Importance of sustainability assessment and circular economy in agricultural machinery production

by *Giuseppe Gavioli (Gavioli Consulting LLC)*

USA

1. Introduction

There are different and contrasting theories about the possible evolutions of the Earth climate conditions, but surely human activity has a very significant impact, and power of change, on it.

"*In terms of their influence on the carbon cycle and climate, the human-driven changes of the Anthropocene are beginning to match or exceed the rates of change that drove past, relatively sudden mass extinction events*" [1; 2].

Just this only point should make us resolutely switching from a sort of "observation mode" to a very active approach instead. All of us, and in particular our economic organizations, have to stop consuming and wasting resources without being aware of what we do, how much we consume, and how much we could improve in making our activities sustainable.

"*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs*." (United Nations World Commission on Environment and Development). Therefore, sustainability must be our new framework, in everything we do.

Indeed, many industrial companies, all over the world, have already adopted a proactive approach to sustainability, launching a variety of sustainability projects inside their organizations and toward the external environment. But they are still a minority, often consisting of big corporations; instead, really global and relevant improvements will be the result of a very wide adoption of sustainable practices by a majority of economic entities in the world (farms, industrial companies, commercial activities, governmental organizations, private citizens).

In substance:

- We have to adopt new principles to guide our development, as the old "consume and throwaway" model did not work.
- We have to act, measuring and assessing the status of our processes and behaviors, and establish plans for change.
- Plans must be supported by quantitative indicators of trends and results.

2. Consumption of Planet Resources

"The fact that has shocked me the most is the Overshoot Day: by July 29th, we used up all the regenerative resources of 2019. From July 30 we started to consume more resources than the planet can regenerate in a year. It's very serious. It's a global emergency".

Pope Francis, La Stampa, August 9, 2019

There are many research works on the consumption of Earth resources by human activity, of which one is based on the definition of Ecological Footprint and Biocapacity of a territory [3], whose ratio can indicate an Ecological Deficit or Reserve [4]. **Figure 1** shows how many countries in the world are in Ecological Deficit.

The global measure of it is the indicator called Overshoot Day. The Earth Overshoot Day marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year.

In 2019 the Overshoot Day has been July 30. Today humanity uses the equivalent of 1.7 Earths to provide the resources we use and to absorb our waste. This means it now takes the Earth one year and eight months to regenerate what we use in a year. The trend from 1970, when the Overshoot Day was January 1st, has been rapidly deteriorating (**Figure 2**).

So, the goal, and the challenge, is to decouple economic growth from environmental degradation [5].

This paper has a micro-economic focus, to explore concrete ways to improve sustainability of the farm machinery industry, always keeping an eye on the global consistency of goals and efforts among different economic and social subjects.

3. Sustainability Assessment and Metrics

The first step toward sustainability is awareness.

Everything we do has an impact, it consumes resources and produces waste. In particular, all our professional and manufacturing activities do. Therefore, we can start taking a picture of the current status, measuring all the parameters that qualify our activity in terms of output versus resource consumption, ability to regenerate resources, quantity and quality of waste. From here we can use sustainability indicators go to assess the impact of what we do.

Sustainability is a multi-disciplinary area, and the assessment tools are always in evolution [6].

The environmental assessment is the most common and widely used methodology, as it focuses on the consumption and regeneration of natural resources (energy, water, minerals, biological elements), and on the impact of waste.

To get a reasonably accurate picture of the sustainability position of a given process/product, a preliminary inventory of all the aspects to consider is prepared. The result is a list of:

- input materials (type, characteristics, quantity, cost)
- process factors (energy, water, air, land, labour, safety)
- output products (type, characteristics, quantity, cost)
- waste (type, characteristics, quantity, cost, risk)

Often the environmental assessment of a product or a process is accurate but too focused on a limited perimeter, not considering the broader effects and implications outside the considered scope. Upstream requirements and resource consumption, e.g. to produce the raw material or the energy consumed on the analysed process, may have a more than relevant environmental impact.

Same for downstream use or waste. All these implications and connections led to adopt methodologies like the Life Cycle Analysis, where the attempt is to expand the vision to a broader scope of investigation, both for what concerns the number of items considered and the full cycle of creation, use, and end of life [7], [8].

So other elements have to be added to the inventory:

- inbound logistics
- energy and material history of the input materials, including waste generated by upstream processes
- source and environmental history of the utilized process factors
- outbound logistics
- use and reuse of the product after production
- use termination and end of life of the product

For a complete set of guidelines and tools to carry on an LCA assessment the natural reference are ISO standards [9], of which the main ones on LCA are:

- ISO 14040 – principles and framework for life cycle assessment (LCA) (**Figure 3**)
- ISO 14044 – requirements and guidelines for LCA
- ISO 14049 – illustrative examples of LCA application

In addition to the impact on the environment, social and economic aspects are two other very relevant dimensions of sustainability. A complete sustainability assessment should consider these aspects as well, in particular in the modern world, where multiple and broad interconnections exist with a variety of stakeholders, multiple places in the world are impacted, broad social differences and political implications exist [10].

Just one example for all: sourcing raw material from one place of the world or another may have completely different social implications, due to existence of conflicts, inequalities, slavery, etc.

Of course, it's impossible to consider every possible connection and implication in a product/process life cycle assessment, but it's important to consciously define the scope and boundaries of the analysis itself, keeping it as wide as possible. Several regulations recently came into existence in different countries, that also drive an increased awareness and proactivity about people safety elements (e.g. REACH in Europe and Conflict Minerals in the USA).

4. Environmental Management System

The assessment of how much our activities and products are sustainable is just the starting point.

A powerful second step is to establish an Environmental Management System in our organization. This means to define rules, methodologies, standards and procedures, all consistent and effective in driving increasingly sustainable processes.

The best way to do that is to use and follow the ISO 14000 family of standards [11], that includes:

- ISO 14001 – a complete framework of rules and criteria to establish an Environmental Management System, that can be certified
- ISO 14004 – general guidelines on implementation
- ISO 14005 – guidelines for a phased implementation
- ISO 14006 – guidelines for eco-design
- ISO 14031 – design and use of environmental performance evaluation

Many companies in the world have implemented various levels of Environmental Management Systems, ISO 14001 certified.

The general theme of sustainability is becoming more and more studied and debated, in particular for what concerns the environmental impact, by many authors and think tanks.

Moreover, an increasing number of organizations are undertaking concrete initiative to assess and improve the sustainability of their operations. Several big companies have set metrics, defined objectives and invested significant efforts in organizing and publishing Annual Sustainability Reports as part of their standard set of business reports [12], [13]. Several companies have also incorporated, in their plans and reports, actions of *corporate social responsibility*, so widening their approach to sustainability to social aspects. This behaviour is also driven by growing expectations of employees, customers, and local communities, who tend to associate more and more value to these aspects of the company ways of doing business. In the farm machinery industry some companies are also quoted at the Down Jones Sustainability Index and other similar international indices. The indices serve as benchmarks for investors who integrate sustainability considerations into their portfolios, and provide an effective engagement platform for investors who wish to encourage companies to improve their corporate sustainability practices [14].

5. The Circular Economy

In recent years, the old concept of "circularity" of goods and resources [15] has been adopted and developed as a fresh and renovated approach to sustainable economic activities, mainly thanks to the initiative of the Ellen McArthur Foundation [16].

The simple and revolutionary approach of the circular economy concept is to abandon the old (and mostly current) *take-make-waste* linear model and migrate to a circular economy, "one that is restorative and regenerative by design" [16].

According to Ellen MacArthur Foundation, "a circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems".

5.1. Principles

The fundamental principles of the circular economy are:

I. design out waste and pollution;
II. keep products and materials in use;

III. regenerate natural systems.

The first principle focuses on probably the most critical aspect of sustainability, to limit the kind of waste generation that cannot be absorbed by the Earth in the short term and without long term pollution consequences. Organizations have to start eliminating waste before generating it: as early as in the product and process design phase. The keyword is design for no waste.

The second one is all about keeping products and materials in the economy, avoiding or delaying their disposal as much as possible. This can be done in many ways, depending upon the nature of products; material goods can be designed for lasting, for being reused, for being easily repaired or remanufactured, extending a lot their useful life. Some products can be offered as services, or dematerialized. Products that cannot last, like food, can be re-collected and processed/transformed to limit waste. The keyword here is design for extended life.

The third principle is centred on not only protecting the natural environment, but actively regenerating it. Trying to mirror the natural chain of transformation, for which nothing is waste, everything is “food” for something else.

These principles represent the new ethics for an economy that respects the environment and looks to the future. They can surely help people and companies to adopt a new, different, and better mindset for what concerns sustainability.

Moreover, they are so candid, understandable and actionable, they can actually inspire and drive a lot of practical and effective actions to transform and improve economic and business processes.

5.2. General Application to Agricultural Machinery

The circular economy approach has a very general scope and it can be successfully applied to a variety of economic activities. In particular we will explore here some possible specific applications to the agricultural machinery industry.

Farm machinery is a complex industrial product, based on multiple technologies applied to a variety of materials, to provide farmers with a lot of functions and services. On one hand there are multiple opportunities to look for sustainability improvements in this industry; on the other hand, the product complexity and the interconnection of multiple technologies surely discourage simplistic approaches.

Still, there are opportunities for quick and easy wins and also for more ambitious and long-term targets.

6. Circular Economy Applications to Agricultural Machinery

6.1. Materials

One good starting point of farm machinery is that a big portion of the product is made by metal, especially iron-carbon alloys, that is are a very sustainable material because it can be recycled almost indefinitely, with a considerable reduction of the need to mine and transform new materials; also recycling metals consumes less energy and produces much less waste. Therefore, keep using metals and do research on metallic materials with always better characteristic.

Tires are also commonly recycled or regenerated, even if the recycled material is mostly used for other applications, due to the nature of the tyre fabrication process and the limits of the recycling techniques that do not allow for a recovery of the original raw material. Rubber recovered from tires has multiple uses as construction material, while steel can be isolated from rubber and recovered as quite pure metal. Scrap tires used as fuel, under controlled conditions, can produce the same amount of energy as oil and 25% more than coal.

Plastic is more and more used on farm machinery, as in many other industrial equipment, and this is a real issue for sustainability. Even if the plastic components production process is often simpler and more sustainable than others, the problems comes when the plastic component is no more usable or useful. Recycling of plastic is difficult and expensive, mainly because only a limited number of plastic materials can be actually recycled or regenerated.

So, if we start from a collection of different plastic components, one step of the recycling process must be dedicated to separate different kind of plastic and isolate the ones that are recyclable. The others can still be reused, but mainly as inert filling or low performance bulk for other plastic components.

The biggest issue is the end of life of plastic materials, as most of them, for one reason or another, end up in landfills and in water (groundwater, rivers, and sea), with a long residual life and a high pollution potential. What can be really done is to carefully investigate and design the kind of plastic to use in farm machinery applications, either choosing the materials with a higher degree of recyclability or making disassembly and separation easier and less expensive (in order to enable some kind of end of life processing). The most affordable solution in the short term is to use plastic materials that can be really and easily reused in other applications and to design plastic components easy to disassemble.

6.2. Design for limited waste and limited pollution

An essential point of attention is, as early as in the product concept phase, to minimize the waste during the production process of farm machinery and at the end of product life.

An efficient process, that uses limited energy, water, land and other key resources, is a powerful contributor to the sustainability of a product and of an entire business. Designing processes for no waste is the key target of the lean manufacturing methodologies, that have already demonstrated their successful applicability and effectiveness. But this is not enough: our processes must really be designed and evolved to avoid any kind of material scrap. Only very few scrap materials can be easily and rapidly recycled, like metal; most of scrap goes to generic scrap dumpers, that is the beginning of a sad story of indistinguishable, discarded, and useless stuff. When something becomes useless, “waste” to our perception, our attention goes away, we re-direct it to something else, and the perceived waste becomes finally and hopelessly real waste. The majority of this waste then goes to landfills, where it’s almost impossible to do anything more to recycle and to avoid pollution.

We have to change our perception, and to do so we have to change our sensitivity, our ability to recognize, identify and hate waste. Perceive it as a problem to be resolved now and before it is too late.

In most of the cases no-waste is only a distant theoretical target, because there are no known ways to actually do it; but what's important is keeping a constant tension, a strong drive toward actions to limit waste. The key is to keep striving for reachable improvements. What appears impossible today will become possible tomorrow, in a way we don't know yet, but that is somewhere just beyond the horizon; we will go there only if we keep walking.

If no-waste is not yet possible in many of our activities, it becomes even more important to make sure our unavoidable waste is not going to be a significant source of pollution for the environment.

This can be done substantially in two ways:

- eliminating or reducing the presence of dangerous substances in the waste;
- protecting the waste from being dispersed in the environment.

What a farm machinery manufacturer can do is, for example, organizing the disassembly and recovery of electronic circuit and their components, which are full of potentially highly pollutant elements. If the cost of identification and disassembly of electronic devices at the end of product life is minimized by design, it will not be impossible to recover materials and value, directly or in partnership with other organizations. Other potentially risky substances may be incorporated by design into parts that don't release them into the environment, even when discarded at the end of product life.

Although these examples are may be only first steps in improving the sustainability of a product, and not the best solutions, still they are absolutely necessary. In absence of the perfect solution, rarely available on-the-spot, it's of paramount importance to keep the tension and the attention toward the sustainability objectives. An uninterrupted progression of improvement is the real important thing, as other and better improvements will surely come with time and experience.

6.3. Remanufacturing

Product life can be extended by design, facilitating reuse, repair, and remanufacturing.

Farm machinery is intrinsically made to last, as the machines are designed to sustain heavy loads and high mechanical stress for long periods of time; therefore, it's normal to repair and replace some components after a period of use and get back a machine used but still very much operative. This supports several reuse instances of the machine, through a very active second-hand market.

Another strong help to the machine life extension is to remanufacture the worn-out parts of the product, in a way that the product gets a new life, with specifications and characteristics that are almost the same as the original ones [17]. Indeed, remanufacturing is not a simple repair operation: it's usually a set of complex and carefully designed operations, customized not only for the given product but also adapted to the actual wear or damage status of components. Many companies now exist, specialized in remanufacturing of important sub-systems, including some used by farm machinery, like diesel engines or hydraulic systems [18].

Remanufacturing itself is a way to increase sustainability of the industrial processes, as normally less resources are used to remanufacture a component, compared to the original manufacturing process, in particular raw material and energy. Therefore, both from the product and the process sustainability point of view, remanufacturing is a brilliant application of the circular economy approach.

6.4. Smart Logistics

Independently from any other improvement to the manufacturing processes, one single thing that can be immediately done in most of the companies, is to avoid the waste caused by poor inventory management.

It is of fundamental importance to know exactly what materials and components are daily received and stored, what have been picked from inventory and used for production and parts, what have actually been incorporated into the end product, what is scrapped, and what is shipped.

Materials and parts inventory control seems easy and obvious, but it is not, and, in reality, its importance is often underestimated, creating room for a lot of material lost, not known, stored in the wrong place, wrongly identified or not identified, with inaccurate recorded quantities. Any of these issues inevitably leads to create waste: wasted materials, wasted time, additional costs to procure material not present or not found, etc. The recommendation here is to invest in tools and processes to organize and keep under strict control materials and parts inventory and flow, applying the approach and methodologies of the lean manufacturing or lean organization.

Moreover, the adoption of smart logistics business models, allows for a very effective optimization of the product transportation (to distribution network, to customer, from customer to repair and recycle, from and to industrial and commercial partners for collaboration and synergies, etc.), opening opportunities for saving costs and reducing CO_2 emissions into the atmosphere.

6.5. Product-as-a-service Business Model

Another very interesting way to extend the life of a product or at least to plan very much in advance the evolution of its life and taking control of it, is to move from the "sell as many products as possible", to the product-as-a-service model. Products are always needed to perform functions, but the customers may be more and more interested to buy the function, the performance, not necessarily the material product that does it. If physical products remain under direct control of the manufacturers for all their life, with manufacturers owning the reuse, refurbishing or recycling loop, it is much more probable that the product itself is designed and managed following the circular economy model, because this would become one of the main interests and profit generator for the manufacturing company. The company can surely manage much better than any end user the complete product life, planning in advance for all the phases of product life, and then being able to actually manage all of them, getting the most from each phase. On the other end, the user can dramatically reduce the investments and the maintenance costs, paying only for what they need and use. One of the most cited examples is the Philips Circular Lighting case [19].

This model is highly applicable to farm machinery too, as many farms may benefit from just buying services performed by machinery, without the burden of owning the machines. Broken ownership, that splits the product life in multiple independent phases, managed in different ways, with different logic, and with sub-optimized relationships among them, does not favor sustainability. Instead it is characterized by incoherent targets by phase, limited control on the other phases of the product life, and focus on short term / limited scope optimization.

The product-as-a-service model is partially already in use in the farm machinery world, with contractor companies that buy and own fleets of machines and offer services to the farms. This surely helps to do some optimization and efficiency in machine use, but still leads contractors to resell used or obsolete machines, in order to buy new ones, without taking too much care about the rest of the machine life; and before that, manufacturers are focused on just selling products. Such interruption of continuity in managing the product life is surely preventing a lot of sustainability actions.

6.6. Digital Twin and Artificial Intelligence

As much as we progress in the analysis of the opportunities for sustainability actions, it appears more and more clear how a key point is to consciously and carefully manage our product's life. From concept and design, down to production, use, reuse, and recycle, the product has to be seen as one subject to manage. This kind of whole lifetime management would surely benefit from the availability of a dematerialized model of the product, that can help studying and simulating situations and alternatives.

Modern technology allows for the creation of a digital twin, a "copy" of the product and its surrounding environment in the digital world [20; 21]. The digital model can have various degrees of accuracy, but it can also integrate information about product use, surrounding environment, and interconnected systems. Such a model can be exploited to make simulations of different conditions of use, to study design alternative's impact on subsequent phases of product life, and to assess and weigh environmental sustainability aspects against economic values and risks.

Moreover, the digital twin can be constantly enriched of data by connected sensors on the product and in the field, or by links with data service providers, and this makes it "alive" together with the physical product. Such connections mark a further step in making the digital twin useful and powerful as a tool to control and manage product life. This reduces the need of abstract assumptions, enables a better knowledge of the real situations, and guides toward the best actions to manage product's future.

The combination of digital twin modelling and the use of Artificial Intelligence (AI) is going to further expand the power of simulation and data-assisted decisions, introducing a new dimension of knowledge. AI, through the use of deep learning techniques, can mine tons of available data, impossible to use with traditional approaches, and develop scenarios and alternatives based on hidden but real trends and weights. If the digital twin is connected to the real world, then AI can continuously update the scenario analysis and build new alternatives as situations change. Furthermore, if new inputs and excitations are injected into the digital model, AI can rapidly deploy sensitivity analysis and update the impact assessment framework.

On agricultural machinery this becomes more and more possible and feasible, with the availability of complete digital models and connected machines fully equipped with any sort of sensors; with application environments monitored by smart and connected sensors; with data and information widely available from service providers.

6.7. Partnership

All the applications of circular economy seen so far, even when focused on specific short-term actions, are very much based on the broad view of the whole product lifecycle. Indeed, only looking to the total perspective, we can choose the single actions that are consistent with, and contributing to, the end target of an increased sustainability of products and processes.

It's also evident that the broad view and the whole product lifecycle smart management is often impossible if there is not an active cooperation between different subjects. A person or a company alone cannot see everything, may not have all the information, could not directly manage all aspects of product lifecycle. The broad view, absolutely necessary to implement the logic of circular economy, definitely implies alliance and collaboration among organizations and stakeholders.

In particular, collaboration and coherence of actions is important in the product supply chain, where only true partnership can generate credible and longstanding results on product sustainability. Suppliers, OEMs and logistic operators cannot be considered anymore as independent, separated subjects: they are part of a continuum, and to be effective in supporting sustainability, they have to all embrace the principles, the culture and the practice of circular economy.

In effect partnership not only means practical collaboration and interaction, but also implies sharing principles and long-term goals. And sharing long-term goals, in a world more and more challenged by lack of resources and unsustainable human impact on nature, is becoming a true priority for economic organizations.

Same considerations are applicable to the relationships among producers of goods, providers of services and users. They all belong to the same extended value chain, where their specific interests and goals may remain achievable on a long-term basis only if that value chain is not broken or discontinue.

7. Impact on Agricultural Practices

Farmers are very linked to tradition, as this is a very powerful way to maintain and only slightly, progressively, improve practices during years; so, they are resistant to change. They know there are many variables outside their control, and they try to manage very well what is under their control.

However, there is a powerful acceleration factor for change in agricultural practices: the observation and imitation of the neighbors. This proves how farmers are smart, attentive and mindful. Evidence of improvements, even the very innovative ones, triggers waves of imitation and change all across entire regions.

Moreover, farmers know how much natural resources are important, and how the long-term view is also essential to get crops not only today but tomorrow as well. So, they are very sensitive to the balance and restoration of natural resources and biodiversity, as that would be for them the only available future.

Therefore, the progressive adoption of the circular economy approach and subsequent implementation of consistent sustainability actions, could find farmers quite receptive and ready to jump on board, as soon as they will see real change and benefits to their practices.

A number of sustainability improvement actions to the farm machinery lifecycle, like reducing the resource consumption and the waste, will directly benefit agriculture in terms of less scarcity of resources and lower pollution of land, water and air, even without any substantial change in agricultural practices. Moreover, actions like dematerialization of products, through provision of services or incorporation of functions into software and information management, will tremendously help agriculture, supporting evolution of practices and simplifying farm resource and asset management. Not to mention precision farming technologies, that are already improving productivity, reducing waste and supporting sustainability of the farm business.

8. Conclusions

Starting from considerations on the absolute necessity of moving rapidly toward a much better sustainability of our economic activities, we have initially underlined the importance of sustainability assessment, as a conscious, scientific, documented process, to support awareness and create the base for building improvement actions. Environmental impact analysis is the first step recommended, up to a structured approach as the full Life Cycle Assessment, using the guidance and tools provided by the ISO 14040 family of standards. The second recommendation is to build, in each economic organization, a true Environmental Management System, as defined and supported by the ISO 14001 family of standards. This gives structure, strength and continuity to improvement actions and sustainability practices.

Introducing then the subject of Circular Economy, the approach suggested by the Ellen MacArthur Foundation has been totally embraced: “a circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems”. Its principles and their general applicability to every product, included farm machinery, have been presented as the most recommended strategy.

Several possible applications of the circular economy approach have been presented, identifying multiple actions and their underlying logic. Starting from materials to use and waste to prevent, the focus moved to reuse and remanufacturing, to introduce some of the many possibilities to extend the active life of products. A mention to smart logistics followed, to underline another way to reduce waste. Moreover, the option to replace ownership of physical goods with a product-as-a-service model has been introduced, to further improve the sustainability of business.

The modern technologies allow for effective introduction of digital twins of our products and their surrounding environment, enabling simulations and anticipations of issues and also of opportunities for sustainability improvement actions. Artificial Intelligence is also a very powerful tool to support the successful use of digital models, enabling the use of big data in complex simulation and alternative analysis. This can boost company ability to assess and plan more sustainable and profitable processes.

At the end some considerations have been made on the real need of partnership between different economic subjects, to join efforts and cooperate on sustainability actions, as most of them require a whole product life view and coherent contributions from multiple parties.

It’s evident that more sustainable farm machinery influences better agricultural practices and a more sustainable agricultural environment.

Conclusion is that environmental sustainability is of paramount importance for the farm machinery industry, as for all other economic activities. It’s also true that the general principles of sustainability and circular economy are absolutely actionable and potentially very effective in our industry. Sometimes difficult to implement, often with partial results at the beginning of the journey, but surely the only credible alternative to build a future of Earth that will be good and acceptable to future generations as well.

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FIGURES

Figure 1 – Ecological Deficit/Reserve *(Source: [4])*.

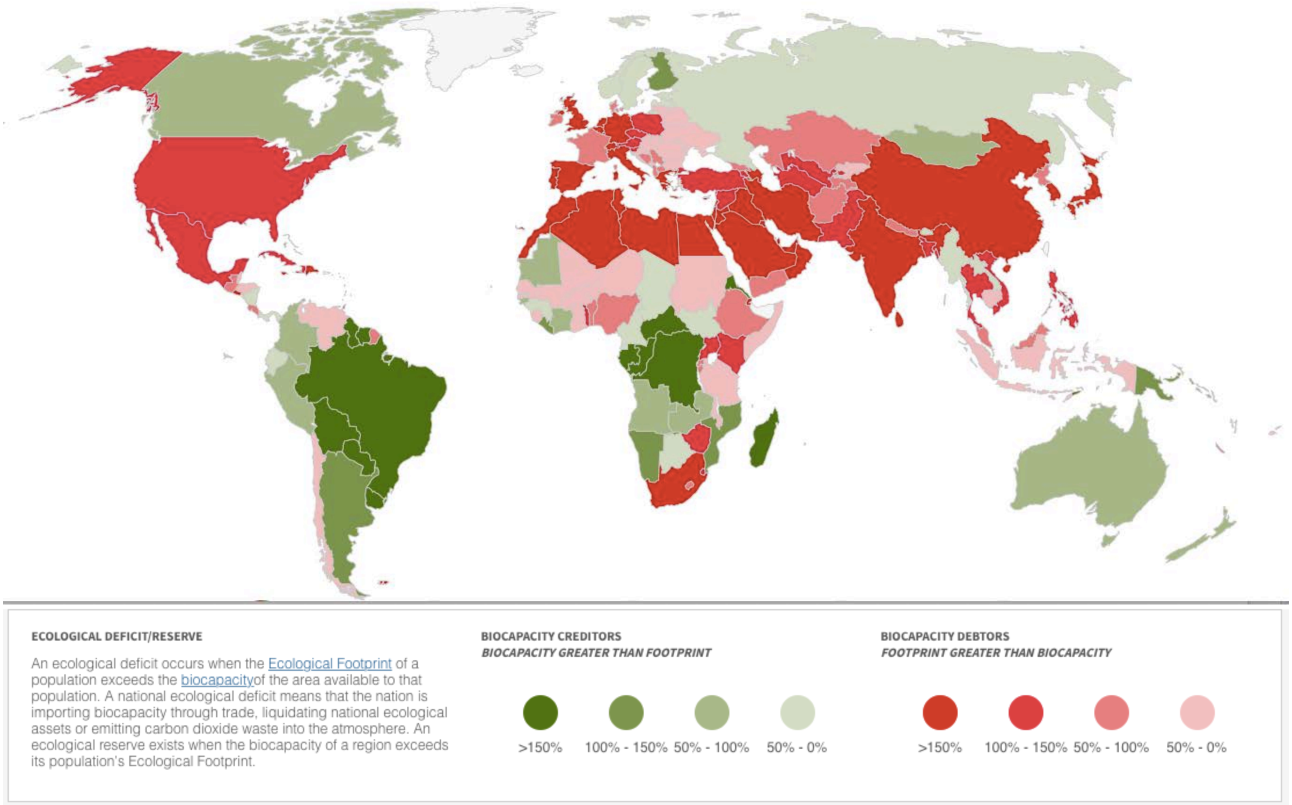

Figure 2 – Earth Overshoot Day *(Source: [4])*.

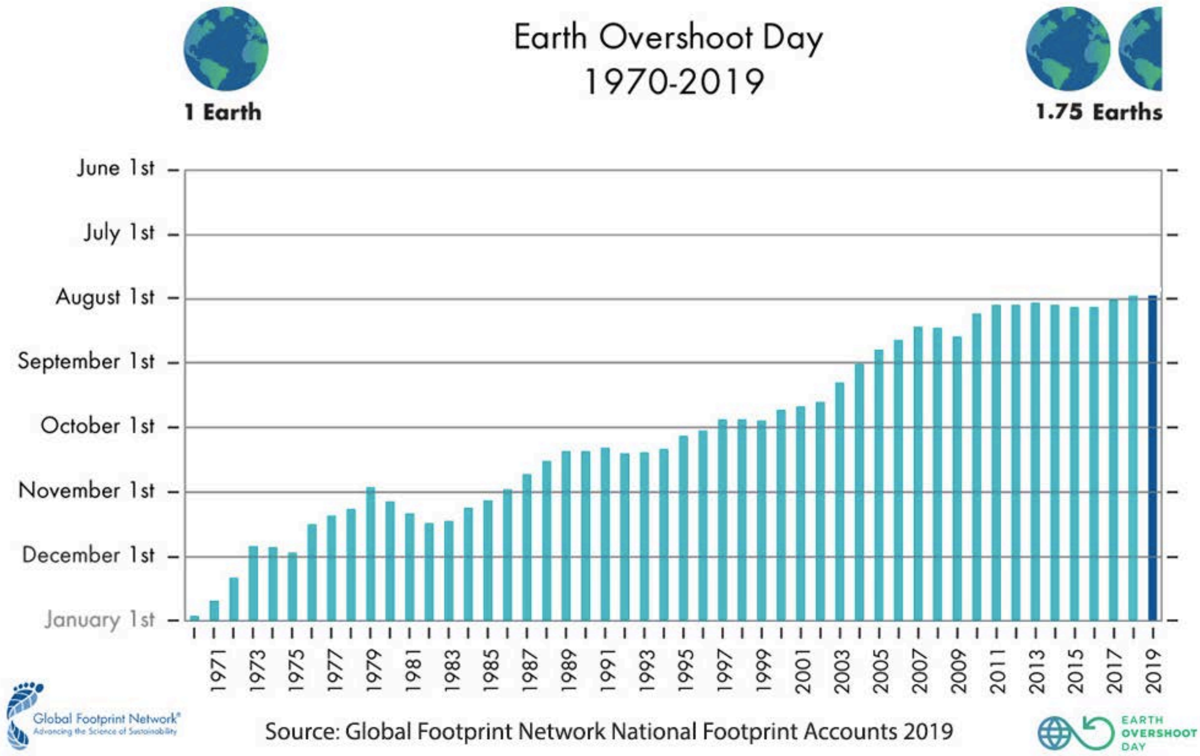

Figure 3 – Life Cycle Assessment Framework *(Source: ISO 14040 standard)*.

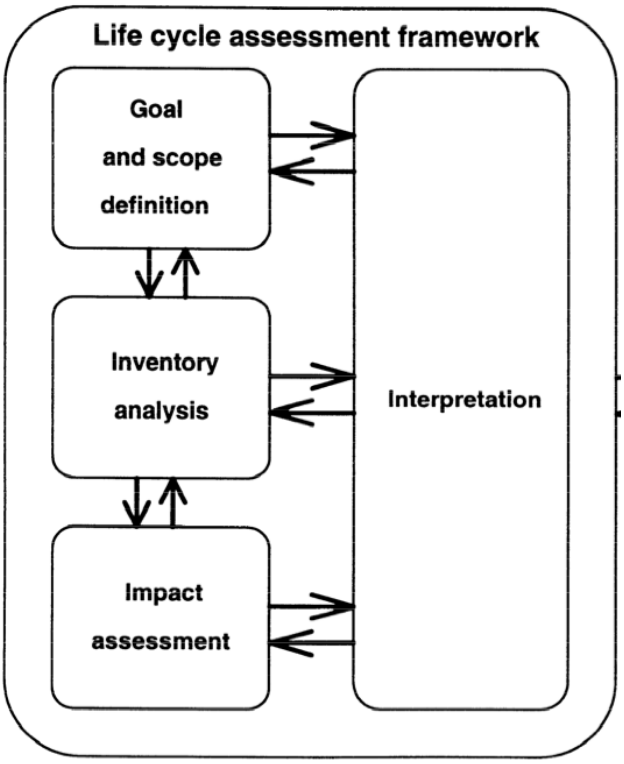

Figure 4 – Circular Economy *(Source: Ellen MacArthur Foundation [16])*.