Total Resource Accounting for the Circular Economy

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1 Background

The desired global transition towards a green economy requires a circular economy where natural and synthetic resources are carefully being kept track of so as to provide trustworthy information not only about their direct identification via (natural light) images, DNA, spectography, touch-sensing and experimentation/use machine works when turned on, coffee tastes like coffee when brewed, but also about their *provenance*.

Provenance encompasses the complete history of materials: what they are made of, how, when and by whom they were produced; what, in turn, the provenance of the raw materials, ingredients, energy, machinery is that was used in their production; where and when they were transported; when, where and how they and their components were identified and tested; when, where and between whom their ownership and possession was transferred and in exchange for how much money (or other resources).

Trustworthy provenance information is crucial facilitator for a circular economy for multiple reasons:

- Production and transportation information about ingredients and ingredients of ingredients provides "historical" information about a resource that permits modeling and calculating the ecological effects and externalities throughout their entire lifecycle, such as how much clean water has been used, toxic sewage produced, CO_2 released from the particular energy sources used.

- Provenance information can be orthogonally combined with direct physical observations and tests to more reliably and correctly identify materials; for example, by connecting (unique or nonunique) QR-codes, markers or (cell phone or specialized equipment) images with a database of materials that match these markers and then selecting those that are more plausible based on their history (e.g. a piece of plastic that was recently observed/scanned nearby is more plausible to be the plastic at hand than another piece of plastic that matches the physical characteristics of the test equally well, but has recently been observed/scanned in another country).

- Provenance in the form of ownership transfers couples the forward flow of materials from "raw" materials to "finished"[1] to finished goods gocircular to with the corresponding reverse flow of payments, which can provide transparency about what producers and transporters along the supply chain are paid and thus whether their actions in reality abide by the environmental, social and governance (ESG) policies they declare.

- Provenance information of in-progress production and transportation can be used to inform, control and optimize both production and transportation, so as to optimize monetary, energy and environmental costs. Rendering this information as data brings the modern gamut of analysis and optimization techniques into play: econometrics, control theory, stochastic simulation, deep learning and other machine learning techniques, Bayesian inference, probabilistic programming and their combinations. A fundamental prerequisite for all of them is having data, preferably massive amounts of them.

- Ensuring that certified resources leaving a plant, region or country require, at a minimum, the same amount[2] of environmentally certified inputs, which in turn pushes demand for environmentally certified materials downstream along a supply chain.

In a democratically regulated, liberal free-market society, achieving the above requires

- Total resource accounting: Digital twins of production and transportation processes including the types and amounts of certified resources they require. Digital twins and the production processes they model are under the control of a single economic agent (company).

- Decentralization: Distributed computer networks and protocols for the secure, direct and privacy-preserving exchange of information between independent economic agents.

The decentralization requirement reflects the idealized working assumption in a liberal free-market economy that economic agents are not subject to inherent information asymmetries, such as a private or government network operator with a dominant cloud computing system and/or commerce and/or financial payment platform that effectively intercepts, mediates and controls information and digital resource exchanges between the other economic agents, withtout sharing that information publicly.

[1] Note that in a circular economy nothing is neither "raw" and pops into existence out of nowhere nor "finished" and magically disappears from existence.

[2] "Amount" can be mass, energy or other units of measurement. Algebraic resource accounting works for any kind and guarantees that resources can only be lost, not gained out of thin air, analogous to the first and second laws of thermodynamics.

2 Objectives

This project is a two-person MS thesis project in computer science, performed ideally in collaboration or synchronized with domain specialists in relevant materials and their production processes; alternatively, the project can be performed without such collaboration by simulation and making explicit assumptions about natural or synthetic materials and their processes.[3]

The overall objective of this project are to design, implement and evaluate a model of *total resource accounting* for natural and synthetic resources such as food, plastics or textiles, based on the discrete event-based REALISTIC modeling method [BDH$^+$21] and algebraic resource accounting [TG20] for business and physical processes.

Note that the notion of processes encompasses not only conventional production steps where certain materials are transformed into other materials using certain forms and amounts of energy, equipment and employees, but also packing (which includes throwing away/throwing together), unpacking (which includes sorting through garbage/refuse), identifying/testing (a machine or human asserting that something has , e.g. a shirt is identified to have 80% cotton and 20% polyester as asserted by a label, by a physical analysis of the materials or by a machine learning-driven image analysis), transporting from one place to another, losing materials (but never adding materials out of thin air) by friction, loss, theft or just for unaccounted reasons.

Decentralization, privacy protection, confidential information and resource exchange and information symmetry between agents are *not* objectives of this project, even though they are bound to be critical for achieving a network effect without concentrating its payoff in a single or few actors. The reason for this is to first explore what can *ideally* be modeled and computed from transactional data (events) before restricting an *Odin view* of everything to agent-specific views of this information that each agent has legitimate access to.

3 Learning objectives

Specific project and learning objectives are:

- designing and implementing a generic client/server-based framework for modeling and expressing resources, events, agents, locations, information, strategies (algorithms), time, identifiers and contracts for production and transportation processes;
- identify resources such as food, textiles, plastics of relevance for facilitating a green transition that have deep supply networks involving many independent economic agents;

[3]The chosen assumptions are to serve as examples of assumptions rather than being hardwired to demonstrate that the model is sufficiently generic that it can be adapted to assumptions/models provided by domain specialists.

- modeling (and thus, via the framework, implement as a digital twin) a designated set of relevant processes in the life cycle of the identified resources;
- specify multiple models for computing the environmental impact of produced resources from the provenance of a material (events) and varying functional assumptions about their properties (e.g. that consuming 1 kWh of electricity causes emission of 1 kg of CO_2 into the atomsphere if produced from a coal plant or that 1 kg of wood in a new forest binds 1.7 kg of CO_2 from the atmosphere);
- implementing a responsive web-app demonstrating for registering events, scanning physical resources (food, textiles, plastics, e.g. via QR-codes or other labels serving as mechanisms for linking physical resources via physical tags/identifiers/images to their digital twins), and providing model- and event-based computed environmental impact;
- evaluating the suitability of REALISTIC as a system design ontology for economic actors, in particular plant operators, in the circular economy;
- discussing REALISTIC as a general ontology and methodology for modeling, formalizing, designing and implementing business and production systems in general;
- presenting the findings of the project as coherent analysis, design, implementation, testing, evaluation and discussion following good principles for software development and communicating computer science [Zob14].

References

[BDH+21] Simon L. Bager, Boris Düdder, Fritz Henglein, Juan-Manuel Herbert, and Haiqin Wu. Event-based supply chain network modeling: Blockchain for good coffee. *Submitted to Blockchain for Good*, December 2021.

[TG20] Juan-Manuel Torres Garcia. Algebraic resource accounting for transfers and transformations. Master's thesis in computer science, Department of Computer Science, University of Copenhagen (DIKU), September 2020.

[Zob14] Justin Zobel. *Writing for Computer Science*. Springer-Verlag London, 2014.