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The Butterfly Framework for the Assessment of Transitions towards a Circular and Climate Neutral Society

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Abstract: The Butterfly framework of Wageningen University & Research (WUR) for assessing transitions towards a circular and climate-neutral society is presented. The Butterfly framework is built after analysis of existing frameworks that could only partly comply with the needs of the full set of stakeholders interlinked and operating in domains like society and well-being; food, feed, and biobased production; natural resources and living environment. It shows that for adequate action perspectives on and in these domains, the socio-ecological, socio-technical, and socio-institutional subsystems should be fully integrated, and stakeholders should be equally consulted and appreciated. In order to advance and integrate action perspectives of different stakeholders in the light of the transition to circularity with high-level ambitions like climate neutrality, stakeholders (groups) need to understand their position and links in a full systems perspective, which the Butterfly framework provides.

Keywords: circular agriculture; circular economy; circular society; climate neutral; system transition; system analysis; framework; interdisciplinarity; multidisciplinary

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1. Introduction

Circularity as a concept to deal with finite resources has worldwide attention, as globally the world is only at 8.6% circularity at the moment [1]. In The Netherlands, a circular and climate-neutral society (CS), interconnecting circular agriculture (CA) and circular industries (CI), has been proposed as an alternative to the current agri-industry as a means to curb climate change and with the objective to decrease pressure on the environment [2]. A variety of conceptual frameworks exist that could potentially assess such transitions in the socio-economic, technical, and ecological domain, but they fail to take the full systems perspective into account, with its choices, wins, and trade-offs for different stakeholders at different scales, and how these affect higher-level societal objectives. In this paper, we demonstrate that for a meaningful assessment, taking into account the full systems perspective is necessary.

A circular society integrates our need for food, feed, and non-food products from renewable resources with the ambition to reduce environmental impact. Impact reduction is reached by minimizing inputs and reducing emissions to the environment, through the efficient use of resources and (re)cycling products and waste streams. CS, therefore, is a concept for the institutional, technical, and ecological organization to create value from our living environment within certain defined limits [3]. These limits are set by the demand for ecosystems services, the availability of resources, and the question of to what extent we can and are willing to use the environment to create specific value. The dilemma is whether to leave the finite resources untouched or use them to produce food and non-food products for a growing population with increasing (dietary and non-food) demands [4,5]. Meanwhile, the transition from a petrol-based to a biobased economy puts extra pressure on these resources [6,7]. The re-use and circulation of finite resources is, therefore, highly desirable.

In short, CS answers the question '*how* to create value from the ecological system with positive climate and other environmental effects', and results from the question '*why* do we want to create *which* value for ourselves or for mankind'.

1.1. Circular Strategies

The question of *how* to achieve a circular society includes, before anything else, the question of the circularity strategy [8]. The 9R framework [9,10] provides an overview of possible strategies. Three main and subsequent strategies are distinguished with increasing levels of circularity.

I The useful application of waste and residual materials (recover and recycle),

II Extend the lifespan of products and their parts (repurpose, remanufacture, refurbish, repair, re-use),

III Reducing consumption and production and smarter product use and manufacture (reduce, rethink, refuse).

These strategies are interdependent and are easier said than done [11]. If resources are used more efficiently, the resource inputs and possible waste streams may be reduced at the same time. Reduced waste streams in their turn reduce opportunities for business cases based on these waste streams.

1.2. Scale, Location, and Time

The advantages and disadvantages of the different strategies are largely determined by issues of scale (closing cycles of material on a local, regional, national, or continental scale), time, and geolocation. They define costs and limitations of what resources we can and are willing to use. Simultaneously, production efficiency, product quality, and product safety (related to recycling waste streams) come into play. These may lead to improvements of the current state and the design of novel production systems, and the valorization of biomass feedstock. Scale, location, and time of application also determine the rate and overall effects of food and biobased production with regards to climate change. This requires a clear understanding of these relationships.

1.3. Circular Action Perspectives

CS strategies must be transformed into concrete action perspectives. In a circular society, these go a step further than value chain optimization, aiming at direct cost efficiency as a mere objective. Sustainability objectives may have put limits to value chain optimization by minimizing negative environmental impacts per unit of product, but have led to unwanted or unacceptable emissions to the environment, loss of biodiversity, and to climate change when expressed per unit of area. For CS new action perspectives are needed. For instance, roadmaps and visions for *true pricing* are developed, where external costs are internalized [12,13] and are available for specific sectors such as agriculture [14]. From these studies, it is clear, among others, that arable products may be underpriced but that livestock products are clearly underpriced [15]. Then there are costs that are often overlooked such as the effects of greenhouse gas (GHG) emissions and land-use change [16].

Creating value influences other system variables which may occur out of sight or not in the interest of individual stakeholders. Take for instance the wish to move from a petrol-based to a biobased economy by making a business of producing bioplastics, which may compete with land use and other requirements for food production [7].

1.4. CS Requires a Systems Perspective

To include the above shortly discussed aspects of *why* and *how* to achieve a CS, a systems perspective is needed. A systems perspective means a focus on the whole picture and not just single elements, awareness of the wider context, an acknowledgment of interactions among different components, as well as transdisciplinary thinking.

This covers, among others, quantitative insights in physical and ecological aspects like resource availability, resource use, and material flows. It also covers socio-economic aspects, e.g., price ratios, forms of cooperation, and the distribution of power. It includes insights into the potential for new technologies. The 'why' question, i.e., 'why do we want to create which value for ourselves or for mankind,' touches upon preferences and perceptions behind decisions and actions. Rational and emotional perceptions aim towards final personal or collective values, being monetary or otherwise, but always towards ultimate well-being. Our decisions may be influenced by others or by external factors.

Further, a circular systems perspective requires acknowledging the views and interests of different types of stakeholders, pinpointing opportunities, defining risks and trade-offs, and identifying topics on which the private and the public actors can take responsible action. Public opinion and social movements also play an important role in the circular transitions and should be included in a circular systems perspective.

A circular systems perspective can provide a proper understanding of the different systems, where they (can) link, and where benefits and costs will be shared [17–19]. In CS especially, trade-offs between higher-level ambitions, competition effects at lower levels, and personal well-being generate dilemmas that need to be in the open, if possible quantified, and dealt with. Categorizing different rationales for involving stakeholders in transdisciplinary research reveal that stakeholders show normative, substantive, social learning, and implementation objectives and that especially the latter require action perspectives [20].

To include all these aspects of the *how* and *why* questions a system perspective is imperative.

1.5. Integration Needed

A circular systems perspective cannot be developed from a single discipline, but also requires integration of different types of knowledge: alpha, beta, and gamma knowledge, as well as scientific and experiential know-how.

In their extensive review on transitions research Loorbach et al. [21] point out that there are three perspectives that each present different ways to understand sustainability transitions: in a socio-technical, a socio-ecological, or a socio-institutional way (Figure 1). These three views are linked to transition studies of different regimes (a regime being e.g., 'forestry', 'education', 'mobility').

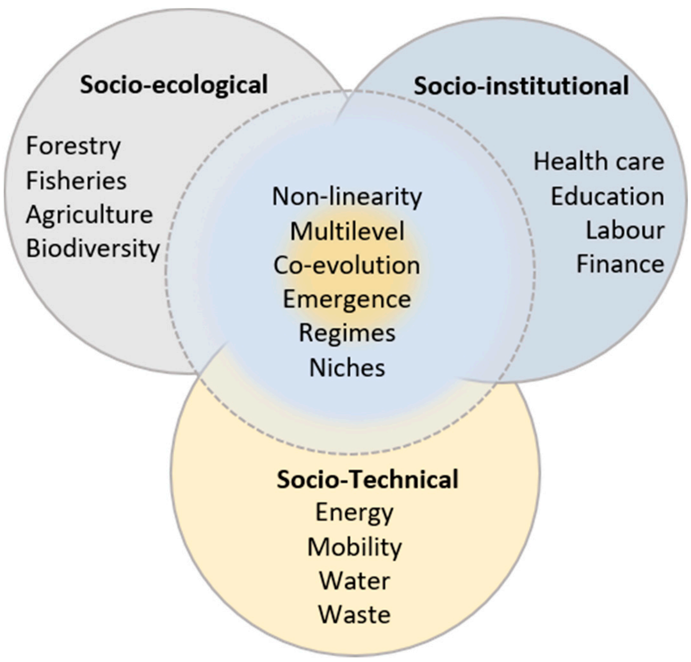

Figure 1. Three perspectives on sustainability transitions. Source: author with permission after [21].

Each of these regime perspectives is more or less represented by different disciplines. However, taking agriculture as an example, the required sustainability transition relates to many of the other regimes presented in Figure 1. In order to develop a systems perspective and translate higher-level objectives into action perspectives for lower-level stakeholders in different regimes, these views need to be integrated into one framework.

In this paper, we present an open framework for this purpose. To be useful in the context of a systems perspective, the framework must meet the following requirements:

- include the relevant aspects, which we discussed above;
- integrate the three perspectives of Figure 1;
- be recognizable for all disciplines;
- be applicable at multiple scales;
- be able to be worked out beginning with each component of the framework.

In the next section, we start our framework development by examining some typical examples of conceptual frameworks that are presently available and could potentially be used as a framework for a circular system perspective.

2. Materials and Methods

In the next sections, we discuss some well-known models that have been developed over the years for the relationship between society, technology, and the environment. The models were collected, proposed, and selected by all members of our multidisciplinary team as being the most relevant in each of our specific areas. We distinguish three approaches: a socio-technical, a socio-institutional, and a socio-ecological approach, following Loorbach et al. [21]. For each, we describe some representative examples. An overview of transition approaches, including a number of relevant aspects is presented in Table 1.

Table 1. Approaches of transition (authors' interpretation of Loorbach et al. [21]).

	Socio-Technical	**Socio-Institutional**	**Socio-Ecological**
Viewpoint	The uptake of new technologies in institutions, practices, regulations, culture	Processes of bonding and bridging; interdependency; power and hierarchy	Evolutionary processes in nature and society
Object	Innovation processes	Agency, power, practices	Ecological processes. Interaction between the natural and the social
Conceptual framework (*1)	Multi-level perspective, SNM, TIS	Triple, Quadruple, or Quintuple Helix	MAES, DPSIR, SES, AQUACROSS
Perspective on transition governance (*2)	Support frontrunners, room for experiments, facilitate upscaling	Broad coalitions between key players e.g., climate tables, national agendas	Evolutionary governance, small wins approach: facilitate societal learning

(*1) See Results for the meaning of model or framework abbreviations and references. (*2) Bos et al. [22].

3. Results

First, we describe the selection of relevant conceptual framework models in the transition approaches of Loorbach et al. [21] (Table 1): the socio-technical approach (Section 3.1), the socio-institutional approach (Section 3.2), and the socio-ecological approach (Section 3.3), with reflective remarks per framework/approach and overall reflective remarks in Section 3.4. Based on these remarks, we propose the new Butterfly framework to deal with stakeholders' action perspectives and integrate their lower-level objectives to higher-level societal objectives. This framework is presented in Section 3.5, with two examples of how the Butterfly framework can be applied in Section 3.6.

3.1. Socio-Technical Approach

There is a huge body of literature on innovation transitions and the management of these transitions. The selected models or frameworks are often used to describe and assess the transitions towards higher-level objectives such as climate neutrality.

Geels and Schot [23] have developed a transition model (Figure 2) that provides a perspective of action for actors who are involved in the development of new technologies and related innovations. It is based on the multi-level perspective (MLP), with three analytical concepts in a technological transition or system change: niche innovations, socio-technical regimes, and socio-technical landscape [23].

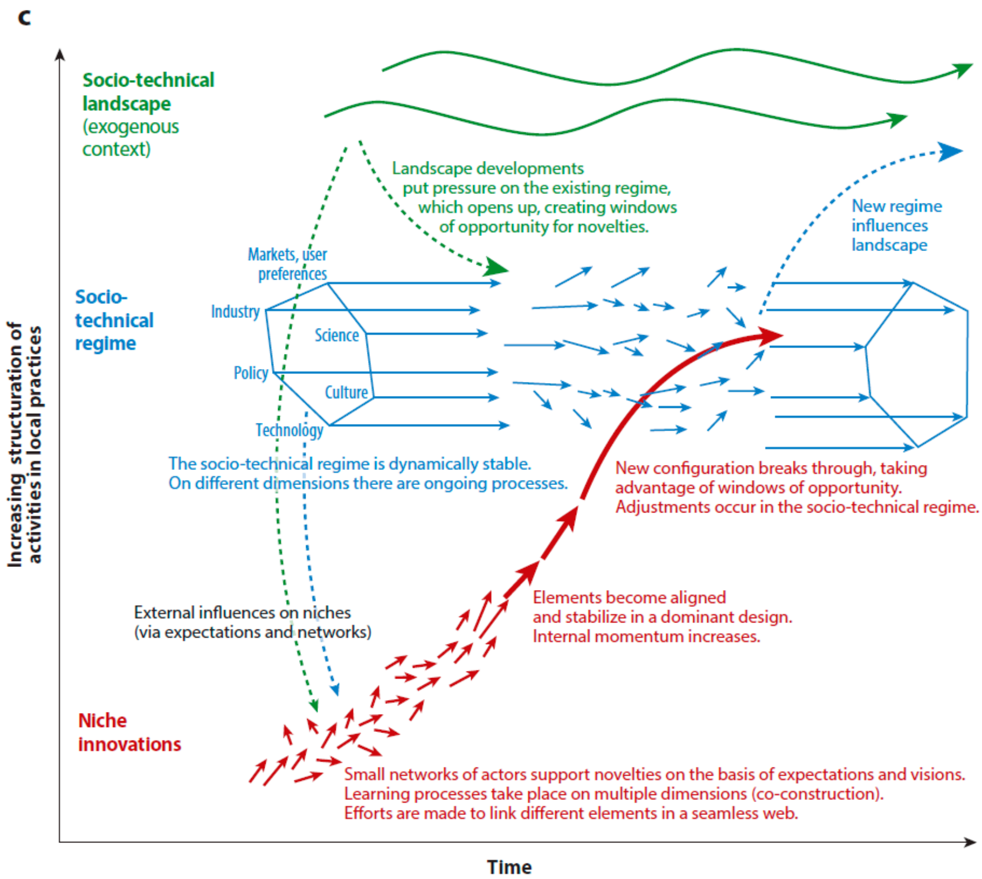

Figure 2. The transition model for new technologies and innovation by Geels and Schot. Adapted version with permission from [21].

Innovative developments at the niche level may cluster and lead to changes at the regime level. Many changes at the regime level may lead to changes at the landscape level and thus to a transition. Instability due to changes at the landscape level may put pressure on regimes and thereby create windows of opportunity for new niche developments at the regime level (the focus of SNM: strategic niche management [23]).

Israël-Hoevelaken et al. [24] present a concise overview of innovation models in the context of setting up co-operations for technological research & development (R&D). One of the first, but still informative, innovation models is the ***linear innovation model***, which presents a sequence or chain of key steps, from basic research, applied research, via development to diffusion, necessary for innovation [25]. This is an offspring of the method of estimating the maturity of technologies on the basis of nine technology readiness levels (TRLs), developed by NASA in the 1970s [26]. However, innovation is not a linear process, and therefore since the turn of the 21st century, ***circular innovation models*** have begun to appear [25,27,28]. These models explicitly reflect that an innovation process is a perpetual process, along a path of activities that has no fixed starting or ending point, stretching out beyond the boundaries of a single firm or actor.

Another model, ***TIS*** (technological innovation system), is based on the innovation system concept introduced in the 1980s [29,30]. According to a TIS, innovation is not determined merely by variables within one company but is simultaneously part of a larger innovation system, which includes the market, government, and research institutes. A TIS, therefore, is a type of innovation model that can be used to analyze and evaluate the development of a particular technological field [31], and as such is relevant for changing the technological system.

Reflective remarks

The transition model of Geels and Schot [23] (Figure 2) has its focus on the adaptation of technological changes, and less on agent-induced institutional changes. The impacts of transitions on the ecological system are not taken into account.

The linear and circular innovation models focus on the actual process of innovation. They do not focus on the transition they potentially may contribute to or the socio-economic effects of these transitions. Furthermore, these models do not take into account the impacts of the innovations or the transition on the ecological system.

TIS focuses on changes in the technological system, it does include market and government, but not the ecological system.

3.2. Socio-Institutional Approach

The ***Triple Helix model of innovation*** is an example of a socio-institutional approach [32]. This model refers to the interactions between knowledge institutions (universities, academies, research institutes), industries, and governments. Just like the double helix of the DNA molecule, these three institutions are linked at several points, each of which contributes to innovation processes (Figure 3). The triple helix can be seen as links between three institutions, but also as links between three kinds of processes in which they participate, the processes of producing value, producing knowledge, and producing the 'rules of the game.' The Triple Helix innovation framework has been widely adopted by industries, universities, and governments as a concept of cooperation. The concept has been successfully applied in many innovation policies and programs on a regional level, like the 'Brainport Eindhoven' or the 'Food Valley' in The Netherlands [33–35].

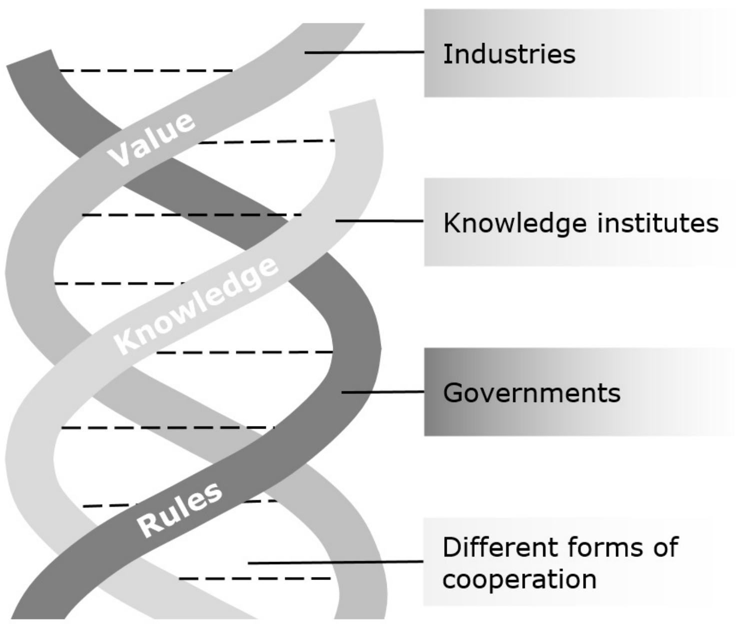

Figure 3. The Triple Helix model of innovation. Source author, adapted from [32].

Reflective remarks

The Triple Helix concept is criticized as being too simple, as well as too favorable for industries [36]. Alternatives are the Quadruple Helix in which civil society is added as the fourth, and the Quintuple Helix in which the natural environment is added. The value of the Triple Helix model is that it shows that a set of different forms of cooperation, even without a master plan, can lead to collaborations in which concrete innovations arise. However, it does not specify a perspective of action for the various actors involved. Furthermore, since the Triple Helix model gives no attention to natural flows, it is too limited for the assessment of circularity and climate neutrality.

3.3. Socio-Ecological Approach

Many concepts and models from a socio-ecological approach concentrate on the impacts of humans on the ecosystem and the function of ecosystems for humans. We discuss three generations of thinking: the pressure approach (DPSIR), the services approach (MAES), and the social-ecological approach (SES).

The ***DPSIR*** *framework* (Driving forces, Pressures, State, Impacts, and Responses; Figure 4) originates from the Stress–Response framework developed in Canada [37]. Later the framework was used by the OECD, the United Nations [38–42], and the European Environmental Agency [43]. DPSIR describes a chain of causal links and a feedback loop, which starts with *drivers:* socio-economic or environmental developments based on human needs. These developments lead to human activities which exert *pressure* on the natural and physical environment and cause a change of the *state* of this system. This leads to *impacts* that can cause several *responses* from society.

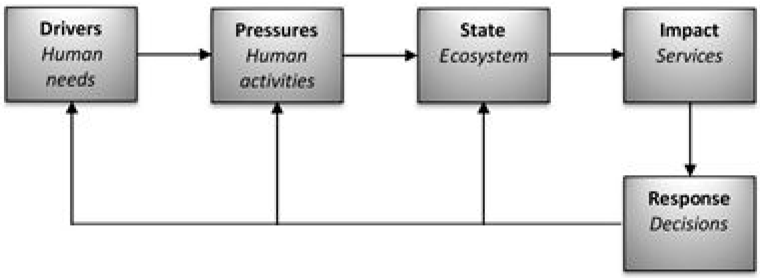

Figure 4. The DPSIR framework.

Reflective remarks

DPSIR distinguishes drivers and pressures on nature. Furthermore, DPSIR emphasizes the physical processes and physical relationships between humans and the natural environment but focuses mostly on the pressures on the ecosystem. The elements and processes in the socio-economic system are elaborated in less detail; they are only represented as policy goals and do not explicitly take ecosystem services into account nor their impact on human well-being. Further, the framework is lacking efforts to find a way of dealing with the multiple attitudes and definitions of issues by stakeholders and the general public [44]. Next to that, technological change and transition are not described by the DIPSR model.

The ***MAES*** *framework.* The model for mapping and assessment of ecosystems and their services (MAES) is developed as a framework for the identification of indicators [45]. It resembles the DPSIR framework, but unlike the DPSIR framework, it also includes the positive effects of nature for society by distinguishing several ecosystem services.

The MAES framework distinguishes two components (ecosystems and humans) and two relationships (ecosystem services and drivers of change/pressures on the ecosystems) (Figure 5). This leads to four types of indicators: pressures on the ecosystem, condition of the ecosystem, services from the ecosystem, and human objectives. The indicators can be used to evaluate nature and environmental policy and to provide information to assess progress towards sustainable development goals.

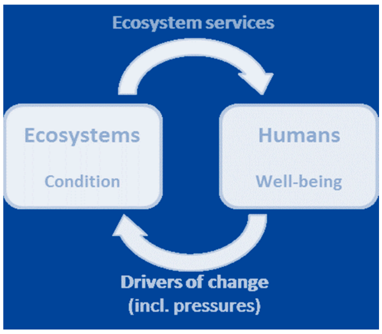

Figure 5. The conceptual model behind the MAES indicator framework. Source: author, adapted from [45,46].

Reflective remarks

The MAES framework pays more attention to ecosystem services than DPSIR, but like DPSIR, it does not take the dynamics of the social system and the technical system into account but limits the social system to goals and the technical system to pressures. In response, models have been developed that take the human aspect into account in more detail.

The ***social-ecological system*** *framework (SES).* The basic thought behind the social-ecological systems framework of Nobel prize winner Elinor Ostrom is that all human use of resources is part of complex, social-ecological systems [47]. She presents a common framework to facilitate multidisciplinary efforts for a better understanding of the functioning of the relationships between social and natural subsystems. Figure 6 provides an overview of the SES framework, showing the relationships among four first-level core subsystems that affect each other as well as the linked social, economic, and political settings and related ecosystems. The framework is meant to study specific social-ecological systems such as parks, coastal zones, or forests, and to identify relevant variables.

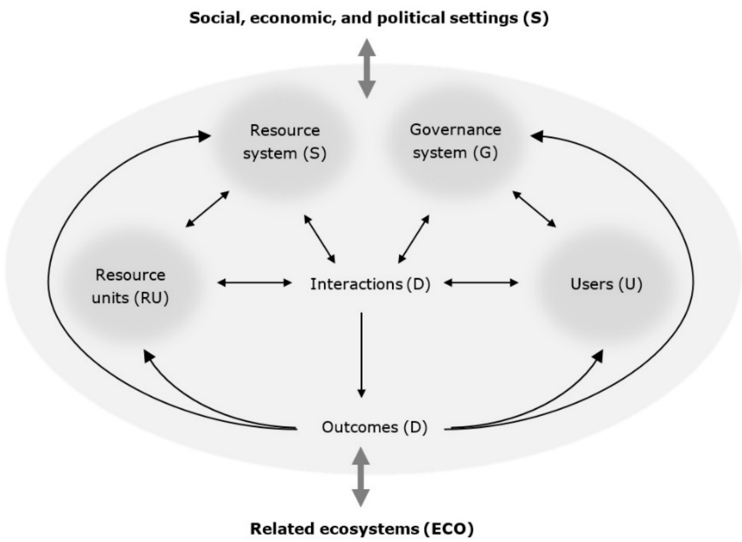

Figure 6. The social-ecological system (SES) framework. Source author, adapted from [47].

Reflective remarks

The SES model focuses on the human use of the ecosystem. It includes the governance system but does not take the technological development and the ways it can be changed into account. The available technology for the users is given and not perceived as a variable.

Ecosystems are defined as a dynamic complex of plants, animals, and microorganisms interacting as a functional unit. Humans influencing the ecosystem are also an integral part of ecosystems. These multiple roles are not conceptualized in either the DPSIR or the MAES framework. The social-ecological system approaches do try to integrate this in their frameworks.

AQUACROSS is another relevant model that takes into account the dynamics of the social system. It was developed as part of the similar named EU Horizon 2020 project [48]. This conceptual model aims to take the best of the DPSIR and ecosystems approach and has three building blocks: the impact pathway analysis (or the DPSIR in its various alternatives), the ecosystem services approach, and the interplay of both through the processes that take place in the social and the ecological systems. AQUACROSS combines both supply-side relationships, from ecosystems to human well-being, and demand-side relationships, from social systems to ecosystem conditions (Figure 7). In the model, this has been done by distinguishing different types of processes that relate to each other as aspects.

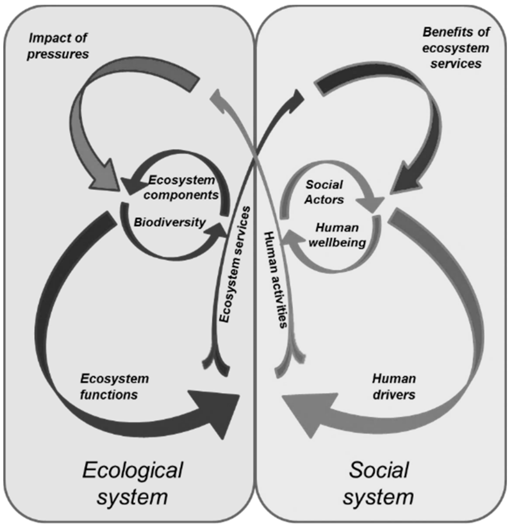

Figure 7. The AQUACROSS representation of the social-ecological system (SES) concept and its processes [48].

Reflective remarks

The concept that the ecological system and the socio-economic system are two different types of processes that manifest themselves simultaneously in every human activity is an important asset to consider. However, in this model, the human activities aimed at intentional interventions in nature, in which the social and the ecological system meet, are not included. Thus, technological development and the ways it can be changed are also not taken into account.

3.4. Overall Reflection

The models discussed here show a conceptual development over time in which society is increasingly taken into account: sometimes as a subsystem (e.g., SES), or sometimes as an aspect system (e.g., AQUACROSS). In general, they fall short in giving a broad systems perspective. Some models have copied and/or adapted parts of other models on their own, which contributes to advances in science, with the re-use of earlier developed valuable concepts (e.g., AQUACROSS, DPSIR).

What is missing from these models for advances in the circular society, i.e., linking and providing action perspectives for multi-stakeholders for themselves and for higher-level societal objectives, is the way in which technological developments take shape and are integrated into the multi-stakeholder system. In most models, technology is mainly included as pressure and not as a system itself with its own characteristics.

We conclude that a comprehensive framework that deals with *all* these aspects is missing. A framework visualizing dilemmas and offering action perspectives to various stakeholders at different levels and integrating effects at different scales is urgently called for to support the transition to CS. We, therefore, present an alternative, more extensive model in Section 3.5, which integrates these aspects in the socio-technical, socio-ecological, and socio-institutional perspective, and can be applied by stakeholders irrespective of their background.

3.5. Description of an Alternative, Integrative Framework (the Butterfly Framework)

In this section, we present a framework that contributes to the narrative on the transitions towards a more circular and climate-neutral society and helps in an interdisciplinary context to understand the interlinkages, synergies, and trade-offs between different aspects and scales of the system. The following three basic premises apply:

1. The objective of the framework is to assess the role of circularity (as a *means*) in relation to climate neutrality (as an *objective*). Both means and objectives relate to flows, therefore, the basic elements of our model are the interconnected flows and cycles of matter (water, carbon, other nutrients), energy, knowledge, and power between entities like components of nature, landscape elements, industries, farms, knowledge institutions, governments, consumers, etc.
2. Flows have two aspects (insofar as they concern humans): a material aspect and the aspect of meaning. Materials relate to (flows of) substances, which in total constitutes the ecological system (nature, ecology, both biotic and abiotic). Meaning relates to changes in (economic) value, social connections, norms, and values that constitute the social aspect system (social in a broad sense, including social, economic, and cultural aspects).
3. In all concrete human activities, matter and meaning conjoin. Particularly in man's attempts to intervene in nature for its own benefit: technology. Therefore the technical system is central to our model.

This assumption leads to a distinction between three systems: the technical system, the ecological system, and the socio-economic system (Figure 8). These systems are defined as follows:

- The technical system includes all the processes in which people try to use natural processes and inputs to improve their quality of life. It is the (sub)set of human activities and processes that intervene with the physical world at a given place and over a defined period of time. The technical system, therefore, is part of both the socio-economic and ecological systems.
- The ecological system is the whole of physical and ecological processes. The ecological system is the physical manifestation of all living and non-living matter and physical flows of materials. Part of these processes take place outside human influence, others include humans and their interaction with the natural system through their physical activities.
- The socio-economic system is the whole of social, economic, and cultural processes. Social processes relate to the dynamics in human relationships based on power, rules, habits, personal preferences, etc. Economic processes are about how individuals and societies choose to allocate scarce resources. Cultural processes relate to shifts in values, meanings, and opinions.

While distinguishing the socio-economic and ecological system conceptually, it is important to be aware that humans—who, in fact, shape the socio-economic system through their behavior—are physically part of the ecological system.

The socio-economic system influences the ecological system by deliberate choices that interfere, but also by unintended actions. The ecological system provides all kinds of services to the socio-economic system which can benefit human well-being but may also have negative impacts with potential knock-on effects on human well-being.

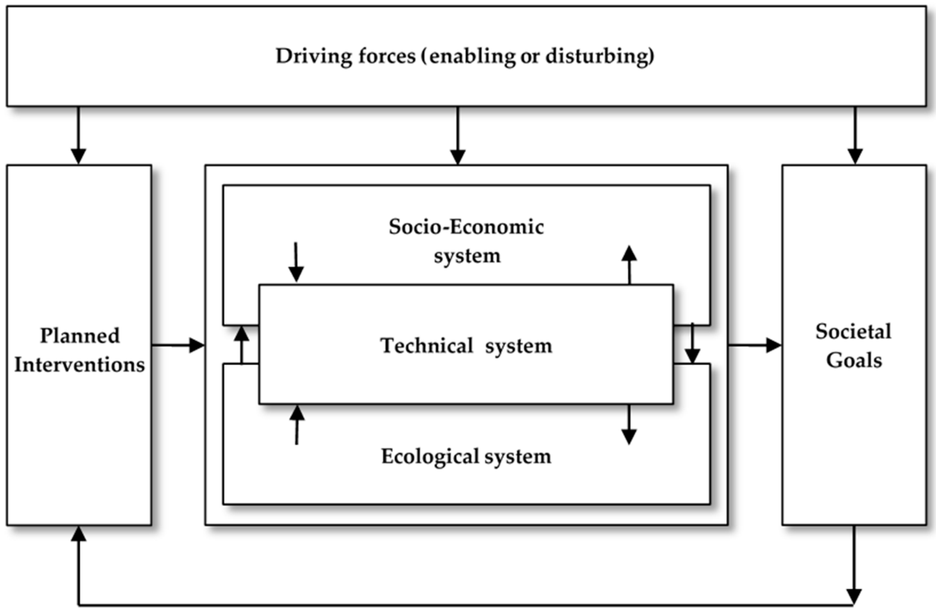

Figure 8. Integrative framework.

From the perspective of achieving a circular and climate-neutral society, the most important flows from the ecological system (often created by the technical system) are the extraction of resources and the deposition of waste flows including greenhouse gas emissions. However, any human activity, whether part of a technical system or not, may have an impact (e.g., on biodiversity). The degree of circularity and the degree of climate neutrality follows from the magnitude of these flows or pressures and their trade-offs.

While the combination of these three systems represents the system as a whole, some aspects require emphasis to understand the relevant dynamics of the system. These aspects are designated separately for clarity but are inherently part of the whole system.

First, we distinguish **the societal goals**. Some internationally relevant frameworks define broadly accepted international policy goals across three aspects of sustainability, i.e., environmental, social, and economic, and can together be considered synonymous to the overarching goal of well-being in the vision of the OECD [49]. Two examples are the People-Planet-Profit (PPP) framework and the Sustainable Development Goals of the United Nations.

Second, we distinguish **planned interventions**. Actors like governments, public administration, NGOs, firms, researchers, and consumers continuously try to make use of or influence the development of the system towards their own goals. Change of the system emerges partly from daily actions (routines) but also results from planned interventions. Both these actions and planned interventions are part of the socio-economic system, but in the framework, the planned interventions are conceptually distinguished. These comprise governmental policies, strategies of large companies, arrangements of civil society, and can take forms like regulations, legislation, fiscal measures, guidelines, service provision, communication, or physical planning.

Last, when this framework is applied to a specific situation, it is useful to distinguish between forces that are part of the situation and forces that can be considered as non-influenceable and external. Therefore, it is useful to distinguish the main (external) **driving forces** of a system. From the perspective of the transition towards a circular and climate-neutral society, there are two kinds of driving forces, those that disturb transitions and those that enable transitions. Driving forces can have an ecological or a socio-economic character: natural developments, but also changes in consumer preferences, technology, demographics, and institutional developments can be considered as a driving force. However, which forces need to be considered as driving forces, depends on the scale of application of the framework. If the framework is applied on a local level or on the level of an individual factory, then e.g., climate change can be considered as a driving force. However, if the framework is applied on a world scale, climate change has to be considered as part of the system. The framework is also meant, however, to integrate local level developments and actions to higher scale levels, to the higher ambitions.

Figure 9 summarizes all these systems and aspects in an artist's impression in which the framework is pictured by the flight of a butterfly. The core of the figure is the butterfly which represents the ecological system and the socio-economic system (the two wings) with the technical system (the body) at its center. Flowers represent the societal goals one aims to achieve. Planned interventions to reach those goals are represented by the signpost in the figure. Driving forces are shown as the wind, sun, and clouds, sometimes driving the system away from, or closer to the societal goals.

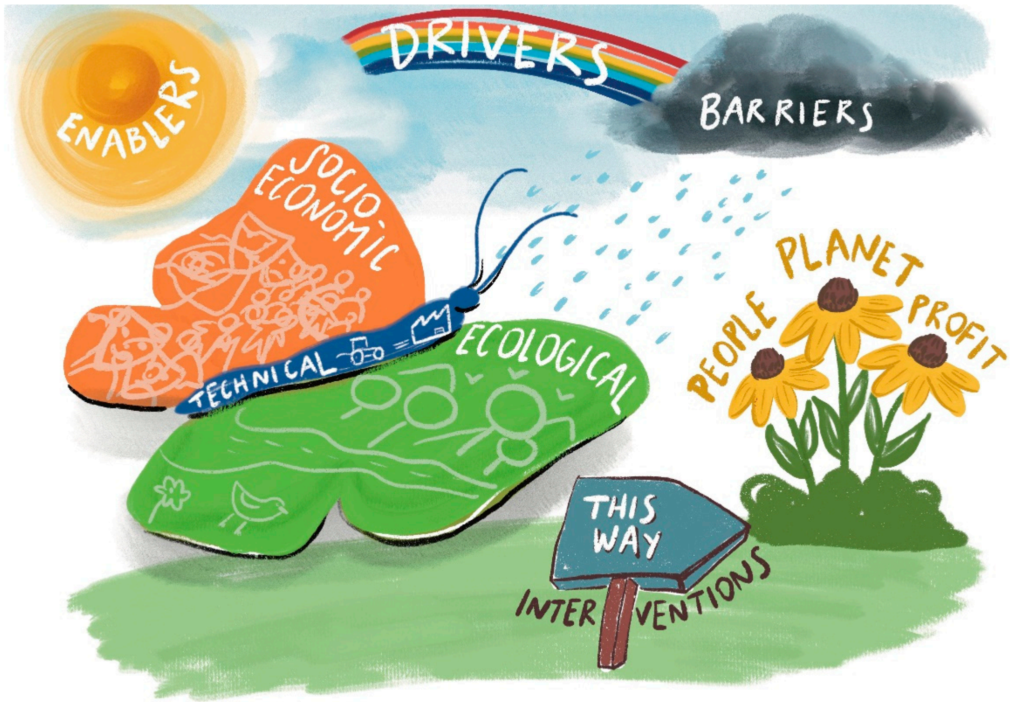

Figure 9. The Butterfly framework.

To summarize, the *Butterfly framework* presents an overview of system relations on the level of the technical system, the ecological system, the socio-economic system, and their interrelations. It includes the aspects of system boundaries and extraneous driving forces. It also distinguishes the available instruments for decision-makers and the consequences of the use of these instruments to reach societal goals. The framework structures the elements that may be included in a monitoring and evaluation framework, including requirements for the integration of effects of activities at lower scales to analyze effects on higher-level ambitions. These make it an inclusive tool for interdisciplinary projects in the field of the bioeconomy. Some specific examples of the application of the framework are presented in the next sections.

3.6. Examples

The framework is applied by generating questions for each element of the framework and elaborating on how these elements can be interpreted (Table 2). The Butterfly framework can be started with any element. The more elements are addressed, the better results for relevant action perspectives for different stakeholders in the system are obtained, and the better outlook on eventual effects at the higher societal objective becomes visible.

Table 2. From the Butterfly framework to general assessment questions.

Butterfly Framework Elements	Assessment Questions
1. General: System Boundaries/Scale/Scope	1 Is the scope in terms of system boundaries of the theme well defined?
2. (Societal) Goals	2.1 Are problems/challenges clearly defined?
	2.2 Are clear and ambitious targets set?
	2.3 How will results be integrated?
3. Drivers	3 Which driving forces are involved? What are the positive and negative impacts of driving forces relevant to the theme?
4. Interventions	4.1 Are relevant stakeholders identified and engaged?
	4.2 Are scenarios used to create an image of autonomous development, intended change, and one's own role in it?
	4.3 Are adequate interventions defined?
	4.4 What is the potential impact of these interventions?
5. Technical System	5.1 What is the (technological) state-of-the-art? What changes are expected?
	5.2 What is the role and the impact of the supply chain in the environmental impact of the whole chain?
6. Ecological System	6.1 What is the expected impact on ecosystem elements?
	6.2 Are there quantifiable effects on ecosystem services?
7. Socio-economic System	7 Is it possible to identify societal impacts?

We provide two examples. In Section 3.6.1, we explore (new) plant breeding (techniques) for circular potato production systems adapted to and counteracting negative climate change effects, and in Section 3.6.2 we explore the business strategy for a sustainability program of a dredging company in The Netherlands.

3.6.1. (New) Plant Breeding (Techniques) for Circular Potato Production Systems

Potato is the most important food crop in the world after maize, wheat, and rice. Potato provides more nutritional value than many other crops. The Butterfly framework is applied to generate questions on the introduction of more circularity in potato production and processing systems, what they should look like, and if, how, and how fast that could be realized, and what that would contribute to climate-neutral or climate robust production systems.

The idea to breed for sustainable and circular production systems fits with higher objectives of climate-positive results if relevant progress can be made towards plant or production system characteristics in view of circularity concepts. New plant breeding techniques (such as gene editing or CRISPR/Cas [50], based on experience with other crops [51]) are assessed as the question is how (fast) such systems can be developed and what these systems could eventually contribute towards the reduction of climate change. Special attention should be given to the negative feedback loop of viruses of which the detection is an important step forward to avoid progressing the negative side effects [52], and to the losses of nutrients that are emitted to air and soil, as these are more pronounced at the end of the response curves of any inputs, following the law of diminishing returns, until at the plateau where additional inputs eventually have no effect at all: they are completely lost to the environment [11,53–56]. It is also important to know how the socio-economic system reacts [57], if there are any ethical issues to address [58], and if NPBT is applied in a viable way [59,60].

When the presented relevant frameworks (Table 1) are applied, it becomes clear that they fail to address the required integrated circular systems perspective to address action perspectives for relevant stakeholders and trade-offs at different scales for societal objectives, such as climate neutrality. The socio-technical frameworks (multi-level perspective, SNM, and TIS) do not take the impacts of transitions on the ecological system and socio-economic effects of these transitions into account. The socio-institutional frameworks (Triple, Quadruple, and Quintuple Helix) give no attention to the natural circular flows; hence climate neutrality is not evaluated. The socio-ecological frameworks (MAES, DPSIR, SES, and AQUACROSS) fail in linking and providing action perspectives for multi-stakeholders for themselves (technological change and transition are not described), nor the effect on higher-level societal objectives.

As shown in Table 3, with the Butterfly framework, assessment questions for (new) plant breeding (techniques) for circular potato production systems can be fully addressed (Table 3).

Table 3. From the Butterfly framework to assessment questions for introducing new plant breeding techniques for circular potato production systems adapted to and counteracting negative climate change effects.

Butterfly Framework Elements	Assessment Questions
1. General: System Boundaries/Scale/Scope	1.1 Who are the potato producers and processors in their production and processing environment? 1.2 Where are they located?
2. (Societal) Goals	2.1 New sustainable circular and viable potato production systems 2.2 Potato production and processing systems adapted to climate change and/or reducing climate impact
3. Drivers	3.1 What are (changes in) consumer preferences (e.g., the wish for potatoes with a reduced carbon or water footprint)? 3.2 What technology is currently applied and how could that change (how and where potatoes are engineered, cultivated, and processed)? 3.3 Demographics (how and where would demographics influence the demand for specific potato products)? 3.4 What institutional factors (regulations, the current tax, and subsidy system, habits and organizational configurations) are involved in more circular potato production and processing systems?
4. Interventions	4.1 What interventions are possible? 4.2 Can we use traditional or do we need to stimulate new plant breeding techniques?
5. Technical System	How we can make potato production systems more circular 5.1 What traditional and/or new techniques such as artificial intelligence, precision agriculture, and new plant breeding techniques (NPBT) are available or should be developed? 5.2 How would traditional and/or new techniques affect optimization and balancing material flows at different geographical locations, at different scales, (with less) land use, (less) nutrient use, (less) water use, (less) crop and soil sanitary agents? 5.3 Which accumulation effects of hazardous (bio) substances should be monitored in more circular production systems? 5.4 How can effects be quantified, monitored, and integrated over the potato producing and processing sectors?
6. Ecological System	6.1 What is the expected impact on ecosystem elements? 6.2 What are the consequences, chances, risks, and trade-offs that should be known, and possibly quantified, with regards to resource use (e.g., land, water, nutrients, crop protection agents) and material flows 6.3 At what scale loops can be closed? 6.4 Are there any hazardous (bio) substances cumulating from circularity? 6.5 Are there quantifiable effects on ecosystem services?
7. Socio-economic System	7.1 What are the drivers for new plant breeding techniques? 7.2 Are new plant breeding techniques acceptable or are there any ethical issues to address?

3.6.2. Assessment of a Business Sustainability Strategy

To use the framework to assess a (business) strategy the parts of the framework can be translated into questions aimed at how the different aspects of the framework in the strategy have been interpreted and converted to measurable indicators, and whether aspects have been completely or partially overlooked.

In this way, the Butterfly framework is applied to the supply chain strategy of Van Oord Dredging & Marine Contractors [61]. In the context of the pursuit of corporate social responsibility, Van Oord Dredging & Marine Contractors was designing a sustainability program for its supply chain with the main purpose of reducing environmental impact, which will be used in procurement procedures. In this program, five themes were distinguished: more transparency; reduce greenhouse gas emissions; reduce air pollution; reduce single-use plastics; stimulate circular business models. For each of these themes, a set of questions was developed, which are summarized in Table 4.

Table 4. From the Butterfly framework to assessment questions for a business sustainability strategy.

Butterfly Framework Elements	Assessment Questions
1. General: System Boundaries/Scale/Scope	1 Is the system limited to just the supply chain or is it the entire business chain?
2. (Societal) Goals	2.1 Is the strategy aimed at the most important sustainability themes according to European policy agendas?
	2.2 Are the identified sustainability themes translated into clear and measurable targets?
3. Drivers	3 What are the positive and negative impacts of driving forces relevant to the identified sustainability themes?
4. Interventions	4.1 How are the suppliers engaged?
	4.2 What is the scope of the intended scenarios?
	4.3 Which interventions are defined for each of the identified sustainability themes?
	4.4 How is the impact of the interventions for each sustainability theme addressed?
5. Technical System	5 What is the role and the impact of the supply chain in the environmental impact of the entire chain?
6. Ecological System	6.1 Is the impact of the interventions on ecosystem elements (sea and land) covered in the strategy?
	6.2 What is intended in the strategy to quantify the effects on ecosystem services?
7. Socio-economic System	7 Will the sustainability strategy also cover societal impacts in the next phase?

We concluded that the aims, targets, and boundaries of the Van Oord sustainability themes are in general well defined and described. The interventions are mostly in line with the objectives and will probably have a positive impact on many components of the environment. However, the application of the Butterfly framework also led to two points of attention. First, the theme of biodiversity received little attention in the strategy. We therefore recommended including possible impacts on biodiversity and ecosystem services. The second point of attention concerned the scope of the strategy. The program is focused on the supply chain, but impacts on sustainability impacts at the entire chain level are not explicitly included. We advised measuring the actual impacts of the strategy also at the chain level. This aspect would have been missed by any of the other frameworks. In Table 4 the assessment questions for a business strategy are addressed.

4. Discussion

As introduced by Loorbach et al. [21], one can consider three perspectives to understand and approach sustainability transitions: a socio-technical, a socio-ecological, and a socio-institutional perspective, each with its specific regimes (Figure 3). Aiming for a circular and climate-neutral society, touches on high-level ambitions involving many and a variety of stakeholders with individual or grouped ambitions at lower levels, thereby dealing with many multidisciplinary and transdisciplinary opportunities, problems, and solutions. We argue that these three perspectives should be fully integrated to support sustainable system transitions with clear action perspectives, and avoid misunderstandings and inefficient solutions. A comprehensive and fully integrated framework can help.

As discussed in Section 2, a variety of models and frameworks exist that have different application areas and purposes. These are valuable building blocks for providing insights and predictions in different domains/regimes.

The Butterfly framework is mainly intended for situations of interdisciplinary cooperation in which policy-makers, business strategists, consultants, innovators, and researchers of different disciplines work together: at the one hand for their own confined interests, ambitions, and objectives, and at the other hand for societal objectives at higher integration levels, such as climate neutrality. The application of the framework is explained more concisely in the Butterfly handbook [62].

The Butterfly framework does not provide solutions but enables to face questions on how to find opportunities, approach problems, and their solutions and deal with trade-offs in an integrated way. It can be used as a checklist or as a map: a scale is selected to define system boundaries, influenceable and uninfluenceable processes (drivers), then questions are posed concerning (problems in) the state of the system, goals (aimed at the preferred state of the systems), interventions, and impacts (on the system).

Circular approaches to curb climate change and decrease pressure on the environment merely seem to address options for using or recycling waste streams in the agricultural production system, or to other business cases for food or non-food production (where increasing the product lifespan gets more and more attention), or renewable biomass replacing finite fossil resources. Although appealing from a business point of view, these partial solutions fail to deal with the whole systems approach. Attention for the other challenges is often lacking, i.e., reducing resource inputs, increasing resource use efficiency, avoiding and/or reducing emissions, and the idea that doing 'nothing' (refuse) would also contribute to specific ecosystem services and personal well-being.

In the framework, we try to give room for all three perspectives on transition processes, by giving a general guide on how to use the framework rather than a fixed set of steps that need to be taken. We focus explicitly on the three dimensions socio-economic, technical, and ecological by describing them separately, but presenting them as one body. To be successful, each of them should be equally important: using the Butterfly framework it should be an open invitation to everyone involved to share their ambitions and knowledge, do justice to each stakeholder's position, look for opportunities, and provide a basis for solving problems on the way.

5. Conclusions

A circular and climate-neutral society is all about delicate balances, interactions, and trade-offs in the socio-economic and in the ecological system, which requires a systems perspective for proper analyses and further action. An integrated systems perspective like the Butterfly framework does not yield short-sighted quick wins or practical solutions, nor unrealistic panoramas for the one or the other, but provides relevant and integrated insights to discuss and investigate different pathways for a balanced circular and climate-neutral bioeconomy, with agroecological production systems well embedded in society, respecting responsible human consumption, a viable agricultural and processing sector, biodiversity, and natural resources now and in the future. The framework is particularly relevant for interdisciplinary groups to exchange information among themselves, develop a common language, and integrate disciplinary approaches.

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