Building Africa's first circular business measurement framework

The results from our first group of businesses

3rd October 2022

FOOTPRINTS AFRICA

Contents

Introduction

Is there evidence to support the circular economy's promise in Africa?

The answer, quite simply, is: not yet.

The circular economy makes big promises on environmental harmony, prosperity and social inclusion. But the benefits of circular business models are not always backed up with data.

This report tells the story of our work to tackle the challenge of proving the benefits of circular business models across the continent.

What's our rationale?

At Footprints Africa we have mapped over 500 case studies of circular businesses from across the African continent - the most complete and detailed record to date. We are doing this to show how much we have to learn about business models from Africa - not outside of it - and to inspire people across the continent by sharing compelling existing examples of what's possible.

The next step: building evidence on the impacts of these business models. We shouldn't diminish the power of the business' stories we are uncovering, but we need to substantiate them with hard data. This will support business decision-making, help them attract funding, convince customers and regulators, and ultimately make the case for broad adoption of future-friendly practices.

To make this happen, Footprints Africa teamed up with the Sustainability Lab at the University of Messina. Since early 2022 we have been working with a pioneering group of five African circular businesses to measure both their circularity and impact. This report highlights our findings and makes recommendations for tangible next steps.

There's a second reason for doing this: we want to raise the bar. Research shows that the sustainability benefits of circular business models are often assumed rather than measured. The latest Intergovernmental Panel on Climate Change (IPCC) report has corroborated this point, saying that claims on the benefits of the circular economy for sustainability and climate change mitigation have limited evidence. Circular solutions can even have unintended negative consequences, such as where recycling involves the consumption of disproportionate amounts of (mostly fossil fuel) energy. So in building this evidence base we are working to distinguish the authentic, bold circular innovations we come across from 'greenwashed' examples, or business models which simply don't deliver on their promise.

A note to you, our dear reader

If you have opened this document hoping for a one-size-fits-all, silver bullet answer to measurement of circularity, let us save you some time by sharing one of our conclusions upfront: the process of measurement is as important as the output. The enquiry and mental machinations that go into spitting out a figure are themselves invaluable for strategic decision-making. For this reason, we deliberately refer to what is presented here as a "framework". Complex systems simply cannot be reduced to single digits.

How to read this report

We wrote this report to highlight the findings from applying a new measurement framework to five companies in Africa to measure the impact of their circularity. We want it to be for anyone interested in circular economy businesses and their impact. We have written it for you to dive straight into the section that interests you and so we have structured it as follows:

- To learn more about the measurement framework and the businesses in the pilot cohort, please go to **Section 1**.
- We reflect on the most important lessons that this work is teaching us in **Section 2**.
- Go to **Section 3** to find out more about each business' measurement process and what we found.
- Lastly, in **Section 4** we give clarity on the assumptions and data used in the presented calculations so as not to detract from the more concise account of each business' measurement journey.

About Footprints Africa's work

At Footprints Africa we started work mapping the circular economy in Africa because we believe in its importance in the light of the extraordinary changes that will happen on the continent over the coming decades. We are also focusing on helping circular businesses build evidence of their impact and explore new business models.

As part of this we are publishing periodic reports on the practices that we are learning.

Our first report showcasing circular economy businesses across Africa is here

Our second report on Regenerative Agriculture is here

You can find more information and a presentation on our extensive case study work on our site: www.footprintsafrica.co.

Profiling the five businesses in this report

Business name	Country/ies	Circular business model	Our focus in this report
LONO	Côte d'Ivoire	Biomass processing: autonomous, small-scale composting systems	Comparing the carbon impacts of a new product line with an old one
The Bug Picture	Kenya and Rwanda	Alternative animal feed proteins: using black soldier fly farming to convert organic waste to alternative animal feed protein and biofertiliser	Environmental impact comparison to test black soldier fly farming's benefits
Pyramid Upcycling	Ghana	Plastic recycling: recycling of plastic waste to produce construction and household products	Identifying impact hotspots in plastic waste recycling
WEEE Centre	Kenya	Electronic waste: collecting and processing various types of electronic waste for repair, upcycling and recycling	Testing the Circular Transition Indicators for an e-waste business
DigiYard (Arup)	South Africa	Waste construction materials platform connecting waste construction materials with builders	Designing a future measurement tool for a construction materials exchange

What we want to do next

Working with these five businesses has been a tremendous learning journey. As you will deduce when reading the report, there are many possibilities for what we can do next. In particular, we are looking for collaborators and working with businesses whose models and impact they want to measure.

We see these priorities as:

- Measuring the impact of more businesses: Footprints intends to undertake this work further with 50 businesses over the next 5 years.
- Producing guides: to make this work more accessible, we intend to transform our company-specific measurement work into guidance for circular businesses. These can also work as tools for the people who are supporting and investing in circular businesses.
- Measuring different kinds of impacts: in this cohort we focused mainly on emissions equivalent impact. Next we want to:
- Quantify social impact;
- Analyse businesses' most material impact domains through a materiality assessment with its stakeholders;
- Benchmark companies performance against competitors.

We need your feedback to understand how we can strengthen our work and make it more useful. Contact us at changemakers@footprintsafrica.co, or through LinkedIn to share your thoughts.

The framework

1

Finding the balance between ACCESSIBLE and RIGOROUS

Our first step was to find a tool that we could apply across a spectrum of circular businesses. It needed to be both accessible and rigorous enough to provide a reliable evidence base. For us accessibility meant taking into account the availability of data, cost of measurement and businesses' capacity to collect it. We also wanted to prioritise usefulness for the businesses themselves.

We chose the Strategic Circular Economy Impact Assessment (SCEIA) framework, developed over four years with support from the European Union's **Cresting project**. SCEIA is a modular[1] framework that supports companies to make better strategic decisions and to build evidence to share with their customers, investors, and other stakeholders. It has been road-tested with an expert panel of researchers and consultancies. Focus groups with five companies across Europe and Africa provided additional feedback to refine and improve the framework.

Benefits of the SCEIA Framework

Its design was done through a review of literature, taking elements from similar approaches. It does five important things:

It enables a holistic (multi-dimensional) assessment: it is designed to capture environmental, social and economic impacts of a business' activity.

It prevents 'burden shifting' to other parts of the value chain, taking a life-cycle perspective means taking a systems perspective. The SCEIA considers impacts from the extraction of natural resources, to their transformation using energy, to their use and, finally, disposal.

It builds on existing assessment tools. It makes use of methods such as Material Flow Analysis (MFA), the **WBCSD Circular Transition Indicators** (CTI) and Life Cycle Assessment (LCA).[2] You can find more information on the scientific basis for the framework **here**.

It helps businesses' strategic decision-making processes. The step-by-step process of the framework is grounded in what businesses need. Data and analysis need to be useful and support risk reduction in the big decisions that entrepreneurs are taking on material and business model choices.

It gives flexibility in terms of scale and measurement experience. The scale on which the framework can be applied depends on the goal of the assessment. It can scale from a single product to an entire organisation. Typically sustainability assessment methods are complex. That's sometimes a barrier for companies with no previous measurement experience. The SCEIA framework is more accessible because it's modular and adjustable to the measurement experience of a business.

1 This means that companies can define their priorities, and that the framework can be adapted to their previous experience with measurement. Not all steps are mandatory!

2 This is also recommended by the upcoming ISO Standard on circular economy measurement. See: **https://www.learn2improve.nl/circular-economy/iso-tc-323-circular-economy.**

The SCEIA framework visualised

Below you will find a snapshot of the key steps we apply through the SCEIA framework.

1. Starting point

- Recognize the need to make a circular economy decision
- Articulate a future vision for the business that measurement should align with
- Determine the business' measurement experience

2. Identification

- Set the scope and boundaries on what to include - and exclude.
- Data collection: Material and energy flows
- Do a materiality assessment to determine the areas of most significant impact

3. Diagnosis

Measure the impacts of the resource- and energy flows within the selected scope. Suggested methods include:

- Environmental impacts: Life Cycle Assessment (LCA)
- Costs: Life Cycle Costing (LCC)
- Social impacts: Social Life Cycle Assessment (S-LCA)

Steps 1 to 3 were the focus for this first cohort

4. Development

Develop circular strategies to address the key impact hotspots

5. Selection

- Choose the best circular strategy/ies using multi-criteria decision analysis
- Develop a plan of action

Steps 4 to 5 will be the focus of potential future follow up

Selecting the businesses

We have been working with a cross-section of circular businesses from our database of 500 circular case studies in Africa. We wanted to 'stress-test' the framework with different business models, ranging from agriculture, e-waste, plastics, construction, to black soldier fly farming. That means it's a deliberately diverse group, covering five different countries: Côte d'Ivoire, Ghana, Kenya, Rwanda, and South Africa.

The cohort's members had different measurement goals, including:

- Measuring the impact of a new design solution (LONO);
- Comparing circular with conventional products (The Bug Picture);
- Identifying their environmental hotspots (Pyramid Upcycling);
- Making an overall assessment of the business' circularity (WEEE Centre);
- Creating a measurement plan for a project still in development (DigiYard).

We began in February 2022 with scoping meetings to understand what mattered most to the businesses to measure. Next was an iterative data collection process, going back and forth between sharpening the data and measurement goals. In May and June, we presented the results to the cohort businesses, to reflect on what we learned, get their feedback and synthesise our findings.

Life Cycle Assessment (LCA) is a standardised decision-support method that allows assessing the potential environmental impacts of a product, process or services throughout its whole life cycle, from raw material extraction to the end-of-life. While data-intensive, it is often used by companies to get insights on the environmental impact of their activities.

We realise that this is early-stage work in applying the LCA to circular business models. While the LCA has been around since the early 1980s, its application to circular economy businesses only took off in the past few years. Overall, only a limited number of LCAs and similar studies have been conducted on the African continent in the past 20 years. Generally, circular economy measurement is still under development, with the International Standardisation Organisation preparing to publish guidelines and standardisation in the next year or so. For these and many other reasons related to scale and complexity, all the cohort's businesses indicated the need for environmental- and social data harmonisation and accessibility. Universities, governments and international institutions all have a role to play in increasing the harmonisation of environmental- and social databases.

What we are learning

2

Some initial conclusions

Working through the SCEIA with these businesses has been a tremendous learning experience. Here are some of the main things we have learned:

- **In every case we found that a circular economy strategy results in a reduction of the impacts that we measured.** In this first cohort, carbon emissions were in the spotlight. The first thing we need to emphasise is that carbon emissions only form a small part of the full environmental impact of a product or business. To capture a wider range of impacts, such as avoided deforestation for Pyramid Upcycling, or preventing groundwater contamination in case of The Bug Picture, more in-depth work would be needed.

- **The businesses found the results useful for two main purposes: (1) internal management improvements and (2) external communications.** Examples of internal insights include the use of the results in design- and transport choices (LONO, The Bug Picture), while Pyramid Upcycling, for instance, saw the opportunity to communicate the results to their peers. For WEEE Centre, the results highlighted data needs in a circular economy, and for DigiYard, the proposed measurement tool can be used in the next stage of development of the business.

- **The LCA is a useful tool - but it needs to be adapted for circular business models.** We used screening LCAs to arrive at the numbers. LCA is recommended by various researchers as an appropriate tool to measure the impacts of circular economy solutions. It has some drawbacks, however, because of its limited accessibility, data quality requirements and methodological challenges specific to circular economy practices.

- **Dedicating the right amount of time and resources are crucial for impact measurement. We found the SCEIA framework was useful to guide the business through the measurement process.** Nonetheless we limited the depth of the analysis because of the timeframe available and to take account of businesses' measurement experience. We also kept the onus for data collection on the first cohort's supply chain partners deliberately light. In this first cohort, all companies are small or medium sized enterprises. In line with the principles of a circular economy, their activities are relatively localised. These two factors led to more accessible supply chains and easier data collection.

- **Generally, environmental databases on African countries are less extensive than for European countries.** For instance, when performing the Bug Picture analysis, the electricity mix for Rwanda was not available in the database we used. We believe they need to be made much more useful and accessible to African businesses in future. Both are quite expensive and need some training before working with them. We hope that a new wave of African sustainability research- and consultancy firms will offer their expertise to drive increased embedding of measurement in circular businesses. But we also hope that businesses themselves can increasingly gain access to useful tools that they can use themselves to measure and improve their work.

- **As a final point we should emphasise that this work is pioneering and experimental.** Circular economy measurement is a field under development and we believe the only way forward is through experimentation and collaboration. We are very grateful for the energy and time committed by this first group of businesses, who contributed so diligently by sharing their data, insights and reflections. Their work, and that of the wide range of fellow African circular economy entrepreneurs, will drive the uptake of future-friendly business models. We look forward to continuing to learn from their work and build even better tools for impact assessment.

The businesses' results

3

LONO: Comparing the carbon impact of a new 'KubeKo' composter

LONO offers products and services for agriculture, renewable energy, bio-fuels and waste management. In this project LONO wanted to understand the impact of reducing the material inputs in a new design of their 'KubeKo' composter.

Name	LONO
Sector	Composting and biodigestion
Countries	Côte d'Ivoire
Year founded	2016
Capacity	60 tonnes of organic waste per year
People	12

The starting point

LONO was founded on the conviction that all countries and communities should benefit from innovation and technology. They address inequality by creating value for farmers and agribusinesses, while making a positive environmental and social impact.

LONO transforms biowaste from farming into energy (gas) and biofertilisers. Biowaste - or agricultural byproducts - is abundant in Côte d'Ivoire since it's a global producer of cocoa beans, cashew nuts, natural rubber and tropical fruits. For LONO this is an opportunity: the waste contains calorific value for energy and minerals that can be cycled to replenish degraded soils. Biogas is a by-product from this process which is captured and used for cooking, itself a preferable alternative to wood or charcoal.

LONO has two different models. First, they produce patented, domestic scale, prefabricated composters and digesters for farmers to process their own biowaste. Their outreach team visits farmers and advises on how to enhance the compost to suit their soil and crops. Second, LONO partners with medium-sized factories to build industrial scale biowaste composting and biodigestion units and avoid waste incineration in the process. Revenue generated from the facility is shared between LONO and their clients. As part of this model, LONO is setting up a compost brand to sell their biofertilisers.

With regards to their capacity to undertake in-depth measurement, the company has in-house expertise with measuring quantities of materials processed, assessing impact of product, and providing consultancy services, including conducting LCAs.

Identification (scoping)

LONO's very specific and timely measurement objective is to understand the impact of reducing the materials in a new design of their Kubeko composter.

LONO has a high level of measurement experience, and already uses measurement in their decision-making. Besides being in line with their purpose, reducing environmental hotspots has often meant reducing costs.

> "The measurement results can be used in our conversations with potential investors, to show them how we use metrics in our design- and decision-making process

N'guessan Kombo Noël
CEO, LONO

The company uses impact assessments to communicate with their investors. With their internal team of engineers, they conducted impact assessments such as:

- Alternative handling of organic waste (comparing instances where it is burned, dumped, left to rot, or used in animal feed);
- The impact of training farmers; and
- Comparisons of the energetic values and environmental impact of existing heating systems, and possible replacement systems including biogas.

The KubeKo solution. Left: old Kubeko composter made from steel. Right: A prototype new Kubeko composter incorporating a heavy duty plastic bag. Images courtesy LONO, Côte d'Ivoire

About the Kubeko composter

This composter transforms organic waste into compost in four weeks, with 400 kg of organic waste producing 150 kg of compost per month. It is a self-sufficient system that farmers can install on their fields or garden, requiring little maintenance. The current KubeKo is mostly made out of steel, but LONO is experimenting with a very different model that features a heavy duty plastic bag. This design change has a number of advantages:

- Transport is easier and more efficient, since multiple units can be transported at once;
- The new model has a modular design, making the repair of single elements possible;
- The material of the bag is lighter, making it easier to get the Kubeko to more remote areas, supporting their goal to address inequality;
- Above all, the new design solution uses considerably fewer materials, which makes it more cost-efficient and reduces embedded environmental impacts of materials such as steel.

LONO was most curious to get accurate insights into the environmental impact of the new design solution, on the basis of its lighter material footprint. Our analysis focused on the embedded carbon emissions of the materials used.

Composting in progress. Image courtesy of LONO

3. Diagnosis (results)

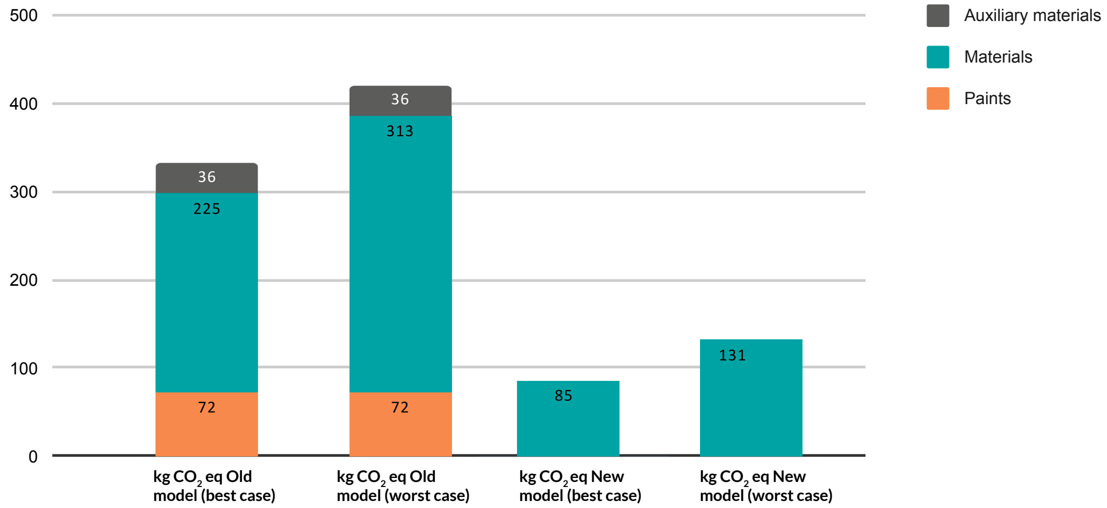

Figure 1: Comparison carbon impact new/old design Kubeko (2022)

The results clearly show the benefits of avoiding carbon-intensive, heavyweight materials such as steel. They also show that the avoided use of paints and other materials saves emissions in the value chain. The case illustrates one of the most effective impact reduction options in a circular economy: using less materials!

As with all environmental analyses, assumptions and underlying data are crucial. Not all material types were available in the ecoinvent 3 database[3] that we use for LCAs, so we had to select the 'next best' options. The most important assumption was probably that, in the new design, the weight and type of materials used were still uncertain, since the design- and testing process is ongoing. To be on the safe side with our estimations, we modelled a version of the new design which would still have a steel frame.

Some reflections on our work with LONO

Even when a product is still in the design phase, the results of the measurement exercise can still be used to improve its design. When a new solution is on the market already, it's easier to collect a complete set of data. Here, LONO's composting solution was in the design phase and they wanted data to improve this design. Finding the sweet spot and right momentum to start the measurement process - when its results can still be used in choosing the optimal solution - is therefore crucial.

We see plenty of directions for further research for LONO. A relevant effect of the new design's easier transportability is that more remote farmers can be reached and therefore that more units will be sold. It will be interesting to see what the implications of this increased range are. Another relevant measurement question will be the reduction in emissions because of fewer truck journeys (i.e. more KubeKos fitting in a single truck).

> "These results make it easier for us to prioritise - or avoid - the use of certain materials in our design process"

Louise Bijleveld
Co-founder, LONO

3 The ecoinvent Database is a Life Cycle Inventory database that supports different kinds of sustainability assessments. You can find more information here: https://ecoinvent.org/the-ecoinvent-database/.

The Bug Picture: An environmental impact comparison to test black soldier fly farming's benefits

The Bug Picture uses black soldier fly farming technology to convert organic waste to a sustainable alternative protein and biofertiliser that is locally produced and competitively priced in the market.

The Bug Picture is interested in using measurement to evidence the sustainability impacts of their products.

Name	The Bug Picture
Sector	Black soldier fly farming
Countries	Kenya and Rwanda
Year founded	2019
Capacity	1.5 tonnes of organic waste per day
People	6

The starting point

By 2050 the population of East Africa will double. If current socio-economic trends continue, this means that demand for meat will more than double as well. This makes for a huge challenge: lightening the environmental footprint of meat production.

The Bug Picture harnesses the power of black soldier fly to convert organic waste to a sustainable alternative protein and biofertiliser. Both are locally produced and competitively priced in the market. The business' goals are to increase sustainability, create jobs, and improve the self-sufficiency of farmers in Kenya and Rwanda.

Dried BSF larvae are a high quality protein source and can be used to produce animal feed. Their excrement (frass) is a highly nutritious organic compound fertiliser. Traditional animal feed is destroying the Earth's forests through intensive soy cultivation, and fish populations through fishmeal production. Chemical fertilisers are often harmful, costly and transport-intensive. The Bug Picture offers a more sustainable and locally-based solution.

The company also has several other projects to address environmental challenges in East Africa through the sustainable use of insects. For example, they use BSF larvae as one way of valorising maize affected by aflatoxin, a carcinogen that significantly affects production in East Africa. They also design and facilitate large-scale training projects on BSF farming.

Identification

The Bug Picture is interested in using measurement to evidence the sustainability impacts of their products. While BSF farming is known for its minimal material- and energy use and self-sufficient nature, measurement is needed to provide solid proof. This can then be communicated to The Bug Picture's suppliers of organic waste, and to their customers.

We had many ideas on what we could measure. After discussion with the Bug Picture we decided to take a snapshot of how the environmental impact of their products compare to their conventional alternatives. We focused on their pilot facility in Rwanda, which processes 1.5 tonnes of organic waste per day. We used the data available on material, energy and transport for one month of operations: this included data on the conventional products avoided by BSF farming.

A simplified version of the BSF process is shown in the figure below. The Bug Picture's main organic waste inputs are spent grain from a brewery, municipal organic waste, and food processing waste (mostly fruit). We used the transport distances- and transport modes from the Bug Picture's data. The spent grain would otherwise have been used by a local pig farm.

> "Metrics help to make the case for black soldier fly farming, evidencing its low-impact nature. These measurement outcomes show the benefits of using a low material input process. We can use the outcomes in our consideration of a new production facility.

Frans Jooste
CEO The Bug Picture, Rwanda and Kenya

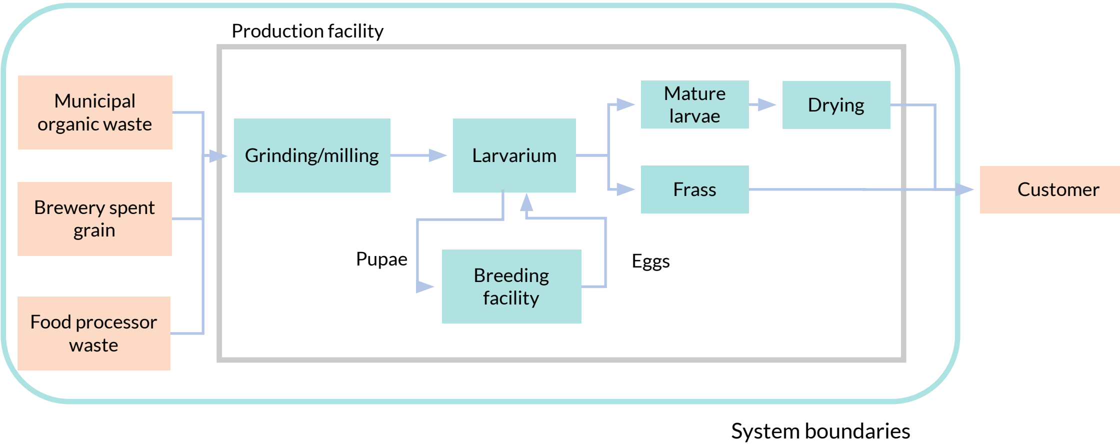

Figure 2: a simplified version of the black soldier fly process

The process is as follows: the organic material is milled before being used to feed the larvae colony. From the larvae, a percentage is removed, dried, and processed to be sold as protein replacement - animal feed. Another output from the larvae is frass, which is captured and sold as organic fertiliser. The remainder of the larvae is fed into the breeding facility, where they turn into flies, which in turn lay eggs, and which are then moved to the larvarium.

Alongside organic waste, the key inputs in the process are electricity and water. The process only needs electricity for the milling/grinding and drying processes. Surprisingly, the electricity mix of Rwanda was not available in the database. Instead, we selected Kenya's electricity mix, which we believe to be sufficiently comparable. The water used is naturally harvested rain water. Lastly, in our model, we also included the transport from the final products to their final distribution location.

The organic material milling process. Image courtesy of The Bug Picture

Diagnosis (results)

The results, showing the business' estimated carbon emissions for one month of operations, underline the highly efficient nature of the BSF process. Apart from plant setup, almost no material inputs are used, except for a small amount of electricity for milling and drying - and the emissions associated with transport of the waste to the facility.

The overall estimated carbon impact is negative. This is because of the avoided emissions of soy-based proteins (replaced by the dried larvae), and the avoided chemical fertiliser (replaced by frass). The high number for frass comes from the higher amount of frass produced in the month of January. Per kilo, the associated emissions of both avoided products (soy-based protein and chemical fertiliser) are roughly similar (around 2-3 kg CO_2/kg of product).

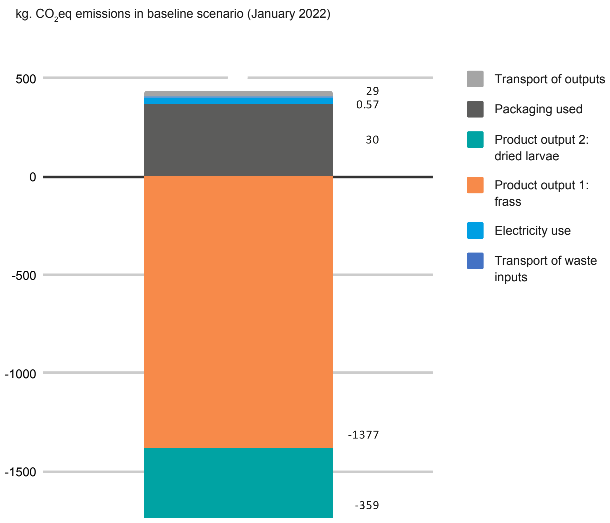

Figure 3: CO_2 emissions from The Bug Picture's operations

There are multiple other benefits from BSF that can be captured as well as avoided carbon emissions. The environmental benefits of using frass instead of chemical fertiliser, for instance, are potentially more extensive. Organic fertiliser has fewer runoff and effects because of the way it is applied (mixing with soil), its organic matter content, micronutrients and the way in which it binds to soil. Indeed, in the results for other impact categories, we see avoidance of freshwater eutrophication,[4] as well as land use impacts from the replaced soy-based protein.

Impact category	Unit	All waste inputs	Electricity use	Packaging used	Transport of outputs	Avoided chemical fertiliser	Avoided soy-based protein	Total
Freshwater eutrophication	kg P equivalent	0.0428	0.009	0.00016	0.0053	-0.3975	-0.032	-0.37
Land use	m2a crop equivalent	10.3	0.27	0.019	0.788	-37	-375.0	-400

Figure 4: Estimated results for the impact categories of freshwater eutrophication and land use for The Bug Picture, for each step in the process

There are likely to be other significant benefits in diverting waste from landfill which are harder to measure with precision. We tried to understand more about the avoided landfilling effects of municipal and food processor waste. This was more complicated; here we had to rely on data from the literature. General database data would not be robust enough, because of the specific nature of the region's waste management. Rwanda faces serious challenges in processing municipal waste. The main landfill site in the Kigali area is the Nduba landfill, where much of the garbage collected from Kigali is dumped. The site poses both a major health hazard to the people living in surrounding areas, and also forms an environmental threat. Examples of such hazards are landfill fires, methane explosions, landslides and leachates threatening rivers and contaminating groundwater.

4 Eutrophication is a phenomenon caused by excess discharge of nutrients in an aqueous system, particularly by nitrogen and phosphorus, especially in lakes, estuaries, and slow-moving streams.

The Nduba landfill site has no lining system to prevent leaching of harmful chemicals from contaminating the ground, and no gas collection facilities. Efforts to improve its management have so far not been successful. However, plans to capture the site's landfill gases are being developed. Currently, these gases simply escape. The amount of escaped methane – a potent greenhouse gas - depends on factors such as waste composition, climate conditions, and oxidation factors. From various reports, this can range from 500kg to as high as four tonnes of GHG emissions per ton of waste. We expect that this will be in the higher range, given the uncontrolled environment at the Nduba site. For other impacts, such as contamination of ground water or direct human health effects, site-specific studies could help quantify this.

Some reflections on our work with The Bug Picture

Our analysis gives some first estimates of the business' carbon performance.

- Similar to the analysis for Pyramid Upcycling (see below), the choice for the replaced products was critical. Fortunately, information was available on the most frequently used protein source and fertiliser. For the input side, we found it challenging to quantitatively express the impacts avoided.
- Measurement is an invaluable tool in site selection. A detailed assessment of transport emissions could be made: this is particularly relevant when 'wet waste' inputs need transport. Also, the business wants to use the measurement results to make the case for BSF. The results underline the process' efficiency: it barely uses any material inputs or energy, and replaces two unsustainable products simultaneously.
- Working with an 'under construction' framework worked well. Trying to build a perfect model without having tested it would not have worked. The Bug Picture was still experimenting with their technology at the time of measurement, so we can consider this analysis a snapshot of their impacts.
- The measurement process did not detract from running the business. The business' staff also mentioned that for them, the measurement work did not take too much of their time: reporting and data collection might take time away from running the business. The data collection process was helped significantly by videos sent from the production site.

> "Measurement should not eat away from the business' focus, which is its day-to-day operations. Fortunately, this measurement process was focused and efficient."
>
> Frans Jooste, CEO, The Bug Picture

Pyramid Upcycling: Identifying impact hotspots in plastic waste recycling

Pyramid Upcycling turns waste plastic into new products with a longer lifespan. The Company currently produces curtain ropes, chair fittings and plastic lumber, all from plastic that is collected from the streets of Accra, Ghana.

Pyramid is interested in quantifying its environmental impact hotspots, focusing on carbon emissions.

PYRAMID
UPCYCLING LTD

Name	Pyramid Upcycling
Sector	Consumer goods/ Construction materials
Countries	Ghana
Year founded	2007
Capacity	Processing capacity of 4-5 tonnes of plastic waste per week
People	15 employees, 20 informal workers

The starting point

Only 2-5% of plastics generated in Ghana are recycled.[5] The rest ends up in landfills, in the ocean, the streets, or simply burned. Recycled and reused plastics can replace virgin resources and have the potential to prevent deforestation where it substitutes for wood in construction.

Pyramid's founder, Ibrahim Yougbare, cares deeply for the environment and this led him to design his own machinery and start recycling plastics in 1999. He established Pyramid Recycling Enterprise (now aptly renamed Pyramid Upcycling) as a company in 2007. Ibrahim's main concern is to address deforestation and to find long-term uses for plastic waste that prevents it from returning to the environment. His most recent innovation is a prototype of a product that can be used instead of wood in construction, which he has been testing for over six years.

In the early days, the company Pyramid Recycling began by focusing on recovering plastic waste. However, they realised that this was not enough to prevent the plastic returning to choke gutters on the streets, as most was transformed into single-use plastic bags. Pyramid invented their own longer-lasting products such as curtain ropes, chair fittings ('chair shoes') and Plastic Lumber 'wood plastics'.

As one of the first businesses to start plastic recycling in Ghana, Pyramid could have exploited their first mover advantage. However, social change has always been at their core and they have trained many others who have gone on to establish local recycling companies. They have also focused on training waste pickers, with a particular focus on supporting single mothers. These informal waste pickers supply Pyramid and other recyclers with plastics - about 65% of the four to five tonnes of plastics Pyramid receives each week. The rest are collected from plastic producing companies' pre-consumer waste. Pyramid's innovative 'wood plastic' has been certified by the Council for Scientific and Industrial Research in Ghana.

The company used to operate informally and is rapidly professionalising; this includes an increase in data collection, and being part of the Footprints' B Corp training programme.[6]

"For circular recycling businesses like ours there is need for more developed metrics, and even new concepts or words to describe flows of items and materials

Ibrahim Yougbare
Pyramid Upcycling

5 https://www.undp.org/ghana/press-releases/behavioural-change-critical-addressing-plastic-menace

6 Footprints supports companies in the food and waste sectors through our 6-month B Corp programme. We support companies to improve their social and environmental impact, working with them using Human-Centred Design approaches to redesign their engagement with the informal sector, a critical actor in their value chains.

Identification

With Pyramid we identified many options for measurement, including:

- Quantifying the difference in impact between a product from Pyramid Upcycling and a conventionally produced product;
- Obtaining insights into the company's social impacts, or
- Determining the direct environmental impacts from its production facilities.

We finally decided to quantify the company's environmental impact hotspots, focusing on carbon emissions. The objective is that the results can be used to inspire other businesses to engage in plastic waste reduction and addressing deforestation. To set about this we estimated the avoided environmental impacts from the three conventionally produced products that Pyramid Upcycling's products replace (in LCA terms what is called a substitution approach). We did not include the avoided alternative 'processing' (or lack thereof) of the plastic waste; this data is uncertain and very context-specific.

- Pyramid's data was available for a four month timeframe, and included:
- The quantities and types of plastics processed;
- Quantities of products being put on the market;
- Energy consumed by each step in the production process;
- Packaging; and
- Transport to retailers.

The functional unit[7] we chose for the LCA was Pyramid Upcycling's operations between November and February 2022.

We assumed that producers of 'conventional' alternative products to Pyramid's core range might use some recycled materials in their production.

Pyramid's pelletising process in progress. Photo credit: Lema Concepts, Ghana

Diagnosis (results)

The results for Pyramid show that the carbon impacts from the company's electricity use, its avoided products, the transport to the retailer and its packaging.
The electricity use comes from the machines that are pre-processing plastics (crushing, pelletising) and then processing them into products (melting, shaping, cooling and cutting). We used the average electricity mix for Ghana from the ecoinvent database.[8]

7 In life cycle analyses the functional unit defines precisely what is being studied, quantifies the service delivered by a system or process, provides a reference to which the inputs and outputs can be related, and gives a basis for comparing or analysing alternative goods or services.

8 See Ghana data at the International Energy Agency's site: https://www.iea.org/countries/ghana.

Our key findings are:

- The overall estimated GHG impact of Pyramid Upcycling is around 6.5 tonnes CO_2eq, using the assumptions and data specific to the four-month scope;
- Across its activities, Pyramid's electricity usage has the largest GHG impact;
- Pyramid's two main products are responsible for around 85% of the business' GHG impacts from energy: curtain ropes and plastic lumber. This result underlines that the relation between the volume of products and their embedded emissions is often linear;
- Waste materials have a lower impact than virgin materials. This means that most of the avoided emissions result from the chair fittings, which use the highest proportion of waste materials relative to conventional alternatives;
- Considering just GHG emissions does not capture the full picture of Pyramid's impact.[9] For example, in a next iteration we can consider a more complete set of effects of using plastic waste to replace red hardwood construction lumber, which would also include the disruption of carbon stored in the soil.

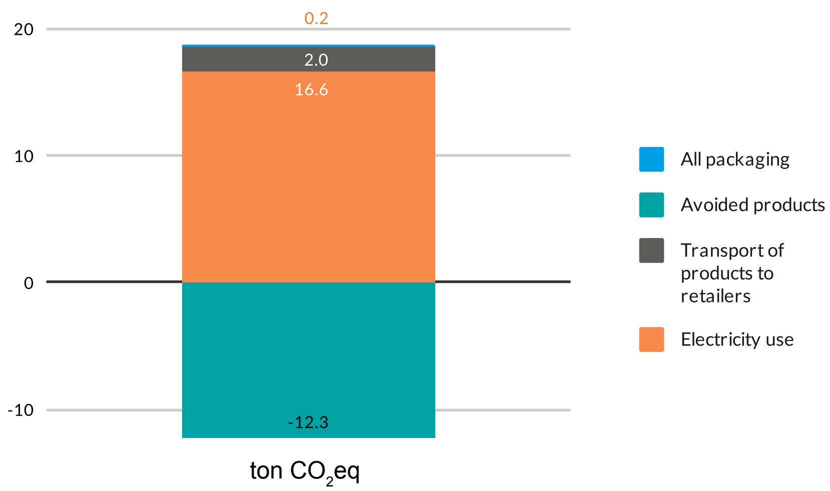

Figure 5: GHG impact (4 months of operation), in ton CO_2eq

Our approach to calculate the avoided emissions from 'conventional' products that have been replaced also warrants more explanation. For certain products, Pyramid Upcycling confirmed that other producers are likely to use recycled materials in their production. We considered this in the model (see table below). Plastic lumber produced by Pyramid Upcycling replaces red hardwood, contributing to the company's purpose of reducing deforestation. Therefore, we also looked at the impact category 'land use'.

Impact category	Unit	Electricity use	Transport of products to retailers	Avoided products	All packaging	Total
Land use	m2a crop eq[10]	31.3	53.9	-7,930	4.1	-7,840

Figure 6: Land use change from Pyramid Upcycling's activities vs "conventional" approaches

Avoiding red hardwood in construction lumber and replacing it with plastic waste is estimated to reduce land use occupation impact by around 7,840 m2a. Even adding this category does not paint the full picture, however. For example, we cannot see the biodiversity and soil conservation impacts of trees not cut down, for which we would need more detailed regional data.

9 For the estimation of GHG emissions, no local carbon storage data was available for the red hardwood, meaning that the database estimations do not accurately capture the on-the-ground GHG impacts.

10 M2a is a unit of land occupation used in LCAs. For more details see: https://core.ac.uk/download/pdf/14925706.pdf.

Possible ways forward

- Given the GHG emissions result from their energy use, Pyramid Upcycling can consider two strategies: (1) a reduction in its energy use, for which the melting, shaping and cutting of both the curtain ropes and plastic lumber are most dominant (2) converting to renewable sources for the energy inputs that cannot be avoided. If solar were adopted, for example, the resulting decrease of GHG emissions would be around 16.6 tonnes in the same timeframe.
- With data proving that plastic waste results in lower emissions than virgin plastics, Pyramid can explore applying for plastic credits - a credit scheme that rewards businesses for removing waste plastics from the environment.
- Pyramid can use this data to communicate to its stakeholders the potential GHG emissions reduction by switching from virgin plastics to recycled plastic waste in products. The CEO has a prominent role in the Association for Plastics Recyclers in Ghana, which he can leverage.

Some reflections on our work with Pyramid

- Continuous measurement means additional (time) investment but doing it brings other benefits to the business Precise weighing and sampling strategies of inputs and outputs are time - and resource intensive! At the same time, collecting more data on the inputs and outputs gives insights into the business' profitability and overall performance. For Pyramid Upcycling, data tracking and measurement form a strong part of their ongoing process of formalisation.
- Social impact is a future priority for Pyramid's measurement goals. Pyramid's social impact is core to their purpose. While this short-term measurement exercise did not allow to include this, social impact assessment can become part of the measurement in the future.
- Assumptions on the materials that are replaced play a key role. More complex avoided impacts, such as carbon storage in soils, could not be included in the model this time round, although they are important to measure. Only a small part of Pyramid Upcycling's continued work to provide solutions to these environmental issues have been captured in this first iteration.

> "It is our responsibility to use metrics to convince other companies to become more circular and sustainable
>
> Ibrahim Yougbare, Pyramid Upcycling

WEEE Centre: Measuring an e-waste business using the Circular Transition Indicators

The Kenya-based business' main business is collecting, processing and recycling all types of electrical and electronic waste from a broad client base.

WEEE Centre uses different circular strategies, such as repair, upcycling, and recycling and wanted to know just how circular the business is in practice.

Name	WEEE Centre
Sector	E-waste
Countries	Kenya
Year founded	2012
Capacity	10 tonnes/week
People	45 employees, 15 casual workers

Starting point

WEEE Centre tackles the challenge of e-waste management in Kenya. In Kenya, for example, only 1% of the estimated 51,000 tonnes of electronic waste produced in 2019 was disposed of appropriately, leading to pollution, hazards to human health and a loss of valuable materials.

WEEE Centre both collects and receives e-waste from at least 500 clients. These include learning institutions, embassies, NGOs, corporate clients and a rising number of private households. All products received are, after inventory, sorted in reusables and recyclables. The latter are dismantled and each element has its own processing line. Products are either recycled locally or exported for recycling in those instances where the technology in Kenya isn't yet advanced enough.

Certain repairable products are sold by WEEE Centre to second-hand electronics dealers. These partners all sign a 'Circular Commitment Letter' stating they will return whatever components they might not use in their repair services and that they will inform customers about the importance of, and drop-off points for, safe disposal at end-of-life of the electronic items.

WEEE Centre is also committed to building awareness on e-waste. The company hosts study visits in their offices and is collaborating with learning institutions, Kenyan county governments and commercial partners, such as Safaricom, Carrefour and TotalEnergies to set up collection points. These number about 100 so far. Beyond Kenya, they are part of a growing continental network with partners in 15 African countries working on similar issues, and to whom they provide training and support.

Identification

WEEE Centre uses different circular strategies, such as repair, upcycling, and recycling. The question that emerged from scoping conversations is as follows: how circular is WEEE Centre in practice? The business aims to increase their circularity, and the share of components and products that are then again returned to the company, keeping them 'in the loop'.

Given this goal, we selected the Circular Transition Indicator 2.0 (CTI) method as the best tool to answer this question. The CTI, developed by the World Business Council on Sustainable Development and itself part of the SCEIA framework is an accessible, quantitative framework

> "For circular recycling businesses like ours there is need for more developed metrics, and even new concepts or words to describe flows of items and materials
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> **Boniface Mbithi**
> CEO, WEEE Center

that can be applied to businesses in all industries. CTI is essentially a self-assessment that determines a company's circular performance. It focuses on the circular and linear mass flows through the company. Its goal is different from impact measurement methods such as LCA, which enable quantifying a product/system's environmental impact. Instead, the CTI focuses on resource flows.[11]

Based on the available data and the goal of the analysis, we selected the 'close the loop' approach. This approach requires information on the % of circular inflow and % circular outflow, the latter consisting of recovery potential and actual recovery rate. WEEE Centre provided detailed data on ingoing- and outgoing mass (both in amount and weight), % of non-virgin content, and the potential- and actual recovery rates.

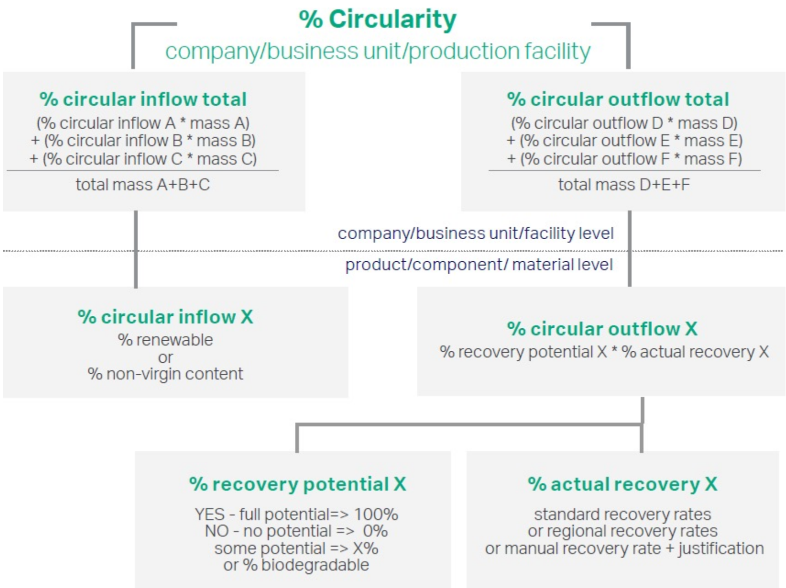


Figure 7: The methodology for calculating a company's % circularity, using the 'closing the loop' approach in WBCSD's CTI.

Diagnosis (results)

Applying these scores when using the CTI approach results in a circularity score of 100%. We explain this result as follows:

The data delivered by WEEE Centre contained information on the inputs and outputs of over a thousand different product types. To keep the analysis manageable and to be able to calculate the business' circularity using the close the loop approach, we selected 25. We did this selection on the basis of high input volumes (10 products) and high output volumes (10 products), plus five additional products that were relevant because of their number or recyclability. Examples of the products we selected included:

- Gambling machines;
- Cathode-ray tube monitors;
- Printers;
- Televisions;
- Keyboard; and
- Miscellaneous types of metals and cables.

Overall, in terms of mass, this selection of 25 out of 1000+ products represented roughly 50% of all inputs processed by WEEE Centre.

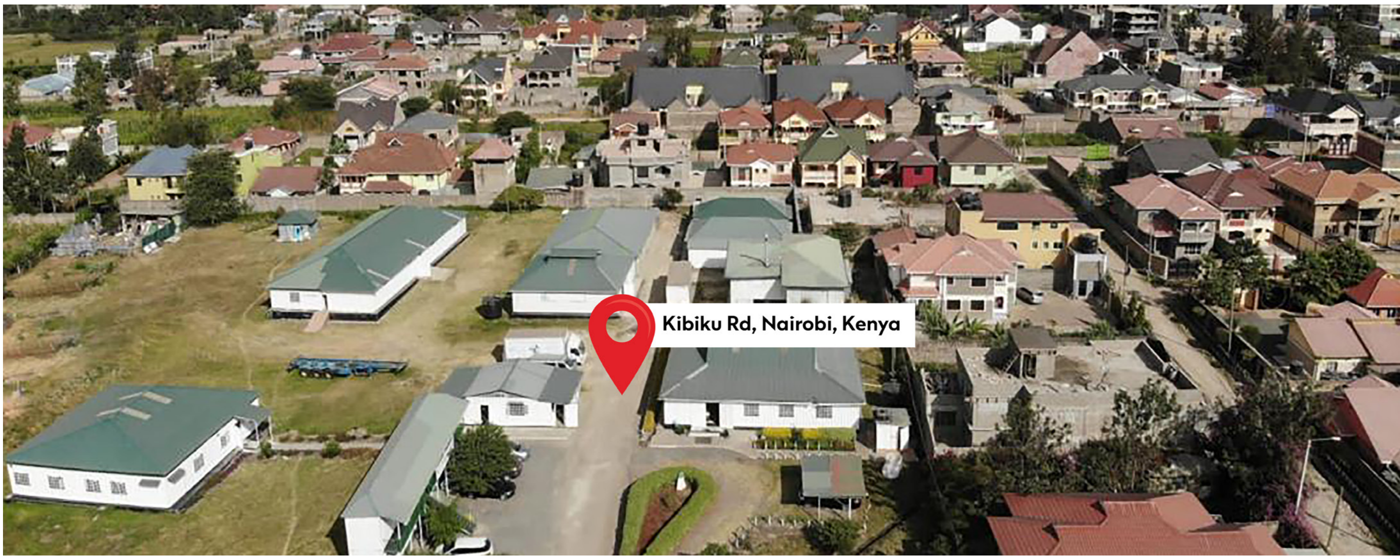
WEEE Centre processes waste materials and so we assigned all inputs a 100% non-virgin score. For the outflow, assigning values was less straightforward. After careful consideration, we set the recovery potential at 100% for all products, meaning that all outflows are, in principle, technically recoverable.

11 The recently released CTI 3.0 methodology offers an add-on method ('impact of the loop') to include the impact of recycled sourcing on greenhouse gas (GHG) emissions reductions. However, for electric appliances that consist of a complex mix of materials, data on material use is scarce, making it highly challenging to apply.

In practice the lack of a business case, appropriate technology or other circumstances could still form a barrier to effective recovery. Materials or products that face these local barriers to recovery are not bought, but stored at WEEE Centre's premises for export to other recycling facilities. We therefore discounted them from the actual recovery estimates.

For the % of actual recovery, we also used a value of 100%. Our reasoning for this is that if materials, components or products are purchased from WEEE Centre, the customer will apply recovery techniques. Our working assumption is that a client will make an effort to recover as much as possible in order to extract the maximum value from the materials they have bought. In the context of this analysis we also have no way of knowing the % of materials - such as the rare earths which are a small component by weight of e-waste - that are unrecoverable.

Dismantling e-waste. Image courtesy of WEEE Centre.



Some reflections on our work with WEEE Centre

- This result of 100% circularity does not imply there is no room for improvement. In fact, the measurement process provided several pointers for priority areas of improving data quality and, following from this, circularity. The CTI is useful but it is more geared towards manufacturing companies that want to (1) increase their share of post-consumer inputs, or (2) increase the recoverability of their outputs. A business like WEEE Centre already does both! It processes non-virgin inputs by definition, and the materials and products put on the market are then used or processed by their buyers. It would be good, for example, to have more extensive data from WEEE Centre's customers in the next phase.
- An interesting future metric could be the rate at which products or components are returned to WEEE Centre, combined with how many years this extends their lifespan. As we have shown, WEEE Centre's business model is not fully covered by the CTI. WEEE Centre encourages clients to return their purchased products at the end-of-life; increasing the % of components/products will keep them 'in the loop'. While we considered using the 'optimise the loop' approach as well, no robust data was available for this yet.

- The percentage of equipment stored could be a useful indicator to identify which recycling technologies are high priority for Kenya (and potentially other African countries). Equipment is stored because of low market price or where the volumes are low, but also where there is a lack of available technology. This could provide policy- and market actors with priority insights. WEEE Centre also expressed a need for recyclability data for different electronic appliances and their materials in Kenya and beyond. This could include (1) the type of available technology (2) a list of companies that apply it.
- The recyclable component-materials (plastics, metals) are currently categorised as separate output streams, while they actually originate from different electronic appliances in the input stream. WEEE Centre is exploring the use of digital systems - both on input and output side - which 'talk' to each other, to trace the exact material flows within the company.
- Applying an 'impact-based' rather than a 'resource flow' based approach will be the next challenge for WEEE Centre - but that needs better and more widely available data. The main limitation here is a serious lack of global data on embedded carbon emissions - let alone other environmental impacts - in electronic equipment. Ideally both government and producers should develop publicly available, harmonised LCA data on WEEE impacts. This kind of democratised data is needed to quantify and understand the impacts of businesses such as WEEE Centre, extending the lifespan of high-impact appliances. It is also very encouraging to see that some businesses are already asking for this information.

> "
> Data on the impact of WEEE recycling is growing, but it's often inaccessible or limited. More data will allow us to prove the value of reuse – even of different items/components and not just of "e-waste in general". We need both recyclability data for different electronic appliances and their materials, and more data on available technology
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> **Simone Andersson**
> CCO, WEEE Centre

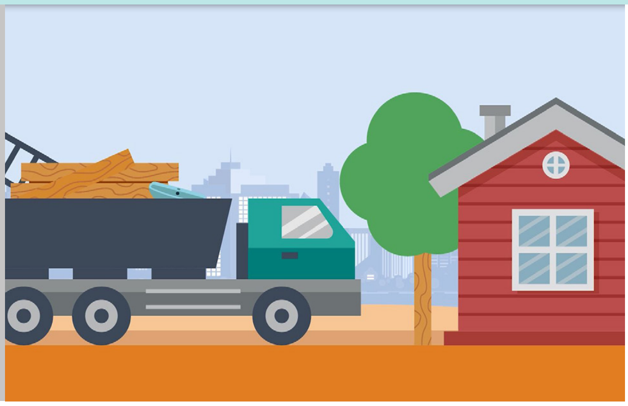
DigiYard: Designing a future measurement tool for a construction materials exchange

ARUP

South Africa-based DigiYard gives people access to high quality building materials that would otherwise be discarded. It repurposes usable construction waste in South Africa by matching up unused construction 'waste' materials with small scale builders and traders in the informal sector.

DigiYard's project is still under development and hard data collection is underway. For this reason we focused on a qualitative description of their projected impact measurement plan, using their internal impact assessment targets.

Name	DigiYard (Arup)
Sector	Construction waste
Countries	South Africa
Year founded	2018
Capacity	Projected capacity of 3,780 tonnes per year
People	7



The starting point

The construction industry has for a long time worked on the basis that waste is an inevitable by-product of doing business. Some 30% of all materials delivered to construction sites in South Africa is wasted, usually ending up in landfill. At the same time, South Africa has an acute shortage of appropriate and affordable housing. Millions of people live in townships on the peripheries of cities. These townships are a legacy of the Apartheid era and their low-quality construction and distance from basic services and economic opportunities, effectively reinforce structural inequalities. To address this imbalance it is increasingly critical not only to recycle more construction waste, but also to repurpose perfectly good materials to address this imbalance.

Together with external partner the Craft and Design Institute, Arup's Cape Town office has begun developing an app-based service, DigiYard. It aims to solve (1) the inefficient nature of the construction sector, in which quality timber, glass, bricks and many other types of materials are often still sent to landfill, and (2) the social challenge of millions of people living in informal housing and are forced to build homes using substandard materials.

The process in the app will work as follows:

- The site manager at a construction site photographs and uploads pictures of unused materials to the platform;
- The app uses artificial intelligence to classify the material type, quantity and price. This information is then displayed on an app where builders in townships can view the materials that are currently available;
- Builders collect the materials directly from the construction site if possible, or from a warehouse;
- The materials are used to build or upgrade homes and build furniture, arts and crafts from low cost but high-quality materials.

The app also encourages users to attend safe building training programmes to improve the quality and comfort of homes that they build.

The DigiYard team indicated that measurement of the impacts of diverting construction materials from landfill would provide an evidence base to their story. This could be interesting to potential investors, who are increasingly asking for circular economy impact data. However, as their data collection is still work-in-progress, for this case study, we made the decision to present a 'future measurement plan' rather than a quantification of the current operations.

> "Sometimes circular economy businesses like DigiYard are confronted with statements such as "circular economy is just smoke and mirrors". With impact measurement results, we can back up our story

Kausar Khan
DigiYard

Identification and diagnosis (results)

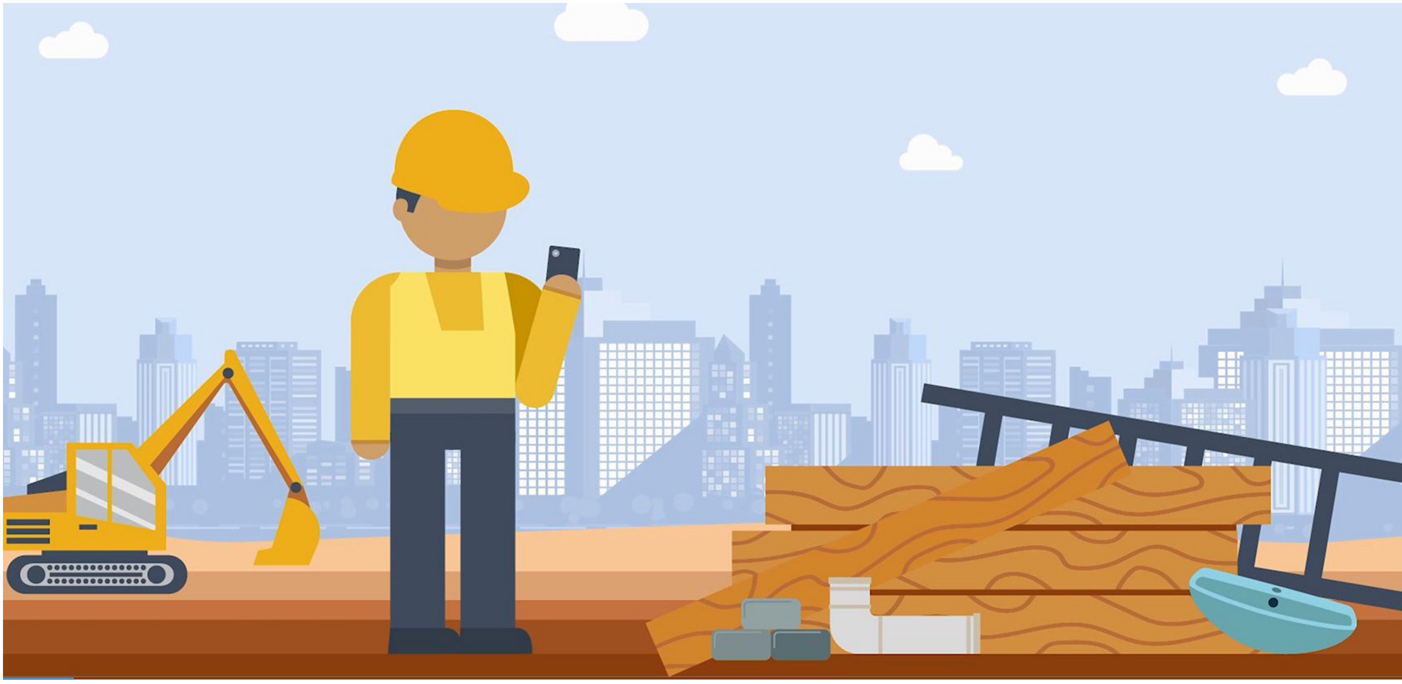
At the time of writing, Digiyard has carried out a first material audit. They sampled three potential construction sites to get data on the construction materials available, their quality and quantity. While this provides significant insights, at this stage, the data they collected is quite limited for any robust impact calculations. The two reasons for this are: (1) the sampling took place when relatively few materials were available and, more importantly, (2) the final use of the materials is not yet known. It's hard to say how they will be used and therefore which other materials they might replace.

We therefore focused on a qualitative description of Digiyard's projected impact measurement plan, using their internal impact assessment targets. This impact measurement plan can be used by the business when inventoried materials are assigned to construction projects.

Digiyard uses SDGs 9-13 to guide their sustainability objectives. In addition, the business has listed three concrete outcomes of their project:

- Environmental benefits: encourage better use of materials, lower demand for virgin resources and long-term reduction in landfilling;
- Social benefits: improve the quality of materials used for homes and furniture in lower income communities, stimulate safer living conditions;
- Economic benefits: upskill small-scale builders and home dwellers, enhancing income opportunities through job creation and entrepreneurship.

These are the outcomes that follow from the broader goal of providing builders with access to quality second-hand materials, while reducing landfill and extending material life cycles. From these outcomes, these are the metrics we propose incorporating:



Category	Outcome	Metric	Measurement guidance	Complexity (resources, time)
Environmental	Reduction in landfilling	Materials diverted from landfill (kg)	Material type and quantity (in kg), based on the materials used in construction projects and therefore diverted from landfill. Timescale to-be-decided.	Low
Environmental	Lower demand for virgin resources	Replaced virgin resources (in kg. and their embedded impacts)	From the metric above, an estimation on replaced virgin resources can be made. This will probably need a case-by-case assessment: some builders might replace other secondary materials, while others might replace virgin materials. It could also be a mix. When lower-quality materials are replaced, it is not likely that the secondary materials replace virgin materials because of their high costs. Instead, the impacts will be in the social domain (i.e. improved safety and comfort). The replaced virgin resources can be expressed in kg, but also in their embedded environmental impacts such as GHG emissions. Several databases are available for this, including LCA databases such as the ecoinvent database.	High
Social	Improve the quality of materials used for homes	Number of households reached	This metric provides a direct insight into the number of households impacted by the app.	Low
Social	Stimulate safer living conditions	Number of households of which the living conditions have improved	Qualitative data based on interviews with impacted households can provide insights into the improved living conditions.	High
Economic	Upskill builders	Number of trainings, number of builders reached	Training to (aspiring) builders and the number of builders reached can be used to quantify one of the project's economic outcomes.	Low
Economic	Enhance income opportunities	Number of jobs created (especially in low-income communities)	A longer-term metric could be the number of jobs created in low-income communities. Providing builders with training and access to materials will stimulate their entrepreneurship.	High

Some reflections on our work with DigiYard

While the data that has been collected is not yet robust enough for quantitative calculations, the measurement process and conversations along the way allowed us to reflect on opportunities and challenges of the DigiYard product. Two things stood out:

Understanding the type and quality of the available materials that will be used is key. DigiYard will set strict quality controls, and some on-site sorting might need to take place. This quality control process will guarantee that the construction materials are of high quality, and it will also create jobs. Still, we have two big uncertainties relevant to the measurement work:

We don't know which materials are replaced – these might be harmful, or unsafe, but they might, in some cases, also consist of store-bought materials;

It's still unknown whether the materials will be used for the short, medium- or longer term. Data points on these elements, and on the project's wider social impacts, are challenging to collect in this early stage of the business. This is complicated by the specific and challenging socio-economic context: the data on the number of households that need the materials, for instance, doesn't exist yet.

While using hard, quantitative figures might not be possible yet, storytelling is. We have a situation where viable construction materials are often taken from buildings without considering their secondary use. Through training, DigiYard creates more awareness on what can be done with materials, stimulating more circular approaches in construction. Throughout the next stages of development of their business, the opportunity to collect more data and give hard evidence will grow.

> "Impact measurement is challenging: it can often only be done when the project has been underway for some time. In this early stage of the business, we cannot be too concrete on our to-be-realized impacts. To avoid greenwashing on environmental benefits when they're not yet easy to quantify, we decided to co-develop a qualitative measurement plan
>
> Kausar Khan, DigiYard

Assumptions

4

LONO

Category	Assumption(s)
Materials used - general assumptions	A detailed list of materials used was provided by LONO. For reasons of confidentiality, this is withheld here. Desk research was used to complement the information on materials types and quantities, which were subsequently confirmed by LONO. Remaining uncertainties (i.e. the amount of steel used in the previous model, the amount of steel necessary for the frame in the new model) are reflected in the presented scenarios). Ecoinvent did not always provide processes matching the exact material types. This was particularly important for steel. A sensitivity assessment for different steel types was applied; chromium steel shows to have two to three times higher amounts of embedded carbon in its production chain. After discussion, for steel (both the casing of the previous model as well as the current frame), the global process for unalloyed steel was used. One other challenge for LONO's analysis was that the new model was still in the design phase: we had to make some informed assumptions on its design and material use. One such assumption is that the composting performance of the two models is similar. There was one other complicating factor: since the specific weight of the frame of the new model was still being determined at the time of writing, we used two scenarios: a 'best case' with a 25 kg frame, and a 'worst case' scenario with a frame of 50 kg. For all materials, we used average global data on the embedded emissions of materials.
Materials used - steel	Not all material types were available in the ecoinvent3 database that we use for LCAs, so we had to select the 'next best' options. This is most relevant for different types of steel, which formed the bulk of the impact. The amount of embedded carbon in steel strongly depends on its production: the carbon impact of chromium or stainless steel, for example, can be more than twice that of low-alloyed steel. The most important assumption was probably that, in the new design, the weight and type of materials used were still uncertain, since the design- and testing process is ongoing. To be on the safe side with our estimations, we modelled a version of the new design which would still have a steel frame.

Category	Assumption(s)
Inputs	For all transport of inputs, we used the process "Transport, freight, lorry 3.5-7.5 metric ton, euro3 {RoW}|" from the ecoinvent 3 database. The distances to the waste source were known. The municipal waste is wheelbarrowed. We assumed no emissions, therefore. Other assumptions: Food processor waste goes to landfill in the rainy season, when there's enough organic feed for animals, otherwise it's collected to feed animals. Municipal waste: while the municipality is looking for ways to better use this, this is not happening in practice yet. In the vast majority of cases, the waste is landfilled. Brewery spent grain: this would otherwise have gone to pig farmers.
Energy	Electricity mix of Rwanda is not available in ecoinvent. We used the electricity mix of Kenya instead. This seems comparable to the situation in Rwanda (high % of hydro-generated electricity), but can be modelled more accurately in a future analysis. Energy use of the dryer was based on an estimated 7.5hours of total running time during the month, and its power use was based on data from the manufacturer. For the milling of the organic waste, the power usage was based on an extrapolation of its annual electricity consumption.
Outputs and replaced products	Dried larvae are assumed to replace protein - soybean meal - for animal feed. In ecoinvent, the process "Soybean meal {RoW}| market for soybean meal" in the ecoinvent 3 database was selected. The protein content of BSF was reported to be higher than soy; 1kg of soy is replaced by 750g of dried larvae. Frass is assumed to replace chemical fertiliser.[12] When applying the fertiliser to coffee trees, the replacement ratio is reported to be 1:1. The most commonly used fertiliser in Rwanda is NPK (nitrogen - phosphorus - potassium) (Green World Consult, 2016), with ratios of 17%-17%-17%. The selected processes were "Nitrogen fertiliser, as N {GLO}| market for", "Phosphate fertiliser, as P2O5 {GLO}| market for", "Potassium fertiliser, as K2O {GLO}| market for" from the ecoinvent 3 database. The carbon impact of the modelled process was compared to several LCA studies, which showed results in a similar range. The eggs and larvae outputs (those not dried) are considered free of impacts, since they are 'reinvested' in the mother colony.
Transport of outputs	Both for frass as well as for dried larvae, transport to the distributor location has been modelled. The selected process: "Transport, freight, light commercial vehicle {RoW}|" (ecoinvent 3).

12 Chemical fertilisers are provided to farmers by the government. In case they don't use chemical fertilisers, lower quality organic materials are used. These are expected to have a lower nutritional value and we did not therefore consider them to be an alternative to the Bug Picture's frass fertiliser.

Pyramid Upcycling

Category	Assumption(s)
Processed plastic waste	For all waste inputs: the cut-off approach is used. This means that the waste is considered burden free, except for transport for collection. Since transport from waste pickers to the processing site is unknown and can vary, this has been excluded for now. Avoided impacts for alternative processing - or the lack thereof - have not been considered. One reason is that the impacts of plastic litter and plastic accumulation in water bodies are difficult to quantify.
Energy	Electricity from the grid is used, using the average electricity mix for Ghana provided by the ecoinvent database. Electricity use is split into general electricity use related to the products (melting + shaping + cooling bath + cutting) and those that are reported generally (agglomerator, crusher, and pelletizer).
Quantities of products put on market	For some products and their quantities being put on the market have been extrapolated from smaller data points; i.e. when only one month of production data was available for a certain product, we assigned this data point to the other months as well.
Replaced products	Different ratios of virgin/recycled materials are assumed for the replaced products. For the chair fittings, it's split between waste materials and virgin materials for the low-density polyethylene and high-density polyethylene used. 'Recycled' processes in ecoinvent are selected; however, recycled low-density polyethylene is not available in ecoinvent: we used recycled high-density polyethylene instead. For the curtain ropes, other producers use low-density polyethylene waste plastic as well because of its market price. We assumed that plastic lumber replaces hardwood. In the database, hardwood is reported in m3, while the plastic lumber is reported in kilograms. The density of hardwood is assumed to be between 500-900 kg/m3. We took the average of 700 kg/m3 to calculate how much hardwood, in m3, is replaced.
Transport	The final transport of the product is modelled to the retailer. Their locations and the ratios of products transported to different retailers are known. Cars used for transport are small or medium sized, older passenger cars and modelled to run on petrol. The process selected is: "Transport, freight, light commercial vehicle {RoW}| market for transport, freight, light commercial vehicle" in the ecoinvent 3 database. Passenger cars could not be selected, as they do not allow for adding weight (tkm) in ecoinvent.
Packaging	The packaging for the curtain ropes consists of high-density polyethylene ropes. For the chair fittings, HDPE sacks are used as packaging material. No packaging is used for the plastic lumber.

Front cover image courtesy of The Bug Picture.

See www.footprintsafrica.co for more information on the programmes Footprints Africa runs to support businesses to develop purpose-driven cultures and so empower their employees to improve their social and environmental impact.