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Development of an Indicator to Measure the Circularity of a Product in Circular Economy: A Review

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Abstract: The important raw materials required for production are depletable in nature. Further, most of the other synthetic materials are difficult to dispose off such as plastic. Current economy of "take-make-use-dispose" is the linear economy and is not sustainable. A Measurement system (Indicator) is necessary to develop for a circular economy. Circular indicators do not in themselves achieve a successful transition to a circular economy, but are an important tool for aiding progress towards this goal. Many existing tools, available are available for measuring the product circularity but only few studies have been focusing on efficiently or effectively measurement of the circularity of a product there is no commonly accepted approach for measuring the circularity of product. Many tools have been developed till now but only some tools are popular like Circular Economy Toolkit (CET), Circular Economy Indicator Prototype (CEIP), Circularity Potential Indicator (CPI) and Material Circularity Indicator (MCI) but still no one indicator are accepted universally still so many gaps are available for the development of the circularity measurement indicator in circular economy.

Keywords - **Circular Economy, Circularity Indicator, Circularity index, Material Circularity Indicator**

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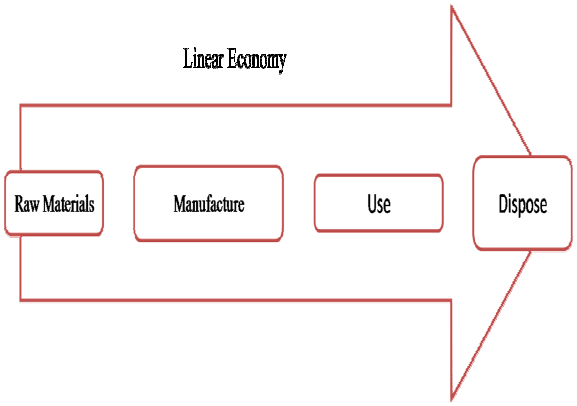
I. INTRODUCTION

As the economy grows, we need more raw materials for the production of goods and we produce more waste. The important raw materials required for production are depletable in nature. Further, most of the other synthetic materials are difficult to dispose off such as plastic. Current economy of "take-make-use-dispose" is the linear economy and is not sustainable. Due to the complexity of the concept of circular economy (CE), the linear economic model is still dominant. Identification of the circularity of a model requires monitoring of economic, social, and environmental impacts. Therefore, successful development of CE requires monitoring and evaluation tools such as circularity indicators. Several indicators have been developed in the literature but no commonly accepted way of measuring circular economy exists till date. This is why no strict policies are made and

the industries are reluctant in implementing the concept of CE.

The Linear Economy is not working well. There are some reasons for this:

1. Problem of getting resources like fossil fuels, food and water.
2. Decline biodiversity worldwide.
3. Crashed the financial system.



The linear approach follows by human diminish our source of supply and producing waste by a product. So we need to adopt the cyclic model by re-designing products, components and also re-thinking the way of use products.

Circular Economy: The idea of the circular development is the complete reorganization of the principles of human existence. People always used a simple economic scheme, called the linear economy:

In the living world there is no landfill, instead, materials flow. One species waste is another's food, energy is provided by the sun, things grow, and then die and nutrients return to the soil safely. And it works. Yet as humans we've adopted a linear approach: we take, we make, and we dispose. A new phone comes out so we ditch the old one. Our washing machine packs up, so we buy another. Each time we do this we're eating into a finite supply of resources and often producing toxic waste. It simply can't work long term. So what can? If we accept that the living world's cyclical model works, can we change our way of thinking so we too operate a circular economy?

Since the field of Circular Economy has only gained transition in the last ten years and the development has also come from practitioners, the amount of grey literature on Circular Economy is relatively high. Therefore, this research was also making use of grey literature (e.g. non-academic reports, newspaper articles, websites, etc.) as important references in order to be able to capture and represent the latest developments in this field. Also, a number of the identified Circular Economy assessments were developed by practitioners rather than academics.

The circular economy isn't about one manufacturer changing one product. It's about all the interconnecting companies that form our infrastructure and economy coming together. It's about energy. It's about rethinking the operating system itself. We have a fantastic opportunity to open new perspectives and new horizons. Instead of

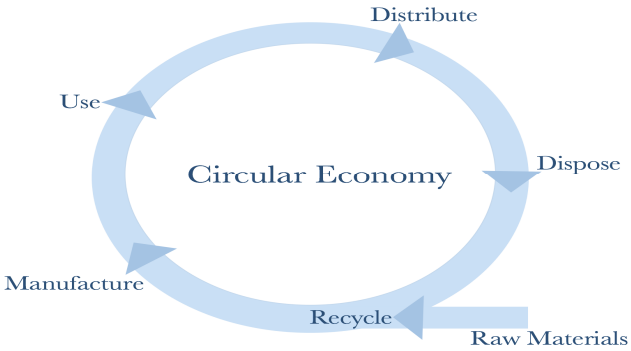
remaining trapped in the frustrations of the present, with creativity and innovation, we really can rethink and redesign our future

The Circular Economy, in contrast, aims to radically limit the extraction of raw materials and the production of waste. It does this by recovering and reusing as many of the products and materials as possible, in a systemic way, over and over again. The Circular Economy is a "make/remake – use/reuse" economy.

Essential elements of the circular economy concept (*European Parliamentary Research Service 2016.*):

1. Waste is a resource. Materials should be recycled effectively and processed to maintain the maximum value as long as possible.
2. Society has a preference based on services. Materials are designed for recycling and durability.
3. The society welfare grows by sharing and cooperation
4. Innovative business models.
5. Ideas are taken from ecology and living systems, where materials are used to restore the economic and ecological system.
6. The use of energy is reduced and entirely comes from renewable sources.
7. The circular economy system is flexible, adaptable due to design, diversification and risk reduction.
8. The ecological system improves by eliminating toxic materials.

In the living world, one species' waste is another's food, and energy is provided by the sun. This is the inspiration for the Circular Economy.



The figure: illustrates the linear open model and the circular closed loop model, based on the descriptions of circular economy and linear economy by Pollard et al. (2016), TU Delft (2017), Ellen MacArthur Foundation (2015a).

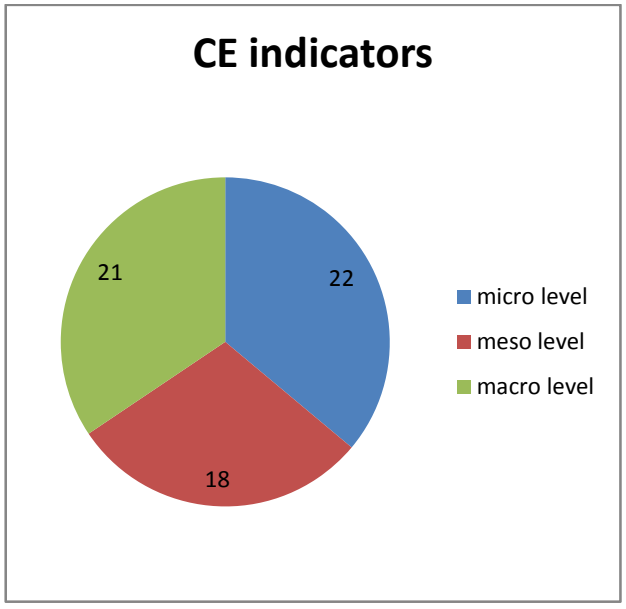
II. Materials and Methods:

Achieving a circular economy is a continuous process which requires the monitoring of economic, social, and environmental impacts, introducing

preventive and corrective action whenever necessary. Therefore, successful development of CE requires monitoring and evaluation tools such as indicators. CE indicator frameworks are developed with different purposes and with different scopes, it is rarely possible to take one set of indicators and use it for another purpose or scope. Every indicator framework has its own specific requirements regarding its purpose, scope, and design.

Many existing tools, available online or on-demand for free, aiming at measuring product performance in a context of circular economy, have been selected through the literature review analysis.

With regard to the CE implementation level, 22 CE indicators available at the micro level, 18 CE indicators at the meso level, and 21 CE indicators at the macro level were identified.



Categorisation of C-indicators according to the micro-, meso- and macro- levels of the CE

Level	Application	Example 1	Example 2	Example 3
Macro	Cities, Regions, Nations	Evaluation of CE Development in Cities (ECEDC)	Regional CE Development Index (RCEDI)	National CE Indicator System (NCEIS)
Meso	Businesses, Industrial Symbiosis	Sustainable Circular Index (SCI)	Circular Economic Value (CEV)	Circle Assessment (CA)
Micro	Products, Components, Materials	Circular Economy Indicator Prototype (CEIP)	Product-Level Circularity Metric (PCM)	Material Circularity Indicator (MCI)

Existing reviews, experimentations and critical analysis of C-indicators

References Authors and Year	**Type of publication or journal's name**	**Type of review and analysis**	**Number and names of C-indicators considered**
CIRAIG, 2015	Environmental Report	Description	MCI, CA
Otero, 2015	Master's Thesis	Description and comparative analysis	MCI, ICT, CECAC, CA
Akerman, 2016	Master's Thesis	Description and comparative analysis	MCI, CA, NCEIS, IPCEIS
Wisse, 2016	Master's Thesis	Description and	FCIM, NCEIS, IPCEIS, EPICE

		comparative analysis	
Banaité, 2016	Journal of security and sustainability issues	Description	BCI, ECEDC, ERCE, DEA, IEDCE
Cayzer et al. 2017	International Journal of Sustainable Engineering	Description experimentation developed indicator	CEIP, CET, MCI, EVR, RDI, NCEIS, IPCEIS
Saidani et al. 2017a Saidani et al. 2017b	MDPI Recycling Int. Conference Paper	Description, experimentation and critical analysis	MCI, CET, CEIP, CPI
Linder et al. 2017	Journal of Industrial Ecology	Description experimentation developed indicator	CEI, MCI, C2C, EVR, RP, PCM
Acampora et al. 2017	Int. Conference Paper	Description and relevance to a specific sector	CEPI, RPI, CEIP, CET, CEI, MCI, EISCE, FCIM
Elia et al. 2017	Cleaner Production	Description and classification	RPI, CEI, MCI, EVR, HLCAM, RP, FCIM, NCEIS, IPCEIS, ZWI, RCEDI, EPICE, EWMFA
Azevedo et al. 2017	MDPI Resources	Description and classification	RPI, CEI, MCI, EVR, HLCAM, RP, FCIM, NCEIS, IPCEIS, ZWI,
			RCEDI, EPICE, EWMFA
Pauliuk, 2018	Resources, Conservation	Description and classification	CEPI, CEIP, PCM, CEI, MCI, C2C, EVR, RDI, EISCE, NCEIS, IPCEIS, ECEDC
Walker et al. 2018	MDPI Sustainability	Description, experimentation and critical analysis	CEIP, CET, CEI, MCI, C2C, VRE
Cong et al. 2019	The Journal of Mechanical Design (JMD)	Description and comparative analysis	EPVR
Niero and Kalbar. 2019	Resources, Conservation and Recycling	Description experimentation developed indicator	MCDA-ML
Ameli et al. 2019	Resources, Conservation and Recycling	Description and classification	SDEO
Iacovidou et al. 2019	Science of the Total Environment	Description and classification	TQP
Cottafava et al. 2020	Resources, Conservation and Recycling	Description experimentation developed indicator	MCI, BCI, PBCI

Heisel et al. 2020	Journal of Cleaner Production	Description experimentation developed indicator	UMAR
McCausland, T. (2021).	Taylor & Francis Online	Description and comprehensive yet flexible for company analysis	The Circular Transition Indicators (CTI)

III. Result and Discussion:

The results of the analysis show that all 4 core (reuse, repair, refurbish, remanufacturing) CE principles are taken into account only in some of the analysed indicators (i.e. CEIP, CET, MCI, and CPI). Other indicators are focus on the different factors like durability, end of life, sustainability, economic, environmental, and social etc. c) The majority of indicators focused on recycling, end-of-life management or remanufacturing, while fewer indicators consider disassembly, lifetime extension, waste management, resource-efficiency or reuse, and the majority of the papers are published in the last few years. Material circularity indicator (MCI) is most common indicator but it also missing some important factors like durability, useful life, economic, social etc. It mainly based on material flow in the system.

CONCLUSION

There is an urgent need for a well-established approach to quantify product circularity, aiming to estimate the progress of circularity transition. The development of indicators is a key accelerator for circularity that allows data-driven decisions to be made and tracked.

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