CREATE

Centre de Recherche en économie de l'Environnement, de l'Agroalimentaire, des Transports et de l'Énergie

Center for Research on the economics of the Environment, Agri-food, Transports and Energy

A METHODOLOGICAL APPROACH TO DESIGN CIRCULAR ECONOMY (CE) INDICATORS IN AGRICULTURE

Roger Rukundo[1*]
Stéphane Bergeron[1]
Ibrahima Bocoum[1]
Nathan Pelletier[2]
Maurice Doyon[1]

Cahier de recherché / Working Paper 2020-02

Octobre / October 2020

[1] Department of Agricultural Economics and Consumer Science, Laval University, Quebec City, 2425, rue de l'Agriculture, G1V 0A6 Quebec (Quebec), Canada. E-mails: roger.rukundo.1@ulaval.ca, stephane.bergeron.4@ulaval.ca, Ibrahima.Bocoum@fsaa.ulaval.ca, npelleti@mail.ubc.ca, Maurice.Doyon@eac.ulaval.ca
[2] Department of Biology, Irving K. Barber Faculty of Science, University of British Columbia Okanagan,1177 Research Road, Kelowna, BC V1V 1V7, Canada
*Correspondence: roger.rukundo.1@ulaval.ca ; Tel.: +1 418-571-8312

Les cahiers de recherche du CREATE ne font pas l'objet d'un processus d'évaluation par les pairs / CREATE working papers do not undergo a peer review process.

ISSN 1927-5544

A METHODOLOGICAL APPROACH TO DESIGN CIRCULAR ECONOMY (CE) INDICATORS IN AGRICULTURE

Roger Rukundo[1*], Stéphane Bergeron[1], Ibrahima Bocoum[1], Nathan Pelletier[2], Maurice Doyon[1]

[1] Department of Agricultural Economics and Consumer Science, Laval University, Quebec City, 2425, rue de l'Agriculture, G1V 0A6 Quebec (Quebec), Canada. E-mails: roger.rukundo.1@ulaval.ca, stephane.bergeron.4@ulaval.ca, Ibrahima.Bocoum@fsaa.ulaval.ca, npelleti@mail.ubc.ca, Maurice.Doyon@eac.ulaval.ca

[2] Department of Biology, Irving K. Barber Faculty of Science, University of British Columbia Okanagan,1177 Research Road, Kelowna, BC V1V 1V7, Canada

*Correspondence: roger.rukundo.1@ulaval.ca ; Tel.: +1 418-571-8312

Abstract: Analyzing production systems from a circular economy (CE) perspective helps pinpoint interventions to reduce the ecological footprint by reducing the use of resources, waste recovery, prolonged usage of products, recycling and reuse. Few studies exist on the measurement of the CE at the micro-level. Also, available metrics propose indicators that study only certain aspects of the CE's socio-economic metabolism leaving other important components of the CE concept. Other frameworks propose a single indicator that aggregates and summarizes several facets of the CE into a one-dimension information. These frameworks are limiting since no single existing indicator encompasses all the requirements of the CE paradigm. This study develops a structured methodological approach and an analytical framework for designing indicators to holistically assess CE at the micro (unit of production) level in agriculture. The approach proposed is based on a literature review, the ECOGRAI[1] method for indicator development and on validation methods with experts and final users. The proposed methodology is applied to a case study of egg production in Canada. For this case, 25 performance indicators (PIs) were generated for 11 decision variables selected as important for the sector, and the whole resulted to a practical tool which proposes fourteen (14) concrete actions of intervention to improve economic circularity (EC) within egg farms. Not all PIs will be evaluated in the same standard for all farms: a trade-offs analysis (using decision trees for example) may help judging the best practices according to the specific environment of the farm. Our methodological approach could be replicated to identify EC performance of other agricultural sectors.

Key words: Circular economy, methodology, indicators design, agriculture

---

0. Introduction

The Circular economy (CE) model of production offers opportunities to reduce the ecological footprint by reducing the use of resources and increasing waste recovery. It is a sustainable response to the organizational problems of the standard linear model which consists in extracting, producing, consuming and throwing away (Aurez et al., 2016; Ducq et al., 2003; EMF et al., 2015; Justyna, 2016; Le Moigne, 2014; Ross-Carré, 2016; Sauvé, Normandin, et al., 2016). The uniting and synthetized definition of the CE is given by Kirchherr et al. (2017) who reviewed 114 CE definitions which were coded on 17 dimensions. They define it (CE) as:

> "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic

---

[1] Developed in France (University of Bordeaux), this acronym stands for (in French): **ECO**: Economy, **GRAI**: Groupe de Recherche en Automatisation Intégrée *(Research Group for Integrated Automation)* (Doumeingts et al., 1995).

prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers” (Kirchherr et al., 2017, p. 229).

The transition to a circular economy happens in parallel to already ongoing efforts under the umbrella of sustainable development (SD), including resource efficiency, supply chain management, critical raw material risk mitigation, and more (Pauliuk, 2018). While sustainable development (SD)[2] (Brundtland, 1987), is a much broader concept than CE (Le Moigne, 2014), CE may be considered as a promising framework towards attaining SD objectives (Diesendorf, 2000; Geng & Doberstein, 2010; Ghisellini et al., 2016; Sauvé, Bernard, et al., 2016). In that perspective, the recent goal of the European Commission to close material loops and develop the European economy towards a more circular system reflects the insight that a more CE is an important requirement for achieving the overall sustainability objective (European Commission, 2015b; Geissdoerfer et al., 2017). This view is also supported by countries like Canada, China, Japan, USA and organisations such as the OECD and the United Nations (OECD, 2015; Parchomenko et al., 2019).

To facilitate the transition to CE, industries need not only a clear vision of the different CE options, but also indicators and targets to monitor progress towards its objectives (Saidani et al., 2019). Despite efforts to make the transition from a linear economy towards a more CE, there is no accepted monitoring framework to assess progress towards a CE (European Commission, 2015a; Smol et al., 2017). Moreover, common practice is to study only certain aspects of the CE’s socio-economic metabolism such as waste disposal and recycling efficiency, even though the CE concept requires inherently a systems perspective For example, the European Commission (2015) states on resource efficiency, which is most frequently understood as producing more output from less input, that the existing metrics miss the main goal of the CE, which is to maintain the value of products, parts, and materials over a maximum period of time (European Commission, 2015a). Therefore, pure resource efficiency metrics do not necessarily track progress to a more CE, because their main aim is not the cyclic use of materials and products, but a reduced resource consumption (Bocken et al., 2016).

The lack of systemic assessment of CE by the available metrics is also highlighted by Parchomenko et al. (2019) and Saidani et al. (2019). Parchomenko et al. (2019), analyzing how the 63 CE metrics and 24 features relevant to CE, such as recycling efficiency, longevity and stock availability, are associated and related each other, found poor integration of resource-efficiency and product-centric perspectives, while the product-centric and system-dynamic perspectives are least frequently assessed. They also showed that only a few CE metrics assess CE features that are related to the maintenance of value (Parchomenko et al., 2019).

The unavailability of adequate indicators to holistically measure the CE at the micro scale is found as a major obstacle to its application (EMF et al., 2015; Pauliuk, 2018). Elia et al. (2017) analyzed fourteen environmental assessment methodologies of products, services and processes, in relation to their ability to accurately and comparably measure different CE objectives (reduction of inputs and use of natural resources, increasing the share of renewable or recyclable resources used, reducing emissions, reducing losses of valuable resources, increasing the sustainability of product value). They concluded that none of these methodologies satisfactorily meet all of these objectives (Elia et al., 2017).

On the other hand, the agricultural sector offers a lot of opportunities to move towards greater sustainability because of the considerable size of wastes generated throughout the agri-food supply chain (Borrello et al., 2016). However, developing suitable indicators to monitor this progress faces many challenges, especially at farm level, one of which being identifying an appropriate conceptual framework (Repar et al., 2017). Furthermore, while the literature is very abundant on environmental and economic sustainability of farms, there is a considerable lack of exhaustive approaches able to evaluate the social dimension of sustainability (Gaviglio et al., 2016). Finally, although the literature offers many indicators at the farm level, few publications address their development and applicability (Bonisoli et al., 2018; De Olde et al., 2016).

[2] **Sustainable development** is defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs” (Brundtland, 1987, p. 37).

The literature on CE is an interesting starting point for strengthening sustainability indicators for agricultural farms, because it considers the three pillars of sustainability and also because of the immanent characteristics of agricultural activities - the use of biological cycles and the wide range of possibilities for bio-waste to become inputs for new production (Justyna, 2016). Positive impacts (economic, social, ecological and on biodiversity) generated by the adoption of CE strategies can be and are often well described. However, while we know that CE indicators are an important tool to monitor the adoption of circularity strategies, no such indicators exist to monitor progress achieved in applying CE principles and strategies in the agricultural sector.

This paper develops CE indicators to monitor the implementation of more sustainable practices at the farm level in agriculture. Specifically, this study aims at (i) proposing a methodological approach to design CE indicators as well as steps to test and validate them using inputs from stakeholders and environmental scientists; (ii) to aggregate indicators in actions that can be taken at the farm level.

To illustrate the use of the methodology, it is applied to egg production in Canada. This sector is of interest due to its short value chain, its profitability and its capacity for innovation (Tamini et al., 2016). Additionally, egg production incurs roughly 60% of energy, greenhouse gas and nutrient emissions of the complete egg supply chain (Pelletier et al., 2018).

The section 1 of the chapter I reviews relevant literature on measurement of CE and proposes an analytical framework for systemic assessment of CE at the unit of production level. In the section 2 of the same chapter (I), the methodological approach for CE indicators is developed and it is illustrated through an application to a case study: egg production sector. Then come chapter II and III respectively dedicated to results and discussion. The last chapter concludes.

I. Materials and Methods

I.1. Literature review method and identification of relevant materials and resources

The research method employed is a systematic and extended literature review. The identification of relevant literature for various chapters of this article was done with the search of literature reviews on the CE measurement, methods of indicators design and methods of scientific validation via Web of Science and Google Scholar, using different combinations of key search words in title, abstract and keywords fields. Academic and non-academic have been identified and used: peer-reviewed journals articles or conferences papers and grey literature. Indeed, in addition to academic literature, complementary sources (e.g. reports, policy and guidelines communications) were consulted to widely cover the existing knowledge on the subject.

I.2. Analytical frameworks of CE measurement at micro (unit of production) level

Measuring CE at micro level is recent. The EASAC (2016) underlined that many available indicators may be appropriate for monitoring progress towards a CE and grouped them into sustainable development, environment, material flow analysis, societal behavior, organizational behavior and economic performance. Yet, only macro-level indicators were considered and other aspects, such as product circularity performance, were not directly considered in these indicators (EASAC, 2016).

Despite these progress at the micro level, Geng et al. (2012) and Elia et al. (2017) have called "for further research about more effective CE strategies evaluation". In fact, from the existing framework, over 60% of available metrics propose a single indicator that aggregates the circularity performance at the micro scale, summarizing therefore several facets of the CE into a one-dimension information (Cayzer et al., 2017). However, there is no existing standardized method to aggregate the performances of all the CE loops into a single indicator (Elia et al., 2017). These authors add: "no single existing indicator encompasses all the requirements of the CE paradigm. To them, "focusing on one single dimension of the CE (e.g. resource use) represents a limitation in the assessment of CE models, leaving other important factors, such as emissions and energy use". Only few of the CE indicators attempt to provide a more holistic approach taking into account both intrinsic circularity and the effects of this circularity e.g. on the three pillars of sustainable development (Elia et al., 2017; Singh et al., 2012). On this basis, coupled approaches mixing several CE indicators appear as a solution for an augmented measurement of the circularity (EMF et al., 2015; Figge et al., 2018; Pauliuk, 2018). Figge et al. (2018) encourage the combination between circularity measures and life cycle sustainability indicators. The analytical framework to be developed for our study will be constructed in the light of these recommendations.

Ellen MacArthur Foundation (EMF[3]) and its collaborators (2015) identified four main categories to consider for economic circularity assessment (CECA[4]) (EMF et al., 2015): (1) resource productivity; (2) circular activities; (3) waste production & reduction; and (4) energy & greenhouse gas emissions.

The British Standards Institution: BSI[5] (2017) was the first normative framework for designing CE indicators at the unit of production level (Pauliuk, 2018). This framework defines indicators with the 5 following economic circularity (EC) objectives: (i) restore, (ii) regenerate, (iii) maintain the utility, (iv) maintain financial value and (v) maintain nonfinancial value (BSI, 2017).

Pauliuk (2018), indicates that BSI framework focuses mainly on circular activities and waste production & reduction and proposed an analytical framework that includes broader categories such as: (a) resource efficiency; (b) environment; (c) energy and (d) stock & sufficiency (Pauliuk, 2018).

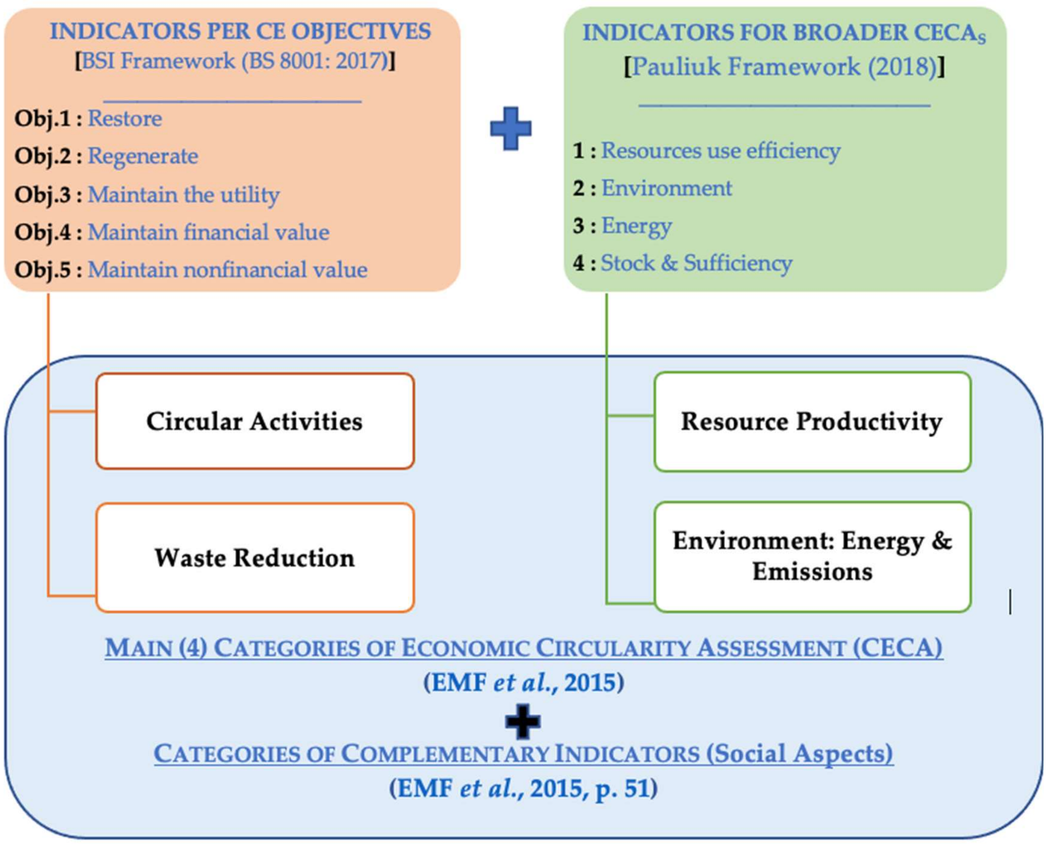
For our part, it seems rather appropriate to combine the two frameworks: BSI (2017) and Pauliuk (2018). This, for two main reasons: (i) circular activities and waste production & reducing, are, as explained in previous sections of this paper, very important for the agricultural sector; (ii) it is only this combination that would allow to cover the four main categories of economic circularity assessment (CECA) as identified and recommended by the Ellen MacArthur Foundation and collaborators (EMF et al., 2015).

To facilitate the assessment of the EC in all its components, the EMF et *al*. (2015) recommend adding to the four (4) CECAs, a *"category of complementary indicators"* that are to be chosen depending on the productive sector. A set of 45 parameters that can be considered for this category is proposed (EMF et al., 2015, p. 51). We select 7 of the most relevant and important for the agricultural sector in view of the definition and components of CE: *(a) economic performance, (b) indirect economic impacts, (c) employment, (d) occupational health and safety, (e) supplier assessment for impacts on Society (includes procurement practices & policy), (f) effluent management and (g) biodiversity (plant protection and animal welfare)*. These parameters are identified as to the best of our knowledge: i.e. there is no established method which could be readily used to precisely target and choose specific parameters for a given sector of production. However, the scientific validation should lead us to keeping the most relevant for our sector of interest.

Figure 1 presents the analytical framework we propose for economic circularity assessment in the agricultural sector.

[3] **EMF**: The Ellen MacArthur Foundation
[4] **CECA**: Categories of Economic Circularity Assessment
[5] **BSI**: British Standards Institution

***Figure 1**: Analytical framework for CE indicators design at the unit of production level*



CE: Circular Economy, **CECA**: Categories of Economic Circularity Assessment, **BSI**: British Standards Institution

Source: Authors (2020).

Our analytical framework for CE assessment is more comprehensive and adds CE features that are not covered by other available frameworks such that of Wisse (2016) and Akerman (2016). A more detailed discussion on the advantages of our framework is done in chapter III (Discussion). Also, there are other indicator frameworks, such as 4Agro (Bertocchi et al., 2016) and IDEA (Briquel et al., 2001; Vilain, 2008). But, these frameworks are mostly useful for integrated farms, and are not suitable for inspiring the design of circularity indicators for agricultural sectors with highly specialized farms (Vilain et al., 2013).

I.2. Methodological steps to design CE indicators

First, we present an overview of the phases of the methodological approach and followed by a detailed description of each phase.

I.2.1. Methodological phases

Our approach consists of a methodical suite of development, validation (general, *practical and scientific*) and transformation in actions of CE indicators. This methodological approach is summarized in Table 1.

Table 1: Summary of the phases of the methodological approach

Phase (s)	Objective (s)	Methods & Tools	Step (expected) results
Indicators Development	Development of CE indicators at the unit of production level using relevant analytical framework & design method	-Selected analytical framework (*BSI, 2017*; *EMF et al., 2015*; *Pauliuk, 2018*) -*ECOGRAI design* method (*Doumeingts et al., 1995*; *Ducq & Vallespir, 2005*; *Ducq et al., 2003*)	A dashboard of theoretical indicators
General Validation	Check the specificity of theoretical indicators for the concerned production sector	-*Focus Group* with representatives of farmers and other key stakeholders -*Interview guide*	Specific theoretical indicators
Practical Validation	Ensure that the indicators are practical enough and that the data needed for their measurement could be easily available for farm managers	-*Reality tests* on farms (with farm managers) -*Directive interview using semi-structured interview*	Tested practical indicators
Scientific Validation	Consultation with experts on prioritization of indicators and trade-offs between specific options	-*DELPHI consultation method* (*Adler & Ziglio, 1996*; *Kuusi & Meyer, 2002*; *Wissema, 1982*) -*DELPHI Questionnaires*	- Validated (*scientifically*) practical indicators - Important variables to be considered for CE improvement & assessment.
Transformation of indicators in actions	Ensure the practicality of final (*selected as important*) indicators for CE measurement	- *Final reality tests* on farms for indicators through actions -*Directive interview (with farm managers) using semi-structured interview*	- Actions associated with indicators to monitor the EC performance of egg farms

CE: Circular economy, **EC**: economic circularity.

Source: Authors (2020).

I.2.2. Methodological Phase 1: Indicators development

The expected result of this phase is a set of theoretical indicators for measuring EC in agriculture. To this end, we use the ECOGRAI[6] method which is a recommended method for performance indicators design (Doumeingts et al., 1995; Ducq & Vallespir, 2005; Ducq et al., 2003) thanks to its originality and controllability (Ducq & Vallespir, 2005).

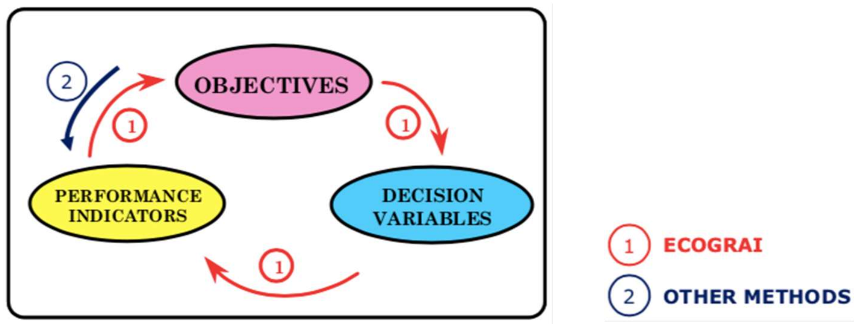
The originality of the ECOGRAI method is not in the definition of performance indicators, but the search of decision variables on which stakeholders can act to reach their objectives (Figure 2). Thus, the core of the method is its controllability principle: it is based on the triplet: Objectives – Decision Variables – Performance Indicators (PI) by a top-down approach for the design and a bottom-up approach for the implementation (Ducq & Vallespir, 2005).

One of the advantages of ECOGRAI method is that it can be used in any production system while offering an original approach to clearly define objectives (Ducq et al., 2003). The ECOGRAI

[6] Developed in France (University of Bordeaux), this acronym stands for (in French): **ECO**: Economy, **GRAI**: Groupe de Recherche en Automatisation Intégrée *(Research Group for Integrated Automation) (Doumeingts et al., 1995).*

method has been used by several researchers to design indicators (Bitton, 1990; Bonvoisin, 2011; Ducq & Vallespir, 2005; Lobna et al., 2013). Labona et al., (2013) applied this method to develop performance indicators of a maintenance process. In Bonvoisin (2011), the method is used to develop performance assessment tools for operating theatres in hospitals. Ducq and Vallespir (2005), who are the designers of the method, applied it to develop definition and aggregation of a performance measurement system in three aeronautical workshops. In Bitton (1990) who used ECOGRAI method to design a steering structure supporting a factory with a high degree of automation.

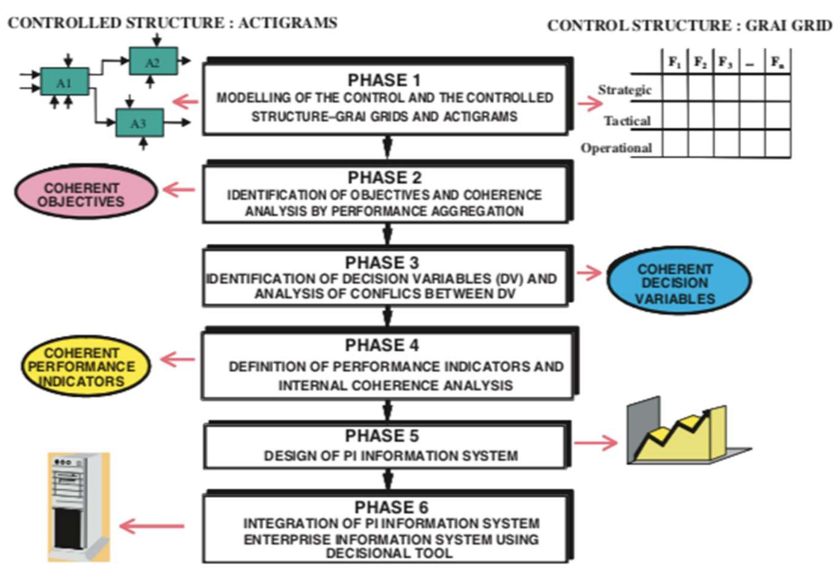
***Figure 2**: The performance controllability principle (originality) of the ECOGRAI approach*



Source: (**Doumeingts et al., 1995**)

The logical structured approach of the method is decomposed into six steps (Ducq & Vallespir, 2005): the first step consists in modeling the control structure (*decision system*) and the controlled structure (*physical transformation system*) of the enterprise or the studied domain. The second and third steps of the method aim at identifying the coherent objectives (*performance to achieve by the controlled activity of the physical system*) and the decision variables to reach this performance. The fourth step consists of identifying the performance indicators, the fifth in designing the information system to build the performance indicators, and the sixth in implementing it inside the enterprise information system. Figure 3 shows the 6 steps followed in the ECOGRAI methodology to design performance indicators.

Figure 3: Six steps of ECOGRAI method of indicators design



Source: (Ducq et al., 2003)

A more detailed description of each step is made along with our empirical example by which we will show how each step has been executed in the development of indicators for the egg production sector.

- Step 1 ECOGRAI: Modeling of the control structures of the physical system

The physical system considered in this study is focused on a farm or unit of production. Specifically, our system is an agricultural production, traditionally done by combining various inputs or raw materials (seed, feed, water, energy, etc.) and other resources such as land, equipment & machinery and labor. Our application will focus on the production of egg (landless) destined to the table egg market. Although the egg processing sector will not be considered in our study (washing and grading), transport to grader will be considered. In summary, our physical system is represented by the circularity of the production process and the activities that take place on or that are related to the farm.

Following this logical frame of the ECOGRAI, the control structure to design CE performance indicators in agriculture will be the CECAs that we developed and that are presented in our analytical framework (Figure 1).

- Step 2 ECOGRAI: Identification of CECA objectives and coherence analysis

This phase aims to identify the objectives of CECA and their coherence (Ducq & Vallespir, 2005). Applying this to the egg production sector and following a top-down approach, we identified first the objective of the whole system and then the objectives of each CECA. The overall objective of our system is to improve the economic circularity of egg production at farm level. A literature review (BSI, 2017; EMF et al., 2015; FAO, 2013; Pauliuk, 2018) made possible the identification of objectives for the four CECA in the egg sector. For egg production, and the same would apply to most agriculture sector, activities of our system are performed in parallel following a precise production scheme (i.e. generalized and decomposition type[7]). Coherence is verified since at least one of activity category is associated with one or more objectives. Table 2 presents the internal coherence that allowed classification of identified circularity objectives by CECA.

***Table 2**: Circularity objectives by Category of Economic Circularity Assessment (CECA)*

CECA:		**Resource Use Efficiency**		**Waste Reduction & Circular Activities**
Circularity OBJECTIVES	**1**	Minimize use of material and inputs	**4**	Maximize rates of materials reuse, recycling and recovery
	2	Minimize global energy consumption	**5**	Prevent waste production
	3	Reduce water consumption and use	**6**	Eliminate and dispose waste in such a way that they don't endanger human health and ecosystems
			7	Minimize food waste
CECA:		**Environment (Energy & Emissions)**		**Complementary Indicators (Social & Biodiversity)**
Circularity OBJECTIVES	**8**	Maximize the use of renewable (sustainable) energy	**12**	Ensure a decent work environment (sanitary facilities, safe and ergonomic work environment, etc.)
	9	Contain GHG emissions	**13**	Support local economy through employment and added value creation

[7] See Ducq and Vallespir, 2005, p. 168 for a complete discussion of decomposition type in the ECOGRAI method.

10	Prevent emissions of pollutants and air contaminants	**14**	Protect animals from hunger, thirst, injury and disease
11	Eliminate ozone-depleting substances	**15**	Keep animals in conditions adapted to their species and without discomfort, pain, fear and distress

Note: For the category (CECA) of complementary indicators, out of 7 aspects deemed relevant and important for the agricultural sector (Cf. Section II), only two aspects have been considered for the studied domain (egg production). They are: Social (occupational health and safety, supplier assessment for impacts on society) and biodiversity (animal welfare) aspects.

Source: Authors (2020) from (BSI, 2017; EMF et al., 2015; FAO, 2013; Pauliuk, 2018)

- Step 3 ECOGRAI: Identification of decision variables

It is necessary but not sufficient to know the objectives to build relevant performance indicators. Therefore, the decision variables corresponding to each objective of the CECA need to be identified. This identification must be interpreted as one of the steps leading to the building of the control triplet {*Objectives/Decision variables/Performance indicators*} (Doumeingts et al., 1995).

Using a more extensive literature (BSI, 2017; EMF et al., 2015; FAO, 2013; Pauliuk, 2018; Pelletier, 2017; Pelletier et al., 2018; Veleva & Ellenbecker, 2001), we have identified 14 decision variables (DV) for the four CECA of the physical system of egg production. These DVs are described in Figure 4.

- Step 4 ECOGRAI: Definition of performance indicators and internal coherence analysis.

This article adopts the OECD (2014) view where an indicator is defined as "a quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor"(OECD, 2014). Therefore, both quantitative and performance qualitative indicators are developed in our study.

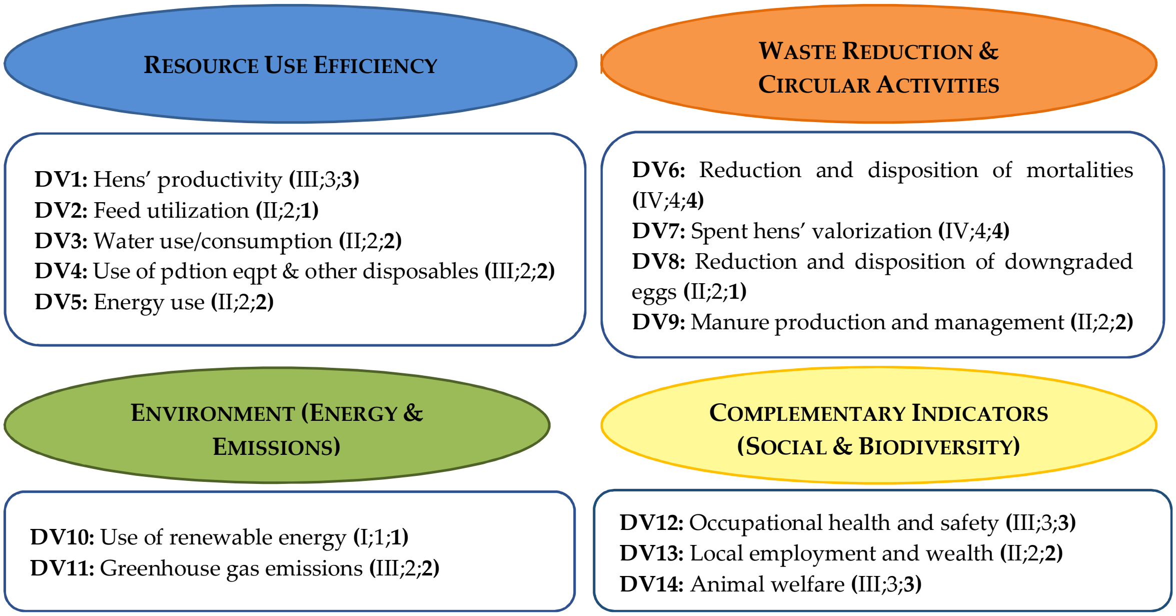
Performance indicators are developed from the DVs that are classified by CECA after controlling for an internal coherence. Using the literature, performance indicators are identified for each DV. A performance indicator is then considered coherent (both with its respective DV and CECA) if it allows measuring the efficiency of an activity or a set of activities deployed in the process of reaching the objective and is influenced by actions on the decision variables (Ducq et al., 2003). In order to verify this, coherence panels are built. These panels provide a pairing of the various links between the elements of the CECA as well as their weight. The links between the CECA elements are classified according to the connection: strong link (**), weak link (*), no link ( ) (Ducq & Vallespir, 2005).

Applying it to egg production, performance indicators have been identified and designed taking into account recommended qualities and characteristics (*S.M.A.R.T. criteria*[8]) for a good indicator (Drucker, 1954). In Figure 4, beside each DV, the number of associated theoretical indicators which have been elaborated based on information taken from relevant literature (Arnsperger & Bourg, 2016; Aurez et al., 2016; BSI, 2017; EMF et al., 2015; FAO, 2013; Ghisellini et al., 2016; Justyna, 2016; Pauliuk, 2018; Pelletier, 2017; Pelletier et al., 2018; Ruiter, 2015; Sauvé, Bernard, et al., 2016; Veleva & Ellenbecker, 2001; Verbeek, 2016) is indicated in parentheses in roman numerals (non-roman numerals represent numbers of indicators that will be discussed later). A total of 36 theoretical indicators have been identified.

---

[8] ***S.M.A.R.T. Criteria*** are: **S** for *Specific* (simple, sensible, significant), **M** for *Measurable* (meaningful, motivating), **A** for *Achievable* (agreed, attainable), **R** for *Relevant* (reasonable, realistic and resourced, results-based), and **T** for *Timeline bound* (time-based, time limited) (Drucker, 1954).

Figure 4: General architecture of CE indicators for egg production (14 decision variables with indicators: theoretical, practical and validated)



Legend:

⬭ : Categories of Economic Circularity Assessment (CECA)

▭ : Set of Decision Variables (DV) for each CECA

( ) : Number of indicators for each Decision Variable (DV)

Source: Authors (2020)

Coherence analysis for the information gathered in Figure 4 with circularity objectives of CECA has been performed using previously explained coherence panels as illustrated in Table 3 for the CECA "Resource Use Efficiency". The panels for the remaining CECA can be found in the *supplementary material S1 (i.e. S1-c and S1-d)*[9]. If we consider the coherence panel, one can remark that all the circularity objectives are related to a performance indicator and that all the decision variables influence at least one indicator.

- Steps 5 and 6 ECOGRAI: Design of performance indicators information systems and their integration inside the enterprise's information system.

ECOGRAI is oriented towards the possible automation of the performance evaluation system. For step 5, two aspects are considered: the data aspect (*which information is necessary?*) and the processing aspect (*the processing that is necessary to build the indicators, starting from basic information*) (Ducq & Vallespir, 2005).

[9] All supplementary materials are available on request to the correspondence author or to CREATE.

Table 3: *Coherence analysis*

CECA : **RESOURCE USE EFFICIENCY**

	Performance Indicators developed for the CECA	Unit of measurement
PI 1	Laying rate	Percentage (%)
PI 2	Duration of the production cycle	Weeks
PI 3	Variability of the duration of the downtime period	Percentage (%)
PI 4	Food conversion rate	Kilogram of feed / kilogram produced egg
PI 5	Quantity of fresh water used	Liters/ton egg produced
PI 6	Share of food that is wasted in farm's operations. Of this percentage, what part is recovered or reused?	Percentage (%)
PI 7	Strategy for responsible wastewater management	Indicator of Good Practices (*IgP*)
PI 8	Cost of production materiel and other disposables	$/dozen eggs produced
PI 9	Share of packaging material used that re made of biodegradable matter	Percentage (%)
PI 10	Total (quantity of) energy used	Kilowatt-hour (kWh)/dozen eggs produced
PI 11	Renewal rate of light production equipment (cages, feeder and waterers, scraping pads, etc.)	Percentage (%)
PI 12	Strategies to reduce energy consumption	Indicator of Good Practices (*IgP*)

COHERENCE PANEL[10]

CE Objectives	**CO 1**	Minimize use of material and inputs	**	**	**	**	*	**	*	**	**	*	**	*
	CO 2	Minimize global energy consumption		*	*							**		**
	CO 3	Reduce water consumption and use		*	*		**		**					
		Performance Indicators	**PI 1**	**PI 2**	**PI 3**	**PI 4**	**PI 5**	**PI 6**	**PI 7**	**PI 8**	**PI 9**	**PI 10**	**PI 11**	**PI 12**
Decision Variables	**DV 1**	Hens' Productivity	**	**	**	**		**						
	DV 2	Feed utilization		*	*	**		**						
	DV 3	Water use/consumption		*	*		**		**					
	DV 4	Use of production equipment & other disposables		*	*					**	**		**	
	DV 5	Energy use		*	*							**		**
	DV 6	Reduction and disposition of mortalities												
	DV 7	Spent hens' valorization												
	DV 8	Reduction and disposition of downgraded eggs												
	DV 9	Manure production and management												
	DV 10	Use of renewable energy										*		*
	DV 11	Greenhouse gas emissions									*	*	*	*
	DV 12	Occupational health and safety												
	DV 13	Local employment and wealth												
	DV 14	Animal welfare												

[10] The links between the Performance Indicators (PI), Decisions variables (DV) and Circularity Objectives (CO) are marked with (**): **Strong link**, (*): **weak link** and **(blank): no link**

The tool that guides in defining these aspects is the specification sheet for each indicator. It contains: the identification of the indicator, the objectives and the decision variables related to the indicator, the identification of the data required for the implementation of the indicator and how to represent the indicator (Doumeingts et al., 1995).

The last two steps (fifth and sixth) of ECOGRAI method consist in implementing the indicators in the company's information system for automation of the performance evaluation system.

For a study like ours, whose objective is to develop CE types indicators that could be used to monitor the implementation of more sustainable practices (i.e. without integration of these indicators in the farm's information system for an automative evaluation), only the first four steps of the ECOGRAI process will be executed for our empirical case study.

To conclude on phase 1 of our methodological approach (*indicators development*), the application of ECOGRAI method to our analytical framework in egg production led to the identification of 36 coherent theoretical indicators (*roman numerals reported in parentheses beside DVs in Figure 4*).

I.2.3. Methodological phase 2: General validation

Theoretical indicators were presented to a focus group composed of nine egg producers that are on the research committee of a provincial egg board. An interview outline guided the conversation while allowing open discussion.

As a result, some theoretical indicators were revised to better match terms and units used on production sites. Furthermore, we eliminated three theoretical indicators that were determined to be of low value, reducing the number of indicators from 36 to 33 (*Cf. first set of non-roman numerals reported in parentheses beside DVs in Figure 4*).

I.2.4. Methodological phase 3: Practical validation

The practical validation was executed on three egg farms where every element of the indicator (formulation, unit of measurement, etc.) was validated by farm managers. This ensured (1) that selected specific indicators are practical enough and (2) that the data needed to measure them are available at the farm and would be willingly shared. The questionnaires at this phase was specific, as researchers already narrowed down the typed of information needed in the previous phase.

This phase resulted in the removal of one (1) indicator because it was non-practical. Also, other indicators were reformulated to be easier to understand by farm managers. In sum, this phase led to a set of 32 indicators (*Cf. last non-roman numerals reported in parentheses beside DVs in Figure 4*).

I.2.5. Methodological phase 4: Scientific validation

The DELPHI method is a structured and interactive process aimed at gathering the opinions or knowledge of a group of experts on a specific topic (Adler & Ziglio, 1996). This method is known to be efficient to validate new concepts for which the academic literature provides insufficient guidance, as is the case for the measurement of CE at the farm level. The DELPHI process consults a group of experts that are anonymous to each other using a questionnaire. After each round of questions, an anonymous summary of the experts' opinion or prediction and their justifications is prepared by the facilitator and returned to the experts, who are encouraged to revise or justify their initial responses in light of information from others. The goal of these iterations is to continue until a certain level of consensus among the experts is reached (Mayer & Ouellet, 1991; Okoli & Pawlowski, 2004). The use of questionnaires avoids interferences of interactive social behavior that may occur in a face-to-face discussion (Wissema, 1982).

For the purpose of this study experts having published in environmental peer reviewed journals on subjects related to circular economy were contacted. The questionnaire consisted of two objectives:

(i) identify the order of priority of the variables to improve economic circularity in the egg production sector, (ii) rank tradeoff between various management options. The DELPHI questionnaire was administered online using LimeSurvey (2019) software. The questionnaire is available *as supplementary material S2.* Sixteen (16) experts were invited (*8 from Europe and 8 from North America*), seven of them agreed to participate. This number, based on the literature (Caffey et al., 2000; Schmidt et al., 2001), is appropriate. Using the final ranking of the experts, 11 DVs (out of 14 DVs assessed) were identified as important for the egg production sector. As per the general architecture of CE indicators for egg production (Figure 4), these 11 DVs are measured through 25 performance indicators. The classification (final ranking) of DVs is presented in detail in chapter II of results.

I.2.6. Methodological phase 5: Transforming indicators into Actions and final test on egg farms

The twenty-five (25) important indicators (for the 11 DVs deemed important for the egg production sector) were transformed into fourteen farm level actions to improve CE. The transition from indicators into Actions was tested on three egg farms in two provinces of Canada (Québec and Ontario).

II. Results

The proposed methodological approach resulted in three main outputs (1) identification of important variables selected for the egg production sector, (2) the ranking of options for better trade-offs, and (3) the way the final indicators could be transformed into actions for a more practical improvements of EC performances.

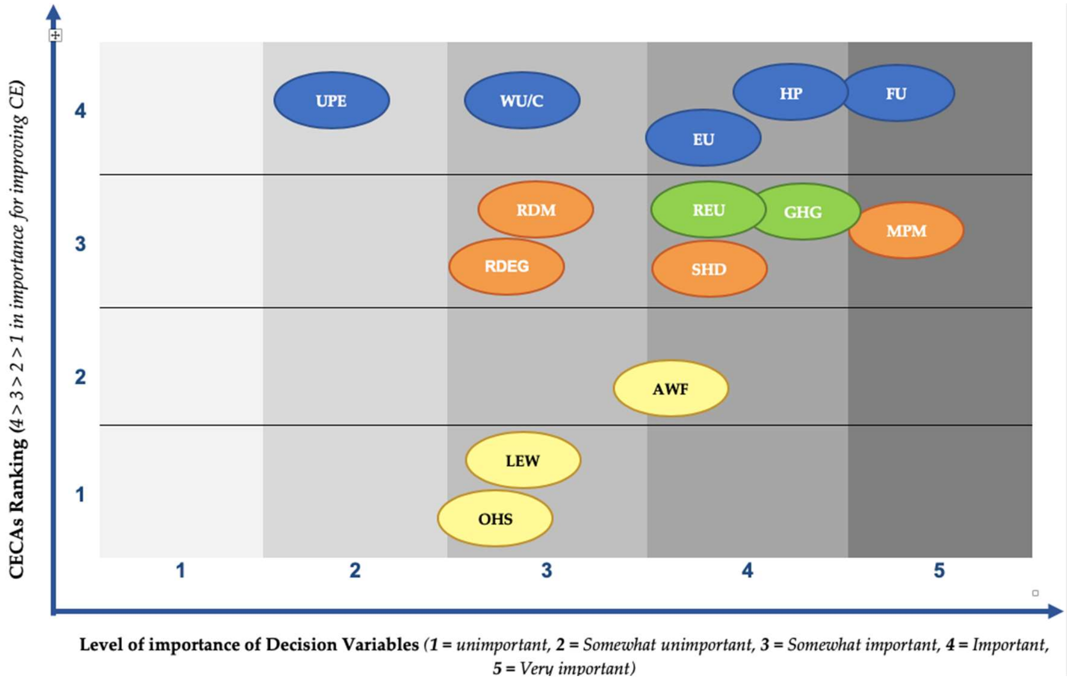
Note, that as the objective of this paper is not centered on the results but rather on the methodological approach that can be used to design CE in a other agricultural sector. The goal is not to present detailed results that apply specifically to the egg sector. The intention is rather to show the application of the methodology and illustrate results that could be carried over to other agricultural sector/production.

II.1. Results of DVs ranking

The experts participating in the DELPHI survey ranked the 14 DVs as well as the 4 CECA by degree of importance (a two-level ranking). Figure 5 illustrates the results with the top-right being the DVs ranked most important. Following this ranking, 3 DVs have been dropped as they were unanimously classified as of lesser importance for the egg production sector. These DVs are: LEW: *Local employment and wealth*, OHS: *occupational health & safety* and UPE: *use of production equipment & other disposables*. Therefore, 11 DVs that are associated with 25 indicators of CE in egg production sector remain as important variables to be controlled by the egg farm aiming to improve the economic circularity of their production model (Cf. Table 5).

Figure 5 shows that *feed utilization (DV_1)* and *manure production & management (DV_2)* are two (2) variables that have been ranked as very important, five (5) other variables: *hens' productivity (DV_3), energy use(DV_4), use of renewable energy(DV_5), GHG emissions prevention(DV_6) and, spent hens' disposition (DV_7)* were ranked as important while *animal welfare (DV_8), water use/consumption(DV_9), reduction and disposition of mortalities (DV_{10}) and reduction & disposition of downgraded eggs (DV_{11})* were ranked as fairly important for circularity in the egg production sector.

***Figure 5**: Matrix of Decision Variable (DV) ranking*



Legend:

Decision Variables for the DC (CECA): RESOURCE USE EFFICIENCY

UPE: Use of production equipment and other disposables; **WU/C:** Water use/consumption; **EU**: Energy use; **FU:** Feed utilization; **HP:** Hen's Productivity

Decision Variables for the DC (CECA): WASTE REDUCTION & CIRCULAR ACTIVITIES

RDM: Reduction and disposition of mortalities; **RDEG**: Reduction and disposition of downgraded eggs; **SHD**: Spent hens' disposition; **MPM**: Manure production and management.

Decision Variables for the DC (CECA): ENVIRONMENT (ENERGY & EMISSIONS)

REU: Renewable energy use; **GHGEP**: Greenhouse Gas emissions (prevention)

Decision Variable for the DC (CECA): COMPLEMENTARY INDICATORS

OHS: Occupational Health and safety; **LEW**: Local Employment and Wealth; **AWF**: Animal Welfare.

Source: Authors (2020)

II.2. Ranking of options for better trade-offs

As previously mentioned, the DELPHI survey was used to ask experts about the ranking of various options for variables with trade-offs consideration. Among the 11 important DVs, those that have been identified as having trade-offs options in egg production are: *Manure use & management, Energy use, Spend hens' disposition, Animal welfare, Reduction and disposition of mortalities*. Table 4 gives an example of the results of options ranking for *energy use* (*DV_4*). The same exercise of options ranking has been performed for all the above-mentionned variables with trade-offs options. Similarly, an example of trade-offs options analysis is shaped and discussed (Cf. Figure 6 in chapter II: Discussion) as from the arguments provided by experts consulted during the DELPHI consultative process.

***Table 4:** Ranking of sources of energy used on farm (egg), from CE perspective*

Rank attributed *1=Best Option or Source, 10=Worst Option or Source*	
Source of energy	**Rank**
Wind	**1**
Hydroelectricity	**2**
Solar	**2**
Geothermal energy	**3**
Biogas	**4**
Biomass	**4**
Natural gas	**6**
Propane	**7**
Other electricity	**8**
Coal based electricity	**9**

Source: Authors (2020) from the DELPHI Survey

II.3. Actions to monitor final (important) CE performance indicators

The last phase of our methodological phase made it possible the transformation of the final (or validated) indicators into Actions that can be taken at the farm level for a better monitoring of EC performances. Of these fourteen Actions, eleven rely on benchmark (B) and are associated with seventeen indicators while the remaining three Actions (associated with ten indicators) rely on decision tree (DT) for better trade-offs analysis. Table 5 presents the fourteen Actions and their relationship with the twenty-five indicators. Figure 6 (in chapter II: Discussion) illustrates an example of one of trade-offs considerations for one Action (with its associated indicator-s) which relies on decision tree.

***Table 5:** Actions (14) to measure the EC on egg farms and their associated indicators (25)*

#	Actions	#	Associated Indicators	Relies on
1	Keep the feed conversion rate lower or equal to 1.71 (2.08) in cage (alternative) systems	**1**	Food conversion rate (*Kg of feed / kg produced egg*)	**B**
2	Maximize hen productivity: targeted laying rate > 92.2% (89.5%) in cage (alternative) systems	**2**	Laying rate (*in %: average for the entire production cycle & for the 51st week of the laying cycle*)	**B**
		3	Variability (*in %*) of timeout between production cycles	**B**
3	Reduce the amount of energy used under 218.4 (367.4) kWh / ton of egg produced in cage (alternative) housing systems (	**4**	Total direct used energy (*kWh/dozen eggs produced*)	**B**
4	Minimize overall energy consumption by adopting zero-energy buildings and LED lighting	**5**	Strategies to reduce energy consumption	**B**
5	Prioritize the use of renewable energy sources that are efficient from the CE perspective	**8**	Share of the total energy used which is from renewable sources (*in %*)	**B**
6	Prevent GHG emissions by reducing the distance traveled for input supply and for product delivery	**6**	Total annual distance *(in km/1000 dozen eggs produced)* done for inputs supply	**B**
		7	Total annual distance (*in km/1000 dozen eggs produced*) done for products and by-products delivery	**B**
7	Keep hens' viability at a higher rate to 97.79% (97.36%) in the cage (alternative) systems	**9**	Hens' viability rate (*100 - mortality rate*)	**B**
8	Ensure that all animals live without disease, pain or stress and in conditions that suit their species	**10**	% of animals living with a good health status without curative treatments (*annual basis)*	**B**
		11	% of animals kept with possibility to exhibit their natural behaviors throughout their life cycle (*annual basis)*	**B**

#	Actions	#	Associated Indicators	Relies on
		12	% of animals living without pain, discomfort or stress throughout their life, including during transport and the slaughter process (*annual basis*)	B
9	Reduce and maintain overall water consumption below 2.4 (2.73) L / ton egg produced in cage (alternative) systems	13	Total (*quantity*) water used (*Liters/ton eggs produced*)	B
10	Preserve water resources by adopting good management practices	14	Strategies for responsible water management	B
11	Ensure the recovery of all unsold eggs (downgraded on farm: approximately 0.9% (0.42%) in cage (alternative) systems	15	Share of unsold eggs that are recovered on farm (*in %*)	B
12	Aim for the best options for manure valorization according to the specific context of the company / farm	16	Share of manure used for soil fertilization (*in %*)	DT
		17	Manure management strategies	
13	Ensure the recovery of all spent hens and mortalities through the best options available depending on the context of the company / farm	18	Share of spent hens valorized through human consumption (*in %*)	DT
		19	Share of spent hens valorized through rendering (*in %*)	
		20	Share of spent hens disposed through composting (*in %*)	
		21	Share of spent hens disposed through incineration and/or landfilling (*in %*)	
		22	Share of mortalities valorized through rendering (*in %*)	
		23	Share of mortalities disposed through composting (*in %*)	
		24	Share of mortalities disposed through incineration and/or landfilling (*in %*)	
14	Maximize hen's production by exploiting the animal stock as long as possible	25	Total duration of the production cycle (*in days*)	DT

Legend: **B** for benchmark; **CE**: circular economy; **DT** for decision tree; **GHG**: Greenhouse gas; **%:** percentage; **LED**: light emitting diode.

III. Discussion

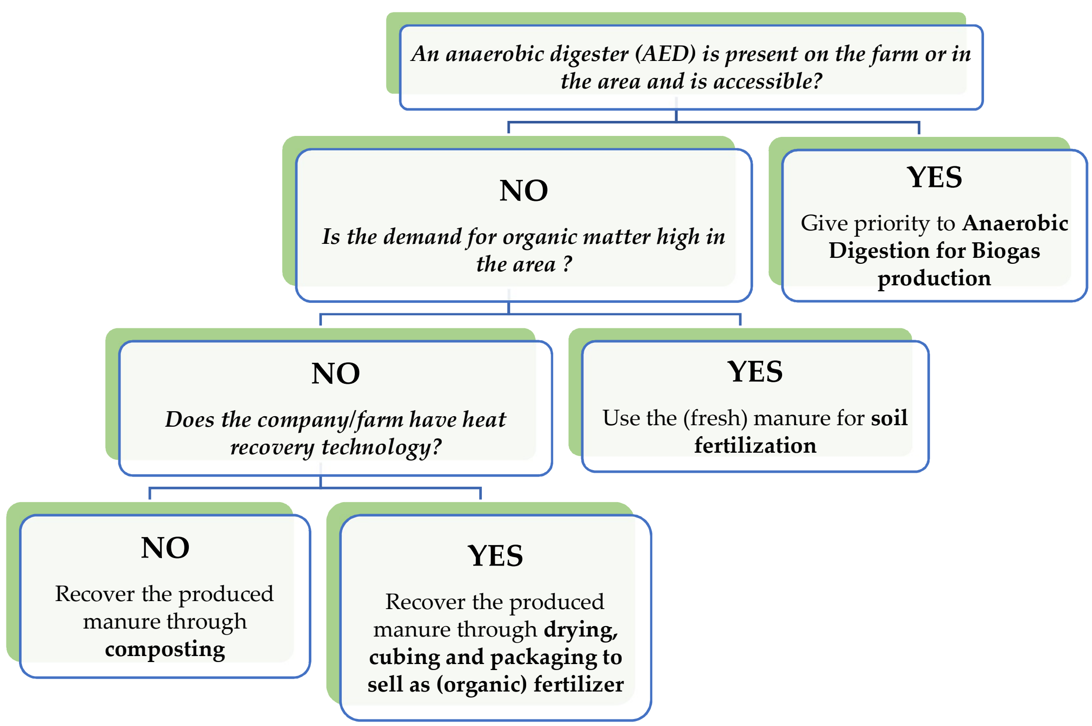
Our analytical framework, being a mix of the three complementary frameworks: EMF et al. 2015; BSI, 2017; and Pauliuk, 2018, makes it possible to cover more CECAs compared to other available frameworks such as that of Wisse (2016) and that developed by Akerman (2016). Wisse (2016) identified three prominent types of frameworks for measuring the CE: (i) material flow accounts; (ii) eco-efficiency indicators; and (iii) hybrid indicators. Reviewing both sustainability and C-indicators, Akerman (2016) established differences between CE core indicators and adapted sustainability indicators. He divided these indicators into five categories: (i) resource productivity; (ii) environmental aspects; (iii) economic opportunities; (iv) social aspects; and (v) waste management.

Compared to the frameworks of Wisse (2016) and Akerman (2016), our framework proposed 5 CECAs: 4 main CECA of CE assessment (as recommended by the Institutions such as the EMF and actors that have been the first ones to work on the conceptualization of CE theory and components) plus a CECA of complementary indicators that cover other aspects deemed important (social & biodiversity), is more comprehensive. Furthermore, our framework, by integrating the areas of CE assessment of the BSI (2017) framework, adds and takes into account CE features that are related to the maintenance of value (financial and non-financial) of products, parts, and materials. This aspect lacks in many available CE metrics as highlighted by Parchomenko et al. (2019) and the European Commission (2015a).

The ECOGRAI method of indicators development revealed itself of interest to accurately design CE indicators that are coherent both with CE objectives and important variables (DVs) for circularity in the agricultural sector. While we didn't execute the two last steps of the ECOGRAI protocol given the objective of our study, for farms which are willing to take on the next level: having an automative monitoring system of CE performances, there would be a way of deploying the entire protocol of the method (ECOGRAI).

One important point of discussion is the trade-offs analysis that has to be done between options or practices that are implemented. In fact, to improve circularity on egg farms several management practices can be adopted. However, the most suitable option is not always straightforward. While the DELPHI survey provided us with results of ranking of the available and implemented practices for variables with trade-offs options (*Manure use & management, Energy use, Spend hens' disposition, Animal welfare, Reduction and disposition of mortalities*), one must take into consideration the different farms' environment to judge for the better practice for a given farm. In fact, not all management options are suitable on all farms. Decision trees are one of the tools that can be used to help assessing the performances of indicators whose evaluation cannot be generalized (Cf. indicators designated as relying on DT in Table 5). Figure 6 offers an illustration of the decision tree for options for *manure valorization*. Note that this decision tree is associated with two indicators (Cf. Table 5): *1-share of manure directly used on agricultural field (IP_{16})* and *2-strategy of manure valorization (IP_{17})* (*anaerobic digestion to produce biogas, drying, cubing and packaging to sell as fertilizer and composting*). Our recommendation is that, decision trees could be used for indicators whose evaluation must consider specific environment of the assessed company or farm.

Figure 6: *Trade-offs between options for manure use*



Source: Authors (2020) from the DELPHI Survey

IV. Conclusion

This paper presents a structured methodological approach and a framework for designing CE indicators at the micro (unit of production) level in agriculture. The approach we propose is based on an in-depth literature review validated by stakeholders and experts in environmental science.

The proposed methodology consists of three major steps. The first step is to use the analytical framework that we developed in conjunction with the ECOGRAI method to generate a theoretical set of indicators. The second step is to validate the theoretical indicators through consultations with stakeholders, test on farms and consultation of experts using the DELPHI method. The third and final step is to transform indicators into Actions that can be measured and help guide production decisions. This allows to identify areas for improvement of the EC at the farm. As an empirical application, 14 Actions associated with 25 final indicators have been developed.

Not all these performance indicators will be evaluated in the same standard for all farms: a trade-offs analysis will be necessary to help judging the best practices by taking into consideration the specific environment of different farms. The ECOGRAI method of indicators development showed its usefulness since it enabled to accurately design CE indicators that are coherent both with CE objectives and important variables (DVs) for circularity in the agricultural sector.

Our study provides a novel application for the development of systemic indicators for circular economy at the farm level in agriculture. The methodological approach developed could also be replicated in other agricultural production sectors.

As next step, the indicators developed in the form of Actions could be transformed either into a user-friendly computerized program or into a self-administered technical tool which allows producers to isolate the critical points for improving the EC on the farm and/or to get informed in order to seize future opportunities or amend planned investments, in the perspective of better economic circularity.

= = 0 = =

Acknowledgments: The authors address a special thanks to the international experts who participated in our DELPHI survey, the farmers and farm managers that have participated in the study.

Funding: This project was funded by the Egg Farmer of Canada Research Grant Program and by the Economic research chair for the egg industry in Canada.

References

ADLER Michael, & ZIGLIO Erio. (1996). *Gazing into the oracle: The Delphi method and its application to social policy and public health*: Jessica Kingsley Publishers.

ARNSPERGER Christian, & BOURG Dominique. (2016). Vers une économie authentiquement circulaire. Réflexions sur les fondements d'un indicateur de circularité. *Revue de l'OFCE, 145*(1), 91-125. doi:10.3917/reof.145.0091

AUREZ Vincent, GEORGEAULT Laurent, STAHEL Walter, & BOURG Dominique. (2016). *Économie circulaire : système économique et finitude des ressources*. Louvain-La-Neuve: De Boeck Supérieur.

BERTOCCHI Mattia, DEMARTINI Eugenio, & MARESCOTTI Maria Elena. (2016). Ranking farms using quantitative indicators of sustainability: the 4Agro method. *Procedia-Social and Behavioral Sciences, 223*, 726-732.

BITTON Maurice. (1990). *ECOGRAI: Méthode de conception et d'implantation de systèmes de mesure de performances pour organisations industrielles.* (University Thesis), Bordeaux 1, Retrieved from https://www.theses.fr/1990BOR10635 (accessed February 12, 2018).

BOCKEN Nancy M. P., DE PAUW Ingrid, BAKKER Conny, & VAN DER GRINTEN Bram. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering, 33*(5), 308-320. doi:10.1080/21681015.2016.1172124

BONISOLI Lorenzo, GALDEANO-GÓMEZ Emilio, & PIEDRA-MUNOZ Laura. (2018). Deconstructing criteria and assessment tools to build agri-sustainability indicators and support farmers' decision-making process. *Journal of Cleaner Production, 182*, 1080-1094.

BONVOISIN Frédéric. (2011). *Evaluation de la performance des blocs opératoires : du modèle aux indicateurs.* Université de Valenciennes et du Hainaut-Cambresis. , Retrieved from https://tel.archives-ouvertes.fr/tel-00626150 (accessed March 10, 2018).

BORRELLO Massimiliano, LOMBARDI Alessia, PASCUCCI Stefano, & CEMBALO Luigi. (2016). The seven challenges for transitioning into a bio-based circular economy in the agri-food sector. *Recent patents on food, nutrition & agriculture, 8*(1), 39-47.

BRIQUEL Vincent, VILAIN Lionel, BOURDAIS Jean-Louis, GIRARDIN Philippe, MOUCHET Christian, & VIAUX Philippe. (2001). La méthode IDEA (indicateurs de durabilité des exploitations agricoles): une démarche pédagogique. *Ingénieries-EAT*(25), p. 29-p. 39.

BRUNDTLAND Gro Harlem. (1987). Brundtland report. Our common future. *Comissão Mundial*.

BSI. (2017). BS 8001:2017. Framework for Implementing the Principles of the Circular Economy in Organizations – Guide. The British Standards Institution, London.

CAFFEY Rex H, KAZMIERCZAK JR Richard F, & AVAULT James W. (2000). Developing consensus indicators of sustainability for Southeastern United States aquaculture. *LSU AgCenter, Department of Agricultural Economics & Agribusiness Working Draft Bulletin*(2000-01).

CAYZER Steve, GRIFFITHS Percy, & BEGHETTO Valentina. (2017). Design of indicators for measuring product performance in the circular economy. *International Journal of Sustainable Engineering, 10*(4-5), 289-298.

DE OLDE Evelien M, OUDSHOORN Frank W, SØRENSEN Claus AG, BOKKERS Eddie AM, & DE BOER Imke JM. (2016). Assessing sustainability at farm-level: Lessons learned from a comparison of tools in practice. *Ecological Indicators, 66*, 391-404.

DIESENDORF Mark. (2000). Sustainability and sustainable development. *Sustainability: The corporate challenge of the 21st century, 2*, 19-37.

DOUMEINGTS Guys, CLAVE F, & DUCQ Yves. (1995). ECOGRAI—A method to design and to implement Performance Measurement Systems for industrial organizations—Concepts and application to the Maintenance function. In *Benchmarking—Theory and Practice* (pp. 350-368): Springer. Retreived on https://link.springer.com/chapter/10.1007/978-0-387-34847-6_39 (accessed December 07, 2020).

DRUCKER Peter F. (1954). The Practice of Management, 1954. *Col-47*.

DUCQ Yves, & VALLESPIR Bruno. (2005). Definition and aggregation of a performance measurement system in three aeronautical workshops using the ECOGRAI method. *Production Planning & Control, 16*(2), 163-177. doi:10.1080/09537280512331333066

DUCQ Yves, GENTIL MH, MERLE C, & DOUMEINGTS Guys. (2003). Conception et implantation de systèmes d'indicateurs de performance, in: Tahon, Christian (2003), Edition Hermès, Evaluation des performances des systèmes de production. *Chapitre, 7*, 143-175.

EASAC. (2016). European Academies' Science Advisory Council. Indicators for a Circular Economy. *EASAC policy report 30*.

ELIA Valerio, GNONI Maria Grazia, & TORNESE Fabiana. (2017). Measuring circular economy strategies through index methods: A critical analysis. *Journal of Cleaner Production, 142*, 2741-2751. doi:10.1016/j.jclepro.2016.10.196

EMF, GRANTA, & LIFE. (2015). Circularity Indicator. An approach to measuring circularity. Methodology.

EUROPEAN COMMISSION (EC). (2015a). Resource Efficiency Scoreboard 2015. Accessed September 23, 2020 through https://ec.europa.eu/environment/resource_efficiency/targets_indicators/scoreboard/pdf/EU%20Resource%20Efficiency%20Scoreboard%202015.pdf.

EUROPEAN COMMISSION (EC). (2015b). Closing the Loop - an EU Action Plan for the Circular

Economy, vol. 614, p. 21. Accessed October 22, 2019 through https://eur-lex.europa.eu/resource.html?uri=cellar:8a8ef5e8-99a0-11e5-b3b7-01aa75ed71a1.0012.02/DOC_1&format=PDF.

FAO. (2013). Sustainablity Assessment of Food and Agriculture Systems. Guidelines_Final_12_2013.

FIGGE Frank, THORPE Andrea Stevenson, GIVRY Philippe, CANNING Louise, & FRANKLIN-JOHNSON Elizabeth. (2018). Longevity and Circularity as Indicators of Eco-Efficient Resource Use in the Circular Economy. *Ecological Economics, 150*, 297-306. doi:https://doi.org/10.1016/j.ecolecon.2018.04.030

GAVIGLIO Anna, BERTOCCHI Mattia, MARESCOTTI Maria Elena, DEMARTINI Eugenio, & PIRANI Alberto. (2016). The social pillar of sustainability: a quantitative approach at the farm level. *Agricultural and Food Economics, 4*(1), 15.

GEISSDOERFER Martin, SAVAGET Paulo, BOCKEN Nancy MP, & HULTINK Erik Jan. (2017). The Circular Economy–A new sustainability paradigm? *Journal of Cleaner Production, 143*, 757-768.

GENG Yong, & DOBERSTEIN Brent. (2010). Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. *International Journal of Sustainable Development & World Ecology, 15*(3), 231-239. doi:10.3843/SusDev.15.3:6

GHISELLINI Patrizia, CIALANI Catia, & ULGIATI Sergio. (2016). A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production, 114*, 11-32. doi:10.1016/j.jclepro.2015.09.007

JUSTYNA Goździewicz-Biechońska. (2016). The role of agriculture in the circular economy. *Przegląd Prawa Rolnego*(1 (18)), 81-95.

KIRCHHERR Julian, REIKE Denise, & HEKKERT Marko. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221-232. doi:https://doi.org/10.1016/j.resconrec.2017.09.005

KUUSI Osmo, & MEYER Martin. (2002). Technological generalizations and leitbilder—the anticipation of technological opportunities. *Technological Forecasting and Social Change, 69*(6), 625-639. doi:https://doi.org/10.1016/S0040-1625(02)00182-8

LE MOIGNE Rémy. (2014). *L'économie circulaire : comment la mettre en œuvre dans l'entreprise grâce à la reverse supply chain?* Paris: Dunod.

LOBNA Kallel, MOUNIR Benaissa, & HICHEM Kamoun. (2013). *Using the ECOGRAI method for performance evaluation in maintenance process.* Paper presented at the 2013 International Conference on Advanced Logistics and Transport.

MAYER Robert, & OUELLET Francine. (1991). *Méthodologie de recherche pour les intervenants sociaux*: G. Morin.

OECD. (2014). Measuring and Managing Results in Development Cooperation: A Review of Challenges and Practices among DAC Members and Observers. . In: OECD Paris. Accessed September 27, 2020 through https://www.oecd.org/dac/results-development/docs/Measuring-and-managing-results.pdf.

OECD. (2015). Material Resources, Productivity and the Environment, OECD Green Growth Studies. In: OECD Publishing Paris.

OKOLI Chitu, & PAWLOWSKI Suzanne D. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & management*, *42*(1), 15-29.

PARCHOMENKO Alexej, NELEN Dirk, GILLABEL Jeroen, & RECHBERGER Helmut. (2019). Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, *210*, 200-216. doi:https://doi.org/10.1016/j.jclepro.2018.10.357

PAULIUK Stefan. (2018). Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resources, Conservation and Recycling*, *129*, 81-92. doi:https://doi.org/10.1016/j.resconrec.2017.10.019

PELLETIER Nathan. (2017). Life cycle assessment of Canadian egg products, with differentiation by hen housing system type. *Journal of Cleaner Production*, *152*, 167-180.

PELLETIER Nathan, DOYON Maurice, MUIRHEAD Bruice, WIDOWSKI Tina, NURSE-GUPTA Jodey, & HUNNIFORD Michelle. (2018). Sustainability in the Canadian Egg Industry- Learning from the PAst, Navigating the Present, Planning for the Future. *Sustainability*, *10*(10), 3524.

REPAR Nina, JAN Pierrick, DUX Dunja, NEMECEK Thomas, & DOLUSCHITZ Reiner. (2017). Implementing farm-level environmental sustainability in environmental performance indicators: A combined global-local approach. *Journal of Cleaner Production*, *140*, 692-704.

ROSS-CARRÉ Hervé. (2016). *L'économie circulaire*. La Plaine Saint-Denis: Afnor éditions.

RUITER Cindy. (2015). The Circular Economy Performance Index. . In: VU University Amsterdam. Retreived on https://dspace.library.uu.nl/handle/1874/337188 (Accessed November 13, 2017).

SAIDANI Michael, YANNOU Bernard, LEROY Yann, CLUZEL François, & KENDALL Alissa. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542-559.

SAUVÉ Sébastien, BERNARD Sophie, & SLOAN Pamela. (2016). Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. *Environmental Development*, *17*, 48-56.

SAUVÉ Sébastien, NORMANDIN Daniel, & MCDONALD Mélanie. (2016). *L'économie circulaire : une transition incontournable*. [Montréal, Québec]: Les Presses de l'Université de Montréal.

SCHMIDT Roy, LYYTINEN Kalle, KEIL Mark, & CULE Paul. (2001). Identifying software project risks: An international Delphi study. *Journal of management information systems*, *17*(4), 5-36.

SINGH Rajesh Kumar, MURTY H. R., GUPTA S. K., & DIKSHIT A. K. (2012). An overview of sustainability assessment methodologies. *Ecological Indicators, 15*(1), 281-299. doi:https://doi.org/10.1016/j.ecolind.2011.01.007

SMOL Marzena, KULCZYCKA Joanna, & AVDIUSHCHENKO Anna. (2017). Circular economy indicators in relation to eco-innovation in European regions. *Clean Technologies and Environmental Policy, 19*(3), 669-678.

TAMINI Lota D, DOYON Maurice, & ZAN Micheline M. (2016). Investment behavior of Canada egg producers: Analyzing the impacts of change in risk aversion and in the variability of eggs prices and production costs. *British Food Journal, 120*(1), 96-107.

VELEVA Vesela, & ELLENBECKER Michael. (2001). Indicators of sustainable production: framework and methodology. *Journal of Cleaner Production, 9*(6), 519-549. doi:https://doi.org/10.1016/S0959-6526(01)00010-5

VERBEEK L. H. (2016). A Circular Economy index for the consumer goods sector. *Utrecht University*, 78.

VILAIN Lionel. (2008). *La méthode IDEA: indicateurs de durabilité des exploitations agricoles*: Educagri éditions.

VILAIN Lionel, K. Boisset , P. Girardin , C. Mouchet , P. Viaux , & F. Zahm (2013). IDEA3_ Fiche Outil. Accessed May 20, 2018 through http://www.plage-evaluation.fr/webplage/images/stories/pdf/ficheidea.pdf.

WISSEMA Johan G. (1982). Trends in technology forecasting. *R&D Management, 12*(1), 27-36.