**A circularity accounting model: neural networks and movement building 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 recent decades, there is increasing interest in the development of more sustainable forms of doing business. Global economic and health emergencies of recent years, apparent unstructured use of natural resources, questions of biosphere integrity and climate change are among factors which have heightened alarm about the necessity of changes to patterns of production and consumption. Aware of planetary boundaries, the European Commission has recently published the EU Green Deal (European Commission, 2019) addressing the development of innovative research to foster the transition toward more sustainable ways of consumption and production. This proposal reiterates the relevance attributed by the European Commission (European Commission, 2014; Schulze, 2016) to the use of circular economy as a tool to guide the sustainable transition of all sectors. Following the same path as that of Europe, circular economy (CE hereinafter) has been proposed and promoted by several governments around the world including China and Japan (Ogunmakinde, 2019).

CE ideas support creating economic benefit (CIRAIG, 2015; European Commission, 2014; Schulze, 2016) and most important from a sustainability perspective, it is expected to allow economies to become environmentally sustainable (CIRAIG, 2015; European Commission, 2014, 2015). The issue of circularity is intrinsically linked with the duality of economics (monetary vs physical flows). Interestingly, in traditional economics, while the monetary flow is described as a circle with money moving freely through society, in contrast, the “real” flow was designed in a linear extract-produce-use-dispose material and energy flow model, which is intrinsically unsustainable (Daly, 1985; Frosch & Gallopoulos, 1989). This linearity of the physical economy is one of the main challenges that CE attempts to overcome.

Despite a large number of initiatives focused on how to transform this linearity in a circular flow model proposed by CE, it has been explored almost exclusively by practitioners (European Commission, 2014; CIRAIG, 2015 for example), as a consequence it still presents serious limitations and needs further development for successful implementation (Korhonen et al., 2018). Furthermore, the theoretical foundations and practical applicability of circular economy, remains limited (Christ & Burritt, 2015). The proper tools for CE implementation, and of particular interest of this paper, the proper *accounting tools* for implementing CE have not been clear.

Accounting can develop a mediation role in the implementation of sustainable practices (Miller & O’Leary, 2007) and therefore, accounting has the potential to mediate in the implementation of circular economy practices (Lapsley et al., 2010). Furthermore, it has been noted that circular economy projects and processes need to be carefully analysed for global environmental sustainability performance (Korhonen et al, 2018). In this regard, it can be argued that doing a proper assessment of circular project and processes at different levels (corporations, products, supply chains) requires the development of appropriate accounting systems that improve circularity in the use of natural resources.

The aim of this paper is to advance in answering questions of connecting the anthropological impact of economics to the natural environmental system (Bebbington et al., 2007; Bebbington & Larrinaga, 2014; Russell & Thomson, 2009). This connection allows the implementation and operationalization of circular economy and develops a sustainability accounting. To this purpose, the paper proposes the use of the movement-building approach (Funke, 2014; Cabaj & Weaver, 2016) in the introduction of neural networks (Hinton et al., 2006) for perceiving economic objects and predicting supply-disposal chains to further the development of the anthropological-natural connection.

The contribution of this paper is twofold. First, from a theoretical standpoint it acknowledges that complex sustainability issues such as the operationalization of CE cannot be solved in the isolation of one single discipline. The paper explores the application of movement building and neural networks in the development of a circularity accounting model (CAM)[[1]](#footnote-1) to frame accounting within planetary boundaries (Rockström et al., 2009), and overcome deficiencies in ecological literacy and accounting (Whiteman et al., 2013), and encourage cross-disciplinary research (Lawrence & Despres, 2004). Secondly, it explores the application of neural networks to develop a carbon estimator able to measure the use of carbon in products along its lifespan within the carbon chain. In the present paper, the accounting of the carbon chain incorporates the entirety of the supply, consumption and disposal chain, similar the way in which Schaltegger and Csutora (2012) conceptualize carbon management accounting. Carbon is chosen because carbon dioxide (CO2 hereinafter) is a main driver of climate change, which has exceeded some critical limits (Rockström et al., 2009). The estimator reflects for each transaction, the computation of that transaction’s contribution toward or away from CO2 boundaries, and by derivation, contribution to vectors that intersect other planetary boundaries such as ocean acidification or biodiversity loss.

The remainder of this paper is organized in the following way:

XXXXEntonces volviendo a la estructura del paper: 1) Introduction, 2) Theoretical framework, 3) Model- Arquitecture, 4) Carbon estimator and example of Yakoult case, 5) ConclusionsXXX

Section two presents the theoretical basis of the study. Section three describes the context and circumstances of application of the CAM. Section four explains the methodology followed for the development of the carbon accounting estimator. In section five, the paper presents the CAM, a model that measures the circularity of a product’s carbon accounting chain. It also introduces a description of the potential of the use of CAM at a global scale. Section six contains conclusions and some final remarks.

**2. Individual action as a catalyst toward collective agency and transformation**

Accounting has been recognised as taking a mediation role in the implementation of sustainable practices (Miller & O’Leary, 2007; Larrinaga et al., 2018) such as in the United Nations Sustainable Development Goals (SDGs) (Bebbington & Larrinaga, 2014; Bebbington & Unerman, 2018) and therefore, there could be a role for accounting in mediating the implementation of sustainable and circular economy practices (Lapsley et al., 2010). In order to advance in the development of circular economy, alternative forms of accounting are needed to transform waste from an item into a source of value. This can be possible by providing measurement systems of the circularity of the economy at different levels (Di Maio et al., 2017; KPMG, 2019). This paper adopts Latour’s views on “dis-hoping”. Latour (2017) claimed that we need to came to a solution to climate change through action and not merely “hoping” for an instant solution. In other words, not trusting in hope alone to deal with the problem. Although in the past a vast amount of sustainability accounting research focused in the fact that corporations have the most significative negative environmental impact, however we cannot forget that ultimately corporations are formed by individuals (see Osterblom et al, 2015 for the discussion about these two standpoints). Additionally, we cannot forget that individuals represent consumers, corporations would not survive if consumers stop buying its products. Therefore, it is extremely relevant to provide individuals with information systems that allows them to improve their decision making (Rodrigue and Rome, 2021). Individuals usually tend to be more sensitive and reactive to localized experiences and so more exploration of individualized, local information and engagement are needed (Latour, 2017). Furthermore, the agency of individuals is not possible ‘‘without the installation of instruments capable of tracing the loops that make the least of our actions react in response to its causes” (Latour, 2017, p. 252).

**2.1 Individuals: agency, speed and action**

The Anthropocene era is marked by the physical impacts of advanced production systems (Levy & Egan, 2003), which this paper proposes as being enabled by recursive increases in the speed of agency. Over previous spans of years and decades, transactions among physical object products have not increased in speed as much as transactions through data transmission and processing. Figure 1 presents the increasing trend of CO2 emissions along with the empowerment in economics of human agency, machine agency, and non-human agency.

**Figure 1.**

Figure 1 shows the increasing speed of agency and its relationship with CO2 emissions, and in consequence with the planetary boundary of climate change. The horizontal axis shows the evolution of time divided in three periods: human agency, machine agency and non-human agency. The first period is where economic activity was performed exclusively by human agency. During this period, a slow increase in CO2 emissions occurred, and therefore anthropologic climate change. Subsequently, the second period shows the increasing of CO2 emissions when machine agency was integrated into economic activity, originating an amplification of human activity. The last period shows the application of non-human agency to the economy. Through the second to third period, CO2 emission increase becomes exponential. Through the periods disclosed in figure 1, there is a recursive increase in the speed of agency together with an increase in the CO2 emissions generated by human economic activity.

Computing economic agendas using symbols enabled an increasing speed of monetary flows, faster than for physical flows (Leblanc 1990 for example). It is easier and faster to move money than heavy objects, and it is easier and faster to move data compared to ‘money’ as money requires additional encoding and decoding processes.

Early financialization, understood here as the process in which money in all its forms becomes more important than the real object supporting these abstractions of value, was limited to the speed and volume of money. These barriers were removed when money became encoded in electrons and photons rather than large masses like coins or paper (Leblanc, 1990). While the edges of an organization’s possible economic growth are financial, it is still constrained by physical limits of planetary boundaries. At issue is that the financial economy, which is expressed in transactions of monetary units, and the ‘physical economy’ measured in transacting movements of mass can be different sizes by orders of magnitude. They maybe be thousands of times different in speed, milliseconds for machines vs. seconds for people (Kirilenko et al., 2017). When financialization allows an increase in the speed of economic transactions, more economic activity per unit of time can be accomplished within the financial system without interacting with slow and massive objects. When faster economic activity causes a corresponding increase in physical activity, then the speed of movement toward physical limits may be increased. It has been a trend over the previous decades that faster economic systems produce CO2 at a higher rate, though this trend may change with energy sources.

When an economy operates at a faster speed, it reaches planetary boundaries more quickly. An economic system operating with physical objects in non-circular economy can reach planetary boundaries faster than a slower economy.

+++HERE information about individual action, maybe be including some of Beck’s ideas

M & R 2021: We suggest that accounting potentially serves as the most important ‘‘mechanism” in this informative capacity. Therefore, we propose a complementary

individualized focus within accounting systems and SEA research, creating a sense of individual urgency and empowerment toward collective action (i.e., dis-hope).++ This highlights the need for accounting’s provision of an additional perspective beyond that of corporate organizations – if we are to account for the anthropic interactions with Gaia toward agency and impact, accounting systems should provide information at the lowest level of resolution possible (Gray, 1992), that of the individual++

5.2. The need for accounting to communicate relationships between individuals and Gaia

We continue to call for alternative accounts toward accountability (e.g., Arjaliès, 2020; Gray, 2002; Lehman, Annisette, & Agyemang, 2016; Perkiss & Moerman, 2018), and more imaginary emancipatory accounts (e.g., Banerjee & Arjaliès, 2020; Gray, 2002; Tinker, 1985; Tinker, Neimark, & Lehman, 1991), potentially providing visibility of the

connection between humxn inequities and oppressions and environmental degradation ++ Adding a focus to the ability for accounting to provide individual feedback loops connecting social inequities and environmental degradation offers possibilities to alter individual behavior, aggregating toward collective agency++ Individual accounting could add nuances to the extensive research stream on accountability (Roberts, 1991, 1996, 2009), aiming toward a new accountability, one of social individualism, based on moral sensitivity to the Other (e.g., Levinas, 1986).++ The main goal of individual accounting information organized around feedback loops is to develop individual reflexivity because it is through a reflexive understanding that the relationships to the Other develop, creating a sense of moral agency (Schweiker, 1993).+++ As Latour (2017) argues, ‘‘The limits [of agency] cannot be dictated from

the outside simply because they are deemed to have been ‘objectively determined by the Laws of Nature.’ These limits have to be felt, they have to be generated, they have to be discovered, they have to be decided on from within the peoples

themselves” (p. 275). Influences on our ability to become sensitive and act depend on our experiences with laws, politics, science, religion, the arts, among others (Latour, 2017). Accounting, by informing and creating visibilities, can help remind us of what specifically matters within our own realm of being, our own sense of morality, and ‘‘focus our

attention upon what is of value to us in a way that is consistent with a more holistic and environmentally conscious perspective” (Gallhofer et al., 2000, p. 392).

From Individualization🡪 Beck & Beck

La individualización (Beck and Beck, 2003)

Scott Lash: La teoría de la modernización reflexiva de Beck se sustenta en dos tesis: (i) la tesis del riesgo (medioambiental). (ii) la tesis de la individualización. Este libro trata del “proceso de hacerse individuo” en contraposición al individualismo posesivo y egoísta del modelo neoliberalista del mercado libre. Tampoco es igual al individualism etico y altruista de la Ilustración (enlightenment), que es un individualismo de “ser individuo”, típico de la primera modernidad. La primer modernidad se basa predominantemente en una lógica de **estructuras.** La segunda modernidad, siguiendo a Manuel Castells implica una **lógica de flujos.**

“ Thus Hegel understood the shift from the anomic excesses of the French Revolution to the institutionalized individualism of property, contract, the bourgeois family and civil society of The Philosophy

of Right. The same sort of process is at stake in the transition from industrial to the second, informational modernity. First an anomic individualism. The point for Beck is that even after the transition to reflexive modernity, the new individualism does not become routinized. It is, even in its mature phase indeterminate, full of risk and precarious freedom.” ++ In many respects both Habermas and Giddens wrote from a dissatisfaction with the structural functionalism ++ Both Habermas and Giddens had affinities with Marxism. Both featured a stress on the importance of agency in contrast to structure++ At stake in this, and the defining thematic of this book, is a decidedly nonlinear notion of the individual and individualization. In the first modernity, the modernity of structure, society is conceived as a linear system.++ The reflexive individualization of the second modernity presumes the

existence of non-linear systems. Here system dis-equilibrium and change is produced internally to the system through feedback loops. These are open systems. The point is that the feedback loop, that is the defining property of non-linear systems, passes through the individual. Individualization now is at the same time system destabilization. Complex systems do not simply reproduce. They change.++ Thus the objectivity of simple-modernity individualism is replaced by the intentionality of knowledge in the second modernity. This intentionality is again at centre stage in *Risk Society*, now tied up with the ecological problematique. Science and industry for all their claims to objectivity, and to being somehow objective and outside of the world, are indeed in the world with own their own proper interest constituted intentionality. The problem here, although it is at the same time its saving grace, is that what is intended leads to the most extraordinary unintendedness, to side effects, to unintended consequences.++ The contemporary individual, Beck never tires of saying, is characterized by choice, where previous generations had no such choices. What Beck often omits to say is that this individual must choose fast, must -- as in a reflex -- make quick decisions. Second-modernity individuals haven't sufficient reflective distance on themselves to construct linear and narrative biographies. They must be content, as Ronald Hitzler has noted, with *Bastelbiographen*, with bricolagebiographies in Levi-Strauss's sense. The non-linear individual may wish to be reflective but has neither the time nor the space to reflect. He is a combinard (dodger, artificioso, engañoso). He puts together networks, constructs alliances, makes deals++ What is happening however is not just an outsourcing but also an insourcing. Anthony Giddens of course has always been well aware of this. A number of properties, functions and activities previously attributable to the nation-state, the welfare state, the hierarchical firm, the family, and the centralized trade union have been otherwise located. Some of them have been extensively displaced onto global instances, while others have been intensively displaced, onto the individual, to conscious or unconscious subjectivity: in any sense more private instances. Even the shift of activities onto small forms have been such an intensification. Today's start-ups -- not so much the dot.coms, but patent-generating technology firms and copyright-generating new media firms, have very private, personal and intense characteristics. They are not so to speak paternalistic as they were in the bygone days, not the least because women now run a number of them. It has to do with the fact that so many of the employees are freelance and subcontractors and hence eminently individualize.++VIP: Thus we have globalization, on the one hand, paralleled by individualization on the other -- both as the constitutive features of the second modernity++

Zygmunt Bauman: To put it in a nutshell, `individualization' consists in transforming human `identity' from a `given'

into a `task' -- and charging the actors with the responsibility for performing that task and for the consequences (also the side-effects) of their performance: in other words, it consists in establishing a *de jure* autonomy (although not necessarily a *de facto* one).+++ Let there be no mistake: now, as before, individualization is a fate, not a choice; in the land of individual freedom of choice, the option to escape individualization and to refuse participation in the individualizing game is emphatically *not* on the agenda+++ People endowed with fewer resources, and thus with less choice, had to compensate for their individual weakness by the `power of numbers' -- by closing ranks and engaging in collective action. As Claus Offe pointed out, collective, class-oriented action came to those lower down the social ladder as `naturally' and `matter-of-factly' as individual pursuit of their life-goals came to their employers+++

Prologue from the authors:

The ideological notion of the self-sufficient individual ultimately implies the disappearance of any sense of mutual obligation -- which is why neoliberalism inevitably threatens the welfare state. A sociological understanding of *Individualisierung* is thus intimately bound up with the question of how individuals can demystify this false image of autarky. It is not freedom of choice, but insight into the fundamental incompleteness of the self, which is at the core of individual and political freedom in the second modernity.++ To put it in a nutshell -- individualization is becoming *the social structure of second modern society itself.* Institutionalized individualism is no longer Talcott Parsons' idea of linear self-reproducing systems; it means the paradox of an `individualizing structure' as a non-linear, open-ended, highly ambivalent, ongoing process++

Chapter 1:

To summarize our basic idea: if highly individualized societies can be bound together at all, it is only, first, through a clear understanding of precisely this situation and second, if people can be successfully mobilized and motivated for the challenges present at the centre of their lives (unemployment, destruction of nature etc.).++ Where the old sociality is `evaporating', society must be reinvented. Integration therefore becomes possible if no attempt is made to arrest and push back the breakout of individuals. It can happen if we make conscious use of this situation and try to forge new, politically open, creative forms of bond and alliance. The question of whether we still have the strength, the imagination -- and the time -- for this `invention of the political' (Beck, 1993) is, to be sure, a matter of life and death.++ We live in an age in which the social order of the national state, class, ethnicity and the traditional family is in decline. The ethic of individual self-fulfilment and achievement is the most powerful current in modern society. ++ The life of one's own is a reflexive life. Social reflexion -- the processing of contradictory information, dialogue, negotiation, compromise -- is almost synonymous with living one's own life. Active management (and that does seem the right word) is necessary for the conduct of life in a context of conflicting demands and a space of global uncertainty. Self-realization and self-determination are by no means merely individual goals; they are often also public stopgaps, the reverse side of the problems that all partial systems unload onto citizens by suddenly deeming them `mature and responsible'. This compulsion to self-realization, this departure for the foreign continent of the life of one's own, goes hand in hand with integration into worldwide contexts. Something like individual distinctiveness really appears for the first time through the combination of social crises in which individuals are forced to think, act and live. ++ The decline of values which cultural pessimists are so fond of decrying is in fact opening up the possibility of escape from the creed of `bigger, more, better', in a period that is living beyond its means ecologically and economically. Whereas, in the old value system, the self always had to be subordinated to patterns of collectivity, these new `we' orientations are creating something like a co-operative or altruistic individualism. Thinking of oneself and living for others, once considered a contradiction in terms, is revealed as an internal connection.

**From Dialogos entre Beck y Latour (Tatiana Gomes Rotondaro, 2012):**

++Beck interpreta a *sociedade de risco* como um produto de uma *modernização reflexiva*, na qual a lógica da distribuição de riqueza é progressivamente superposta pela lógica da distribuição de riscos, ou seja, por problemas que atingem a todos indiscriminadamente, ainda que de forma diferenciada, mas dos quais ninguém pode escapar+++ Exatamente por essa característica estaríamos vivenciando um momento no qual não é mais possível falar em outros. Seria o fim dos “*outros*”, enquanto categoria analítica, pois se tratam de riscos que transcendem os limites estabelecidos pelo estado-nação, conforme expressos nas mudanças climáticas globais, com toda sorte de fenômenos que as acompanham como *tsumanis*, furacões, degelo das calotas polares, aumento da temperatura da Terra, bem como os impactos causados, sobretudo pelas novas tecnologias, como a produção de alimentos transgênicos em larga escala sem controle de contaminação, os riscos de catástrofes nucleares, a crise de recursos energéticos, etc. ---apertura antropológica-🡪 formulación de la individualización .

+ estamos diante uma das divergências fundamentais entre Ulrich Beck e Bruno Latour. Enquanto Beck atribui um papel central à agência humana, uma vez que são as *decisões* humanas, com sua intencionalidade, que produzem as incertezas e que também as gerencia, deixando claro aqui o confronto entre projetos políticos diferentes, Latour, irá esvaziar essa ação humana de qualquer conteúdo cognitivo relevante, não reconhecendo a validade de projetos humanos conscientemente e intencionalmente elaborados. Esse tem sido um ponto de sucessivas críticas ao trabalho de Latour, mesmo entre os entusiastas de sua metodologia (Emirbayer; Goodwin, 1994; Pels, Hetherington; Vandenberghe, 2002; Saito, 2011, etc.).++ Contudo, apesar dessa divergência fundamental, não raramente vemos pesquisadores engajados com as preocupações políticas de Beck, mas que continuam buscando fazer uma síntese objetiva da obra dos autores, recorrendo à metodologia proposta pela teoria do ator-rede (ANT), de forma bem pragmática (Saito, 2011)++ vida. Em que pese a conhecida opção de Simmel por se aprofundar nas análises micro, o problema da interação micro-macro por ele proposto ainda não foi superado e de alguma forma e é justamente por esse motivo que alguns cientistas sociais se sentem tentados a buscar a superação da *tragédia da modernidade* através de uma possível síntese Latour-Beck.

===Feedback loops=accounting as a tool = CAM

On feedback loops from M & R 2021🡪: +We argue that feedback loops potentially offer the capacity to assist

individuals in appreciating the repercussions of their own actions toward motivating collective agency while representing

individual engagement in and accountability for the current ‘‘system crises.”++ We argue that feedback loops potentially offer the capacity to assist

individuals in appreciating the repercussions of their own actions toward motivating collective agency while representing

individual engagement in and accountability for the current ‘‘system crises.”++ This leads us to envision an individualized

form of accounting, providing each person with increased awareness of and sensitivity to the complex socio-environmental implications of their actions. ++ More on feedback loops: ++By means of feedback loops, we propose individualized system accountings, assisting individuals in recognizing and appreciating the web of repercussions resulting from their actions, and encouraging individual engagement in and accountability for our current ‘‘system crises.”+

**==**

**Might be useful TO FINISH Section 2:** Based on these ideas, this research proposes an individualized accounting model to empower collective agency for the circularity of the economy, 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). More in detail, it 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; (ii) units of measure: it shifts from monetary units to physical units (CO2) using an estimator based in neural networks; (iii) 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.

**Section. 3. NEW SECtion 3: CAM: Model & Architecture Climate change: the significance of carbon dioxide**

**4. Neural networks and the CO2 accounting estimator**

This section presents the methodology followed for the development of the CO2 accounting estimator. Referring to carbon in the context of the estimator we mean the CO2 equivalent sequestered in an object[[2]](#footnote-2). This paper proposes to use neural networks to accomplish: (i) a method and system called a ‘carbon estimator’ which can detect recognize and classify objects and to calculate their carbon sequestration. (ii) A library of components of the objects so that the costs and implications of the objects is available. (iii) A method of prediction of carbon chain, showing the carbon contributions for an object.

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.

**4.1 Introducing the carbon cost estimator**

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. 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.

**Figure 2**

**4.2 Model Architecture**

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.

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).

**4.3 Example**

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.*

**5. CAM for the operationalization of CE**

Pressure facing societies from planetary boundaries, particularly climate change, makes the connection between individual action and large scale change apparent and critical, but faced with the scale of the problem, individuals may be overwhelmed. There are not always clear actions and behaviours that can be taken by individuals to alleviate the problem. It is necessary to have a clear model of the problem and potential solutions, in detail, so that people can participate and make decisions which reduce carbon footprints and direct carbon use. This paper proposes the consideration of the movement building paradigm and the application of neural networks’ technology to develop the CAM,

Table 1 presents the five conditions of movement building approach applied to the development of the CAM and what is the characteristic of CAM due to the application of each particular condition.

**Table 1.**

The *first* condition is to have a shared vision. In this case, the vision for what issue to address is represented by the framework of the planetary boundaries of climate change (Rockström et al., 2009) and reduction of chain-exiting CO2 (viewed as entropy introduced to the environment surrounding the chain) in carbon accounting chains. Regarding the particular boundary of climate change, human society exports much of its entropy production in the form of CO2 exhaust from directed energy use in transport, power, and production. Life is an entropy generating process at least in the biochemical regime and produces entropy as an energy consuming process (Szilárd, 1929). 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.

The *second* condition in the implementation of planetary boundaries is strategic learning. 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. 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 uses the estimator (section IV) to shift the unit of measurement to the physical value of carbon dioxide required to transform an object along the whole carbon chain. This value is an indicator of contribution to climate change.

The *third* condition is to engage in high leverage activities. Previous decades show a trend of increasing volume of transactions in interactions between humans, machines and NHA, such as artificial intelligence and algorithmic systems in high speed trading (Kirilenko et al., 2017). The proposed solution in this paper is that the CAM applies technology based in neural networks, the estimator, in the implementation of circular economy to help the transformation of products along the supply chain remain within the planetary boundary of climate change. In doing so, the value along the supply chain is not an abstraction of the real flow of goods but is expressed in the physical unit of CO2. The CAM shows the use of a carbon estimator enabling interaction between human and NHAs. The estimator allows CAM to benefit from recursive increase of speed and capacity in the computation of data and therefore engage in high leverage activities.

The *fourth* condition is to foster community engagement. In line with this perspective, the CAM aims to make the carbon estimator an open tool for producers and consumers, together with NGOs, governmental offices, environmental institutions and other involved stakeholders. In this sense, it aims to empower consumers and other stakeholders to be part of the information process and not only passive users. These aims are pursued in the EU Green Deal (European Commission, 2019) driving the transition to a low-carbon and green economy.

The *fifth* condition is to enable containers for change. This paper argues that CAM aims to foster a cross-disciplinary collaboration attending to the need of overcoming deficiencies in eco-literacy and accounting. This study is the result of the collaboration between sustainability accounting and physics, applying insights from social movement research (the movement building approach) in the development of CAM.

Figure 3 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 3.**

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.

**6. 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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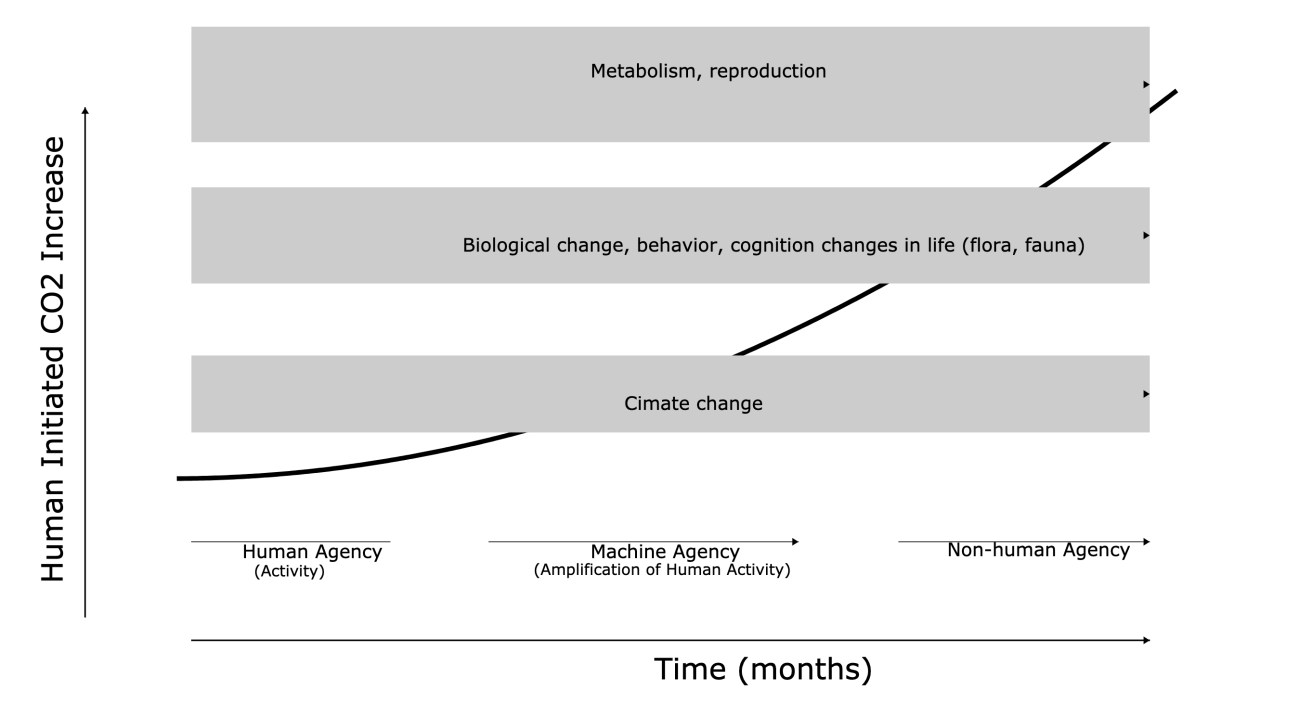
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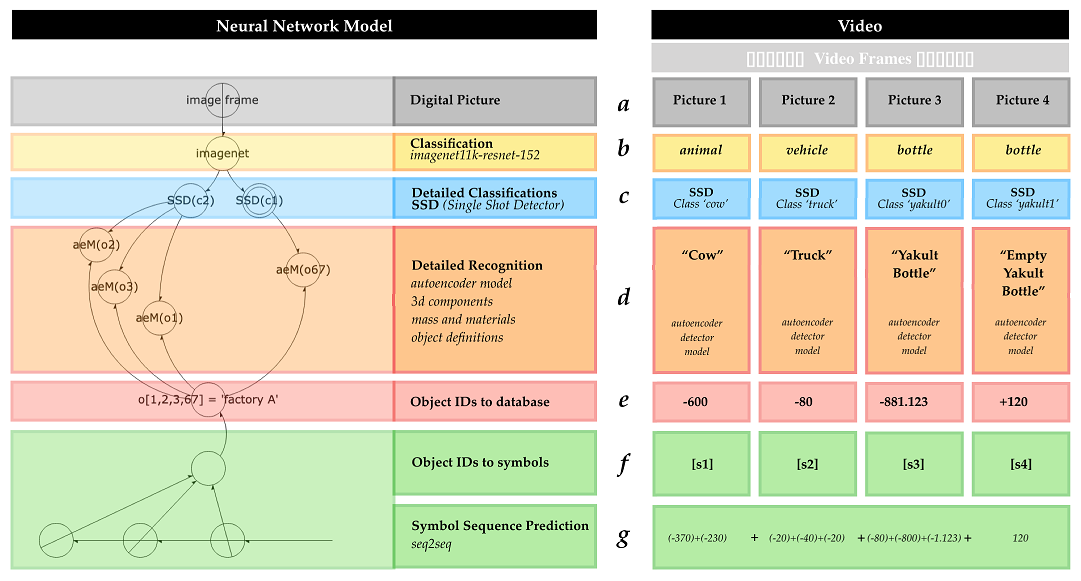
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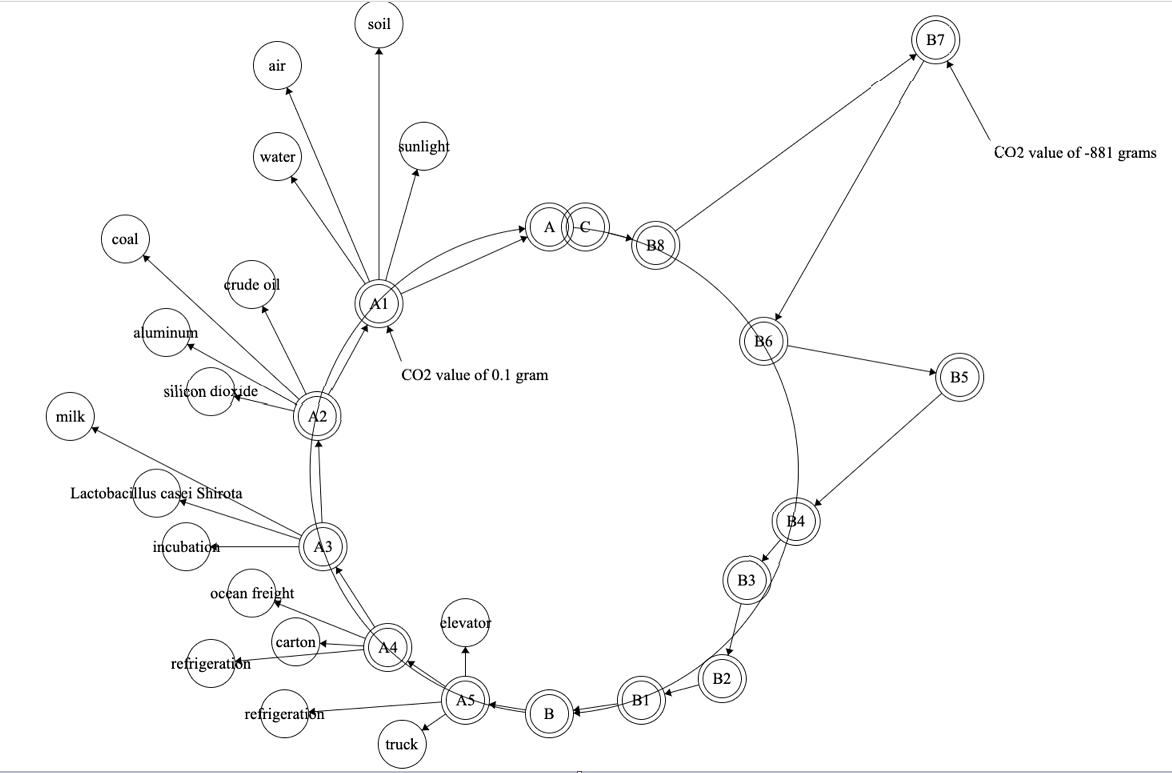
**Figure 1.** **Eras of dominant agency**. Eras plotted with CO2 emission levels and boundaries.



**Figure 2. Model Architecture.**

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**Figure 3. Circularity accounting model.**  *Schain* is apparent in the variance from circularity.

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**Table 1-Conditions of movement building approach applied to CAM\***

|  |  |  |  |
| --- | --- | --- | --- |
| **Code** | **Conditions of movement building (A)** | **Application of (A) in the development of CAM (B)** | **CAM shifts from traditional accounting due to (B)** |
| **1** | Shared vision and aspiration | Planetary boundaries and implementation of CE | Capital to maintain: CAM is focused on the maintenance of natural capital instead of economic capital measured in monetary units. |
| **2** | Strategic Learning | Resistance to the expansion of market rules to the environment | Unit of measurement: CAM uses CO2 instead of monetary units. Accounting entity: CAM considers sustainability control and CO2 emission/sequestration across the whole carbon chain of the product. |
| **3** | High leverage activities | The recursive increase in the speed of agency | Acknowledgement of the interaction of human and NHA |
| **4** | Authentic community engagement | Multiple stakeholders, particularly consumers, are empowerment. | Consumers are not only users of information but also become producers of information. CAM allows for open information feedback. |
| **5** | Containers for change | Further development of circularity accounting | CAM is cross-disciplinary in nature and acknowledges that sustainability issues cannot be solved by one single discipline in isolation. |

\*Own work adapted from Cabaj and Weaver, 2016

1. Assuming a circular economy is not possible in practice, the CAM provides a measurement of the distance of supply-disposal chains from circularity. This measurement of the level of circularity can inform a process of engineering better “circularity” to be more sustainable. [↑](#footnote-ref-1)
2. The terminology *object*, and *economic object* is used as appropriate for the context, where object is a collection of features linked physically or though software, product is an object that has the purpose of entering economic exchange, and economic object is equivalent to *product*. Conceptually an object may be a bound region of space or an environmental feature set like a forest or an ice sheet. [↑](#footnote-ref-2)