NOVA SCHOOL OF SCIENCE & TECHNOLOGY

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BSc in Environmental Engineering

Circular economy self-assessment tool for households: A collaborative approach

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"If I have seen further, it is by standing on the shoulders of giants." (Sir Isaac Newton).

Abstract

Household daily activities, such as food acquisition, housing, and mobility, are closely linked to sustainability impacts, including climate change, raw material use, quality of life, and waste production. However, individuals still don't know how to act to better manage and improve their household sustainability performance, covering sustainable consumption and well-being, among other related aspects. In the context of households, when sustainable consumption is connected with circular economy, financial benefits become a possibility, and a main driver towards a sustainable lifestyle. Multiple studies have been conducted to understand circular economy assessment in products, private or public organizations, eco-industrial parks, and cities. However, there is still a lack of knowledge regarding the assessment of circular economy practices implemented at the household level, including current strategies, and indicators. Thus, the present work aims at developing a self-assessment tool to assess and report the implementation of circular economy-based strategies at the household level, including the definition of consumption activities, and indicators. This study is supported by a two-stage methodology, based on a mix-method procedure, that centres co-creation with residents/ family's representatives in its approach, through the use of questionnaire surveys, and semi-structured interviews with open-ended questions. Through a survey, the householders consumption priorities were identified, encompassing different circular economy practices and scopes. This allowed a qualitative triangulation with an integrative literature review, resulting in a set of 38 household circular economy metrics that enable self-assessment and foster circular economy at the consumer level. Additionally, insights over the use of the self-assessment tool were analysed, following a list of recommendations to optimize the construction of similar mechanisms. The developed self-assessment tool will allow individuals and families to assess, communicate, and reflect on their behaviours about sustainability, in the vein of circular economy. It will foster a pro-environmental mindset, social equity, and economic consciousness in

everyday decisions. This research contributes to the debate on the role of the household in the transition towards a circular economy, and its inherent assessment, and communication, using circular economy indicators.

Keywords: Circular economy; Indicators; Sustainable consumption; Assessment; Stakeholder engagement

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RESUMO

As atividades diárias das famílias, como a aquisição de alimentos, a habitação e a mobilidade, encontram-se significativamente associadas a múltiplos impactes ambientais, sociais e económicos, incluindo as alterações climáticas, a utilização de matérias-primas virgens, a qualidade de vida e a produção de resíduos. No entanto, os indivíduos ainda não sabem como agir para otimizar a gestão e o desempenho de sustentabilidade do seu agregado familiar, abrangendo o consumo sustentável e o bem-estar, entre outros aspetos relacionados. No contexto dos agregados familiares, quando o consumo sustentável está ligado à economia circular, os benefícios financeiros tornam-se uma possibilidade e uma das principais motivações para um estilo de vida sustentável. Múltiplos estudos foram realizados para compreender a avaliação da economia circular em produtos, organizações privadas ou públicas, parques eco industriais e cidades. No entanto, existe ainda uma falta de conhecimento relativamente à avaliação das práticas de economia circular implementadas a nível doméstico, incluindo estratégias e indicadores. Assim, o presente trabalho tem como objetivo desenvolver uma ferramenta de autoavaliação para avaliar e comunicar a implementação de estratégias baseadas na economia circular ao nível das famílias, incluindo a definição de atividades de consumo e indicadores. Este estudo é suportado por uma metodologia estratificada em duas fases, baseada num procedimento de método misto, que centra a sua abordagem na cocriação com os residentes/representantes das famílias, através da utilização de inquéritos por questionário e entrevistas semi-estruturadas com perguntas abertas. Através de um inquérito, identificaram-se as prioridades de consumo dos agregados familiares, abrangendo diferentes práticas e âmbitos da economia circular. Isto permitiu uma triangulação qualitativa com uma revisão integrativa da literatura, resultando num conjunto de 38 métricas de economia circular que permitem a autoavaliação e promovem a economia circular ao nível do consumidor. Adicionalmente, analisaram-se as perceções sobre a utilização da ferramenta de autoavaliação, seguindo-se uma lista de

recomendações para otimizar a construção de mecanismos semelhantes. A ferramenta de autoavaliação desenvolvida permitirá aos indivíduos e às famílias avaliar, comunicar e refletir sobre os seus comportamentos em matéria de sustentabilidade, na linha da economia circular. Promoverá uma mentalidade pró-ambiental, equidade social e consciência económica nas decisões quotidianas. Esta investigação contribui para o debate sobre o papel do agregado familiar na transição para uma economia circular, e a sua inerente avaliação e comunicação, utilizando indicadores de economia circular.

Palavras chave: Economia circular; Indicadores; Consumo sustentável; Avaliação; Envolvimento das partes interessadas

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ACRONYMS

SCP	Sustainable Consumption and Production
CE	Circular Economy
UNCED	United Nations Conference on Environment and Development
RCP	Responsible Consumption and Production
HSC	Household Sustainable Consumption
HCE	Household Circular Economy
LCA	Life Cycle Analysis
EoL	End of Life
SDG	Sustainable Development Goal
KPIs	Key Performance Indicators
MFA	Material Flow Analysis
EF	Ecological Footprint
ENF	Energy footprint
FF	Financial footprint
CSF	Consumption footprint

1

INTRODUCTION

Household consumption practices are associated with major environmental impacts and sustainability challenges, including climate change, freshwater eutrophication, air pollution, raw material use, acidification, well-being, and waste production (Castellani *et al.*, 2019). In this vein, food acquisition, housing – which includes construction, renovations, and energy consumption by the house -, and mobility are main drivers of impact (Castellani *et al.*, 2019; Kalbar *et al.*, 2018; Saleem & Ali, 2018). Although dependent on income level and age, among other factors, lifestyle practices are linked to the aforementioned environmental impacts (Kalbar *et al.*, 2018). When comparing the environmental impact in countries such as Pakistan and China, Saleem and Ali (2018) understood that, aligned with an increase in people's income, in the past 50 years, there was a higher energy, and product consumption-based lifestyle. Thus, economic growth and consumption patterns are closely associated (Caeiro *et al.*, 2012; Distefano & Kelly, 2017), namely in food (Gerbens-Leenes *et al.*, 2010), and electricity acquisition (Shi *et al.*, 2020). In this context, the concept of sustainable consumption was brought forward, centralizing the need for individuals, organizations, and nations to reduce their pressure on the environment and society (Anantharaman, 2018).

The origin of sustainable consumption is found in the term of Sustainable Consumption and Production (SCP), which was introduced at the United Nations Conference on Environment and Development (UNCED), in Rio de Janeiro, in 1992 (Glavič, 2021). This concept was brought forward, with Agenda 21, stating that there was a resource over-consumption (Anantharaman, 2018). Recently, as a key global initiative, the Agenda 2030 (UN, 2016) has been promoting the concept of Responsible Consumption and Production (RCP), in the form of the 12th Sustainable Development Goal (SDG) (Glavič, 2021); therefore, fostering all United Nations Member States to invest in this matter (Orellano *et al.*, 2020). However, for the consumer, the main benefits

are of psychological nature, as sustainable consumption takes on a symbolic role (Abdulrazak & Quoquab, 2017). Nonetheless, through circular economy-based strategies, the consumer can also find a financial benefit, which then acts as the main driver towards a circular economy (CE) model (van Weelden *et al.*, 2016).

Following this reasoning, when linked with SCP, CE can work as one of the strategies to tackle the environmental impacts associated with consumption patterns (Goyal *et al.*, 2021). In a comprehensive and systematic analysis of 114 CE definitions, Kirchherr *et al.* (2017, p. 229) characterize CE as "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling, and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity, and social equity, to the benefit of current and future generations". In Potting *et al.* (2017), the scope of circular economy-based strategies is expanded, including: (i) refuse; (ii) rethink; (iii) repair; (iv) refurbish; (v) remanufacture; and (vi) repurpose. Among the ones mentioned in the definition proposed by Kirchherr *et al.* (2017). Furthermore, Potting *et al.* (2017) ranks the strategies from linear to circular economy, prioritizing the ones that allow the consumption of fewer natural resources and a lower output in environmental pressures. In this vein, in the form of a consumer, the household takes on a central role, in enabling the CE transition (Shevchenko *et al.*, 2023). As stressed by Shevchenko *et al.* (2023), the circular consumer holds three roles: (i) as a customer, acquire products with the minimum environmental impact and refrain from buying; (ii) as an user, careful use, and maintenance, acquire technical services and repair, and sell or donate the products if no longer needed; and (iii) as an EoL product holder, timely discard and use the appropriate circular discarding channel.

To foster CE progress at the macro, meso and micro level, performance evaluation and communication represents a core step (Droege *et al.*, 2021; Sassanelli *et al.*, 2019). Through a systematic literature review, Sassanelli *et al.* (2019) understand that, in function of the CE domain, different assessment methods are used, which can highlight certain aspects of the CE model. Nevertheless, and despite the diverse range of assessment methods and approaches in CE, multiple authors underline the use of indicators to assess, monitor, and communicate CE progress (Howard *et al.*, 2017; Saidani *et al.*, 2019; de Oliveira *et al.*, 2021). However, most developed CE indicators measure material flow or recirculated value of a system, and consequently, dominant assessment method and tools are focused on cleaner production, resource-efficiency, material stocks and flows, and product-centric areas (Droege *et al.*, 2021; Droege *et*

al., 2021a; Opferkuch *et al.*, 2022; Opferkuch *et al.*, 2023); whereas, the consumer level, including customer, user and EoL product holder (Shevchenko *et al.*, 2023), is being poorly analysed (Harris *et al.*, 2021). Nonetheless, CE indicators can foster circularity, namely in public policy decision making (De Pascale *et al.*, 2021; Droege *et al.*, 2021a).

In the context of Household Sustainable Consumption (HSC), Caeiro *et al.* (2012, p. 80) recommend the use of indicators to assess this matter, as communication represents a major challenge, in which the indicator system should be: "(i) easily comprehensible and meaningful to family members; (ii) developed with a bottom-up process with emphasis on public participation and empowerment; (iii) use an integrative approach among the different domains; (iv) facilitate practical dynamic behaviours, actions and routines in implementing HSC; (v) provide transparent evaluation of the HSC performance; (vi) provide guidance via illustrative best practices; and (vii) provide financial and non-financial incentives for achieving continuous HSC improvements". Thus, to foster a CE transition at the micro level, including at household and family level, empowerment can play a complementary role, since it enhances people's skills, increases community ownership, and awareness towards sustainability related issues (Marchesi & Tweed, 2021).

However, there is a knowledge gap in how CE should be assessed at the household level. Multiple studies have been conducted to understand CE assessment at the organizational level (Sassanelli *et al.*, 2019), products and processes (Ahmed *et al.*, 2022), eco-industrial parks (Zhao *et al.*, 2017), and cities (Gravagnuolo *et al.*, 2019), and the role of the circular consumer was analysed (Shevchenko *et al.*, 2023). Furthermore, in the context of HSC, Caeiro *et al.* (2012) developed an approach to define the main criteria to build HSC assessment tools based on indicators sets. Through a Life Cycle Analysis (LCA), Castellani *et al.* (2019) determined the environmental impacts of household consumption, in Europe. With a similar objective, Peng *et al.* (2021) defined the consumption activities of rural households. Nonetheless, little attention has been given to the assessment of CE at the household level, similar to how regular organizations and their individuals are assessed, including their inputs, processes, outputs, outcomes/impacts, and related indicators. Moreover, in the form of a consumer, the household represents a key element, in enabling a transition towards a CE model (Camacho-Otero *et al.*, 2018; Shevchenko *et al.*, 2023). Therefore, the present work aims at developing a self-assessment tool to assess and report the implementation of circular economy-based strategies and practices at the household level. This includes defining circular indicators specifically tailored for householders, with support from a collaborative approach. Thus, to develop a household CE self-assessment tool, the present study aims to answer the following research questions:

i) How important are the CE practices at the household level?
ii) What are the indicators that can be used to enable the self-assessment of CE implementation into households?

This paper is structured as follows, after this chapter: (i) The literature review presents an overview of the studies conducted in the matter of Household Circular Economy (HCE) practices, in the context of the CE framework (Potting *et al.*, 2017), a description of CE indicators, and a review multiple self-assessment tools; (ii) The methodological approach indicates the steps taken to evaluate the CE practices at the household level and indicators, through the use of a mix-method approach, based on a questionnaire survey and semi-structured interviews; (iii) The results are presented, with the illustration of the aforementioned components; (iv) afterwards, the discussion explores the main findings with the existing literature; and (v) lastly, conclusions, limitations, and further research are presented.

2

OVERVIEW OF HOUSEHOLD CIRCULAR ECONOMY ASSESSMENT APPROACHES

2.1 Household circular economy practices

At the household level, refusing strategies follow the definition proposed by Potting *et al.* (2017), in which the individual abandons the function or acquires it through a different product or service. Therefore, acquiring products certified with an eco-label, as it communicates, in general, an object with a lower environmental pressures and resource consumption, enables a high circularity role for the household (Zotti & Bigano, 2019; Edbring *et al.*, 2016). Furthermore, individuals can minimize packaging, decorative elements, and reduce the use of unnecessary accessory materials, e.g. plastic straws (Wang *et al.*, 2022), in the form of plastic waste (Potting *et al.*, 2017; Reike *et al.*, 2018; Morseletto, 2020). However, the lack of information and economic incentives, and availability of a product or service replacement for a given function, can act as a barrier, in the household transition towards a CE (Grafström & Aasma, 2021).

Although it can be interpreted as a combination strategy of refusing and rethinking, acquiring a product, in the form of a service, fosters CE in this level, making product use more intensive (Shevchenko *et al.*, 2023; Potting *et al.*, 2017). Thus, using a sharing service of washing machines and dryers (Potting *et al.*, 2017), vehicles (Atsaja *et al.*, 2022), or bicycles (Henriksson & Scalzotto, 2023), promotes environmental-friendly and CE trends, that minimize population expenses, and maximizes function accessibility (Atsaja *et al.*, 2022).

Reduce, re-use, recycle and recover strategies, at the household level, have been documented in environmental related concerns, regarding resource consumption and environmental pressures, including (Paparella et al., 2023; Kumar *et al.*, 2022): (i) the consumption of energy (Adan & Fuerst, 2016); (ii) the use of water (Gómez-Monsalve *et al.*, 2022); and (iii) waste

production (Varotto & Spagnolli, 2017). For the first, products characterized by their energy efficient design, in the use phase, allow a reduction in the consumption of resources, which can be further improved through behavioural practices (Barkhausen *et al.*, 2022; Richter, 2010). Reduction strategies depend on the household income and livelihood strategy, family size, and end-use behaviour (Jiang *et al.*, 2019). Regarding the second, water consumption is constricted by multiple barriers, including lack of motivation, information, and financial incentives to engage in conservation behaviour, since water efficient products are costly (Addo *et al.*, 2018). McCarton *et al.* (2022) proposes a strategic hierarchy to foster the transition towards the CE of water, in which reduction shows the highest priority, followed by re-use, recycle, and recover measures. At the household level, the authors recommend reduction and re-utilization practices, promoting water efficient products, and rainwater harvesting to supply non-drinking purposes. In regard of the waste domain, through a literature review, Ghisellini *et al.* (2016) states that the use of materials, in the form of waste, represents one of the core elements of CE. At the household level, multiple studies have been conducted, in the context of household waste sorting and recycling behaviour, regarding organic, and electrical and electronic equipment (Varotto & Spagnolli, 2017; Nainggolan *et al.*, 2019; Zhang *et al.*, 2022; Parajuly & Wenzel, 2017). In these studies, household participation represents a core element, in enabling CE and reducing the respective waste quantities. Additionally, in some situations, the product still holds a monetary value (Parajuly and Wenzel, 2017).

Lastly, repair, refurbish, remanufacture, and repurpose strategies are linked with the extension of the lifespan of products and its parts (Potting *et al.*, 2017). Thus, these actions foster a slower loop, with a lower environmental pressure and resource consumption (Rizan *et al.*, 2022). However, Terzioğlu (2021) found that multiple barriers restrict the individual from repairing the product, including technical, value and emotional variables. For instance, it requires time and effort, skills and knowledge, and accessibility of materials and methods. Doubts over the condition of the product, and the financial factor represent a constraint. In Morseletto (2020), these factors are further expanded to the remaining measures, and summarized in three categories: (i) costs/availability of the procedure; (ii) product design that allows these options; and (iii) culture based on a fast-consumption mentality.

2.2 Circular economy indicators

CE indicators can be defined as a quantitative or qualitative measuring instrument of several CE strategies individually or simultaneously, accounting for the material flows, and, although with its limitations, the use phase of a product (de Oliveira & Oliveira, 2023). In recent studies, other descriptions have been brought forward. Khadim *et al.* (2022) critically reviewed multiple micro-level circularity indicators and frameworks, suggesting that most CE Key Performance Indicators (KPIs) focus on material loop, disassembly, adaptability, and reusability evaluation. From a public organization CE assessment perspective, Droege *et al.* (2021) considers a holistic thinking approach, recommending a triple-bottom line in its framework; thus, considering the social and environmental implications of CE, and highlights the importance of stakeholder engagement. In sum, these metrics can be characterized as a method to assess the performance and progress of, and towards, a CE model (Saidani *et al.*, 2019).

As stressed by Saidani *et al.* (2019), CE indicators enable assessment, reporting and communication across all CE levels (micro, meso, macro). In fact, multiple types of CE indicators and frameworks have been developed (Droege *et al.*, 2021; Helander *et al.*, 2019; Padilla-Rivera *et al.*, 2021; Sánchez-Ortiz *et al.*, 2020; Yadav *et al.*, 2020; Rincón-Moreno *et al.*, 2021). For instance, Gravagnuolo *et al.* (2019) suggested a circular city assessment framework, focusing on seven sectors: (i) built environment; (ii) energy and mobility; (iii) waste management; (iv) water; (v) industrial production; (vi) agri-food; and (vii) citizens and communities. From an eco-industrial park perspective, Belaud *et al.* (2019) developed a toolbox, considering a life cycle thinking approach. Similarly, product centric CE assessment frameworks tend to depend on a LCA procedure (Corona *et al.*, 2019). However, in the context of private organizations, Opferkuch *et al.* (2023) understood that companies were also worried about sustainability trade-offs and reducing potential claims of CE-related greenwashing, among the progress and performance of implemented CE strategies. Although the continuous increase in scientific literature regarding CE assessment, Corona *et al.* (2019) and Shevchenko *et al.* (2023) stressed on the literature gap regarding consumer-based metrics.

Among multiple other benefits, CE assessment through indicators promote an extensive comprehension of the current state of CE. Although it depends on the evaluated level (micro, meso, macro) and on the implemented strategy and practice (e.g., refuse, rethink, repair, amidst similar others, see Potting *et al.*, 2017), CE indicators allow and foster benchmarking, decision making, learning and identification of improvement opportunities (Saidani *et al.*, 2019;

Sánchez-Ortiz *et al.*, 2020). Additionally, most CE indicators show a multi scale applicability, and can be used across different industrial sectors (Rincón-Moreno *et al.*, 2021).

Overall, CE indicators is still an underexplored field of research with multiple limitations and challenges. In fact, as stressed by Droege *et al.* (2021) and Harris *et al.* (2021), in a scoping review, CE assessment practices mostly depend on a LCA, Material Flow Analysis (MFA) and Input/Output Analysis approach. However, these methods have numerous limitations and disadvantages, including (Droege *et al.*, 2021; van Stijn *et al.*, 2021; Lu & Halog, 2020): (i) time intense execution; (ii) dependence on data quality and availability; (iii) requirement of technical expertise; (iv) lack of indicator diversity; (v) greenwashing impacts; and (vi) non- applicability in ex-post assessments and certification. To measure efficiency in CE, data gathering represents a significant barrier (Sánchez-Ortiz *et al.*, 2020). Due to the multiple CE definitions and levels, the indicators may be poorly positioned or inadequately address the issue at hand (Saidani *et al.*, 2019). According to Helander *et al.* (2019), CE indicators aren't able to properly assess the environmental pressures derived from CE activities, recommending a complementary approach with tailored metrics. Additionally, most CE indicators focus on the analysis of a single CE activity, which can enable problem shifting and a rebound effect. Padilla-Rivera *et al.* (2021) and Luthin *et al.* (2023) propose the same arguments for the social impacts derived from CE activities. Moraga *et al.* (2019) were not able to identify CE indicators capable of measuring higher circularity strategies, including refuse, rethink, and reduce. Jerome *et al.* (2022) understood that most CE indicators cannot assess the use phase of a product, and lifetime extension strategies (e.g., repair, remanufacturing, repurposing, refurbish).

2.3 Household assessment tools

According to Fahim *et al.* (2019, p. 45), self-assessment can be defined as "the process of critically observing one's own self in order to assess important aspects of one's personality". Thus, it relies on the assumption that the individual can assess themselves (Elimelech *et al.*, 2019). Multiple types of household self-assessment tools have been developed, to analyse individually or aggregately the domains of sustainability (Vanham *et al.*, 2019; Wu *et al.*, 2021; Fang *et al.*, 2016; Xie *et al.*, 2020). Within the sustainability spectrum, the "footprint", based upon the original concept of ecological footprint developed by Rees (1992), is a tool commonly used for the household or individual self-assessment (Syrovátka, 2020; Castellani *et al.*, 2019). Nevertheless, it also displays other scales of application, such as cities, countries, regions, higher

education institutes and private and public sector organizations (Kassouri, 2021; Pan *et al.*, 2019; Lambrechts & Liedekerke, 2014; Jurić & Ljubas, 2020).

Matuštík and Koči (2021) emphasize that an official environmental footprint definition hasn't been developed, due to the lack of methodological standardization and unification. Nevertheless, in the review elaborated by Čuček *et al.* (2012), the footprint took the role of assessing social, economic, and environmental issues, converging on a triple bottom-line sustainability analysis. From an environmental perspective, footprints quantify resource use and/or emissions. Thus, it works as an aggregated indicator, or index, that assesses the pressure derived from anthropogenic activities on the environment. Furthermore, within the concept of footprint family, trade-off-based analysis becomes a possibility (Vanham *et al.*, 2019). As an individual or household self-assessment tool, the footprint (e.g., ecological footprint [EF]) encourages a critical self-reflection process, which may further extend into pro-environmental behaviour (Friedland & Balkin, 2022; Tolppanen & Kang, 2021).

However, multiple authors criticise the methodological weaknesses of footprints, such as the EF, associated with the construction of the indices, inability to account for some pollutants and/or calculate the ratio between land use and land availability (Kharrazi *et al.*, 2014; Lin *et al.*, 2015; Franz & Papyrakis, 2011; Sutcliffe *et al.*, 2008). Among other aspects, the lack of encouragement of pro-environmental and community engagement actions in these footprints (e.g., beach cleaning, tree planting, amidst similar other environmental impact offset measures) suggest that individuals can't achieve a sustainable lifestyle (Franz & Papyrakis, 2011). In the vein policy setting, Kharrazi *et al.* (2014) acknowledge that there are methodological short comes.

The work conducted by Čuček *et al.* (2012) presents a review of footprints (Table A1), namely the ones highly associated with the individual and household assessment. Furthermore, for the analysis carried out in the present research, those approaches were aligned with the CE framework proposed by Potting *et al.* (2017). The footprints present a trend, in which resource flow quantification is stressed (Matuštík & Kočí, 2021). Thus, most identified tools target consumption-based behaviours, in which refusing and reducing represent a nuclear role (Castellani *et al.*, 2019).

As stressed by Rondoni and Grasso (2021), consumption behaviour greatly influences the performance assessed by environmental footprints, including the actions directly correlated with resource and/or land use (e.g., energy footprint [ENF]). Although socio-economic status influence resource consumption (Eisenmenger *et al.*, 2020), economic, and social footprints (e.g., financial footprint [FF]) don't focus on the use of raw materials; thus, not allowing an assessment of circular economy-based strategies.

Additionally, consumption and waste related footprints (e.g., consumption footprint [CSF]) provide a broader spectrum of assessment criteria, including the sharing aspects of mobility, and the EoL of consumer goods and services (Salas *et al.*, 2022; Kok & Barendregt, 2021; Buhl *et al.*, 2019). This allows a higher influence in the CE framework, since it considers rethinking and re-use, among the aforementioned strategies. Assessment tools that consider the multiple phases of the life cycle of a product display a greater positive impact on the CE model (Lei *et al.*, 2021).

3

METHODS

To develop the Household Circular Economy (HCE) self-assessment tool, an exploratory mix-method approach was adopted, combining the methods of an integrative literature review and sequential explanatory research design, supported by a questionnaire survey and semi-structure interviews. Denscombe (2010) and Saunders *et al.* (2016) stress that this process is highly recommended to provide an adequate answer, as both approaches complement each other. It results in a wider understanding of the aims being researched, since it offers more than one perspective. Also, it allows the collection of information, based on the lived experiences of the participants (Mayoh & Onwuegbuzie, 2015). This methodological architecture forms the nucleus of a collaborative process recommended by Caeiro *et al.* (2012) for the development of household sustainable consumption assessment tools.

In this research, residents/family's representatives (henceforth designated as householders) took the role of citizen as a co-designer of the developed assessment tool. Citizen as a co-designer can be characterized as involvement regarding the content and process of service delivery (Voorberg *et al.*, 2014). Caeiro *et al.* (2012) suggested a collaborative and participatory process for the development of a HSC assessment tool, stating that it should be built on the views and opinions gathered from the stakeholder engagement, along the process. By using a collaborative approach, it can be possible to reduce the conceptual distance between the project and the benefits of its realization, enabling the shaping of the self-assessment tool in function of the stakeholder's perspective (Keeys & Huemann, 2017).

Based on the literature review, the initial set of the HCE dimensions and indicators was formulated. The integrative literature review was qualitatively triangulated with the results of the quantitative empirical stage (i.e. questionnaire survey). A triangulation approach allowed a

deeper understanding of the results (Saunders *et al.*, 2016). In the present research, it permitted the study of HCE practices and indicators.

The overall methodological approach was elaborated based on four stages (Figure 1): (i) HCE metrics were identified, from the results of the integrative literature review; (ii) the HCE indicators were qualitatively triangulated with the data collected from the quantitative method (i.e., questionnaire survey), resulting in a clustering of metrics; (iii) the self-assessment tool was evaluated with stakeholders, based on a qualitative procedure (i.e., semi-structured interviews), providing insights over the use of the tool; and (iv) the results were analysed, using descriptive statistics techniques for close-ended questions and content analysis for open-ended questions.

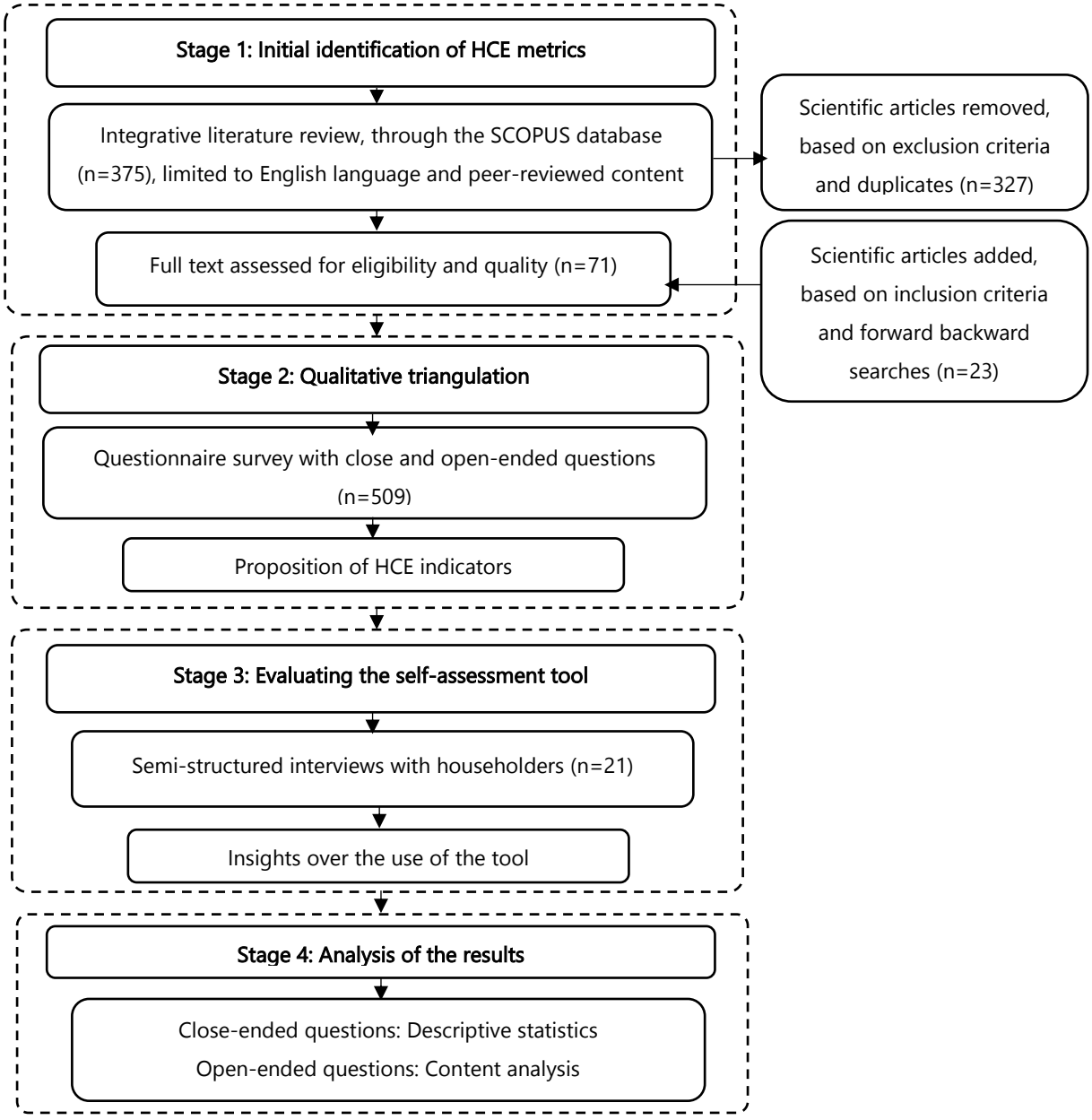

Figure 1 - Methodological approach towards the understanding of CE practices implemented in a household, identification of CE indicators, and evaluation of the self-assessment tool.

3.1 Stage 1: Identifying HCE metrics

To identify the initial set of HCE metrics, an integrative literature review of scientific articles was developed. Through synthesizing and studying the existing body of papers, this approach allows the test of hypotheses and the advancement of knowledge, based on previous work (Xiao and Watson, 2019). The Scopus database from Elsevier was selected, since it is the largest data base for scientific journals, comparable to Web of Knowledge (Valderrama-Zurián *et al.*, 2015). The search was conducted, using the string TITLE-ABS-KEY ((“circular econom*” OR “circularity”) AND (“indicator*” OR “indice*” OR “index*”) AND (“individual*” OR “famil*” OR “household*” OR “consumer”)), resulting in the identification of the initial set of scientific articles (n=375). These keywords were selected, as they encompass a wide range of metrics relevant to the research questions.

After the removal of duplicates, as recommended by Valderrama-Zurián *et al.* (2015), 375 publications were manually screened by title and abstract, to exclude articles with content unrelated to the research questions. Furthermore, inclusion and exclusion criteria were established, in function of the research questions, to further refine the screening process (Xiao & Watson, 2019). Regarding the exclusion criteria, publications focusing on CE at nano, meso and macro levels or non-consumption related practices (Shevchenko *et al.*, 2023) were removed. Additional records were identified through forward backward searches, based on inclusion criterion related to CE assessment frameworks (n=23). A total of 71 full-text articles were assessed for eligibility and quality, since they provided an outline of HCE indicators and practices. The HCE activities were characterized in relation to the CE strategies defined by Potting *et al.* (2017) and the tri-dimensional role of the circular consumer described by Shevchenko *et al.* (2023), see Table A2.

3.2 Stage 2: Clustering of HCE indicators

The householders’ knowledge and perceptions allow an in-depth understanding of the daily activities inherent to a household. Therefore, a survey research approach grounded on a web-based questionnaire survey was used to collect a quantitative description of the importance of HCE strategies and activities, from which HCE indicators were established. The HCE indicators were defined based on the importance level that the respondents attributed to the HCE practices and weighted by the literature.

The survey was distributed through online channels, and as stated by Bethlehem (2009), online surveys allow access to a large pool of potential respondents, while being cost-effective and time efficient. The survey consisted of open-ended and close-ended questions. The questionnaire had 42 questions divided into three main sections (see Appendix B), which were defined based on the main thematic groups of HCE strategies and activities, identified through the literature review. In particular, those sections were based on the tri-dimensional role of the circular consumer described by Shevchenko *et al.* (2023), to help understand consumer behaviour in the CE. Table 1 presents a description of the main sections considered in this survey.

Table 1 - Summary description of the topics covered in each section of the questionnaire survey.

Section	Description
Customer in a CE	Aimed to understand CE oriented activities conducted by the consumer, in the form of a customer. According to Shevchenko *et al.* (2023), the customer should prioritize product acquisition with the least environmental impact, and, when possible, refrain from buying.
User in a CE	Structured to determine circular economy-based activities conducted by the consumer, in the form of a user. In this category, careful use and maintenance of the product, search for technical services and repair, and sell or donate the products, when no longer needed, should be the main role (Shevchenko *et al.*, 2023).
EoL product holder in a CE	This section goals are to define the activities conducted by the consumer, in the form of an EoL product holder. As stressed by Shevchenko *et al.* (2023), the individual should timely discard the product, and use the appropriate discarding channel.

Close-ended questions were used in two situations: (i) A five-point Likert scale was designed to quantitively assess the level of importance of a HCE practice, as a *customer* – "When buying, do you consider important…", as a *user* – "When using, do you consider important…", and as an *EoL product holder* – "When discarding, do you consider important…". The rating was from one ("Not important at all") as the lowest to five ("Absolutely essential") as the highest. For instance, one question asked if the participant frequently avoids products with excess packaging, to understand if the refusal strategy is relevant in this situation; (ii) A binary, and multiple-choice questions were used to allow the respondents to indicate the adoption of a CE practice, and for which consumption domains (e.g., clothes, electric and electronics

equipment), respectively. This type of questions enables a lower and easier survey response time, and are easier to compare (Saunders *et al.*, 2016). The open-ended questions were used to provide the respondent the opportunity to comment on the CE strategies they adopted, as similarly done in Klein *et al.* (2022). Since it allows the participant to give a more in-depth answer, where they can use their own words (Saunders *et al.*, 2016; Bethlehem, 2009).

The questionnaire survey was launched in May 2023, and remained for two weeks. As stressed by Saunders *et al.* (2016), a two-week distribution period is deemed reasonable. Although certain household consumption domains are seasonally influenced (Spence, 2021), the data retrieving period did not affect the results, since, unlike certain industries (Dissanayake & Weerasinghe, 2021), most HCE practices can be applied independently of the season. A non-probability convenience sampling technique was used. Although this procedure is prone to bias and offers less accuracy to the results, it is used widely, since it provides an adequate approach to exploratory studies (Saunders *et al.*, 2016). In this study, it allowed the collection of insights of householders' regarding the relevance of HCE activities. It targeted the general population of individuals with 15 years or above living in Portugal, since consumers become more aware of their consumption habits, and associated consequences, in their adolescence and early adulthood (Busse & Menzel, 2014). Other nationalities were not considered, since, in some situations (e.g., organic food products, energy, apparel), consumer behaviour depends on the cultural and sociodemographic background of the individual (Singh & Verma, 2017; Frederiks *et al.*, 2015; Scheerder *et al.*, 2011).

Before the aforementioned period of data collection, the survey was sent to 30 individuals from the householders' category, and academia to ensure the clarity, understandability, and validity of the questions (Bethlehem, 2009). In fact, Bethlehem (2009) suggests a population of 25-75 individuals, during the pre-test. Moreover, to determine the internal consistency of the responses across the five-point Likert scales used to inquire about the HCE practices implemented by customers, users and EoL product holders, the Cronbach's alpha was calculated with a threshold of 0.7 or above. The Cronbach's alpha of the first, second and third Likert scale were 0.93, 0.82, and 0.72, respectively. Thus, the questionnaire survey had a high reliability (Saunders *et al.*, 2016).

The questionnaire survey yielded 509 valid responses. According to INE (2023), Portugal has a total population of 9 011 878 individuals with an age equal or above 15 years. A sample size of 509 allowed for a 95 % confidence level with a margin of error of 5.0 %, which is above the minimum sample size (n=384). The minimum sample size was determined through the methodology from Bartlett *et al.* (2001), for categorical survey data analysis.

3.3 Stage 3: Evaluating the self-assessment tool

Caeiro *et al.* (2012) recommended that the indicators should be "easily comprehensible and meaningful to family members". The householders' perspective enables an in-depth understanding of the clarity of the self-assessment tool, and its influence on their everyday actions. Thus, to evaluate the understandability and operability of the self-assessment tool, semi-structured interviews with open-ended questions were conducted. This approach is a qualitative method, in which the interviewer is recommended to be flexible, and explore the ideas developed by the interviewee (Denscombe, 2010). In this case, the interviews were conducted to gather insight over the use of the self-assessment tool and develop the final list of indicators. For instance, if the interviewee wouldn't understand an indicator, the latter would be removed or adjusted, in function of the interviewee's suggestion.

The interviewees were selected through a snowball method (Bryman, 2016). The interviews were elaborated between 04/06/2023 and 18/06/2023, until data saturation was reached – where new data confirmed the existing one instead of adding input (Denscombe, 2010) -, resulting in 21 interviews with an average duration of 22 minutes.

At the beginning of the interview, the participant used the self-assessment tool, and provided insight over its use. As recommended by Saunders *et al.* (2016), a document was created to structure and guide the interview (see Appendix C). The document consisted of 6 open-ended questions concerning the general evaluation of the self-assessment tool. All semi-structured interviews were conducted on-line, and audio recorded. This provides a cost and time-effective approach to this method (Denscombe, 2010). Furthermore, these were transcribed, and reviewed with the respondent, as recommended by Denscombe (2010). As stressed by Saunders *et al.* (2016), ethical issues regarding the audio recording, confidentiality, and anonymity were considered. The interviewees were free to withdraw from the interview and ask for the deletion of the data. The interviewees approval was obtained through informed consent.

3.4 Data analysis

To analyse the results of the questionnaire survey and interviews two techniques were applied: (i) for close-ended questions, descriptive statistics was used to measure the central tendency, and dispersion of each answer, in absolute (numerical) and relative (percentual) terms (Saunders *et al.*, 2016); and (ii) for open-ended questions, content analysis, as a supplementary technique, was used to code and categorize the retrieved qualitative data (Krippendorff, 2004;

Saunders *et al.*, 2016). In the case of the descriptive statistics, the data showed a nominal, and ordinal nature. Hence, it required different statistical tests (Saunders *et al.*, 2016). For the nominal data, a frequency table with percentages was used to summarize the categorical data. For the ordinal variables, the mean score was used to compare the importance level of the HCE practices. According to Chu and Hwang (2008), the minimum requirement to include any particular item in a study is a combined participation agreement of 75%. As stressed by Saunders *et al.* (2016), if respondents have insufficient knowledge, they may guess at the answer or overestimate the relevance of the item. Based on these criteria, the HCE practices with a mean score under 3.75 (within the five-point Likert scale) were given a negative connotation. Regarding the open-ended questions, the tri-dimensional role of the circular consumer described by Shevchenko *et al.* (2023) and the CE strategies described by Potting *et al.* (2017) were used to support the content analysis of the qualitative data.

A collaborative approach helps bridge the gap between theory and practice. However, communication difficulties between the general public or practitioners and researchers can undermine the results (Kieser & Leiner, 2012). Thus, as recommended by Saunders *et al.* (2016), the results were triangulated with the current scientific body of literature on the topic (Table A2). In this context, only the empirical data collected from the questionnaire survey that is supported by scientific literature was considered in the stage 2. For instance, HCE practices related with dietary activities showed a mean score below 3.75 but are described as one of the main pillars in CE (van Loon *et al.*, 2023; Paparella *et al.*, 2023; Kumar *et al.*, 2022). Hence, it was accepted for stage 2.

4

RESULTS

In this section, an overview of the HCE practices and indicators was conducted, while lining out the surveyed participants perceptions over the use of the self-assessment tool in two parts: (i) in Section 4.1, the surveyed participants profile, HCE practices and initial clustering of indicators were analysed; and (ii) Section 4.2 shows the interviewed participants characteristics as well as insights over the use of the self-assessment tool.

4.1 Overview of HCE practices and indicators

4.1.1 Participants profile and HCE practices

In total, 509 valid responses were received from 510 individuals. Among the participants, 38.1 % were male, 61.7 % were female, and 0.2 % were nonbinary. The largest number (37.3 %) of respondents had 15-24 years, and 19.4 % had 25-34 years. All age-groups were covered by the questionnaire survey, with individuals over the age of 65 years representing the lowest relative weight (4.5 %) (Table 2). The participants had different education levels: 15.9 % of them did not pursue an university degree, whereas 48.5 % had a bachelor's degree, 30.1 % held a master's degree, and 5.5 % obtained a PhD degree. About 63.9 % and 36.1 % reside in apartments and houses, respectively. Amidst the surveyed, 9.8 % live alone, whereas the remaining participants cohabite with one or more individuals. The majority (78.8 %) of the respondents were familiarized with the concept of circular economy, demonstrating the high level of awareness in this topic.

Table 2 - Surveyed participants characteristics.

	Respondents

		(No.)	(%)
Gender	Male	194	38.1%
	Female	314	61.7%
	Nonbinary	1	0.20%
Age group	15 - 24 years	190	37.3%
	25 - 34 years	99	19.4%
	35 - 44 years	53	10.4%
	45 - 54 years	87	17.1%
	55 - 64 years	57	11.2%
	> 65 years	23	4.5%
Education	Non-university	81	15.9%
	Bachelor	247	48.5%
	Master	153	30.1%
	PhD	28	5.5%
Type of housing	Apartment	325	63.9%
	House	184	36.1%
Household dimension (no. of individuals)	1	50	9.8%
	2	129	25.3%
	3	146	28.7%
	4	143	28.1%
	> 4	41	8.1%
Familiarity with the concept of CE	Yes	401	78.8%
	No	108	21.2%

Table 3 presents the scoring of the surveyed HCE practices. As stressed in the Methods section, the HCE practices with a mean score below 3.75 were cut-off from the initial list. However, negatively marked empirical data collected from the survey that is clearly supported by scientific literature was considered for stage 2 of this study. In this context, although HCE practices concerning dietary choices and second-hand product acquisition were scored below the cut off value, they were made eligible for stage 2, due to its relevance in promoting CE (Coutinho *et al.*, 2017). Among the HCE practices, 10 were considered ineligible, belonging all

of them to the customer dimension. No HCE practices were removed from the remaining dimensions. Nonetheless, it should be noted that the HCE practices were excluded to prioritize the main consumption activities. To foster circularity, the eliminated HCE practices still hold a significant relevance, as stressed in multiple studies (Lu & Kwan, 2023; van Bueren *et al.*, 2023; Valls-Val *et al.*, 2023; Prakash & Ambedkar, 2022; Ahmed *et al.*, 2023).

Table 3 - HCE selected and removed practices.

Dimension	HCE practice	Mean score	Std. Deviation	Eligibility for stage 2
Customer	Acquiring eco-labelled products	3.0	0.89	×
	Reject/avoid products produced through child labour or in other abusive and objectionable ways	5.0	0.85	✓
	Search for the shop with the least negative environmental impact (with a recognised environmental certification)	3.0	0.95	×
	Search for the shop with the least negative social impact (with a social responsibility certification)	3.0	0.98	×
	Looking for the product in the form of a service	3.0	1.13	×
	Looking for electrical or electronic products with the best performance in the energy certificate	4.0	0.86	✓
	Seek out locally produced foods/food products	4.0	0.89	✓
	Reject/avoid products with excessive packaging or packaging quantities where possible	4.0	0.96	✓
	Look for bulk products or with reduced packaging quantities if packaging is unavoidable	4.0	0.97	✓
	Looking to buy second-hand rather than new products	3.0	1.17	✓

Trying to buy repaired products instead of new ones	3.0	1.11	✗
Seek to purchase refurbished/reconditioned products (e.g. an old product that has been upgraded to current quality standards) rather than new ones	3.0	1.09	✗
Try to buy "remanufactured" products (made from parts of another product with the same function) rather than new ones	3.0	1.07	✗
Try to buy "re-purposed" products (products that have acquired a new function) rather than new ones	3.0	1.08	✗
Try to buy products made from recycled materials rather than new ones	4.0	0.98	✓
Try to buy recyclable products or products that can be dismantled	4.0	0.96	✓
Seek to purchase the product in its dematerialised format, where possible	3.0	1.13	✗
Try to buy the product with the longest possible durability	5.0	0.81	✓
Look for reusable products, rather than single-use items	4.0	0.89	✓
Look for products that can be shared, when bought together	4.0	1.13	✓
Seek to rent the product rather than own it	3.0	1.17	✗
Seek dietary alternatives with better environmental performance	3.0	1.25	✓
Seek to buy foods that partially replace animal-based consumption	3.0	1.29	✓

	Try to satisfy the residence's energy needs through renewable sources	4.0	1.12	✓
	Try to buy products that minimise energy consumption needs without losing thermal comfort	4.0	0.95	✓
	Try to buy products that increase the durability of the main product	4.0	0.90	✓
	Look for multifunctional products, rather than one product for each function	4.0	0.99	✓
	Try to buy products with a money-back guarantee	4.0	0.95	✓
User	Use the product in the most resource-saving way	4.0	0.79	✓
	Avoid/reject using the product if there is a more sustainable alternative	4.0	0.89	✓
	Use the product as intensively as possible	4.0	1.0	✓
	Save leftovers, to be consumed at another time, when possible, instead of discarding them	5.0	0.79	✓
	Repair the product or purchase a repair service, rather than disposing of it when necessary	4.0	0.87	✓
	Renovate/recondition the product or purchase a renovation/reconditioning service rather than dispose of it	4.0	0.88	✓
	"Remanufacture" the product or purchase a "remanufacturing" service, rather than discarding it	4.0	1.0	✓
	"Reproposing" the product or acquiring a service that allows you to "repropose" it, rather than discard it	4.0	0.93	✓
	Use the land/area of your residence to produce your food, when possible	4.0	1.1	✓

	Sell or donate the product, rather than dispose of it, if it is still in good condition and able to fulfil its function	5.0	0.85	✓
EoL product holder	Give priority to using the recycling containers, when appropriate, instead of the undifferentiated waste containers	5.0	0.80	✓
	Give priority to sending organic waste for composting, rather than using the undifferentiated waste container	4.0	1.1	✓
	Give priority to using a container or special waste collection service rather than disposing of the waste in a public place or littering	5.0	0.81	✓
	Separating waste at home	5.0	0.84	✓

Legend:

✓ - Eligible; and,

× - Ineligible.

In the customer dimension, the participants response showed two main tendencies: First, product acquisition with an indirect and unclear benefit, namely of a financial or environmental nature, showed a lower importance level. For instance, the acquisition of products produced or categorized based on lesser-known CE strategies (e.g. repaired/remanufactured/repurposed/refurbished/eco-labelled products) was given a lower mean score (3.0). Whereas products with more recognizable advantages (e.g. durability, multifunctionality, reusability, recyclability, among similar others) had a higher mean score (4.0 and above). On the other hand, practices that involve products with direct social and environmental benefits were prioritized by the respondents. In fact, refusing practices (e.g., rejecting products produced through child labour or with excessive packaging) were highly favoured. Second, physical product ownership was an important criterion for the surveyed individuals. As shown in Table 3, dematerialization, renting and product as a service practices were classified with a lower importance level (3.0).

Among the remaining HCE dimensions (*user* and *EoL product holder*), all HCE practices were given a positive connotation. In fact, service acquisition practices to extend the lifetime of a product or its parts (e.g., repairing, remanufacturing, refurbishing, repurposing) were given a high importance. Similar eco-friendly behaviours were classified with the same mean score. For instance, for the respondents, using resource saving/more sustainable approaches in day-

to-day activities (e.g., public transport or active mode of transport usage, energy, and water efficient practices) or donating/selling the product in its EoL constituted a priority. Moreover, lower circularity-based strategies, including waste separation system, recycling, and composting, were also highlighted.

4.1.2 Clustering of HCE indicators

The initial list of HCE indicators was obtained through the results of the questionnaire survey and integrative literature review (Table 4). These metrics were obtained through a qualitative triangulation between the HCE practices with a mean score above 3.75, and the CE indicators derived from the integrative literature review (see Table A2). In addition, some HCE practices required more than one indicator. For instance, for the HCE practice "*Try to buy products that minimise energy consumption needs without losing thermal comfort*", three variables were selected: (i) Comfort; (ii) Electric or electronic products acquired or replaced to reduce energy consumption; and (iii) Energy consumption *per* m^2. The present set of indicators allow the self-assessment of circular economy-based strategies at the household level, and consider key criteria defined by Caeiro *et al.* (2012) for household indicators. Thus, it enables the evaluation of the HCE practices showcased in Table 3.

Table 4 - List of HCE indicators for the self-assessment tool.

Dimension	HCE indicator	Code	Description	Reference
Customer	Socially irresponsibly produced products refused (dimensionless)	C1	Measures the frequency a customer refused to acquire a product, for socially responsible reasons (e.g. produced from child labour, poor working conditions, un-paid labour).	Padilla-Rivera *et al.* (2021); Bianchini *et al.* (2022); Blinova *et al.* (2023)
	Electric or electronic products acquired or replaced to reduce energy consumption (no.)	C2	Describes the amount a customer acquired or replaced an electric or electronic product to reduce energy consumption, per type of product (e.g. procurement of a refrigerator, freezer, laptop, dishwasher, among similar others with high energy efficiency).	Scarpellini *et al.* (2020); Ahmed *et al.* (2023); Yazan *et al.* (2022); Andreou *et al.* (2022)
	Acquisition of locally produced food (dimensionless)	C3	Determines the frequency of locally produced food purchased, relatively to the total amount of food purchased, per type of	Bux *et al.* (2022); Lami *et al.* (2022); Trollman *et al.* (2021)

		food (e.g., poultry meat, vegetables, nuts, seasonal fruit).	
Products with excessive packaging refused (dimensionless)	C4	Measures the frequency a customer refused to acquire a product, due to excessive amounts of packaging.	Kovacs (2021); Otto *et al*. (2021); Colasante and D'Adamo (2021); Droege *et al*. (2021); Klug and Niemand (2021)
In bulk products acquired (dimensionless)	C5	Measures the frequency of products acquired in bulk, to reduce the amount of packaging, per type of product.	Klug and Niemand (2021); Lami *et al*. (2022)
Second-hand products acquired (%)	C6	Measures the share of second-hand products procured, relatively to total product acquisition, per type of product.	Kovacs (2021); Valls-Val *et al*. (2022); Andreou *et al*. (2022); Chun *et al*. (2022); Klug and Niemand (2021)
Products acquisition with recycled materials (%)	C7	Measures the share of products produced with recycled material acquired, in relation to total product acquisition, per type of product.	Boyer *et al*. (2021); Jiang *et al*. (2022); Lizundia *et al*. (2023)
Recyclable products acquired (%)	C8	Measures the share of recyclable products acquired, in relation to total product acquisition, per type of product.	Colasante and D'Adamo (2021); Lami *et al*. (2022)
Dismantlable products acquired (%)	C9	Measures the share of dismantlable products acquired, in relation to total product acquisition, per type of product.	Mazzoli *et al*. (2022); Abadi and Moore (2022)
Durable products acquisition (%)	C10	Measures the share of products acquired with durability as a priority, in relation to total product acquisition, per type of product.	Trollman *et al*. (2021); Abadi and Moore (2022); Baratsas *et al*. (2022)
Reusable products acquired (%)	C11	Measures the share of reusable products acquired, in comparison to total product acquisition (reusable and single use), per type of product.	Colasante and D'Adamo (2021); Baratsas *et al*. (2022); Hafsa *et al*. (2022)
Product sharing, among owners (dimensionless)	C12	Measures the frequency an acquired product was shared,	Andreou *et al*. (2022); Ahmed *et al*. (2022)

		among owners, per type of product.	
Animal dietary products acquired (no.)	C13	Measures the quantity of animal dietary products acquired, per type of animal dietary product (e.g., poultry meat, beef meat, fresh seafood, eggs).	Frehner *et al.* (2022); Droege *et al.* (2021)
Non-animal dietary products acquired (no.)	C14	Measures the quantity of non-animal dietary products acquired, per type of non-animal dietary product (e.g., vegetables, seasonal fruit, tropical fruit, legumes).	Frehner *et al.* (2022); Droege *et al.* (2021)
Renewable energy consumption (%)	C15	Measures the share of renewable energy consumed to satisfy the household energy needs, in relation to total energy consumption.	Motte *et al.* (2023); Sadowski (2021)
Water self-sufficiency (%)	C16	Measures the share of water self-sufficiency in a household, including rainwater harvesting, water re-use and wastewater recycling, in relation to total water consumption.	Sadowski (2021); Nadal *et al.* (2018); Kim *et al.* (2022)
Energy consumption per m^2 (J/m^2)	C17	Measures energy consumption (J) per area (m^2) of the household.	Droege *et al.* (2021); Sadowski (2021); Kosanović *et al.* (2021)
Water consumption (l) per m^2 (l/m^2)	C18	Measures water consumption (l) per area (m^2) of the household.	Sadowski (2021); Kim *et al.* (2023); Cozzolino and Giovanni (2023)
Comfort (dimensionless)	C19	Measures how frequent an individual feels comfortable inside their household, including thermal comfort and basic sanitation.	Padilla-Rivera *et al.* (2021); Sadowski (2021); Kosanović (2021)
Products with increased durability (dimensionless)	C20	Measures if the customer acquired a protective equipment for the main product, to increase longevity (e.g., procurement of a phone protective cape, to promote the phones' durability), per type of product.	Yamamoto and Murakami (2021); Baratsas *et al.* (2022);

	Multi-functional products acquired (%)	C21	Measures the share of products with multiple functionalities, in relation to the total products that would have been needed for the same amount of functions (e.g., acquiring one Swiss blade, instead of a knife, corkscrew), per type of product.	Scarpellini *et al.* (2019); Trollman *et al.* (2021)
	Products with a take-back policy acquired (%)	C22	Measures the share of products that the customer acquired with a take-back policy, per type of product.	Baier *et al.* (2020); Bruno *et al.* (2021)
User	Energy saving usage of a product (dimensionless)	U1	Measures the frequency the user practices the most resource saving method of a product (e.g. using the dishwasher/washing machine in the lowest temperature option and when completely full).	Stamminger *et al.* (2020); Lami *et al.* (2023)
	Water saving usage of a product (dimensionless)	U2	Measures the frequency the user practices the most resource saving method of a product (e.g. using the dishwasher/washing machine when completely full).	Stamminger *et al.* (2020); Lami *et al.* (2023)
	Public transport usage (dimensionless)	U3	Measures the frequency the user travels by public transport, per public transport, instead of using a private vehicle.	Ahmed *et al.* (2022); Colasante and D'Adamo (2021); Lami *et al.* (2023)
	Active mode of transport usage (dimensionless)	U4	Measures the frequency the user travels by bicycle or by walking, instead of using a private vehicle.	Andreou *et al.* (2022); Lami *et al.* (2023)
	Carpool frequency (dimensionless)	U5	Measures the frequency the user carpooled or used a carpooling service while travelling by private vehicle.	Andreou *et al.* (2022)
	Time in use per product (hours)	U6	Measures the amount of time (hours) a product was used.	Droege *et al.* (2021)
	Leftovers rate (%)	U7	Measures the share of leftovers that are consumed, instead of discarded, in relation to total leftovers production.	Bux *et al.* (2022)

	Post-sale services (no.)	U8	Measures the use of post-sale services, to prolong the longevity of the original product or create a new product from the parts of the product, including repair, refurbish, remanufacture, and repurpose.	Bianchini *et al.* (2022); Bradley and Persson (2021); Lanaras-Mamounis *et al.* (2022)
	Product maintenance (no.)	U9	Measures the independent use of product or part of product lifetime extension practices, including repair, refurbish, remanufacture, and repurpose.	Lanaras-Mamounis *et al.* (2022)
	Product self-sufficiency (no.)	U10	Measures the number of products produced independently (e.g. gardening vegetables, producing own cosmetics).	Klug and Niemand (2021); Sadowski (2021); Nadal *et al.* (2018)
	Donated products (dimensionless)	U11	Measures the frequency of products that were donated in a good condition and able to fulfil its function, instead of discarded.	Shittu *et al.* (2021); Kréziak *et al.* (2020)
	Sold products (dimensionless)	U12	Measures the frequency of products that were sold in a good condition and able to fulfil its function, instead of discarded.	Shittu *et al.* (2021); Kréziak *et al.* (2020)
EoL product holder	Recycling frequency (dimensionless)	E1	Measures the frequency an EoL product holder recycles the product at its EoL.	Adu-Gyamfi *et al.* (2023); Ng and Yang (2023)
	Composting frequency (dimensionless)	E2	Measures the frequency an organic EoL product holder composts the organic product at its EoL.	Boesen *et al.* (2019); Do *et al.* (2021)
	Littering frequency (dimensionless)	E3	Measures the frequency an EoL product holder litters, instead of using a waste container.	Klemeš *et al.* (2020)
	Household waste sorting (dimensionless)	E4	Measures the presence of a waste sorting system in the consumers household.	Adu-Gyamfi *et al.* (2023); Nainggolan *et al.* (2019); Ng and Yang (2023)

As shown in Table 4, a total of 38 HCE indicators were identified. Among the indicators, 22 are integrated in the *customer* dimension, followed by 12 in the *user* dimension, and 4 in the

EoL product holder dimension. To ensure the key criteria defined by Caeiro *et al.* (2012), namely comparability and robustness, dynamic behaviours, actions and routines, target audience and type of language, and comprehensibility and communication, multiple indicators adopted a frequency and percentage-based assessment, while lining out denominators, including household area (m^2) and per capita.

Although the time horizon for the implementation of HCE practices differ in function of the product and activity, the self-assessment tool can be used by the householder or other related entity (e.g., municipality services; condominium management) as a periodic tool, e.g., every trimester, depending on socio-cultural context and needs. For instance, procuring a repairing service for a private vehicle is seldom, whereas recycling, acquiring food or using the public transport can be evaluated on a weekly basis. Thus, to tackle this issue, each metrics was tailored based on of the frequency of the activity and product. For example, for the indicator "*Recycling frequency*" the respondent was asked to consider a typical week. This approach has been similarly done in other assessment tools (e.g. Beylot *et al.*, 2017; Salas *et al.*, 2022; Kok & Barendregt, 2021, see Table A2).

Regarding the customer dimension, the HCE indicators focus on the evaluation of procurement practices adopted by consumers, reflecting the implementation of higher circularity-based strategies described by Potting et al. (2017), including refuse, rethink, reduce and reuse. It provides a set of metrics that unlock the potential of lifespan extension approaches or lower circularity strategies. For instance, the acquisition of recyclable products enables an easier upcycling or downcycling process. On the other hand, procuring dismantlable equipment allow an easier repairing, refurbishing, repurposing, or remanufacturing service; thus, underlining the influence of implementing circularity-based criteria upstream, to generate sustainable behaviours downstream.

For the user dimension, decentralization-based practices to extend the lifespan of products and its parts are a key probe in the assessment process. The nucleus of this dimension is the evaluation of public services and community engagement activities. For the former, public transport usage represents the core indicator. Regarding the latter, localized post-sale services, donating, second-hand selling, and product self-sufficiency represent the main metrics.

Lastly, EoL product holder indicators unlock the potential of materials in upcycling and downcycling activities, through waste management strategies. This set of metrics aims to reduce output flow, by providing useful applications to products and its parts at their EoL, through recycling and recycling enabling practices (i.e. household waste sorting).

4.2 Evaluating the self-assessment tool

The findings of the questionnaire survey enabled the development of a HCE self-assessment tool (Appendix D) supported by indicators, which were presented in the previous section. However, to evaluate the presence of the key factors described by Caeiro *et al.* (2012), including the comprehensibility and meaningfulness of the indicators, 21 semi-structured interviews were conducted with householders. Appendix E provides additional details regarding the list of interviewees. In this context, five criteria were applied to evaluate the proposed indicators and respective assessment scheme, based on deductive and inductive coding: (i) usability; (ii) usefulness; (iii) indicator comprehensibility/difficulties; (iv) recommendations; and (v) meaningfulness.

Concerning the criterion usability, the majority of the interviewees (e.g. I2; I3; I6; I11; I14; among others) were able to use the self-assessment tool with ease, stating: "Yes, it was intuitive" (I11). However, some participants noted that it was long, and, for some indicators, difficult to answer. For instance, I3 and I21 argued that "It was easy to use, although extensive" (I21). Regarding the latter, the interviewees (I7; I10; I15; I17) indicated that they were not able provide the information requested by the indicator, as a result of the lack of awareness over their own consumption habits, "I didn't know the answer for some of the questions. (…) sometimes I don't know if something has excessive packaging" (I15). This was specifically seen in the questions that aimed to collect relative values from the user, as underlined by I4 and I7: "It was easy to use; however, it would have been easier if I had ranges to select from in the questions that asked for percentages" (I7). Albeit the positive feedback, one interviewee (I12) lined out some difficulties that represented a challenge in the use of the tool: "I was able to use it more or less, but I don't think it was easy. (…) certain technical terms are being used that I do not understand".

Although for different reasons, all interviewees considered the self-assessment tool useful. The majority underlined that it was a very informative tool, helping in introspection exercises regarding daily household activities, as stressed by I2, I4, I8, I9, I10, and I11, among others: "Yes, it was useful, in the way that it increased the perception I have over my consumption habits and everything else" (I4). Interviewee I6 also added that: "It is useful to understand better, for my family and I, the activities we do around the house". In addition, some participants (I1; I10; I12; I15; I20) argued that certain habits are rooted in their daily activities, due to convenience: "I consider it useful, (…), and to remind myself of certain habits that, due to convenience, I tend to slouch" (I20).

Regarding the difficulties associated with the use of the HCE self-assessment tool, the opinions are divided among the participants: (i) The tool and indicators were easy to use, understand, and answer, albeit aforementioned difficulties associated with the lack of awareness over their consumption habits; and (ii) The metrics were challenging to comprehend, and answer. In relation with the former, some participants (I5; I7; I17) argued that: "Yes, none were particularly difficult to interpret or answer, except for the fact that I do not know my own data" (I17). However, in householders with a higher awareness over their consumption activities (I3; I11; I13; I19; I21), no challenges were identified, "(The indicators were) easy to answer and comprehend" (I21). However, in the context of latter, multiple barriers were identified (I4; I5; I6; I7; I12; I15; I16; I18): (i) Difficulty in understanding technical terms, "I am not familiarized with the concepts of all of the indicators, definition wise" (I1); (ii) Lack of information regarding consumption habits, including energy, water and/or product characteristics (recyclability, locally produced, among similar others), "For the questions regarding if a product was recyclable or (…), most of the times I do not know that or the store itself does not make that information available" (I5); and (iii) Inability to provide a relative value, "In some situations, it was a little difficult to write a percentage value. It requires effort to think of my household activities" (I6).

However, multiple recommendations were made by the interviewees (I3; I5; I7; I10; I12; I14; I15; I16; I18; I19): (i) Provide a description/definition/example of the technical terms used, "I think that a description and providing some examples would help understand and answer the questions" (I16); (ii) Indicate reference values, "I think there should be some base information (to compare). For instance, I do not know how much water I consume, but I am more or less aware that I consume less than the average (Portuguese) person" (I7); (iii) Create ranges of values for the metrics that ask for percentages, "For the percentage questions, also have ranges, instead of a free answer" (I19); and (iv) Indicate that certain information (e.g. energy consumption, water consumption) will be needed beforehand, "For the indicators that need quantitative data, pre warn the person to bring the information" (I3). Thus, since the present amendments enable a more in-depth understanding of the HCE indicators, no metrics were removed from Table 4.

Lastly, multiple interviewees (e.g. I1; I2; I3; I4; I5; among others) found the self-assessment tool meaningful, as the participants were able to reflect over their actions and adopt new circular economy-based behaviours. As a customer, some individuals (I1; I4; I6) reflected over the lack of consciousness in procurement practices: "Yes, I understood that I give little attention to whether a product was locally or sustainably produced. (…). I realized I could have a higher environmental and social influence (in my daily habits)" (I1). For the user dimension, the

participants (I1; I2; I15) underlined that certain practices are rooted in routine, due to convenience, such as private transport usage, "(…) most of the things I do are defined by routine. (This tool) forces us to think about what we do (on our daily activities)" (I2). Since most of the interviewees had already implemented EoL product holder practices, the self-reflection exercise took two roles (I8; I12; I20): (i) reviewer, "Yes, I believe, in this case, the actions I do were confirmed by the tool" (I8); and (ii) self-satisfaction, "Yes, the only thing I do not is compost. In the remaining practices, I reviewed myself with satisfaction" (I20). In addition, the majority of the interviewees (e.g. I3; I4; I5; I8; I10; among others) were willing to adopt a new circular economy-based behaviour, after using this tool. Among them, the user dimension was privileged by the participants (I14; I16; I19; I20), "There is one practice I would like to implement, which is repairing. I tend to throw away the product when it stops working and buy a new one, but I am going to start repairing" (I20).

5

DISCUSSION

5.1 HCE practices and indicators

The present results indicate that consumers are a key enabler in driving circular economy strategies and practices. Although the *customer* dimension is the starting point in unlocking and fostering circularity-based organisations (Shevchenko *et al.*, 2023), the *user* and *EoL product holder* dimensions constituted a higher priority. This could have resulted from the inherent motivations and barriers associated with consumption practices. According to Terzioğlu (2021) and Varotto and Spagnolli (2017), *user* and *EoL product holder* related strategies (e.g. repairing and recycling, respectively) are driven by emotional and value aspects, including environmental and social concerns. In addition, when compared with product replacement, lifespan extension practices represent, in general, lower costs. On the other hand, procurement practices are primarily driven by economic reasons. Nonetheless, although second-hand repaired/remanufactured/repurposed/refurbished products tend to cost less, when there are clear traces of the previous owners the consumer feels reluctant to acquire them (Edbring *et al.*, 2016).

Among the customer HCE practices, the results suggest that products with a clear or direct financial, environmental, and/or social advantage(s) (e.g. high energy certificate, multifunctionality, durability, recyclability) are more favoured by the consumers. This finding is in line with the scientific literature. For instance, Richter (2010) stressed that the majority of the consumers prioritize an higher energy labelled product, when acquiring dishwashers, due to financial reasons and convenience. Barkhausen *et al.* (2022) and Atsaja *et al.* (2022) underlined the importance of fostering the durability criteria in product design, as a result of environmental and economic metrics: On the one hand, it is more cost effective; and, on the other hand, it reduces the need for constant product replacement, avoiding toxic substances release, among other

environmental benefits. Furthermore, these advantages can also derive from the implementation of the refuse practice, described in Potting *et al.* (2017). Although the increasing need for consumer responsibility in procurement practices (Ghisellini *et al.*, 2016), lack of awareness of the production process inherent in a product represents one of the main CE barriers (Grafström & Aasma, 2021). However, when backed by perceivable benefits, the consumer refuses unsustainably made products; thus, increasing demand for circular economy-based market opportunities with social and environmental benefits (Grafström & Aasma, 2021). In addition, as emphasised in multiple studies (Grafström & Aasma, 2021; Edbring *et al.*, 2016; Ghisellini *et al.*, 2016), product ownership was identified as an important factor for consumers, since dematerialization, renting and product as a service practices were characterized with a lower importance level. This result derives from a modern culture social norm that expresses a desire to own and is mostly connected to products that are consumed for their primary function than for products that have high associated social status (Edbring *et al.*, 2016). For example, albeit a bike sharing initiative addresses several sustainability challenges, including climate change and wellbeing, privately owned bicycles constitute a consumer preference (Henriksson & Scalzotto, 2023). In fact, Edbring *et al.* (2016) found that, in situations of short-term renting, consumer attitude is largely positive, since it provides the opportunity to test the product, before acquiring it. On the other hand, long-term renting is linked with a negative perception.

The present set of HCE indicators obtained by the triangulation between the integrative literature review and the questionnaire survey define a comprehensive evaluation system, considering the multiple aspects of the circular consumer defined by Shevchenko *et al.* (2023) and CE strategies described by Potting *et al.* (2017). On the one hand, the self-assessment tool could foster circularity in a householder lifestyle, increasing awareness and consumer responsibility. On the other hand, as a key enabler in circular economy business models and urban metabolism (Shevchenko *et al.*, 2023), indicators and related assessment tools aim to help consumers unlock the potential of circular economy-based management/strategies at their multiple levels of implementation (micro, meso, macro), by the aid of a bottom-up approach (Gravagnuolo *et al.*, 2019; Corona *et al.*, 2019).

The proposed HCE indicators are in line with current trends that aim to challenge the LCA approach in circular economy assessment practices (e.g. Droege *et al.*, 2021; Padilla-Rivera *et al.*, 2021), which tends to be more expensive, highly dependent on data quality, and technical expertise (van Stijn *et al.*, 2021; Lu & Halog, 2020). The present tool addresses these issues, by providing a relatively simple and context-dependent evaluation process, as seen in other frameworks (see, e.g., Ramos *et al.*, 2021; Droege *et al.*, 2021; Saidani *et al.*, 2019). Although the

present list of metrics was collaboratively designed for consumers self-assessment, Rincón-Moreno *et al.* (2021) suggest that most CE indicators show a multi scale applicability. Thus, the present framework can be adapted to other levels, including organisations, cities, regions, or nations, since – according to Opferkuch *et al.* (2023) and Gravagnuolo *et al.* (2019) – all are concerned with smarter product or service use, product/resource acquisition, extending the lifespan of products and its parts, and the useful application of materials (following the descriptions of Potting *et al.*, 2017).

The self-assessment tool development depended on a collaborative approach with householders. Therefore, the process allowed the consumers to indicate the most important aspects of their consumption practices, especially their demands. This process is in line with similar studies: (i) in CE corporate disclosure, see Opferkuch *et al.* (2023); and (ii) in CE assessment for public sector organisations, see Droege *et al.* (2021). Therefore, results indicate, within the CE context, what constitutes a priority for the consumer; and what needs to be bridged to foster circularity.

Moreover, despite being part of the CE nucleus (Paparella *et al.*, 2023; Kumar *et al.*, 2022), second-hand acquisition, and less animal-dependent dietary choices were scored with a lower importance level. This could have resulted from the use of a collaborative approach; and thus, the communication difficulties between the general public and practitioners/researchers (Kieser & Leiner, 2012). However, to ensure the comprehensibility and meaningfulness of the HCE indicators and self-assessment tool, semi-structured interviews were conducted.

5.2 Self-assessment tool insights

Results indicate that the self-assessment tool and HCE indicators were relatively simple to understand and respond to, providing opportunity for equitable benchmarking. This feedback is in line with the overall consensus over the characteristics needed for a self-assessment tool (Matuštík & Koči, 2021; Caeiro *et al.*, 2012): (i) comprehensibility; and (ii) meaningfulness. In relation with the former, context provision (Vanham *et al.*, 2019), selecting a comprehensive set of questions around the object of evaluation (Franz & Papyrakis, 2011), and making the general design, and data input clear and fun (Kok & Barendregt, 2021) is highly recommended, fostering communication and empowerment for more sustainable lifestyles (Kok & Barendregt, 2021). These types of features should be carefully considered during the initial stages of planning and implementation of the CE self-assessment tool.

Although some individuals are willing to overlook certain difficulties and the extensiveness of the metrics, the majority aims to explore and compare their daily activities, in a given context (Kok & Barendregt, 2021). Regarding the latter, results suggest that the self-assessment tool was highly meaningful, as an informative and self-reflection aiding mechanism. In fact, multiple interviewees were interested in adopting new circular economy-based practices into their lifestyle. These findings are in line with the works of Kok and Barendregt (2021) and Buhl *et al.* (2019), which underlined that people were more willing to engage in pro-environmental behaviour after using a sustainability-based self-assessment tool, when compared to the general public.

However, some difficulties were mentioned regarding understandability of technical terms, length of the evaluation process, and consumer lack of awareness over their own procurement habits, including data availability for metrics that aim to collect relative values. Similar challenges have been noted by multiple authors (Kok & Barendregt, 2021; Syrovátka, 2020; Tolppanen & Kang, 2021; Kharrazi *et al.*, 2014). For instance, Kok and Barendregt (2021) indicate that a trade-off between completeness and usability exist. Buhl *et al.* (2019) also argue that lack of information hinders one's ability to evaluate themselves. Furthermore, a discrepancy in opinions was found over the self-assessment tool difficulty. According to Kok and Barendregt (2021) this could have resulted from the participant's profile: environmentalists are willing to put more effort into getting more accurate results; whereas the general public does not want to spend a lot of time on data entry without any clear beneficial outcome.

5.3 Theoretical and practical implications

Multiple insights were drawn from this study, from a theoretical perspective. First, the self-assessment tool aims to break some of the CE barriers defined by Grafström and Aasma (2021), specifically the social/cultural challenges, by increasing consumer awareness and enthusiasm, acceptance for circular economy models, and overall knowledge of a more sustainable lifestyle. Hence, it aims to expand on the number of HCE practices that can be implemented by a householder. Based on the integrative literature review (Table A2), no study has compilated a list of circular economy practices that could be executed by consumers at household level. Shevchenko *et al.* (2023) described the tri-dimensional role of the consumer in the CE. In addition, multiple authors (e.g. Paparella *et al.*, 2023; Addo *et al.*, 2018; Edbring *et al.*, 2016; Terzioğlu, 2021; Varotto & Spagnolli, 2017) have studied single aspects of CE at the consumer level, including resource (e.g. water, energy, food), acceptance of circular economy-based

business models (e.g. sharing, renting, second-hand consumption), and individual circular economy strategies (e.g. repairing, recycling, reducing, re-using). However, to the best of our knowledge, so far, no study has developed a list of HCE practices and/or associated it with the consumer importance level.

Second, the list of HCE indicators (Table 4) attempts to resolve some of the limitations and challenges integrated in the CE indicators field of research, including the gaps identified by Moraga et al. (2019, p. 458), Jerome et al. (2022, p. 5), and Shevchenko *et al.* (2023). Regarding the first, the authors were not able to identify CE indicators capable of measuring the higher circularity strategies described by Potting *et al.* (2017). Among the HCE metrics, two indicators (e.g. "*Socially irresponsibly produced products refused*" and "*Products with excessive packaging refused*") were defined to measure the refuse strategy. For the second, the researchers mentioned that most CE indicators cannot evaluate the use phase of a product, and lifetime extension strategies. Similarly, among the HCE indicators, three metrics that can address those issues were proposed (e.g. "*Time in use per product*" and "*Post-sale services*"). In relation with the third, the authors emphasize the significant lack of metrics for the consumer, in the CE context. The present research proposes several tailored HCE indicators to address this gap.

Third, the results provide a set of recommendations to improve the comprehensibility and meaningfulness of the proposed self-assessment tool. These suggestions can be used in the development of future similar mechanisms. The interviewees emphasized that the indicators should be more intuitive, by providing a description of technical terms, indicate reference values, to enable benchmarking with the national average, and create ranges of values for the metrics that ask for percentages, to facilitate the user's ability to answer. These findings are in line with other research, namely the work of Kok and Barendregt (2021), where among the aforementioned suggestions, also underlines that a self-assessment tool should also mention clear financial and health benefits associated with the implementation of these practices. In addition, householders are interested in receiving advice to improve performance, in function of the answers.

From a practical perspective, several implications/lessons can be drawn from this study. In particular, the proposed HCE tool could support local organisations and municipalities in understanding what consumers prioritize in the circular economy scope, and help future HCE assessment initiatives, conducted at municipal, parish, neighbourhood, condominium, or other specific scale. This could also enable tailored product design and business opportunities that follows CE strategies, as emphasized by Schevchenko *et al.* (2023), and plans and programs that foster circularity in cities, according to Gravagnuolo *et al.* (2019). Thus, it aims to bridge

the gap between householders and entities/plans/programs, as mentioned by Grafström and Aasma (2021).

6

Conclusions

Household consumption practices are linked with multiple sustainability challenges, including climate change and well-being. However, individuals still don't know how to act, and feel little motivation to change certain habits, since most procurement practices are driven by economic reasons. CE can work as one of the strategies to tackle these issues, by providing a financial incentive to more sustainable lifestyles. This explanatory study aimed to develop, through a collaborative approach, a self-assessment tool that aided households in adopting HCE practices, by: (i) understanding the importance level consumers allocate to certain activities, within the CE vein; and (ii) describing a set of metrics that can help householders communicate, and gain awareness over their acquisition strategies. Furthermore, it provided several insights over the use of the self-assessment tool that can support the construction of future similar mechanisms.

A collaborative research process was adopted to develop and optimize the set of HCE indicators, grounded on comprehensibility and meaningfulness criteria. First, a list of HCE practices was built. The findings derived from the questionnaire survey suggested that certain *customer* activities do not constitute a priority for the consumer, as a result of economic barriers, lack of trust in second-hand products, and a modern culture social norm. On the other hand, *user* and *EoL product holder* practices showed a higher importance level since most activities are easier to implement by consumers and are not challenged by the aforementioned arguments. Based on a triangulation approach that combined an integrative literature review and a questionnaire survey, the aforementioned list reflected multiple metrics. Second, to refine the assessment framework, semi-structured interviews were conducted. The results obtained through this procedure demonstrated that the self-assessment tool was meaningful, as multiple interviewees were willing to adopt new HCE practices. Nonetheless, although

complemented with recommendations, several difficulties were identified. According to the participants, the main challenge was the lack of awareness over their own consumption practices, resulting in the inability to provide the information asked by certain HCE indicators.

The householder's participation was a key component in the development of the self-assessment tool. In addition to the aforementioned reasons, the collaborative approach helped bridge the gap between the conceptual model and the benefits of its realization. Moreover, this study aimed to solve certain limitations linked to the CE indicators field of research. First, it proposes several metrics that enable assessment opportunities of higher circularity strategies, including refuse, and rethink. Second, it conceptualizes a first attempt to develop an evaluation HCE tool for consumers. Third, it provides multiple recommendations to support the construction of future similar mechanisms or to put the proposed tool into practice. Fourth, it could guide organisations and municipalities in the development of products and services, within the CE scope, that satisfy the consumers priorities.

However, several potential limitations inherent to the methodological approach could have constrained this study, including bias, sample size, oversimplification of certain aspects, and under coverage.

Future research should be conducted to further expand the underdeveloped field of circular economy at the consumer/household level, especially in the assessment field. In the development of this research, multiple underexplored gaps were identified, including: (i) what are the drivers and barriers for the householder in the circular economy; (ii) how can the user of the self-assessment tool be scored (i.e. what are the relative weights of each metric); (iii) how would a multi stakeholder approach help bridge the conceptual and practical gap between households and organisations and municipalities; and (iv) when single-studied, how could each circular economy strategy or HCE dimension be evaluated. The findings of this research document aim to foster investigation in these levels, to: (i) On the one hand, help consumers find more sustainable and financially approachable lifestyles, through the lens of the CE; and (ii) On the other hand, unlock innovation, drive investment, and create jobs, based on a CE approach, in private and public sector organisations.

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Annexes

A.1 – Overview of household assessment tools

Table A1 - Individual and household assessment tools within the scope of CE: R0 = Refuse; R1 = Rethink; R2 = Reduce; R3 = Re-use; R4 = Repair; R5 = Refurbish; R6 = Remanufacture; R7 = Repurpose; R8 = Recycle; and R9 = Recover (see Potting et al., 2017 and Čuček et al., 2012).

Tools	Circular economy framework										Description	Reference
	R0	R1	R2	R3	R4	R5	R6	R7	R8	R9		
Blue footprint	✓	×	✓	×	×	×	×	×	×	×	Determines the impact of water usage by individuals and cities on the world's freshwater resources. Considers the water consumption, resource stress and water quality. Hence, it measures the depletion of surface and groundwater resources during the production of goods and services.	Čuček et al. (2012) and Chai et al. (2020)
Carbon footprint	✓	✓	✓	×	×	×	×	×	×	×	Measures the amount of CO2e emitted over the full life cycle of a process or product. Thus, within the household, it calculates the amount of CO2e that is emitted into the atmosphere based on the energy, product and service consumption and transportation.	Čuček et al. (2012) and Zeng et al. (2021)

Crop land foot-print	×	×	✓	×	×	×	×	×	×	×	Quantifies the necessary land area to produce the crops consumed by a population.	Čuček et al. (2012) and Dietz et al. (2007)
Con-sumer foot-print	✓	✓	✓	✓	✓	✓	×	×	×	×	Calculates the environmental impacts derived from the consumers' choices and con-sumption patterns.	Salas et al. (2022)
Ecolog-ical foot-print	✓	✓	✓	×	×	×	×	×	✓	×	Assesses the human demand for land and water ecosys-tems, by paring the human consumption of resources and waste production with the natural capital capacity to regenerate. Therefore, it esti-mates the user's/household's ecological footprint based on the individual/family lifestyle and consumption patterns.	Čuček et al. (2012) and Kok and Bar-endregt (2021)
Energy foot-print	✓	×	✓	×	×	×	×	×	×	×	Determines the sum of all ar-eas used to sequestrate CO2 emissions from the consump-tion of non-food and non-feed energy. Thus, it is the necessary area to absorb the Greenhouse gases (GHG) emissions derived from the sum of the energy intensities and expenditures of all the	Čuček et al. (2012), Fang et al. (2014) and Min and Rao (2017)

											household consumption sectors.	
Financial footprint	×	×	×	×	×	×	×	×	×	×	Measures an individual expenses, by analysing their retirement funds, investments, insurance, tax, and estates.	Čuček et al. (2012)
Fishing-Ground footprint	×	×	✓	×	×	×	×	×	×	×	Quantifies the area needed to produce the fish and seafood products for human consumption. Thus, integrating demand for inland and marine water ecosystems in the needs to support aquaculture and seafood restocking.	Čuček et al. (2012) and Solarin et al. (2021)
Forest footprint	×	✓	✓	✓	✓	×	✓	×	×	×	Calculates the volume of timber and forest area required to satisfy the consumption of households.	Čuček et al. (2012) and Staelens (2022)
Human footprint	✓	×	✓	×	×	×	×	×	×	×	Assesses the energy quantities, resources, and products consumed by an individual throughout their life. Hence, it measures land transformation, population density, grazing density, human access, and electrical power infrastructure.	Čuček et al. (2012) and Yin et al. (2020)
Health footprint	✓	×	✓	×	×	×	×	×	×	×	Determines the individual's health, and its effect on those around, by targeting	Čuček et al. (2012)

											consumption and non-consumption-based risk factors (diet, physical inactivity, tobacco smoking, alcohol).	and Harrison et al. (2011)
Material footprint	✓	✓	✓	✓	✓	×	×	×	✓	×	Quantifies the use of materials from a consumption perspective, associating the extracted and used raw materials to its domestic demand. In its assessment, it integrates six components: i) nutrition; ii) construction and housing; iii) consumer goods; iv) mobility; v) leisure activities; and vi) vacations.	Vanham et al. (2019) and Buhl et al. (2019)
Nitrogen footprint	✓	✓	✓	×	×	×	×	×	×	×	Measures the total amount of reactive nitrogen (Nr) released to the environment as a product of an individual activities, namely: i) food; ii) housing; iii) transportations; and iv) goods and services.	Čuček et al. (2012) and Leach et al. (2012)
Phosphorous footprint	✓	×	✓	×	×	×	×	×	✓	×	Assesses the phosphorous (P) imbalance within crops, integrating the required P concentration and the P loss to the environment.	Čuček et al. (2012) and Dhar et al. (2021)

Work environment footprint	×	×	×	×	×	×	×	×	×	×	Determines the number of lost days at work per unit of product, by analysing eight variables: i) Fatal accidents; ii) Total number of accidents; iii) Central Nervous System (CNS) function disorder; iv) Hearing damages; v) Cancer; vi) Musculo-skeletal disorders; vii) Skin diseases; and viii) Psycho-social diseases.	Čuček et al. (2012) and De Benedetto and Klemeš (2009)
Water footprint	✓	×	✓	✓	×	×	×	×	✓	×	Quantifies the total volume of direct and indirect freshwater used, consumed, and/or polluted to produce the goods and services acquired by individuals or communities or produced by the business. It integrates three components: blue, green, and grey water footprints. These represent the consumption of surface and ground water, rainwater, and the volume of water necessary to dilute the pollutants to water quality standards, respectively.	Čuček et al. (2012) and Fan et al. (2019)
Waste footprint	✓	×	✓	×	✓	×	×	×	✓	✓	Calculates the amount of waste produced by sourcing ingredients and materials, manufacturing and processing, and transportation. Within the household	Čuček et al. (2012) and Beylot

											consumption scale, it represents the sum of the waste derived from economic activities associated with the demand for goods and services, and the postconsumer waste.	et al. (2017)

A.2 - Integrative literature review of HCE indicators

Table A2 - List of HCE indicators.

Title	Author(s)	Year	Description	10R	Consumer role
The potential of local food, energy, and water production systems on urban rooftops considering consumption patterns and urban morphology	Toboso-Chavero et al.	2023	Sustainability, environmental, social, and economic indicators, including resource self-sufficiency.	Rethink	User
When Do Supply Chains Strengthen Biological and Cultural Diversity? Methods and Indicators for the Socio-Biodiversity Bioeconomy	Saes et al.	2023	Basic sanitation.	N.A.	User
Key Corporate Sustainability Assessment Methods for Coal Companies	Blinova et al.	2023	Environmental, social and governance indicators, including packaging materials, child labour, among others.	Refuse, rethink, reduce	All
Circularity indicators and their relation with nutrient use efficiency	van Loon et al.	2023	Input/Output analysis-based indicators.	N.A.	N.A.

in agriculture and food systems					
Product Design Evolves to Implement Circular Economy Principles	Lizundia et al.	2023	Circularity indicators, including repairability, use of recycled materials in the manufacture of the product. Also, considers lifetime extension, re-use of product parts or recyclability of materials.	Re-use, repair, remanufacture, recycle	User, EoL product holder
Construction waste recycling in the circular economy model	Mikhno et al.	2023	Disassembly related metrics, waste sorting, recycling.	Recycle	User, EoL product holder
Development of a system model to predict flows and performance of regional waste management planning: A case study of England	Ng & Yang	2023	Recycling rate, household waste sorting.	Recycle	EoL product holder
Developing circularity, renewability, and efficiency indicators for sustainable resource management: Propanol production as a showcase	Motte et al.	2023	Share of renewable sources.	Refuse, rethink, reduce	Customer
How to map industrial waste metabolism at a geographical level?	Gambarotto et al.	2022	Repair of equipment's.	Repair	User

A proposal for a composite indicator					
An Evaluation of Circular Economy Development in the Baltic States	Jakubelskas & Skvarciany	2022	Circularity, waste, and environmental related indicators, including packaging, renewable energy, recycling, re-use.	Refuse, reduce, re-use, recycle	All
Does Carbon Footprint Play a Relevant Role in Food Consumer Behaviour? A Focus on Spanish Beef	Lami et al.	2022	Locally produced food, use of bicycles, public transport, packaging, efficient use of products (energy, water), bulk products, recyclable products.	Refuse, rethink, reduce, re-use, recycle	All
The (un)shared responsibility in the reverse logistics of portable batteries: A Brazilian case	Castro et al.	2022	Legal, socioeconomic, organizational, operational, and working indicators, including use of protection equipment.	Reduce	Customer
Evaluation of harvesting urban water resources for sustainable water management: Case study in Filton Airfield, UK	Kim et al.	2022	Water management indicators, including rainwater harvesting, greywater recycling, reusable water, resource saving behaviour.	Reduce, re-use, recycle	User, EoL product holder
Measuring product-level circularity performance: An economic value-based metric with the indicator of residual value	Jiang et al.	2022	Circularity metrics, including products produced with recycled materials.	Reduce	Customer
Performance assessment of circular driven sustainable	Kumar et al.	2022	Sustainability indicators, including green material consumption, resource	Refuse, rethink, reduce,	All

agri-food supply chain towards achieving sustainable consumption and production			utilization, waste management, employee well-being.	recycle, recover	
Assessing and Developing Circular Deep Renovation Interventions towards Decarbonisation: The Italian Pilot Case of "Corte Palazzo" in Argelato	Mazzoli et al.	2022	Circularity metrics, including disassembly, materials' origin, and reusability, repairable, refurbish able, remanufactured, recyclable.	Reduce, re-use, repair, refurbish, remanufacture, recycle	All
Is there a need for new kitchen design? Assessing the adaptative capacity of space to enable circularity in multi residential buildings	Ollár et al.	2022	Circularity metrics, including refurbish, rethink.	Rethink, refurbish	User
Innovative Development of Circular Systems While Ensuring Economic Security in the Industry	Kuzior et al.	2022	Circularity indicators, including change in duration of use, recycling, resource conservation, resource intensity.	Reduce, recycle	User, EoL product holder
Selection of Circular Proposals in Building Projects: An MCDM Model for Lifecycle Circularity Assessments Using AHP	Abadi and Moore	2022	Circularity metrics, including disassembly, longevity, embed recycled materials, reduce material input, efficient use, repair, repurpose.	All	All

How to Monitor the Transition to Sustainable Food Services and Lodging Accommodation Activities: A Bibliometric Approach	Bux et al.	2022	Leftovers rate, locally produced food, among other food related indicators.	Refuse, reduce, re-use	Customer, user
Stakeholder Assessment on Closing Nutrient Cycles through Co-Recycling of Biodegradable Household Kitchen Waste and Black Water between Rural and Urban Areas in South India	Fendel et al.	2022	Ecological, social, technical, economical, and connective indicators, including waste sorting.	Recycle	EoL product holder
A Framework to Assess Social Indicators in a Circular Economy Perspective	Bianchini et al.	2022	Tactical objectives and operational social-based indicators, including child labour.	Refuse	Customer
Clarify the nexus between life cycle assessment and circularity indicators: a SETAC/ACLCA interest group	Saidani et al.	2022	Circularity and LCA indicators, including re-use rate.	Re-use	Customer
Practical solutions for circular business models in the fashion industry	Dragomir & Dumitru	2022	Circularity indicators for apparel, including type of fibre procurement, recyclability, water re-use, greywater recycling social conditions with	Refuse, reduce, re-use, recycle	All

			production, excessive packaging among others.		
Improved Copper Circularity as a Result of Increased Material Efficiency in the U.S. Housing Stock	Wang et al.	2022	Circularity indicators, including energy label.	Refuse	Customer
Consumer strategies towards a more sustainable food system: insights from Switzerland	Frehner et al.	2022	Consumer food-based indicators, including meat consumption reduction.	Reduce	Customer
In silico assessment of household level closed water cycles: Towards extreme decentralization	de Walle et al.	2022	Water circularity indicators, including rainwater harvesting, water re-use, greywater recycling, among others.	Rethink, reduce, re-use, recycle	User, EoL product holder
Key metrics to measure the performance and impact of reusable packaging in circular supply chains	Betts et al.	2022	Circularity indicators, including remanufactured, re-use, repurposed, recyclable, compostable products.	Reduce, re-use, remanufacture, repurpose, recycle	All
Portfolios of sustainable practices for packaging in the circular economy: an analysis of Italian firms	Cozzolino & Giovanni	2023	Environmental indicators, including energy and water consumption.	Reduce	User

Consumer attitude and acceptance toward fish fed with insects: a focus on the new generations	Baldi et al.	2021	Food-based indicators.	Reduce	Customer
Implementation of the New European Bauhaus Principles as a Context for Teaching Sustainable Architecture	Sadowski	2021	Thermal comfort indicators, renewable energy share, energy efficiency of buildings, greywater recycling and rainwater harvesting, vegetable planting, self-production of food.	Rethink, reduce, re-use, recycle	All
Measuring spatial access to the recovery networks for WEEE: An in-depth analysis of the Italian case	Bruno et al.	2021	Take-back service, as well as spatial access to WEEE networks indicators.	Reduce	User
Framework for Comparative Evaluation of Car-Sharing Alternatives for Urban and Suburban Regions: Case Study of Mumbai, India	Das et al.	2021	Car-sharing and carpool related indicators, including accessibility.	Rethink	User
A Circularity Indicator Tool for Measuring the Ecological Embeddedness of Manufacturing	Trollman et al.	2021	Circularity metrics, including locally and ethically sourced products/resources, remanufactured, refurbished, repurposed, repair, longevity, multiple functions (multi-functionality), among others.	All	All

Smart Waste Management System as a Sustainable Social Enterprise Model	Nasar et al.	2021	Use time of products, such as vehicles.	Reduce	User
Energy Refurbishment of Family Houses in Serbia in Line with the Principles of Circular Economy	Kosanović et al.	2021	Circularity metrics for energy efficiency, including refurbishment and thermal comfort, energy consumption.	Reduce, refurbish	User
Selection and evaluation of a septage management concept for islands: The case study of Brač Island	Margeta	2021	Environmental, social, economic, and technical indicators, including access to basic sanitation.	Reduce, re-use	User
Social circular economy indicators: Selection through fuzzy delphi method	Padilla-Rivera et al.	2021	Social circular economy-based indicators, including child labour, sanitation, thermal comfort, labelling.	Refuse	Customer
Recirculation potential of post-consumer /industrial bio-based plastics through mechanical recycling - Techno-economic sustainability criteria and indicators	Briassoulis et al.	2021	Circularity indicators, including biodegradability, waste sorting.	Recycle	EoL product holder
Social Life Cycle Assessment of Product Value Chains Under a Circular Economy Approach: A Case Study	Reinales et al.	2020	Social-based circularity indicators, including products produced with recycled materials.	Refuse	Customer

in the Plastic Packaging Sector					
Indicators to Measure Efficiency in Circular Economies	Sánchez-Ortiz et al.	2020	Circular economy metrics for efficiency.	Refuse, reduce, re-use, recycle	All
The Drivers of Sustainable Apparel and Sportswear Consumption: A Segmented Kano Perspective	Baier et al.	2020	Sustainability-based indicators for apparel, including take-back policy.	Refuse	Customer
A review of micro level indicators for a circular economy – moving away from the three dimensions of sustainability?	Kristensen & Mosgaard	2020	Circularity metrics, including recycling, remanufacturing, re-use, resource efficiency, disassembly, lifetime extension, waste management, EoL management, and multidimensional indicators.	Reduce, re-use, remanufacture, recycle	User, EoL product holder
Creating sustainable value through remanufacturing: Three industry cases	Jensen et al.	2019	Environmental, economic, and social indicators for remanufacturing, including after-use service acquisition for remanufacturing.	Remanufacture	User
Bio-Based Products: Suggestions for Eco-label Criteria and Standards in Line with Sustainable Development Goals	Wurster et al.	2019	Indicators for labelling.	Refuse	Customer

Developing a set of sustainability indicators for product families based on the circular economy model	Mesa et al.	2018	Circularity metrics, including multi-functionality of a product.	Rethink	Customer
Rooftop greenhouses in educational centers: A sustainability assessment of urban agriculture in compact cities	Nadal et al.	2018	Circularity indicators, regarding food self-production, rainwater harvesting, thermal comfort.	Rethink, reduce	User
Developing a reparability indicator for electronic products	Flipsen et al.	2016	Indicator for repairing (self and service acquisition)	Repair	User
Reducing waste management challenges: Empirical assessment of waste sorting intention among corporate employees in Ghana	Adu-Gyamfi et al.	2023	Waste sorting indicators in corporate employees	Recycle, recover	EoL product holders
Dynamic capabilities and environmental accounting for the circular economy in businesses	Scarpellini et al.	2020	Multi-functional products, equipment or products replaced to energy consumption reduction	Refuse, rethink, reduce	Customer

A Comprehensive Sustainability Assessment of Battery Electric Vehicles, Fuel Cell Electric Vehicles, and Internal Combustion Engine Vehicles through a Comparative Circular Economy Assessment Approach	Ahmed et al.	2023	Energy consumption, water consumption, recyclability rate, energy source utilization percentage, emissions produced, technology readiness level, vehicles' efficiency, total cost of ownership, national incentives, vehicles' lifetime, range on full tank/charge, range anxiety, recharging/refuelling time and number of available refuelling/recharging stations	Reduce, repair, refurbish, repurpose, recycle	All
DECISION-SUPPORT TOOLS FOR SMART TRANSITION TO CIRCULAR ECONOMY	Yazan et al.	2022	Energy certificates	Reduce	Customer
Assessing Lifestyle Transformations and Their Systemic Effects in Energy-System and Integrated Assessment Models: A Review of Current Methods and Data	Andreou et al.	2022	Ratio of private to public transport, avoidance of airplanes in favour of trains, use of active modes of transport (bicycles, walking), carpool commuting , car-sharing schemes, eco-driving practices (lower speeds), conservation of hot water, recycling, re-using, extending lifetime of consumer goods	Rethink, reduce, re-use, repair, repurpose, refurbish, remanufacture, recycle	All

The circular economy and bioeconomy in the fashion sector: Emergence of a "sustainability bias"	Colasante & D'Adamo	2021	Use of frequency for variables: recycling frequency, avoid buying products from companies that do not respect the environment in their production cycles, frequency of acquisition of products with little packaging or recyclable packaging, use of public transports, acquisition of products in packs that can be refilled/re-used, acquisition of re-usable	All	All
Co-development of a framework for circular economy assessment in organisations: Learnings from the public sector	Droege et al.	2021	Set of CE indicators for public sector organisations	All	All
The lifestyle of sustainability: Testing a behavioral measure of precycling	Klug & Niemand	2021	Refusal of overpackaged products or of products due to environmental or social reasons, acquisition of products in bulk stores (stores for self-filling, self-bottling), prioritizing sustainability made products, self-production of products (cultivating peppers at home, producing one's own cosmetics, etc.),	Refuse, rethink, reduce, re-use, recycle	All

			package re-using, full use of products without waste production (e.g., food)		
Food packaging and sustainability – Consumer perception vs. correlated scientific facts: A review	Otto et al.	2021	GWP, recycling rate of packages, re-use rate of packages, biodegradability of packages	Re-use, recycle	Customer
CIRCULAR FASHION FROM THE PERSPECTIVE OF YOUNG CONSUMERS – MEASUREMENT AND MANAGERIAL RELEVANCE	Kovacs	2021	Acquisition of long-lasting clothes, repurposing clothes, clothes made from sustainable fabrics, second-hand acquisition, purchasing less, rent clothes, clothes give away or swap	Rethink, reduce, re-use, repurpose	All
Tools for assessing qualitatively the level of circularity of organisations: Applicability to different sectors	Valls-Val et al.	2023	Set of indicators for different aspects of CE in an organization, including purchasing, transform, use, reintroduce, rethink, waste management, among others	All	All
What will lead Asian consumers into circular consumption? An empirical study of purchasing	Chun et al.	2022	Re-use/resold a smartphone, refurbished smartphone acquisition, environmentally friendly products prioritization	Re-use, refurbish	Customer, user

refurbished smartphones in Japan and Indonesia					
Consumer Demand for Circular Products: Identifying Customer Segments in the Circular Economy	Boyer et al.	2021	Acquisition of products with recycled materials, acquisition of products with refurbished/re-used parts	Re-use, refurbish, recycle	Customer
Product obsolescence and its relationship with product lifetime: An empirical case study of consumer appliances in Japan	Yamamoto and Murakami	2021	Measure to improve physical durability of a product, encourage repairing, improve modular upgradability	Reduce, repair, refurbish	Customer, user
A quantitative and holistic circular economy assessment framework at the micro level	Baratsas et al.	2022	Set of CE indicators for reduction of material losses/residuals, reduction of input and use of natural resources, increase in share of renewable resources & energy, reduction in emission levels and increase the value durability of products	All	All
Durability of washing machines under real life conditions: Definition and application of a testing procedure	Stamminger et al.	2020	Average energy or water consumption of a washing machine in function of the load and selected temperature	Reduce	User
Community repair in the circular economy – fixing more than stuff	Bradley and Persson	2021	Repairability index	Repair	User

The development of an index for assessing the circularity level of eco-labels	Lanaras-Mamounis et al.	2022	Eco-Label circularity index, considers reduce, repair, sustainability, refurbish/remanufacture, safe disposal indicators	Reduce, repair, refurbish, remanufacture, recycle	All
DEMONSTRATING EEE RECOVERY FOR REUSE IN A DISTINCT URBAN MINE: A CASE STUDY	Shittu et al.	2021	Re-usable, donated, resold products	Re-use	User, EoL product holders
The destiny of replaced technological products: The influence of perceived residual value	Kréziak et al.	2020	Return the product instead of throwing, sell privately, return for a discount, recycle, give away	Re-use	EoL product holders
Plastics: friends or foes? The circularity and plastic waste footprint	Klemeš et al.	2020	Plastic re-use, mechanical recycling and chemical recycling	Re-use, recycle	EoL product holders
Environmental sustainability of liquid food packaging: Is there a gap between Danish consumers' perception and learnings from life cycle assessment?	Boesen et al.	2019	Return or refill package, package made of environmentally friendly materials (renewable sources, recycled material, biodegradable, compostable), package can be repurposed into other activities (storage)	Refuse, rethink, re-use, repurpose	Customer, user

A systematic review of research on food loss and waste prevention and management for the circular economy	Do et al.	2021	Energy and water consumption, waste sorting, among others	Reduce	Customer, user

B. QUESTIONNAIRE SURVEY

This questionnaire was developed in the scope of the master thesis "Circular Economy Self-Assessment Tool for Households: A Collaborative Approach" that is being developed by Alexandre Rodrigues da Silva, student of the Integrated master's in environmental engineering (School of Sciences and Technology, NOVA University of Lisbon (SST NOVA), Portugal) and supervised by Prof. Dr. Tomás B. Ramos (FCT NOVA, Portugal).
The questionnaire is anonymous. However, there is some personal information collected, including age, gender, level of education, type of household and number of people in their residence. This information is necessary to characterise the respondents. The data will be used in aggregate form, never explicitly identifying respondents. Your answers will be entirely confidential, ensuring the security of the information collected, in strict compliance with the General Data Protection Regulation (GDPR). If you have any questions, you can direct them to the data protection officer, by emailing amfr.silva@campus.fct.unl.pt.
Your participation in this study is very important but completely voluntary, and you can withdraw from the questionnaire at any time, as well as request the correction or cancellation of the data already provided.
This survey should take about 3 to 5 minutes of your time, where you will provide your opinion based on your life experiences. There are no right or wrong answers.
Therefore, we would like to confirm that you understand the objectives and scope of this questionnaire, as well as how the data collected are collected, processed, and analysed, and whether you agree to participate in this study.

□ Yes, I agree

□ No, I disagree

Welcome!

Thank you for agreeing to participate in this survey on developing a self-assessment tool that fosters circular economy progress. We appreciate your insights.

Personal information

Please provide some information about yourself. This is necessary to understand the profile of the respondents.

1.1 What is your age group?

□ 15 - 24 years old

□ 25 - 34 years old

□ 35 - 44 years old

□ 45 - 54 years old

□ 55 - 64 years old

□ > 65 years old

1.2 What is your gender?

□ Female

□ Male

□ Non-binary

□ Other

□ Prefer not to indicate

1.3 What is your level of education?

□ High School

□ Bachelor's Degree

□ Master's Degree

□ Doctorate

1.4 In what type of residence do you live?

□ Apartment

□ Townhouse

1.5. How many people live in your residence?

□ 1

□ 2

□ 3

□ 4

□ > 4

1.6. Are you familiar with the concept of Circular Economy (CE)?

□ Yes

□ No

2. 'Customer' in a circular economy

This section aims to understand the level of importance you attach to circular economy (CE) strategies that can be used as a customer, namely in the process of purchasing products/resources for your home. In the context of CE, the customer has the role of purchasing products/resources (e.g. food, energy, water, clothing, household tools, electrical and electronic

equipment) with minimal environmental impact, and refraining from purchasing when possible (Shevchenko *et al.*, 2023).

2.1. Please indicate the degree of importance attached to the following situations:

"When you buy a product/resource, do you think it is important..."

	1 Not important at all	2 Of little importance	3 Of average importance	4 Very important	5 Absolutely essential
2.1.1. Acquiring eco-labelled products?	□	□	□	□	□
2.1.2. Reject/avoid products produced through child labour or in other abusive and objectionable ways?	□	□	□	□	□
2.1.3. Search for the shop with the least negative environmental impact (with a recognised environmental certification)?	□	□	□	□	□
2.1.4. Search for the shop with the least negative social impact (with a	□	□	□	□	□

social responsibility certification)?					
2.1.5. Looking for the product in the form of a service?	□	□	□	□	□
2.1.6. Looking for electrical or electronic products with the best performance in the energy certificate?	□	□	□	□	□
2.1.7. Seek out locally produced foods/food products?	□	□	□	□	□
2.1.8. Reject/avoid products with excessive packaging or packaging quantities where possible?	□	□	□	□	□
2.1.9. Look for bulk products or with reduced packaging quantities if packaging is unavoidable?	□	□	□	□	□

2.1.10. Looking to buy second-hand rather than new products?	□	□	□	□	□
2.1.11. Trying to buy repaired products instead of new ones?	□	□	□	□	□
2.1.12. Seek to purchase refurbished/reconditioned products (e.g. an old product that has been upgraded to current quality standards) rather than new ones?	□	□	□	□	□
2.1.13. Try to buy "remanufactured" products (made from parts of another product with the same function) rather than new ones?	□	□	□	□	□
2.1.14. Try to buy "re-purposed" products (products that have acquired a new	□	□	□	□	□

function) rather than new ones?					
2.1.15. Try to buy products made from recycled materials rather than new ones?	☐	☐	☐	☐	☐
2.1.16. Try to buy recyclable products or products that can be dismantled?	☐	☐	☐	☐	☐
2.1.17. Seek to purchase the product in its dematerialised format, where possible?	☐	☐	☐	☐	☐
2.1.18. Try to buy the product with the longest possible durability?	☐	☐	☐	☐	☐
2.1.19. Look for reusable products, rather than single-use items?	☐	☐	☐	☐	☐
2.1.20. Look for products that can be shared, when bought together?	☐	☐	☐	☐	☐

2.1.21. Seek to rent the product rather than own it?	□	□	□	□	□
2.1.22. Seek dietary alternatives with better environmental performance?	□	□	□	□	□
2.1.23. Seek to buy foods that partially replace animal-based consumption?	□	□	□	□	□
2.1.24. Try to satisfy the residence's energy needs through renewable sources?	□	□	□	□	□
2.1.25. Try to buy products that minimise energy consumption needs without losing thermal comfort?	□	□	□	□	□
2.1.26. Try to buy products that increase the durability of the main product?	□	□	□	□	□

2.1.27. Look for multifunctional products, rather than one product for each function?	□	□	□	□	□
2.1.28. Try to buy products with a money-back guarantee?	□	□	□	□	□

2.2. If you answered positively to question 2.1.10. "Try to buy second-hand rather than new products", which of these products did you buy second-hand?

□ Electrical and/or electronic equipment

□ Vehicle(s)

□ Clothing and/or other textile products

□ Home furnishings (e.g. sofa, chairs, tables)

Other(s) _____

2.3. Do you think it is important to stop or avoid purchasing a product or service or to reduce consumption in general for environmental or social reasons (e.g. avoid/reduce the consumption of animal products or the frequency of car and air travel)?

□ Absolutely essential

□ Very important

□ Of medium importance

□ Not very important

□ Not at all important

2.4. If you have comments on other good procurement practices you have adopted, please write here:

_____

_____

3. 'User' in a circular economy

This section aims to understand the level of importance you attach to Circular Economy (CE) strategies that can be implemented as an user, namely in the use of products/services. In the context of CE, the user has the role of carefully using and maintaining the product, seeking

technical and repair services, and selling or donating the products if they are no longer needed (Shevchenko *et al.*, 2023).

3.1. Please indicate the degree of importance attached to the following situations: "As an user of a product/resource, do you think it is important..."

	1 Not important at all	2 Of little importance	3 Of average importance	4 Very important	5 Absolutely essential
3.1.1. Use the product in the method that allows the greatest economy of resources (for example, use the washing machine when it is full and whenever possible with the lowest temperature)?	□	□	□	□	□
3.1.2. Avoid/reject using the product if there is a more sustainable alternative (e.g. avoid using the printer if it is possible to scan the document; use the bicycle, walk, or	□	□	□	□	□

use public transport instead of own car where possible)?					
3.1.3. use the product in the most 'use-intensive' way possible (e.g. share the tools with family, friends, or neighbours, rather than each purchasing their own)?	☐	☐	☐	☐	☐
3.1.4. Save leftovers for consumption at another time, when possible, rather than discarding them?	☐	☐	☐	☐	☐
3.1.5. Repair the product or purchase a repair service, rather than disposing of it when necessary?	☐	☐	☐	☐	☐
3.1.6. Renovate/recondition the product or purchase a	☐	☐	☐	☐	☐

renovation/re-conditioning service (e.g. re-upholster a sofa) instead of discarding it?					
3.1.7. Remanufacture the product or acquire a remanufacturing service instead of discarding it (e.g. use parts of a product that has been discarded or that you intend to discard)?	□	□	□	□	□
3.1.8. 'Repurpose' the product or purchase a service that allows you to 're-purpose' it, rather than discard it (e.g. turn an old t-shirt into a cleaning cloth, rather than discard it)?	□	□	□	□	□
3.1.9. Use the land of your residence to	□	□	□	□	□

produce your food, when possible?					
3.1.10. Sell or donate the product, rather than dispose of it, if it is still in good condition and able to fulfil its function?	□	□	□	□	□

3.2. If you have comments on other good practices in product/resource use and maintenance that you have adopted, please write here:

_____

_____

___

4. "End-of-life product holder" in a circular economy

This section aims to understand the activities you practice as an end-of-life product holder. In the ambition of the Circular Economy (CE), the individual should dispose of the product in a timely manner and use the most appropriate final destination channel (Shevchenko *et al.*, 2023).

4.1. Please indicate the degree of importance attached to the following situations:

"When disposing of a product, do you find it important..."

	1 Not important at all	2 Of little importance	3 Of average importance	4 Very important	5 Absolutely essential
4.1.1. Give priority to the use of recycling containers, where appropriate,	□	□	□	□	□

rather than the undifferentiated waste containers (e.g. use the recycling container for plastic when you want to dispose of plastic rather than the undifferentiated waste container)?					
4.1.2. Give priority to sending organic waste (e.g. food scraps, plant pruning's) for composting, rather than using the undifferentiated waste container?	□	□	□	□	□
4.1.3. Give priority to using a container or special waste collection service rather than disposing of the waste in a public place (e.g. using a container rather than leaving	□	□	□	□	□

the waste in the street, beach, park, library)?					
4.1.4 Do you separate your waste at home?	☐	☐	☐	☐	☐

4.2. If you have comments on the timely disposal of a product and the use of other good disposal practices you have adopted, please write here:

_____

_____

_____

C. Semi-structured interview guide

Introduction: Thank you for voluntarily participating in this interview on the evaluation of the household circular economy self-assessment tool. The purpose of this interview is to collect information on the use of the self-assessment tool, understand whether the indicators are clear and adequately communicate circular economy progress. Your participation in this study is very important but completely voluntary, and you can withdraw from the questionnaire at any time, as well as request correction or cancellation of data already provided.

1. Personal Information

- What is your age group?
- What gender do you identify with?
- What is your level of education?
- In what type of residence do you live?
- How many people live in your household?
- Are you familiar with the concept of circular economy?

2. Evaluation of the self-assessment tool

After using the self-assessment tool,

- Were you able to use the tool?
- Is it easy to use?
- Do you find it useful?
- Did you find the indicators easy to understand? If not, which were the most difficult to interpret?
- What would make the indicator(s) easier to understand?
- While using the self-assessment tool, were you able to reflect on the actions you take as (i) customer, (ii) user and (iii) end of life product holder? If yes, will you consider implementing circular economy practices in your household?

D. Developed self-assessment tool

HCE dimension	Product/resource	Question	Type of Answer (categories/ranges)
General information		Where do you live?	Country name
		What is your age group?	>64; 55-64; 45-54; 35-44; 25-34; 15-24; <15
		What gender do you identify with?	Male; Female; Non-binary; Other; Prefer not to answer
		What is your highest completed education?	PhD; Master; Bachelor; Secondary school; Middle School; Primary School
		How many people do you live with?	>4; 4; 3; 2; 1; 0
		What type of house do you live in?	Single-Family; Semi-Detached; Multifamily; Town home; Apartment; Condominium; Co-op; Tiny home
		What is the approximate surface area of your house (m^2)?	>400; 301-400; 201-300; 101-200; 51-100; <50
		Are you familiarized with the concept of circular economy?	Yes; No

Customer	Food	How often do you procure?	Almost always; Often; Sometimes; Seldom; Never
	Eggs		
	Yoghurt		
	Cheese		
	Plant based milk		
	Milk		
	Soy-based substitutes		
	Beef meat		
	Pork meat		
	Poultry meat		
	Fresh seafood		
	Shelf-stable seafood		
	Pasta		
	Cereal grains		
	Biscuits and cakes		
	Chocolate		
	Pre-prepared meals		
	Bread		
	Bottled mineral water		
	Coffee		
	Tea		
	Beer		
	Wine		
		How often did you acquire locally produced foods?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		How often did you reject food produced	Almost always; Often; Sometimes;

		in socially irresponsible ways?	Seldom; Never; I don't know
		How often did you reject food products with excessive packaging?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		How often did you acquire these products in bulk?	Almost always; Often; Sometimes; Seldom; Never; I don't know
	Electric and electronic products	How many do you own, currently?	>4; 4; 3; 2; 1; 0
	Refrigerator + freezer		
	Additional freezer		
	Air conditioning system		
	Oven		
	Laptop		
	Coffee maker		
	Kettle		
	Dishwasher		
	Washing machine		
	Tumble dryer		
	Tv screen		
	Vacuum cleaner		
	Hair dryer		
	Mobile phones		
	Vehicle		
	Moped or motorcycle		
	Heat pump		
	Radiator		

	Microwave		
	Stove		
	Printer		
		How often did you reject electric or electronic products produced in socially irresponsible ways?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		How often did you reject electric or electronic products with excessive amounts of packaging?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		What percentage of these products were acquired to increase your energy efficiency?	%
		What percentage of these products were acquired in second-hand?	%
		What percentage of these products were produced with recycled material?	%
		What percentage of these products are recyclable?	%
		What percentage of these products are dismantlable?	%

		What percentage of these products were acquired with durability as a priority?	%
		What percentage of these products were co-acquired?	%
		What percentage of these products have a take-back policy?	%
		Did you acquire a product to increase the longevity of another product?	Yes; No
		How often did you acquire the locally produced version of these products?	Almost always; Often; Sometimes; Seldom; Never; I don't know
	Clothing	How many did you procure?	>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0
		Waterproof shoes	
		Sport, leisure, or fashion shoes	
		T-shirts	
		Blouses	
		Trousers	
		Jeans	
		How often did you reject electric or electronic products produced in socially irresponsible ways?	Almost always; Often; Sometimes; Seldom; Never; I don't know

		How often did you reject electric or electronic products with excessive amounts of packaging?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		What percentage of these products were acquired in second-hand?	%
		What percentage of these products were produced with recycled material?	%
		What percentage of these products are recyclable?	%
		What percentage of these products were acquired with durability as a priority?	%
		What percentage of these products have a take-back policy?	%
		How often did you acquire the locally produced version of these products?	Almost always; Often; Sometimes; Seldom; Never; I don't know
	Other products	How many times do you procure?	>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0
	Newspapers		
	Books		
	Cosmetic products		
	Hygiene products		

		How many do you own, currently?	>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0
	Kitchen items		
	Bicycle		
	Couch		
	Chairs		
	Tables		
	Desks		
	Beds		
		How often did you reject electric or electronic products produced in socially irresponsible ways?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		How often did you reject electric or electronic products with excessive amounts of packaging?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		How often did you acquire these products in bulk?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		What percentage of these products were acquired in second-hand?	%
		What percentage of these products were produced with recycled material?	%

		What percentage of these products are recyclable?	%
		What percentage of these products were acquired with durability as a priority?	%
		What percentage of these products have a take-back policy?	%
		How often did you acquire the locally produced version of these products?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		What percentage of these products are re-usable, instead of single use?	%
		Did you acquire a product with its multifunctionality in mind?	Yes; No
	Housing	Total energy consumption (kWh)	>10 000; 8 001-10 000; 6 001-8 000; 4 001-6 000; 2 001-4 000;0-2 000; I don't know
		Renewable energy consumed (%)	%
		Level of thermal comfort	Almost always; Often; Sometimes; Seldom; Never

		Water consumption (m^3)	>120; 101-120; 81-100; 61-80; 41-60; 21-40;1-20; 0
		Rainwater harvested (m^3)	>120; 101-120; 81-100; 61-80; 41-60; 21-40;1-20; 0
		Water re-used (m^3)	>120; 101-120; 81-100; 61-80; 41-60; 21-40;1-20; 0
		Wastewater recycled (m^3)	>120; 101-120; 81-100; 61-80; 41-60; 21-40;1-20; 0
		Access to basic sanitation	Yes; No
User		When you're using a product (e.g. dishwasher), how often do you use it in the most energy saving method?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		When you're using a product (e.g. dishwasher), how often do you use it in the most water saving method?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		When doing your daily activities (e.g. commuting), how often do you use public transportation?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		When doing your daily activities (e.g.	Almost always; Often; Sometimes;

		commuting), how often do you use a bicycle?	Seldom; Never; I don't know
		When doing your daily activities (e.g. commuting), how often do you go by foot?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		When doing your daily activities (e.g. commuting), how often do you carpool?	Almost always; Often; Sometimes; Seldom; Never; I don't know
		What percentage of your food leftovers do you consume?	%
		How many times do you procure a repairing service or do it yourself?	Service acquisition: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]; Did it myself: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]
		How many times do you procure a refurbishing service or do it yourself?	Service acquisition: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]; Did it myself: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]
		How many times do you procure a remanufacturing service or do it yourself?	Service acquisition: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]; Did it myself: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]

		How many times do you procure a repurposing service or do it yourself?	Service acquisition: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]; Did it myself: [>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0]
		How many products (type of product) do you produce yourself (e.g. gardening vegetables, producing own cosmetics)?	>25; 20-25; 15-19; 10-14; 5-9; 1-4; 0
		How often do you donate products in a good condition and able to fulfil its function, instead of discarding?	Almost always; Often; Sometimes; Seldom; Never
		How often do you sell products in a good condition and able to fulfil its function, instead of discarding?	Almost always; Often; Sometimes; Seldom; Never
	Electric and electronic products	How many hours did you use the?	>60; 45-60; 30-44; 15-29; 1-14; 0
	Refrigerator + freezer		
	Additional freezer		
	Air conditioning system		
	Oven		
	Laptop		

	Coffee maker		
	Kettle		
	Dishwasher		
	Washing machine		
	Tumble dryer		
	Tv screen		
	Vacuum cleaner		
	Hair dryer		
	Mobile phones		
	Vehicle		
	Moped or motorcycle		
	Heat pump		
	Radiator		
	Microwave		
	Stove		
	Printer		
EoL product holder		How often do you recycle?	Almost always; Often; Sometimes; Seldom; Never
		How often do you compost?	Almost always; Often; Sometimes; Seldom; Never
		How often do you litter?	Almost always; Often; Sometimes; Seldom; Never
		In your household, do you separate your waste per type of waste?	Yes; No

E. Interviewees characteristics

		No. of respondents	% of respondents
Gender	Male	10	47.6%
	Female	10	47.6%
	Nonbinary	1	4.8%
Age group	15 - 24 years	8	38.1%
	25 - 34 years	7	33.3%
	35 - 44 years	1	4.8%
	45 - 54 years	1	4.8%
	55 - 64 years	4	19.0%
Education	Non-university	2	9.5%
	Bachelor	14	66.7%
	Master	5	23.8%
Type of housing	Apartment	9	42.9%
	House	12	57.1%
Household dimension (no. of individuals)	1	2	9.5%
	2	5	23.8%
	3	9	42.9%
	4	3	14.3%
	> 4	2	9.5%
Familiarity with the	Yes	9	42.9%
	No	12	57.1%

concept
of CE

2023

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Circular economy self-assessment tool for households: A collaborative approach

NOVA SCHOOL OF SCIENCE & TECHNOLOGY