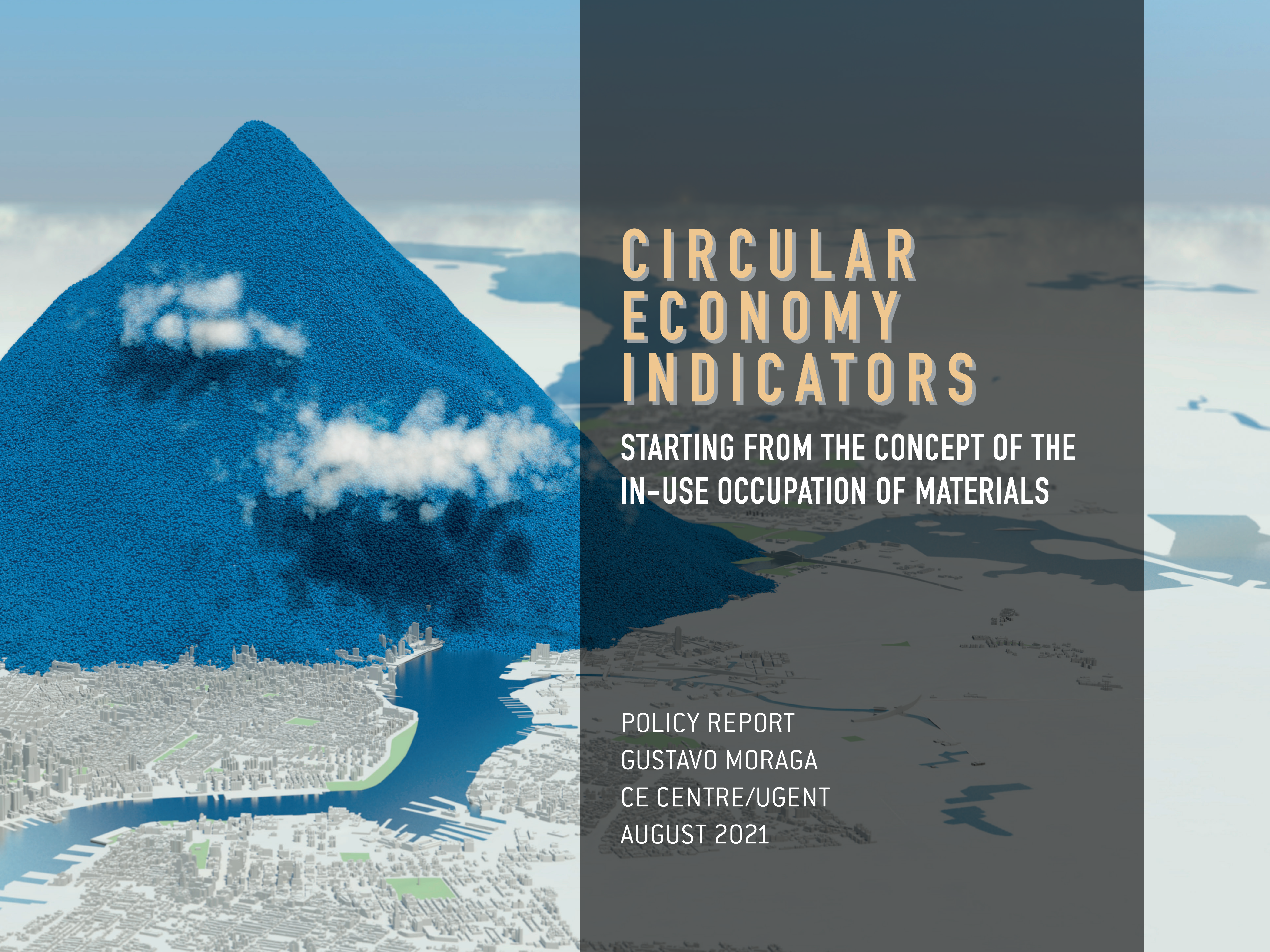

CIRCULAR ECONOMY INDICATORS

STARTING FROM THE CONCEPT OF THE IN-USE OCCUPATION OF MATERIALS

POLICY REPORT

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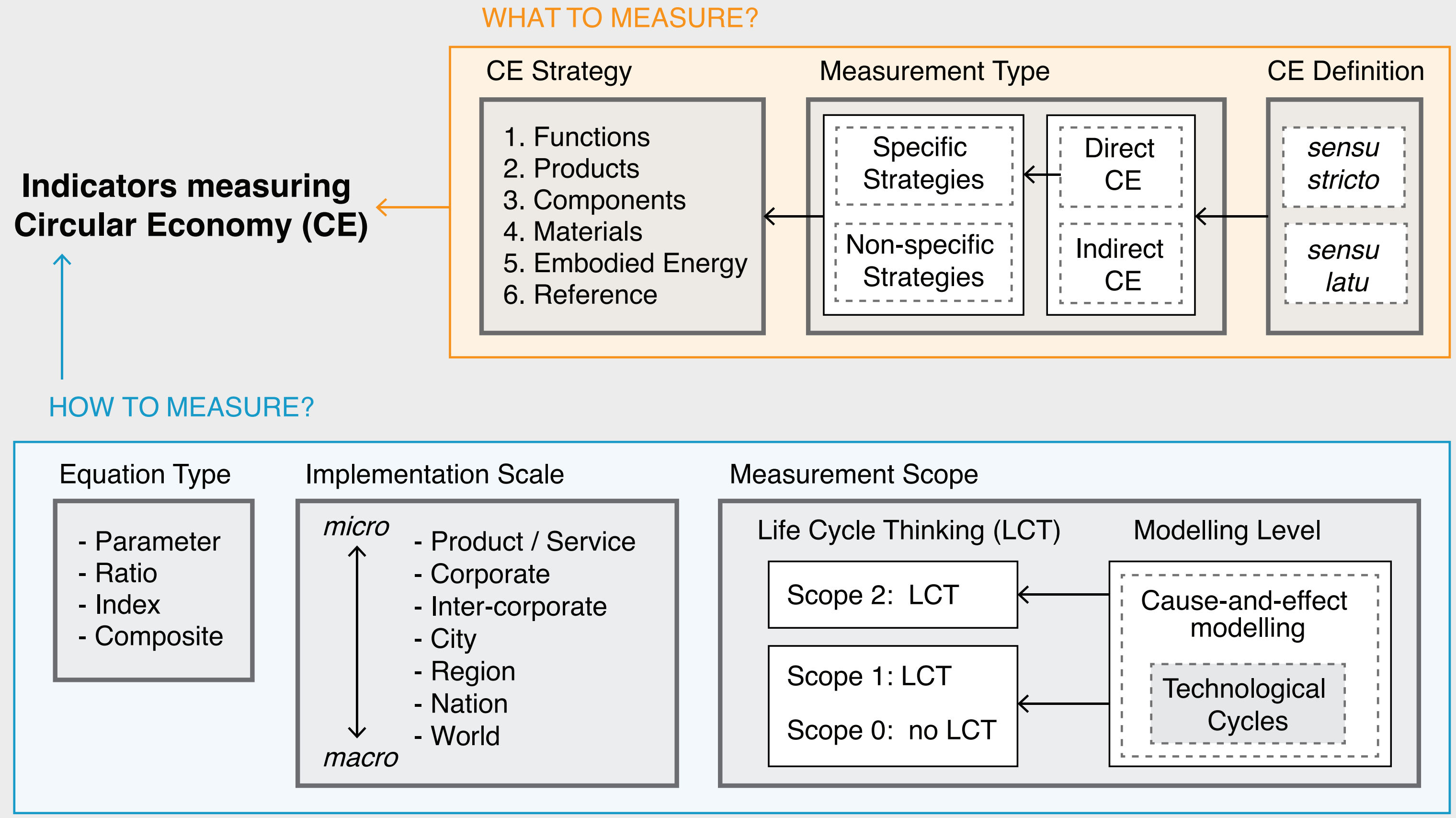
INTRODUCTION

INTRO-
DUCTION

Our society has an astounding and increasing consumption of materials. **By 2050, three planets could be needed to provide resources for our current lifestyle [1].** The world's climate is the direct subject of how the global economy manages natural resources, and resource efficiency will be vital to meet the Paris Agreement's temperature goals. In this sense, the circular economy concept can influence how we manage resources. **The circular economy can promote the responsible and cyclical use of resources**. In recent years, a circular economy has been endorsed as a policy to minimise burdens to the environment and stimulate the economy. The recent New Circular Economy Action Plan intends to achieve carbon neutrality and more efficiency in resources and materials management in the European Union. The supply chain of materials can much benefit from circular economy strategies to recover materials and products. **However, despite the benefits of keeping materials in the loop, there will always be environmental burdens and cumulative use of resources associated with a chosen circular economy strategy.** Thus, to target better policy towards a circular economy, indicators considering sustainability are needed. In the context of the Policy Research Centre for Circular Economy (Steunpunt Circulaire Economie) promoted by OVAM, **this doctoral dissertation aimed to develop circularity indicators of materials in supply chains.**

To achieve this development of indicators, three steps were given. **Step 1:** We try to understand what do circular economy indicators measure, focusing on diverse indicators from academic literature, European policy, and industry. **Step 2:** We propose two indicators, In-Use Occupation Ratio (UOR) and Final Retention in Society (FRS) focusing on the materials that are used in products over time. **Step 3**: Not only the materiality is important when assessing a CE, but also environmental impacts attached to the use of materials. In the last step, we developed resource efficiency indicators that jointly assess the occupation of materials and environmental impacts. To illustrate the indicators, we applied them with case studies for the use of metals and plastics in electronics (Steps 2 and 3) and wood and plastics in garden furniture (Step 2). In the sections below, each step is briefly explained.



CIRCULAR ECONOMY INDICATORS: WHAT DO THEY MEASURE?

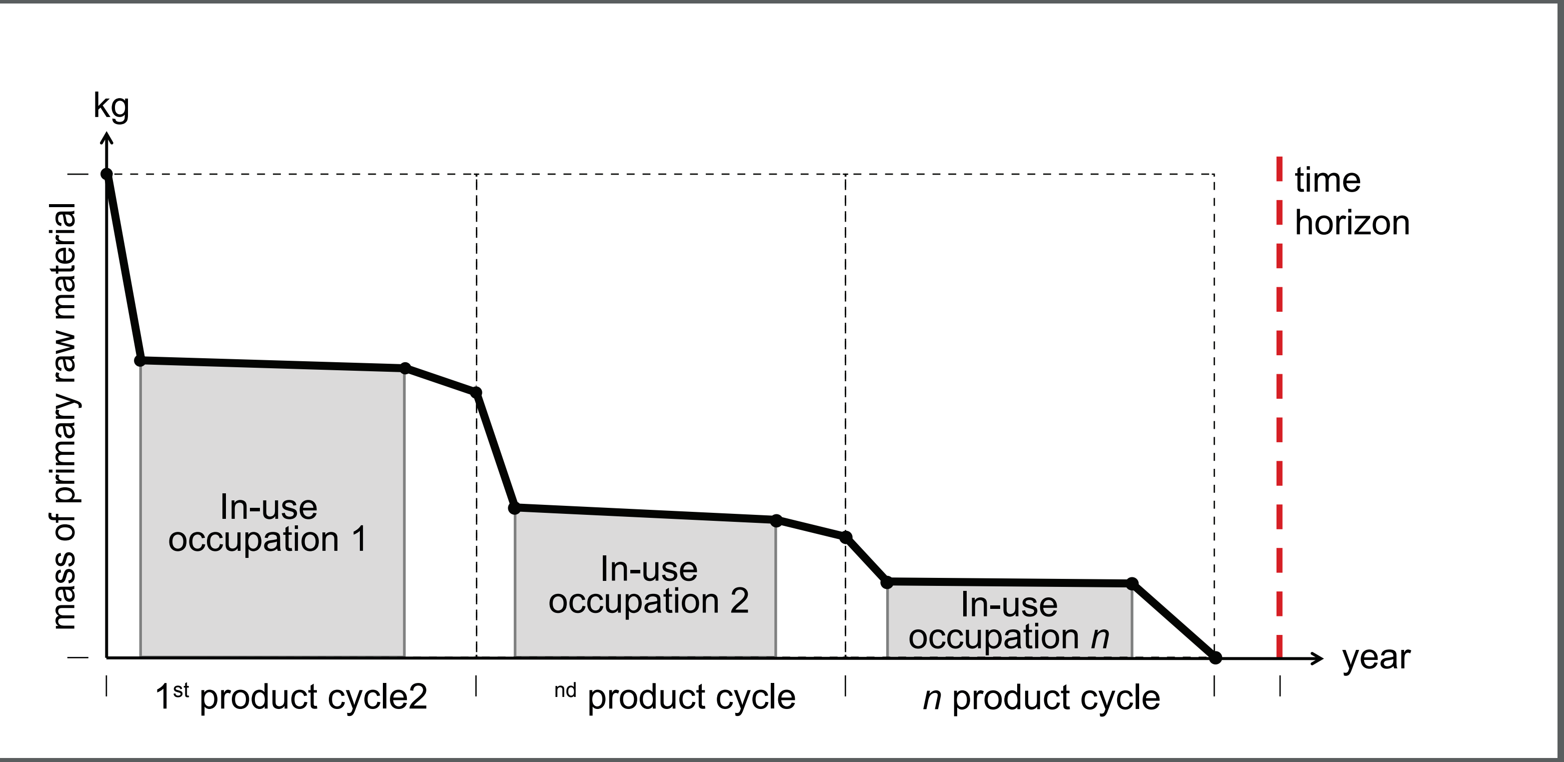
Step 1

As the initial step, this dissertation focused on understanding the state-of-the-art of circular economy indicators. **A classification framework is proposed to categorise indicators according to the reasoning of what indicators measure (circular economy strategies) and how they do so (measurement scopes).** There are plenty of circular economy strategies, but they can be grouped according to their attempt to preserve functions, products, components, materials, or embodied energy. The measurement scope can show how indicators account for technological cycles (with or without a life cycle thinking approach) or the effects of such cycles on environmental, social, or economic aspects. We illustrated the framework with micro-scale indicators from literature and macro-scale indicators from the European Union's 'circular economy monitoring framework'. **The framework illustration showed that most of the indicators focus on preserving materials, with strategies such as recycling. Although micro-scale indicators can assess strategies considering a life cycle thinking approach, the European indicators often account for materials-based strategies without much life cycle thinking consideration.** From the indicators considering life cycle thinking, few indicators assessed time, despite many circular economy definitions explicitly referring to an economy 'where resources are kept for as long as possible.' Furthermore, none of the analysed indicators could assess the preservation of functions (related to circular economy strategies such as sharing platforms). Finally, the framework illustration suggested that a set of indicators should be used to assess circular economy instead of a single indicator.

Step 2

Indicators for the in-use occupation of materials

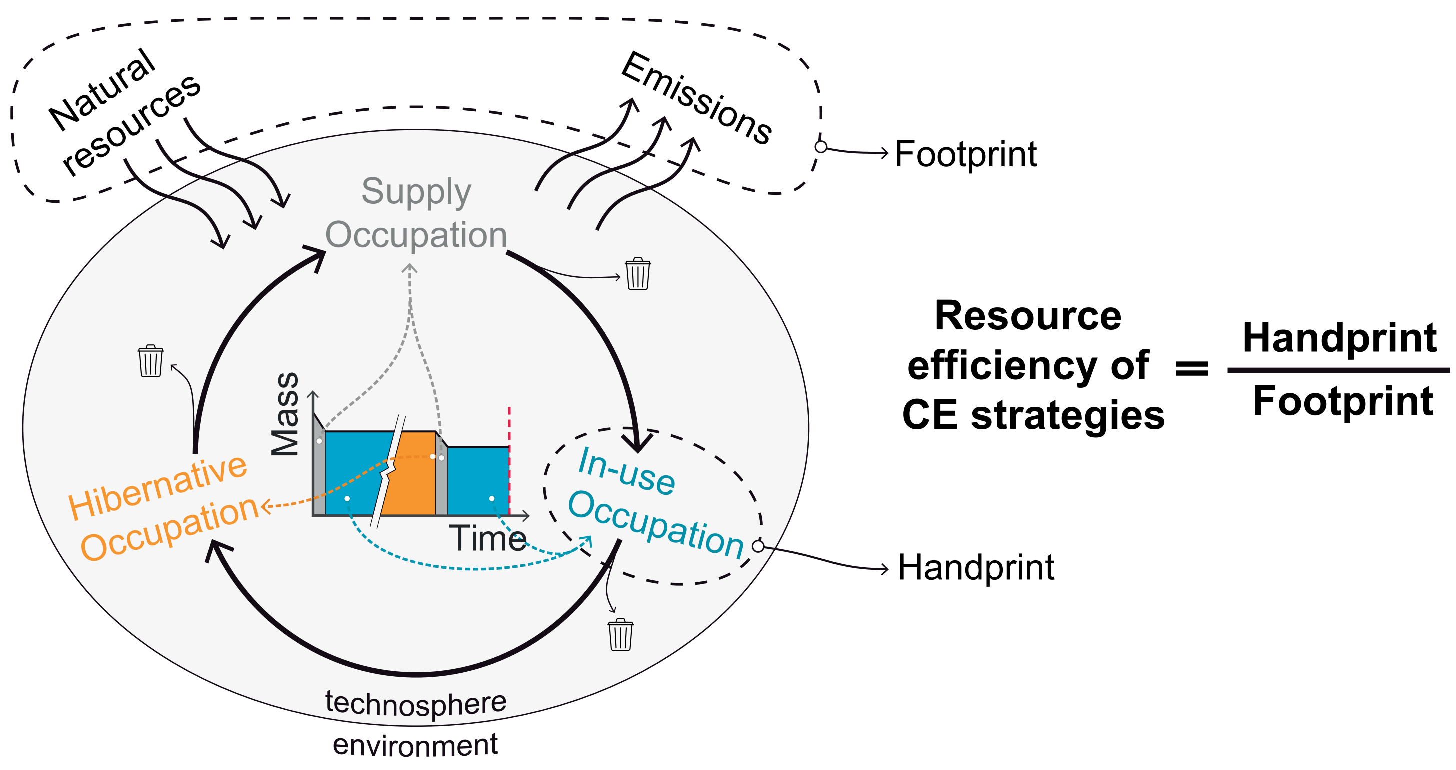
Circular economy strategies of slowing and closing loops of resources have the ultimate goal of keeping materials useful (i.e., in-use) while avoiding losses (dissipation). With this reasoning, we proposed measuring the circularity of materials by quantifying their in-use occupation, that is, the maintenance of materials in a useful state in products for as long as possible while avoiding dissipation or hibernation. Specifically, **two indicators were developed: in-use occupation ratio (UOR) and final retention in society (FRS)**. These indicators were applied in two case studies (materials in laptops and wood products) with three scenarios each: linear, product preservation (reuse), and material preservation (recycling). The reuse scenarios generally presented a higher UOR (41–48% for laptop materials and 53% for wood) compared to recycling scenarios (29–45% for laptop materials and 52% for wood). Only two scenarios of wood products resulted in retaining materials for the next generation (FRS > 0%). We argue that the differentiation between supply, in-use, and hibernation phases is essential for a circular economy.



Step 3

Environmental impacts of the in-use occupation of materials

UOR and FRS can measure the use of materials over time while considering life cycle thinking. In this sense, **the in-use occupation--based indicators are a proxy for the benefit, or handprint, that materials provide in society**. However, these indicators miss the connection with sustainability, particularly the environmental footprint caused by using such materials. **Hence, in this last step, we further developed these indicators using the concept of resource efficiency to indicate the handprint and footprint of the used materials.** We illustrated the developed indicators, resource efficiency of in-use occupation (Eff_{Occ}) and of final retention (Eff_{FRS}), with a case study of four materials (aluminium, copper, iron, and plastics) embedded in laptops. The study included scenarios with different circular economy strategies: energy recovery, recycling, refurbishing, and reuse. The scenarios showed the use of the materials in several cycles of laptops over a 25-year time horizon. Scenarios with cycles of refurbishment and reuse showed an improvement in Eff_{Occ} up to 189% and 157%, respectively, when compared to energy recovery. Nonetheless, it was remarkable that the average Eff_{Occ} and Eff_{FRS} showed a preference for refurbishing scenarios over reuse, considering the 25-year time horizon.



Policy implications

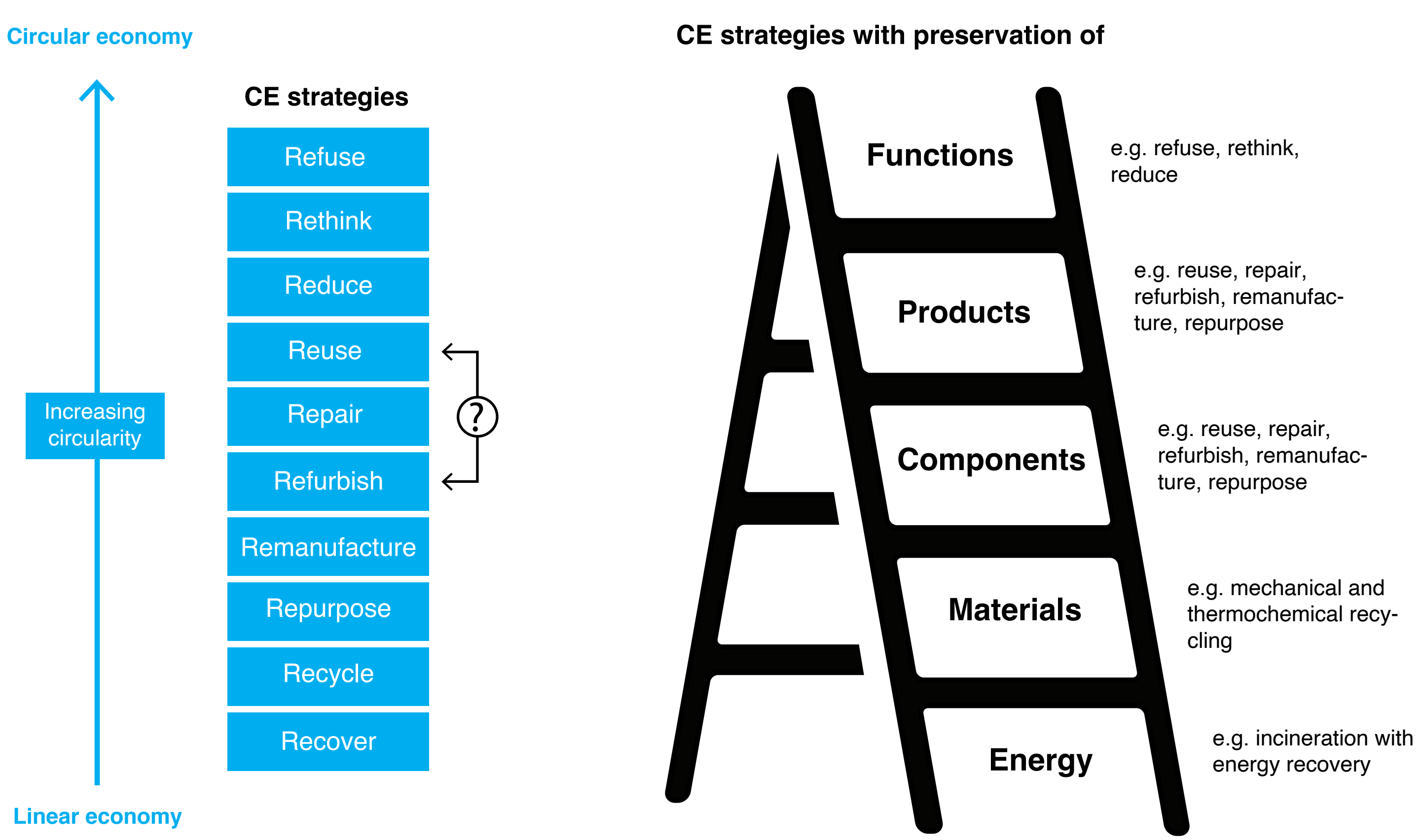
A CAUTIONARY TALE ABOUT CE STRATEGIES

The results of the handprint indicators in Step 3 showed that the in-use occupation is similar for recycling, refurbishing, and reuse. In contrast, the UOR of plastics showed a clear preference for reuse or refurbishing over mechanical recycling. With resource efficiency indicators, scenarios delaying recycling are across-the-board preferred. Reuse and refurbishing scenarios were 25–65% more carbon-emissions resource efficient and 30–60% more natural resource efficient than recycling. Nonetheless, the analysis of only handprint indicators showed that all scenarios could improve considerably (e.g. the FRS was < 25% in all scenarios with plastics). Hence, the resource efficiency for these materials can also improve. Another information from the resource efficiency indicators is that **refurbishing scenarios performed better on average than reuse scenarios.** This was surprising as CE R-ladders usually show another order of preference – a ladder of sorts is shown on page 7 (a). To extend the meaning of the results, some explanations are necessary.

Firstly, the definition of either refurbishment or reuse varies. Reuse is defined as the use of 'discarded product which is in good condition and fulfil its original function.' Refurbishing is defined as 'restore an old product and bring it up to date.' In the case of refurbishment, we used data about a company that buys used laptops and runs performance tests on the products and their components before selling. The company sells a share of these laptops with one year warranty, while the other share is sent to dismantling for materials recycling. In the case of reuse, we assumed that no repairs were made and that the laptops were reused by the same or another user. Hence, in our reuse or refurbishment scenarios, there is no change of parts or inclusion of new materials. However, in the refurbishment scenario, many more actors are involved in the supply chain of the laptops than in the case of reuse. Hence, one could assume that reuse should be preferable over refurbishing and especially over recycling. This, of course, can be true, particularly if strategies are analysed individually considering one product cycle.

Nonetheless, **in the case studies, we showed CE strategies being used in parallel or in a sequential way**. In Step 2, this was implemented limitedly with the analysis of two product cycles. But in Step 3, we assessed 4–5 cycles of materials used in products. Interestingly, the handprint indicator UOR showed similar results for recycling and reusing in Step 2 for materials iron, aluminium, and wood. This was again the case in Step 3 for the materials aluminium, copper, and iron. On the one hand, reuse having a similar result as recycling can be criticised because of the different resource requirements of both strategies, which will generate consequences for the environment. On the other hand, the UOR result shows that the beneficial use of these materials in the analysed products are comparable because of the shorter in-use time of reused products.

(a) CE 10-R ladder (adapted from [2]) (b) CE preservation ladder



CONCLUSIONS

Hence, in light of the more beneficial use of materials, the promotion of reusing needs to be coupled with longer use of reused products with shorter periods of hibernation. Moreover, when resource efficiency is considered, all strategies delaying recycling are preferred. It follows that policy should incentivise strategies to make products more durable while stimulating people to use them longer. The promotion of longer or more intensive in-use of products (and therefore materials) should be promoted but carefully. **Our results showed that the order of preference of CE strategies should be taken with a grain of salt.** Moreover, the assessment of CE strategies for energy-using products needs further investigation, mainly because of energy efficiency improvements of newer products. Energy efficiency increase may be a challenge with the promotion of more durable products. In this dissertation, we assessed energy-using products but disregarded the use phase environmental impacts. Nonetheless, the impacts of the use phase can affect the order of preference of CE strategies.

THE PROMOTION OF LONGER OR MORE INTENSIVE IN-USE OF PRODUCTS (AND THEREFORE MATERIALS) SHOULD BE PROMOTED BUT CAREFULLY.

Considering CE R-ladders, we argue that the one proposed on page 7(b) based on our classification framework (Step 1) is an inclusive type. In our CE-preservation ladder, there is no prescription of strategies but an indication of what the strategies can preserve (i.e. materials, components, products, and functions). It does not give preference for strategies applied to the same subject (e.g. reuse vs refurbish vs remanufacture). However, our ladder indicates a possible preference for the preservation subjects. This follows the reasoning that higher strategies would require shorter loops and thus fewer resources – materials and energy – leading to fewer impacts.

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CONCLUSIONS

INTEGRATION OF THE INDICATORS IN THE CE MONITOR AND FUTURE WORK

The Flemish CE monitor is composed with the aim to fill the gap between micro-level and macro-level indicators. This gap is proposed to be filled with an intermediate (meso) level that monitors societal needs (e.g. mobility, housing, and nutrition). In this sense, **MFA could be used to monitor the amount of material needed for the societal needs.** Indeed, MFA within the scope of housing and nutrition needs exist in varied geographical levels. MFA could be integrated into the handprint indicators (UOR and FRS) to consider 1 kg of material that is initially used in a regional economy (e.g. Flanders) and its maintenance in the economy throughout a time horizon. In the STEN group at Ghent University, some methodologies are being developed to integrate the handprint indicators and MFA, which could be used with the CE monitor to track the fate of metals in different applications.

MFA COULD BE INTEGRATED INTO THE HANDPRINT INDICATORS (UOR AND FRS) TO CONSIDER 1 KG OF MATERIAL THAT IS INITIALLY USED IN A REGIONAL ECONOMY (E.G. FLANDERS) AND ITS MAINTENANCE IN THE ECONOMY THROUGHOUT A TIME HORIZON.

Concerning the resource efficiency indicators in this dissertation, a further improvement can be the footprint estimation approach. In Step 3, we used a conventional process-based LCA to estimate the footprint. With this type of LCA, results can be shown in a detailed resolution for each step in the supply chain of materials. However, process-based LCAs are time demanding because of the data requirement. Another approach would be an input-output LCA (IO-LCA). IO-LCAs are based on Input-Output Tables, compiled by statistical authorities as part of national accounts in most industrialised countries. An analysis with IO-LCA can be a powerful way to estimate the footprint of product's supply chains in reduced time, but it can miss the detailed information about materials management provided from process-based LCAs. Still, **the integration of IO-LCA and our resource efficiency indicators could be a path for future research in the context of policy-making.**

CONCLUSIONS

OTHER POLICY RECOMMENDATIONS CAN BE SUMMARISED IN THREE POINTS:

a. Analysis of multiple CE strategies: With the indicators UOR, FRS, and their resource efficiency counterparts, CE strategies were analysed in a sequential and parallel way. Sequentially because materials are studied in several cycles over the 25 years. Parallelly because in one of the scenarios (refurbishing), the share of not refurbished materials is recycled; hence, recycling and refurbishing are analysed simultaneously. This approach is different from evaluating single circular economy strategies (with indicators such as recycling rate). The analysis of single strategies can potentially show resources diverted from waste, but it also gives incomplete information.

CE STRATEGIES WERE ANALYSED IN A SEQUENTIAL AND PARALLEL WAY

b. In-use time vs durability: In Europe and worldwide, there has been a push for making products more durable. Making products more durable is sensible in the circular economy, as we want to use products longer. Product's technical durability is important information that can easily be added to material passports and labels. Nonetheless, making products more durable is not a guarantee their in-use time will increase. Moreover, the increase in durability may be related to different materials with higher emissions along the supply chain. For example, cotton grocery bags need to be reused more than 170 times to decrease climate change impacts compared to single-use HDPE bags [3]. If products durability increases in disconnection with the in-use time, we may have higher environmental impacts. Hence, policy-makers should be attentive to the increase of in-use time in products.

c. Data governance on time aspects: we argue that in-use time is an important parameter to 'keep the value of resources for as long as possible.' Nonetheless, the availability of in-use time information is scarce. Indeed, in-use time is a complex parameter to observe as it may be highly variable for its dependency on user behaviour. In-use time could be analysed through surveys with the general population for specific products or thematic product groups. A proxy for this information could be the user's future intention to use a product. Many companies ask clients to register their new products on the companies websites (e.g., Apple and Samsung). If companies are required to ask for how long the user intends to use their new product, the intention-of-use time could be used as a proxy for in-use time.

TWO CAVEATS WHEN ANALYSING THE RESULTS OF THIS DISSERTATION:

a. Validity of the methodology in other products: We tested mainly materials in laptops as one product group and, partially, wood in building components as another product group. To extend the validity of our results, the in-use occupation concept and indicators should be tested in other product groups. The methodology proposed here is intended for resources with a material application (that is, not intended for consumption or energy use). Nonetheless, materials used in material applications and in association with consumables (e.g. plastics packaging for beef) need further investigation. This is because the increasing of in-use time in consumable's packaging does not render the same meaning as for durable products. Hence, increasing the in-use occupation of packaging should be investigated with closer attention.

THE ANALYSIS OF THE INDICATORS FOR THE IN-USE OCCUPATION CAN ALSO BE ACCOMPANIED BY THE ENVIRONMENTAL IMPACTS OF SINGLE PRODUCTS

b. Energy consumption during use: Our methodology proposes the analysis of materials embedded in products. Therefore, we did not attribute impacts due to energy consumption during use for energy-consuming products. The exclusion of the energy consumption during use was part of a methodological choice for the evaluation of materials. However, energy consumption during use is important to offset environmental impacts in many products. Indeed, more efficient products are being promoted for several decades in Europe and elsewhere through labelling certification and other policies. With this in mind, the analysis of the indicators for the in-use occupation can also be accompanied by the environmental impacts of single products, such as those provided by the EU's Product Environmental Footprint (PEF).

CREDITS

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The dissertation can be found at:
https://biblio.ugent.be/publication/8718332

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