production from 15 Mt in 1964 (WEF, 2016) to 368 Mt in 2019 (Plastics Europe, 2021), plastic has become the workhorse material of the modern economy (WEF, 2016). Despite its unique combination of unrivalled properties and a collection rate of 14% for recycling, 95% of plastic packaging material is lost to the economy after a single use. Furthermore, an estimated 32% of plastic packaging escapes global collection systems (WEF, 2016) and contributes to marine pollution, open burning, or simply leak into the environment. The vast majority of plastics (90%) are derived from virgin fossil feedstocks accounting for 6% of global oil consumption (WEF, 2016) which is predicted to grow to 20% of the total global oil consumption and 15% of the global annual carbon budget by 2050 (WEF, 2016) on the current trajectory. It is therefore not surprising that the plastic sector is currently under scrutiny to reduce its environmental footprint.

The visibility of plastic pollution and the scale of plastics leaking into the oceans have exacerbated the attention on the impact of plastics in the marine environment. The Japanese Government has prioritised addressing the global marine litter challenge and committed to support developing countries in their efforts to combat marine litter through capacity building and waste management infrastructure development focussing on plastic waste. With funding from the Government of Japan, UNIDO implemented a project titled "Support for transitioning from conventional plastics to more environmentally sustainable alternatives" in partnership with the Council for Scientific and Industrial Research (CSIR) and the University of the Witwatersrand in South Africa with two distinct components:

Component 1 focussed on identifying and implementing opportunities for local production and management of sustainable alternative materials to replace the use of conventional plastic in specific applications, including biodegradable plastic and their end-of-life treatment requirements, if feasible.

Component 2 supported the plastic and packaging industry in their recycling efforts by strengthening capacity for plastic collection and through the integration of the informal waste sector. The focus of the project was on the implementation of capacity building activities, including procurement of necessary equipment, and training to enhance the capabilities and capacity of informal collectors for waste separation and recycling.

The focus of this paper is the evidence collected under component 1 of this project.

IDENTIFIED PRODUCTS FOR REPLACEMENT

The project identified plastic products that are of concern in the South African context, and for which replacement could potentially contribute to the South African economy through local production and conversion. It is acknowledged that material replacement is not a silver bullet solution to reducing the carbon footprint of plastic or material leakage into the environment, but replacement may be beneficial from a life cycle and pollution impact perspective. Careful consideration is therefore required to ensure that replacement materials are indeed more environmentally sustainable throughout the product's life cycle.

The following criteria were used to identify the products with potential for replacement:

- *Is the product currently being recycled*? - to ensure that current recycling industries are not displaced by replacement. If the product is currently recycled, then the focus should be on increasing collection and recycling rates rather than replacement.
- *Is it likely to be recycled in the near* future? – to ensure that research and development investment as a result of extended producer responsibility (EPR) or other policy changes are not unduly interrupted.
- *Does the relevant product responsibility organisation (PRO) identify the product as suitable for material replacement*? – PROs as industry champions for EPR has an important coordination role to play to limit unintended consequences of uncoordinated replacement efforts.
- *Are there commercially available alternative materials to allow for rapid uptake and implementation by manufacturers*? – Many innovations and improvement efforts that show potential have proven to be too fragmented and uncoordinated to have impact at scale. Furthermore, drop-in solutions that can be used in existing manufacturing processes with limited to no adverse effects on business should be favoured over disruptive technologies.

The list of identified products following the criteria and for which alternatives are available in the market is presented in Table 1.

Table 1: Products for which alternatives are available in the market

Product	Polymers used	Commercially available alternatives
Biscuit wrappers	Composite /multi layered/ other	Starch based PLA (Polylactic acid) based PBAT (Poly(butylene adipate-co-terephthalate) based
Candy wrappers	Composite /multi layered/ other	Solanyl – Potato starch-based packaging
Chip packs	Composite /multi layered/ other	Natureflex from Futumura# PHA (Polyhydroxyalkanoates) based laminate
Cling wrap (household)	PVC (Polyvinyl chloride) LDPE (Low density polyethylene LLDPE (Linear low density polyethylene)	PLA based Parchment paper Beeswax paper
Cutlery	HDPE (High density polyethylene) PP (Polypropylene) PS (Polystyrene)	Biopolymer (PLA, Starch) Bamboo
Earbuds	Composite /multi layered/ other	Bamboo PLA based
Take-out containers	PS PET (Polyethylene terephthalate) PP	Paper$ Bagasse$ PLA PBS (Polybutylene succinate) PBAT or PSM (Plastarch material)
Straws	PP	PLA Bamboo Paper Stainless steel (Reusable)

Laminate of two compostable materials

$ Both requires a water/grease proof barrier (e.g., PE/biopolymer internal lining)

Decisions on which of these products to replace with which one of the alternatives must be informed by evidence on the sustainability of each material option throughout the entire life cycle of the products including end-of-life management and disposal. The environmental sustainability of polystyrene take-out containers and cups was analysed further as an example of the process to follow to inform decisions on replacement and with which alternative.

LIFE CYCLE ASSESSMENT OF POLYSTYRENE TAKE-OUT CONTAINERS AND CUPS

The life cycle impacts of polystyrene take-out containers and cups (meal-kit) and various alternatives were assessed using attributional life-cycle assessment (LCA) and the ReCiPe 2016 Midpoint(H) method (Huijbregts et al., 2016), that considers 18 environmental impact categories. Given the lack of a plastic pollution impact category in existing methods, we have developed two additional indicators, namely 1) Persistence (Stafford et al., n.d.) and 2) Material pollution to assess the pollution potential of plastic (and other materials) in the environment. The functional unit was based on the estimated consumption of take-out meals in South Africa and attention was placed in modelling the end-of-life stage to represent the South African context. Economic-based allocation was applied to ensure correct allotment of burdens to products and recyclate production was modelled using system expansion.

The main findings from the LCA study are as follows:

- Raw material extraction and polymer production stages in the product life cycle are responsible for the bulk of the environmental impacts associated with the meal-kit use in South Africa.
- Polystyrene came out as the preferred option from a pure LCA perspective, followed by paper/cardboard and bagasse.
- Adding persistence and material pollution as indicators, biodegradable plastic, biobased plastic, bagasse, and paper are all less persistent in the environment than conventional plastic.
- Polystyrene is at least four hundred times worse in terms of material pollution than paper.
- Local production of all investigated options performs worse from an environmental perspective in LCA, due to the use of fossil fuel generated electricity and Coal-2-Liquid production process (Fisher-Tropsch synthesis) for monomer production.
- Alternatives to conventional plastic with lower environmental burdens are paper/cardboard (locally produced/manufactured), bagasse and PBS (both imported as finished products), with the latter showing potential for organic recycling in industrial composting facilities.
- Increasing recycling rates of current available meal-kits will improve the overall environmental performance of all conventional plastic alternatives by about 30% over a 5-year period (as per EPR Regulations targets)
- Increased recycling of biodegradable and compostable alternative materials will improve the environmental performance by 40% over the same period.
- Using different coating material (biodegradable biopolymers) than PE show a further improvement on the overall environmental performances of both the Bagasse and Paper meal-kit material alternatives; can improve their natural biodegradability of from a persistence and material pollution perspective; and
- may positively impact on the production of the meal-kit (less resource intensive) and at the End-of-Life when organic recycling can be implemented.

These results are well aligned with those from international LCA studies on single-use and re-usable cup and take-out containers, which showed that single-use cups have similar environmental impacts regardless of the material they are made of, with paper to be preferred also to re-usable alternatives if recycling rates can be increased (up to 80%). Single-use food-packaging made of polystyrene (PS), extrusion-gassed polystyrene (XPS) and paper have often a better environmental performance than packaging alternatives made of other materials (PET, PLA, PP and Aluminium) and packaging lightweighting (without compromising its functionality) also show improvements in the environmental performance. However, an important observation from this study is the lack of South African specific data in the LCA datasets.

Since commercially available alternative materials are already applied in South Africa, it was also important to evaluate the availability and location of appropriate treatment technologies in the South African context.

END-OF-LIFE TREATMENT OPTIONS

The typical treatment options for the alternative materials are mechanical recycling, composting, anaerobic digestion, chemical recycling, pyrolysis, thermal destruction, and landfill. Since South Africa is transitioning to a circular economy, landfilling is no longer a feasible option.

Composting of biodegradable plastic requires additional treatment at composting sites to ensure that it does not negatively impact on the end-products and therefore increase the operational costs at these facilities. Thus, composting plants require incentives to accept biodegradable plastic for treatment. Furthermore, biodegradable plastic are reported to come with an expiry date. This means that treatment facilities should also be able to accept and manage relatively large batches of pre-consumer expired product. Composting facilities may therefore be reluctant to accept relative high volumes of expired batch products which are likely to impact on the quality of their end-product. Consequently, alternative management options such as recycling or incineration would be advisable for expired products.

The main finding from the end-of-life treatment perspective is that most of the biodegradable alternative materials require industrial scale facilities which are currently in short supply in South Africa. There is also a high risk of contamination with non-biodegradable plastic and therefore separation at source and accurate sorting are required. The end-of-life treatment options per alternative material are summarised in Table 2.

Table 2: Summary of treatment options available for plastic alternatives from literature

Alternatives	Alternative treatment Options
PLASTIC ALTERNATIVES	
Poly butylene adipate-co-terephthalate (PBAT)	**Mechanical Recycling:** Prescence of moisture interferes with the recycling due to hydrolysis of the PBAT. Pre-drying mitigates this. **Composting:** Will compost under both Home and Industrial conditions. Microbial degradation using *P. mendocina* and *A. elegans* synergistically degrade PBAT. **Anaerobic conditions:** Does break down under anaerobic conditions however, only very slowly. This could be enhanced sped up by *Clostidium botulinum.*
Poly lactic acid (PLA)	**Mechanical Recycling:** Maximises energy saving. **Composting:** Only under thermophilic environment conditions, this is easier achieved under Industrial Conditions. Home composting unable to achieve high temperatures required. **Anaerobic conditions:** Possible under mesophilic but better under thermophilic temperatures of 55°C. **Chemical recycling:** Catalysis (tin II octanoate) and at temperatures of 120°C (or higher) with a solvent (i.e. xylene) is also possible.
Poly butylene succinate (PBS)	**Mechanical Recycling:** The polymer can be manually recycled and extruded. **Industrial Composting:** Will degrade under industrial composting conditions in approximately 90 days. **Home composting:** Will degrade but slowly up to 12 months to breakdown. **Anaerobic conditions:** Degrades very slowly, however if blended with PLA this could be improved.
Mylar ™ (PET)	**Recycling**: Most favoured treatment option in use in South Africa. **Pyrolysis**: especially for contaminated feedstock). **Co-pyrolysis**: using Zeolite and Red Mud. **Microwave pyrolysis**: Between temperatures of 500°C to 900°C to produce a mixture of alkanes and alkenes the proportion is dependent on the temperature.
Latex	**Landfilling:** From a resource recovery and waste hierarchy position this is the least preferred option. **Chemical Disposal**: De-vulcanization is using tetra methyl thiuram di-sulphide in presence of spindle oil at approximately ambient temperature. **Ultrasonic-based**: Using a frequency of at 40 kHz and ultrasonic amplitudes from 5 to 13 µm. **Microwave treatment**: Sulphur bonds can be broken or formed by microwaves treatment. **Biological de-vulcanization**: Possible using a number of bacterial species.
NON-PLASTIC	

ALTERNATIVES	
Bamboo	**Landfilling**: Not recommended due to ongoing ban on organics to landfill. **Thermal destruction**: As a green energy resource. Composting in home and industrial conditions
Beeswax paper (reusable)	**Landfilling**: Not recommended due to ongoing ban on organics to landfill. **Thermal destruction**: As a green energy resource.
Smokey treats ™ – biodegradable cigarette filters	Unknown
Natureflex ™	Unknown
Solanyl ™	Unknown
Paper Substitutes	**Mechanical Recycling**: Mature industry in South Africa. **Thermal combustion**: usually reserved for soiled feed stock material.
Steel Substitutes	**Mechanical Recycling**: Mature industry in South Africa.

Investment in end-of-life treatment infrastructure will require economies of scale and therefore coordinated interventions are required when transitioning from conventional plastic to alternatives.

DEMONSTRATION OF BIOPLASTIC PRODUCTION AND CONVERSION

Demonstration of technologies applied to material alternatives have confirmed that there is potential for local conversion of biopolymers. Trials done using three different grades of PHBH concluded that one grade (PHBH-151C) is suitable for flexible product applications and the other two grades (X331N and 080X) are suitable for injection moulding of rigid products. Research on prototype development by the CSIR is ongoing.

Local production of alternative materials was considered by the Industry-meets-Science Series workshop on bioplastic (DST, 2016) which confirmed that establishing a local bioplastic industry in South Africa is feasible, given the availability of abundant biomass feedstock. The main challenges to overcome (DST, 2016) are:

- Lack of systems to categorise and record available biomass;
- Market competitiveness of bio-based materials (PAGE, 2019); and
- Perceived absence of economic incentives and legislative drivers.

IDENTIFIED ACTIONS

For South Africa to transition from conventional plastic to more sustainable alternative materials, the following interventions are required:

- Decision support ensuring improved sustainability;
- Gate keeping preventing green washing through testing and verification;
- Support for local production enhancing the South African economy;
- Investment in end-of-life infrastructure.

The summary of the Action plan is provided in Table 3.

CONCLUSIONS

Plastic pollution in the environment is a global concern which have resulted in the introduction of alternative materials. However, it is acknowledged that transitioning to alternative materials is not a silver bullet to address the plastic pollution and leakage problem. There is a real concern that replacement of materials may simply shift the pollution away from conventional plastic to other materials.

The life cycle assessment of the meal-kit is a case in point. Polystyrene has been confirmed as the best alternative up to the point of consumption but becomes an environmental burden if not managed appropriately. In the current waste management scenario in South Africa, replacement of plastic with compostable alternatives will likely simply add another material to the leakage problem due to the short supply of industrial composting facilities. Furthermore, biodegradable plastic add complexity to the sorting of waste which is currently mostly undertaken by the informal sector. It is therefore likely that replacement may have a negative impact on current recycling rates. It is further important to note the difference in economic value of conventional plastic for recycling, as compared to compostable plastic for composting. Recyclable plastic has a resource value, as indicated by the willingness of recyclers to pay for the material whereas composting companies are likely to charge a fee to accept compostable plastic to cover the associated additional processing costs.

It is therefore crucial that replacement decisions must be based on scientific evidence confirming the increased sustainability of the alternative material over conventional plastic. Furthermore, replacement decisions must be made in a coordinated way to prevent unintended consequences such as contamination of already established recycling waste streams and to ensure investment in appropriate end-of-life treatment facilities at the required scale and geographical distribution to avoid leakage into the environment.

Table 3: Action plan summary

INTERVENTION	ACTIONS	TIME FRAME	RESPONSIBILITY	COMMENTS
Decision support	• Update of the official LCA datasets with RSA data. • LCSA methodology development and testing	Short term	CSIR	• The CSIR have initiated engagements for the update of the datasets • LCSA methodology is under development but must be published in a peer reviewed journal before it can be applied as accepted method
Gate keeping	• Increasing testing capacity to verify claims of biodegradability. • Development of standards for alternative materials to prevent green washing. • Establishment of a certification body for compostable products • Promote labelling requirements for biodegradable products	Short term	CSIR NRCS/SABS	• CSIR testing labs have been upgraded with UNIDO support. The accreditation of the biodegradation testing laboratory is in process. • NRCS and SABS have initiated the process to develop relevant South African Standards • CSIR and SABS are in discussion to establish a body for certification of locally produced and imported products claiming to be compostable • CSIR and SABS are in discussion about labelling requirements specifying time-frames and conditions of biodegradation
Support for local production	• Confirmation of available feedstock (sources, characteristics, location) • Creation of competitive markets	Medium term	DFFE/DTIC	•

	• Development of economic incentives for industry to produce locally • Development of legislative drivers to support local production • Research and development support for development of novel biomass-based materials and product designed for enhanced circularity			
Investment in end-of-life infrastructure	• Extended producer responsibility schemes for all products. • Strategically located industrial composting facilities to deal adequately with all end-of-life biodegradable polymers. • Increased and adequate integrated waste separation at source (separation at source that integrates waste pickers and adheres to the Waste Picker Integration Guideline and Integration Principles) to optimize the appropriate end-of-life treatment of all materials. • Optimised waste collection systems that build from waste pickers' existing system and integrate waste pickers to maximise collection of all conventional and alternative materials. • Optimised recycling of all recyclable materials.	Short term	DFFE, Local government, Relevant PROs	• The Compostable Plastics Council (COPCO) was formed in 2020 and is working towards establishing an EPR scheme for post-consumer waste management of compostable plastic • Refer to the waste picker integration guideline at https://wasteroadmap.co.za/wp-content/uploads/2021/02/Waste-Picker-Integration-Guidelines.pdf • Output 2 of this project have developed training and capacity building materials to support waste picker integration.

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