**A circularity accounting model: dis-hoping using neural networks for the operationalization of circular economy**

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## Abstract

**Purpose –** The paper discusses critically that circular economy cannot be operationalized applying current dominant managerial paradigms and traditional accounting in financial terms and reflects on how accounting develops a pivotal role in operationalization of a circular economy, proposing the development of a circularity accounting model that takes into account planetary boundaries and individual decision-making.

**Design/methodology/approach –** Drawing on the movement building approach, this paper enquires methodologically into the applicability of neural networks in the development of a carbon estimator useful for circularity accounting. The estimator uses neural networks to accomplish a re-assessment of the use of carbon across global supply chains.

**Findings –** Circularity accounting has the potential to enable the operationalization of circular economy in the search for a more sustainable use of natural resources by portraying a method of prediction of the carbon contribution for a certain object across the entire supply, consumption, and disposal chain.

**Limitations –** The analysis is limited at this stage at an operative level. Some parts of the software system of the estimator portrayed in this research are still untested.

**Contribution –** The study provides two contributions to previous literature. (i) It proposes a cross-disciplinary collaboration exploring the application of movement building and neural networks in the development of a circularity accounting model. (ii) It enquires methodologically into the application of neural networks to develop a carbon dioxide estimator that uses carbon dioxide instead of monetary units as a unit of measure, exposing the use of natural resources otherwise hidden in monetary terms.

**Keywords:** circular economy; climate change; neural networks; movement building, sustainability accounting.

Paper type: Original research

**1. Introduction**

In a separate file

Structure of the rest of the paper: 2) Theoretical framework, 3) Model & Arquitecture of CAM (including carbon estimator), 4) Example of Yakoult case study, 5) Concluding remarks and conclusion.

**2. Theoretical framework**

In a separate file

**Section. 3. CAM: Model & Architecture**

Based on ideas exposed in section 2, this research proposes an accounting model that provides information to individuals with the aim of empowering collective agency: the circularity accounting model (CAM). This individual accounting model aims to operationalize circular economy transforming accounting into a tool aware and respectful with the planetary boundary of climate change (Rockström et al, 2009).

CAM shifts, at least, below accounting rules of measurement and valuation: (i) capital to maintain: it shifts from financial capital to natural capital within the framework of planetary boundaries, particularly the boundary of climate change. The model acknowledges the existence of entropy. Entropy production accompanies life, and human life produces current economies. Within the realm of present technology and planetary boundaries, the limits of CO2 limit economic activity and production of physical products and transportation. The consolidation of energy toward a goal is a process that attracts the attention of economic planners, its symmetric opposite, the divestiture of entropy, is of concern not only of economic planners but also of living creatures. Divestiture of entropy outward is of concern in closed systems (as gas pressure for example). This is as apparent when entropy production is encumbered by a container (PV=nRT, for example), as when economic growth approaches planetary boundaries (a more complex relationship). In the present paper, we may consider entropy production as it is embedded in the production of planetary CO2. Acknowledgment of planetary boundaries as a boundary on entropy production and the assertion that humans cannot exercise economic activity beyond natural limits results in CAM shifting to the maintenance of natural capital as opposed to the focus on economic capital in traditional accounting.

(ii) accounting entity: it shifts from financial control to sustainability control (Antonini & Larrinaga, 2017) along the global supply chain incorporating definitions of entity boundaries, and may thereby improve resolution of responsibility. More clarification NEEDED?

(iii) units of measure: it shifts from monetary units to physical units (CO2) using an estimator based in neural networks. CAM argues that enlarging the boundaries of producers’ reporting to align the disclosure of information with the responsibility over the whole supply chain affected (Antonini & Larrinaga, 2017; Archel et al., 2008) is not sufficient. It is also necessary to connect the economic value of transforming products along the whole supply chain to a physical value. CAM may resist the expansion of market rules to the environment (O´Neill, 2007). In the endeavour to develop CAM as a means for change, it is necessary to reconnect the transmission of data and information with the physical objects that they proxy, instead of valuing all economics according to the market rules and in monetary units. Ultimately, it may be useful to align accounting with quantification of pollution, climate change and biodiversity loss among other planetary boundaries limiting conditions for human development (Rockström et al., 2009). If the accounting framework needs to disclose the value of real flows of good and services, therefore, the measuring system needs to be founded on real (physical) flows of goods and services and not merely on the financial-monetary reflection of it. The planetary boundaries offer the justification to expose the real flow and reflect the physical limitations of the economy and the environment.

Figure 2 discloses the CAM developed in this paper. The CAM measures direct and indirect CO2 emissions of products in a supply-disposal chain with the goal of reducing emissions and increasing awareness of stakeholders. The circle at the centre of the figure represents one full cycle of the supply-disposal chain for one product. The geometric circle is the ideal to be achieved. If a product supply chain moves within a circle, it will end to restart a new cycle with zero lost CO2. Variance from circularity is a measure of entropy introduced to carbon sequestration (carbon accounting chain entropy, *Schain*), which can decrease or increase at each step in the path of production-consumption-disposal.

FIGURE 2 aprox here

Products’ carbon accounting chains are plotted against the circle and variance from circularity shows the entropy profile of a chain *Schain*. Point A in Figure 3 represents the beginning of the supply chain, where the emissions of CO2 are still zero. Point B represents the right half of the cycle where the production and transportation phases end. This can be described as the “production phases”, this point in the circle represents all the additions needed along the supply chain to make the final product available for consumers. Point C represents the point where the supply chain ends. Between point B and C are included all the phases of consumption and waste management. It could be described as the “consumption-disposal phases”. Points A1, A2, etc. represent the different stages within the production phases, where points B1, B2, etc. represent the different stages within the destruction phases. Positions in the supply-disposal chain are unlikely to match the inner ideal circle and each product will have a different shape. For example, in the case of B5 and B7 it is noticeable that both are far away from the inner circle. The journey in the supply-disposal chain from beginning to end on the circle is a translation though resource configuration space, movement on the circle represents the re-ordering of the resource network.

**3.1 Tools/Steps? to implement CAM: Architecture/steps/tools?**

The CAM is implemented in three steps using neural networks:

1. a method and system called a ‘carbon estimator’ which can detect recognize and classify objects and to calculate their carbon sequestration.
2. (ii) A library of components of the objects so that the costs and implications of the objects is available.
3. (iii) A method of prediction of carbon chain, showing the carbon contributions for an object.

@Jesse: Is this part of the architecture?

Carla Antonini Morales

Jesse: 1) what is the difference between the carbon estimator and the method of prediction???!! For me they are the same thing. Can you please clarify?

***“method of prediction of carbon chain” not “method of prediction”. i the ‘carbon estimator’ is a method of prediction for objects. iii ‘A method of prediction of carbon chain’ is for carbon chains, supply-disposal chains.***

2) Do we need this clarification (if so add as a footnote or clarification somewhere) or delete?--> “Referring to carbon in the context of the estimator we mean the CO2 equivalent sequestered in an object”.

***needs clarification if reader doesn’t understand. Lets ask questions and insert the replys in the paper***

Figure 3 shows the ARCHITECTURE of the model (PENDENT FIGURE)

***sure. the architecture is the same figure with variables substituted for the Yakoult product.***

Explanation of figure 3 (ONLY THE ARCHITECTURE// NO Yakoult example)

**3.1.1 Carbon estimator**

In the development of the carbon estimator, this paper undertakes an investigation into defining objects as an encoding in a neural network, so that a network identifies objects andcontains the definitive model of the object. For example, what is milk: a network recognizes *milk* from data, and so ‘milk’ is detected as present when the neural network detects it. Whether the milk is a bottle, or in a bottle, a box, a droplet, or cow these are details which the neural network detector must manage. Employing neural network detectors for the definition of economic objects is in comparison to previous definitions of such objects, in which they are defined in terms of language, and by the work of human agency where a person physically acts on an object, or by a social and legal framework that is enforced by human agency. The CO2 estimator models the ‘CO2 of things’ acting to classify from observer independent definitions of objects which do not require the continuous intervention of human or social agency.

Neural networks which can successfully detect, recognize, and describe real world objects, locations and features are called models, they model a neural network processor. The successful process will result in the detection or recognition of objects or features, from incoming data.

We develop a carbon ~~cost~~ estimator. The estimator is a software tool, which takes sensor input data, and processes it though a neural network, the result is a classification of the object found in the data, into a category, which describes its carbon content. The category is retrieved from a database that lists all known objects, and each object is recognizable by a neural network which has been trained to recognize the object from visual data.

Objects to be analysed are in general sensed through video that is broken into images, each of which is treated as a multidimensional surface of data mapped to a matrix. Each matrix cell might contain colour, intensity, frequency, spatial position, or other characteristics.

***right. will move this.***

An object is not assumed to be a mass which exists, but is a set of data for which an agenda for investigation is followed in an architecture of detectors and classifiers, and finally a specialized recognizer. Popular model architectures in the last decade have been those trained on imagenet (Deng et al., 2010) which classifies incoming images, single-shot-detector (Liu et al., 2016) which detects objects in incoming images, and autoencoders (Sundermeyer et al., 2019; Nourmohammadi-Khiarak et al., 2018; Li et al., 2019) which can recognize the visual details of objects.

The present estimator performs carbon sequestration estimation using (deep) neural network models and is a process of: (i) building and training models of economic objects (products), (ii) obtaining their CO2 sequestration value from existing reports, and (iii) connecting models together. The first two items in this process require the participation of people to acquire samples of data (visual images, photos or video in the simplest case) from the object that is to be estimated, and to assign CO2 values to the objects. The (iii) activity requires instruction from participants on how positions in a carbon chains are connected, how products are composed of parts, and how they are manufactured.

For development of a CO2 estimator, video and image data (*Figure 2.a*) is used to train single-shot-detector models (SSD models) and autoencoder models. The models are trained on wavelength (colour), spatial structure, and other features and components. Networks may also learn from other features such as audio, or spatial position environment.

Carbon sequestration as CO2 from detected objects is computed by matching the detected objects with a database of reported data for man-made products and reported physical estimates for natural items. For this task a general *imagenet* image classifier (*Figure 2.b*) is used to select appropriate SSD models *Figure 2.c*).

The image is passed to the class of autoencoder models (*Figure 2.d*), one of which may encode the definitive model of the object perceived in the incoming image data.

**3.1.2 Library???**

***Does this need a better name?***

A database (Table *Classes*) contains carbon-sequestration data for classes of objects (*Figure 2.d*). This database allows and encourages public contribution of the CO2 values for objects. In this way, consumers are no longer passive stakeholders but can also be part of the production of information. This carbon cost data may be learned by the autoencoder models (at *Figure 2.d*) and obviate a database.

Modelling or predicting a supply and disposal chain from sparse samples (a sample of one object), requires a pre-existing model of the chain, which we can build from reported descriptions of the chain. Prediction of precedence and subsequence in symbol sequences has supporting research in generative and translative models such as seq2seq. We use seq2seq to provide the estimator with a means to encode supply-disposal chains (*Figure 2.f*) and to predict more complete chains from single samples (single positions in the chain).

**3.1.3 Method of prediction???!**

In summary, the proposed solution in this paper is that the CAM applies technology based in neural networks in the implementation of circular economy. It aims to help the transformation of products along the supply chain to remain within the planetary boundary of climate change and minimize deviations from the perfect circle. In doing so, the value along the supply chain is expressed in the physical unit of CO2.

The CAM shows the use of a carbon estimator ***& chain*** enabling interaction between human and NHAs. The estimator ***& chain*** allows CAM to benefit from **~~recursive~~** increase of speed and capacity in the computation of data. ***not recursive, because the CAM is not making products for the production of CAM components***

**4. Example of practical application of CAM: Yakoult case**

This section has to be divided in three different parts correlated with the three different tools (carbon estimator, library and calculation of prediction) explained in previous section but ONLY with information of Yakoult

1parr introduction of the case study (Yakoult) might be helpful

1short parr introduction of the figure of the case study might be helpful

FIGURE WITH ONLY THE Yakoult case around here (pendent figure)

Explanation of figure with Yakoult case here: Each object known to the system is recognizable by a neural network which has been trained to recognize the object from visual data. The resulting networks describe carbon deposits, sequestration or content of an object or region. A carbon deposit (an object for example) which is recognized by the detector networks is classified as a symbol, an index unique to that class of objects. The present system recognizes only economic products but can be trained for any input.

The symbol with which detector models classify input is an index to the detected object’s CO2 equivalent contained in that recognized object or region of space. For example, a bottle of ‘*Yakult*’ yogurt is classified by the symbol ‘yakult’, which indexes a value of -881.123 as the quantity of sequestered CO2 in grams. We can see from the negative value that the creation of the object emitted more CO2 than it sequestered.

The predicted supply-disposal chain for the Yakult is shown in *Figure 2.g.*

Expand as much as possible.

**5. Concluding remarks**

The paper acknowledges the role of accounting in the operationalization of CE within the planetary boundary framework, highlighting the pivotal role, that accounting can exert in the challenge of transforming waste from a product into a source of value. Nevertheless, it discusses that such operationalization cannot be achieved applying dominant traditional accounting in financial terms. The paper explores the appropriateness of the application of movement building (as an alternative to the dominant managerial paradigms) and neural networks in the development of a new alternative accounting model, the CAM, which is based in the following shifts: (i) from economic capital to natural capital to maintain. (ii) From monetary units to physical units to express values and measures of products. (iii) From anthropologic agents to the acknowledgement of the interaction between humans and non-human agents. (iv) From corporate reporting to multi-stakeholder engagement in the creation of information. (v) From mono-disciplinary research to cross-sectional cooperation.

The CAM provides an estimator that focuses on products across global carbon chains providing a new measurement system of circularity. Additionally, the estimator is an open tool that empowers consumers with the capability of not only being passive receivers of information but also to become providers of information for better decision-making.

The operationalization of circular economy could benefit from a shift to an accounting that is aware and observes the planetary boundary of climate change. Hence the proposed CAM serves to provide a feasible tool for measuring circularity helpful to avoid potential failures regarding assessment.

This paper opens avenues for further research in the development of open-source database for training neural networks (a circularity *model zoo*), applications, additional software measuring circularity and further research in multi-stakeholder engagement in measurement systems could prove insightful.

The results of this study are relevant for companies, policy makers and researchers. To achieve the development of accounting tools that prove useful in the operationalization of circular economy, a wide array of stakeholders (consumers, companies and policy makers) would benefit from a dialogue that prioritizes the conservation of natural capital and highlights the importance of integrating planetary boundaries in the measurement of economic activities.

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**Figure 1.** **Eras of dominant agency**. Eras plotted with CO2 emission levels and boundaries.



**Figure 2. Circularity accounting model**

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**NOTE:** *Schain* is apparent in the variance from circularity.

**Figure 3. Example of practical application of CAM**

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