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Shifting towards a circular biobased society

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How can we accelerate the transition towards a circular bio-economy and translate dreams into practice? There is a pressing need to swiftly say goodbye to the linear society as it exists today and move towards a circular one. To underpin this transition with action, we need to use the circular bio-economy principles of **Safeguard – Avoid – Prioritise – Recycle – Entropy** as guidance. Applying these principles requires calls for a fundamental change, including policies, technologies, organizations, social behaviours and markets, into account when we (re)design elements of our agri-food system. This will only work if we change together and if we utilise scale to optimally value our precious resources.

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About Connected Circularity

It is widely agreed that the **physical limits** of the Earth set the ultimate boundaries for all human economic activity. Without a healthy planet, societies cannot thrive and economies cannot flourish (Fischer et al., 2007; Steffen et al., 2015). However, the 'extract-produce-consume-discard' models of our current societies are exhausting the biological and physical resources of the planet. Our food system, for example, releases about a third of all human-induced greenhouse gases and is responsible for a third of global terrestrial acidification and the majority of global eutrophication. Our food system also drives deforestation, loss of biodiversity and land degradation (Crippa et al., 2021; Poore and Nemecek, 2018).

The '**circular economy**' is increasingly seen as an important alternative for a sustainable (food) future, both in science and society (Jurgilevich et al., 2016; Stahel, 2016). Given the mission of Wageningen University & Research (WUR), the investment theme **Connected Circularity** focused on the potential of **biomass** in the circular economy, more specifically on the potential of a biobased society. Biomass is the basis of a biobased society, which comprises those parts of the economy that use renewable biological resources from land and sea – such as crops, forests, fish, animals and micro-organisms – to produce food, chemicals, materials and bio-energy. Although a complete circular biobased society is a bit of a utopia, i.e. a fantasy, as some losses are unavoidable in ecological processes, moving towards a higher degree of circularity in a biobased society is essential for a sustainable future.

Despite increasing interest, only a few studies have addressed the concept of circularity in the context of food or bio-renewable systems (Jurgilevich et al., 2016). De Boer and Van Ittersum (2018) were the first to introduce a conceptual framework for circularity in the food system. Muscat et al. (2021) have extended this framework to also include the production of bio-renewables, such as clothing, bioplastics and bio-energy. They developed **five principles** to guide biomass use towards a circular bio-economy (see text box 1).

While circularity can affect all three pillars of sustainability, it specifically addresses staying within the **planetary boundaries** (see Figure 1). A true, sustainable circular bio-economy also requires respect for the **social foundation**. This foundation includes essential rights for humans and animals, such as the right to healthy and safe

Text box1:
Five principles to guide biomass use towards a circular bioeconomy
(from Muscat et al., Nature Food, 2021)

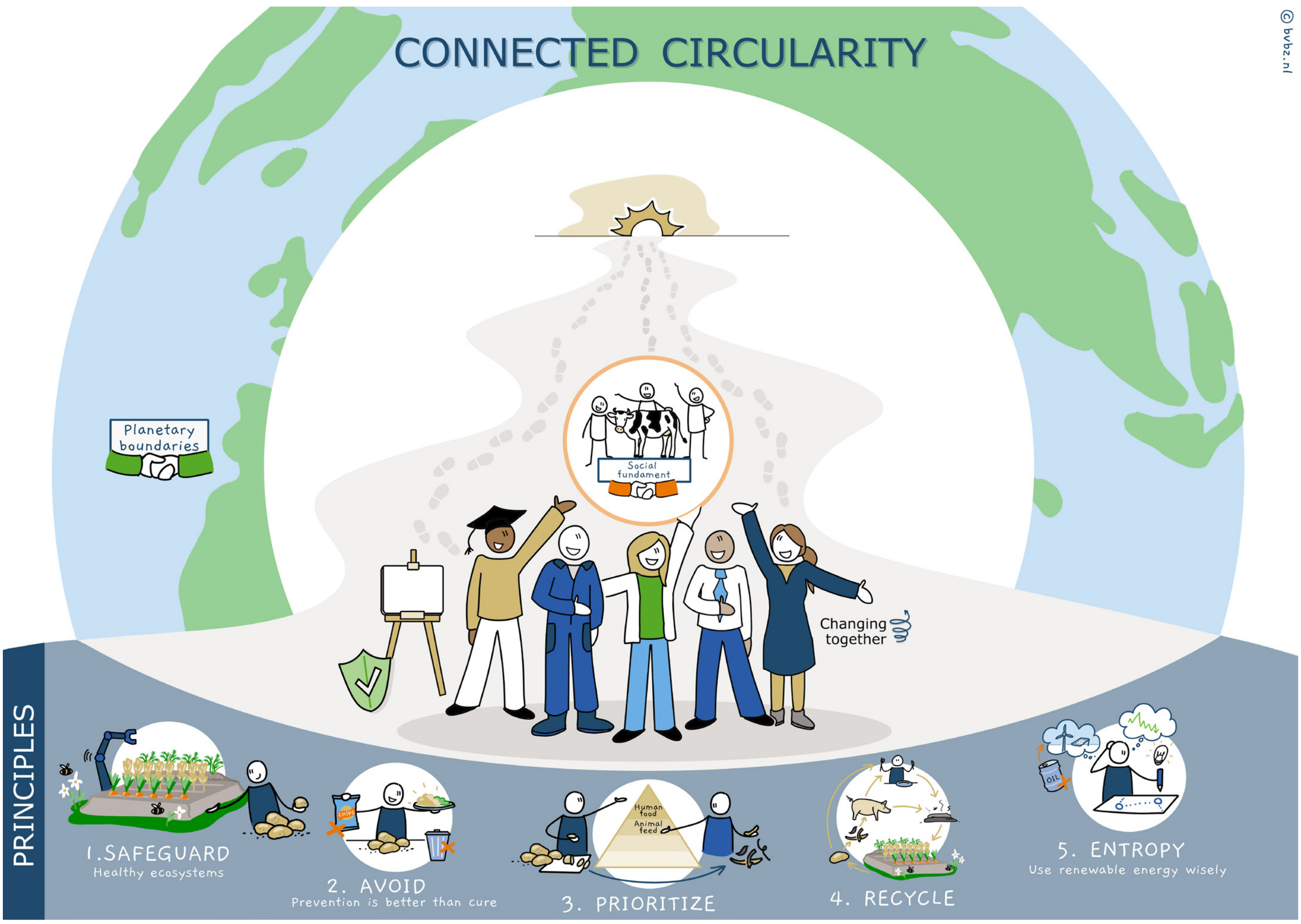
1. **Safeguard.** This principle addresses the importance of safeguarding and regenerating the health of our ecosystems. Biomass production, being the basis of the bio-economy, requires healthy aquatic, arable, grass-land, and forest (agro)ecosystems. To safeguard the health of these systems, farming, fishing and forestry practices must utilise natural resources at a rate that does not exceed their regenerative and absorptive capacity, to ensure current and future availability of natural resources.
2. **Avoid.** This principle addresses the importance of avoiding the production and use of non-essential biobased production, and the losses and waste of essential ones. Avoiding non-essentials can prevent unnecessary exploitation of natural resources, especially as impacts of production are unlikely to be fully offset by recovery and recycling.
3. **Prioritise.** This principle addresses the importance to use biomass effectively. It refers to the priorities in use of biomass. It argues that priority should start with basic human needs (e.g. food, pharmaceuticals, clothes) and sectors without sustainable alternatives (e.g. chemical industry).
4. **Recycle.** Even if waste of food and non-food bioproducts is avoided, the production and consumption of essential food and non-food biobased products results in by-products, such as crop residues, manure, human excreta or slaughterhouse waste. This principle calls for nutrients and carbon from by-products to be effectively (see prioritise) recycled into the biobased system.
5. **Entropy.** The driving force behind the recycling of nutrients and carbon in (agro)ecosystems is energy. Increased circularity and recycling costs energy and a fully circular bioeconomy is difficult to achieve given the loss in consecutive cycles. This principle not only advocates moving towards renewables, but also stresses the importance to minimise energy use.

food, labour protections and farm animals that experience a happy life. Together, the planetary boundaries and the social foundation of our biobased society define the **safe-and-just operating space** where human, animal and planetary wellbeing is ensured (see Figure 1).

A transition towards this safe-and-just operating space for the biobased society, however, calls for **transformative change**, involving technological changes (e.g., reducing dependency on 'virgin' resources, maintaining/revitalising production systems), organisational changes (e.g., reconfiguration of social networks, patterns of interaction), behavioural changes (e.g., in paradigms, in underlying norms and values, in power structures), market changes (e.g. innovative business models, subsidies, taxes, consumption patterns) and institutional changes (e.g., new institutional arrangements and regulatory frameworks). This transition requires **connections** between different actors (public, private), different policy domains and different scales.

To accelerate such a transformative change, we built on the **small-wins framework** developed by Termeer et al. (2017, 2018). The circular economy debate generally results in an immense ambition of realising transformative change that is concurrently in-depth, large-scale and quick. The small-wins framework departs from the assumption that realising this change simultaneously is virtually impossible because of the inherent trade-offs between them and may trigger dysfunctional levels of paralysis and overestimation. Paralysis occurs when people experience or define the wickedness as so overwhelming that it discourages them and prevents them from doing anything about it. Overestimation is the belief that wicked problems can actually be solved, implying a focus on one aspect or a single viewpoint (Roe, 2016).

The aims of the 'Connected Circularity' programme, therefore, were to provide an integrated system analysis of potential futures (dreams) of a circular bio-economy, and to study associated 'small wins' to accelerate a transformation towards a circular economy. The flagship projects within the Connected Circularity programme collaborate with all stakeholders, from small entrepreneurs at the local level to system partners at the global level, to support the transition towards a circular bio-economy. Showcasing various initiatives, challenges and scenarios, the flagship projects deliver insights and tools to translate



circularity in practice. The main issues addressed include the following:

1 **Designing:** How can we create a circular design from the start and not as an afterthought while creating living communities and new ways to use bioresources in an urban environment?
2 **Safeguarding:** How can we ensure the quality and safety of recycling biobased products and materials for animals and humans (e.g. health and welfare risks), and the environment (e.g. accumulation of residues of veterinary or human drugs in soils or water)?
3 **Changing together**: How to accelerate bio-economy initiatives through multi-actor collaboration. Transformation to the bio-economy is embedded in society and, therefore, requires research in clear connection with relevant actors, or in other words a science-in-society approach. Involvement of actors in the design of potential futures (dreams) is needed for the identification and valuation of small wins (real-life in-depth changes).
4 **Scaling:** How can we tackle trade-offs for circularity that occur across different scales (local – regional – national – global), and how can we bring balanced decisions to the table of business and policy makers).

The small-wins framework provides an **alternative governance perspective** by focusing on how transformational change can be shaped through accumulating a series of small wins. Small wins are defined as concrete, completed, in-depth changes towards, in this case, a circular biobased society (Weick, 1984). They can accumulate into transformative change through various **non-linear propelling mechanisms**, such as energising, learning by doing or the bandwagon effect (Weick and Quinn, 1999). The small-wins framework consists of three steps: 1) setting a provocative ambition following the previously explained principles, or in other words identifying aspirations, even dreams; 2) identifying and valuing small wins that contribute to realising these dreams; and 3) activating incentives and unblock barriers to enable accumulation of small wins which thereby lead to transformative change (see also Termeer et al., 2017).

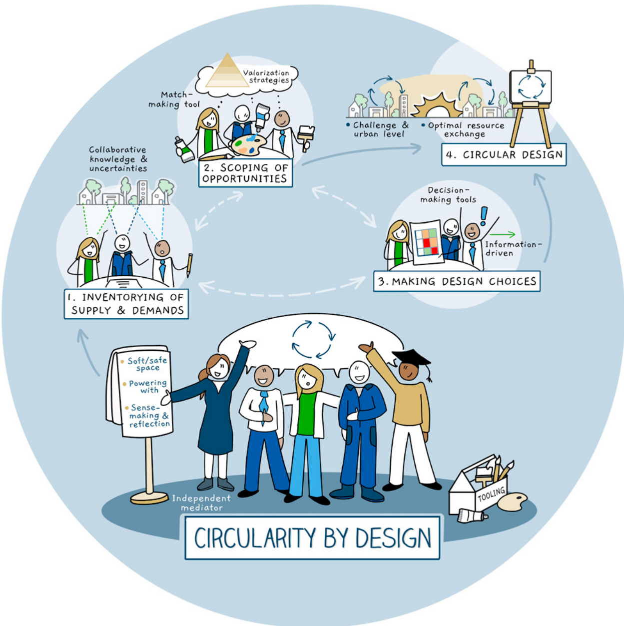
We have focused on projects related to cases that are primarily relevant for the Netherlands, as part of Europe, because circularity forms the basis of the vision of the Dutch government on the food system (e.g., Vision of the Dutch ministry of Agriculture, Nature and Food Quality 'Valuable and connected', 2018).

Design for the urban environment

By Hilke Bos-Brouwers

The importance of a Circular Design perspective for the urban environment

Relatively simple questions guided the research: What does circularity mean within the city context, for example, what happens if you try to close the loop of food and biomass resources, and how can you connect producers, services and consumers in the urban environment?
To answer these questions, one needs to look into the meaning of design and urban in relation to the circular bio-economy.



Design indicates that something is **intentional**, from the onset and throughout. Design does not happen spontaneously, and it cannot be left to its own devises. To support the design process, you need an **devices mediator** who stimulates interaction between all actors involved. The interaction needs to have a co-creative process, which itself needs a soft and safe space for 'designers' to work in. Those involved are committed to **sense-making and reflection**, which is not necessarily easy or in step with any leading consensus. Designers are **working with**—not over—each other. Design also presumes the stage **before implementation**. However, a design typically does not start with a blank sheet: There are likely existing preconditions and even physical elements to take into account (e.g., buildings, infrastructure, organisations' preferences).

Circularity within the urban environment raises important questions about **feasibility**: How circular can a city become? With an ever-growing urban population, the city itself will never produce enough food for its inhabitants. On the other hand, what citizens eat and use influences the demand for resources heavily and shapes supply chains and the regions where food and bio-materials are produced. We are left with additional questions: What is the optimal balance where inputs and outputs operate in an **optimal exchange of resources**, fitting the societal context and needs of citizens? Increasingly, cities are recognised for the role they play in the food system. Ambitions and strategies are being developed to become climate neutral, sustainable, healthy, etc. Circularity by design helps to turn that dream off in the distance into applicable practice. It also **connects grassroots-level challenges with urban-level achievements**.

A circularity-by-design approach

It is aimed to arrive at better designs than the current linear practice. Working with AMS Institute and Challenge Owners from the Amsterdam Metropolitan Area (AMA), we constructed tools to support cities, municipalities and regions in their transition towards a circular bio-economy. Our results inform and encourage stakeholders at the urban and regional levels across the globe to take this circularity-by-design approach. The approach consists of four steps:

Step 1: Taking inventory of supply and demand
The scope of what one person sees is limited, and it bears pointing out that a person does not know what he or she does not know: Combining insights into collaborative knowledge brings insights to the table and creates a common knowledge base. While you are gaining a clearer picture about the demands and supplies regarding resources needs and functions, you will also learn about uncertainties, gaps and disagreements. Only when these wrinkles are front and centre will you be able to work with and around them. To support this inventory step, we have created a circular bio-economy database for by-products within AMA as an example. It is not easy to collect data with sufficient quality, but improvements can be made: The data are meant to help establish ambition levels and also to be able to determine what consequences opportunities or design choices have.

Step 2: Assessing the scope of opportunities
You also need options: what techniques, concepts or solutions can help to create your circular design? What is readily available, and what would be interesting to pursue? A resource-oriented question such as 'What can you do with elephant manure?' can be a good starting

point, but also good starting points might be the creation of a circular communal living site or the redevelopment of a whole high-rise neighbourhood. Cities are neither built in a day or built for only a day—the expectation is that they last a lifetime or even centuries! Options do not necessarily need to be fancy or high-tech: they need to point towards what will become the **new normal** on how to circulate agri-food resources within the city.

Step 3: Making design choices
Resources can be allocated for very different uses, such as for food, feed, bio-materials or improving soil in neighbouring farms. Matching demands with options requires answering questions such as 'What will be the best choice for the specific challenge?' and 'How can I compare different options?' Each option will have a different 'scorecard' with regards to socio-economic and environmental indicators, allowing to prioritise options. We have delivered a set of tools that provide users with a 'one-glance' overview of different valorisation strategies and help for making choices that fit the context and ambitions of stakeholders involved.

Step 4: Circular design
The previous three steps do not necessarily follow a chronological order: circumstances and people involved can change during the design process, in which case it is beneficial to retrace your steps and adjust where needed. The example challenges from the 'Circularity by Design' project function as inspiration and demonstrate that it can be done. They vary in terms of both magnitude and ambition. This is inherent to the design process: priorities vary, and that is fine with us. Besides, we would like to continue exploring!

Next steps for design

We worked with various stakeholders and challenge owners within AMA. The tools are there, but they are not perfect or present a one-size-fits-all solution. A circular design process is not always easy, and in the meantime, real life happens in real-life settings. COVID-19, new people on the job, crossing disciplines… internally and externally, 'things happen'. Not everything goes perfectly on the first try. It is by definition a 'multi' approach: multi-actor, multi-disciplinary, multi-sector and multi-purpose. In the end, however, it is very valuable to experience this approach together.

Aim at circular designs: be ambitious!

Circularity invokes new and radical ideas to be brought to the table because it drives discussion, sense-making and involvement. It requires people to **look at the full picture**. Circular designs are ambitious, robust solutions that transcend individual issues. It is not a patchwork or 'self-serve buffet' of so-called environmentally-friendly technologies. It **avoids fragmentation** when applied from the start onwards.
The circularity-by-design approach follows the five circularity principles, delivers an optimal resource exchange, develops a shared language and provides a better understanding among people involved; finally, it allows the selection of solutions that fit the needs of the city.

Set yourself up for success: include the scientific community

Scientists are **joining forces with** stakeholders from the city. Quick-win actions can be undertaken on one's one and do not need an elaborate approach. However, those actions which really contribute to circularity will benefit from taking a wider perspective, utilising the comparison of options and stressing the importance of making choices jointly. A **scientific foundation** is beneficial to achieve balanced choices, to prioritise efforts and to help mitigate 'intuitive' choices towards transformative choices. Circular design creation requires **knowledge about the alternatives.** Scientific organisations are a treasure trove of expertise, sources and understanding of the matter; these organisations can more easily digest information and make it accessible to the municipality. However, as academics, we are not mere ivory tower know-it-alls lacking empathy for what is happening in the city. We are curious people, and we like to solve puzzles together.

Stimulate parametrisation and data availability

It is crucial to collect data, facts and opinions that should be used to make design choices, thereby turning data into information and making it accessible. Not surprisingly, the research team immediately encountered a lack of data on available resources in the City of Amsterdam. This lack of sufficient data is very likely to be the same for other cities and regions, even across the globe. Knowledge about the resources helps to better understand local phenomena and, therefore, will lead to better design choices. **Dynamic data platforms** can be used to track and monitor circularity performance over time and **feed match-making and decision-making tools**. Supporting tools from the research include, e.g., the 'Circularity Dashboard' to select optimal allocation of resources for challenge owners and in circularity hotspots at city level. The platforms are dynamic as they will need continuous data updates as circumstances change over time.

Connections lead to better choices.

Collaboration is key, as also seen in the 'accelerating' flagship project. It is people who drive change—not technology. Circularity can be designed, but only by different stakeholders, at the same time and at the same table. The design team should be **'multi'**: multi-actor, multi-stakeholder and multi-disciplinary. It takes time to understand the needs and desires of challenge owners and stakeholders, for all to speak the same design language. But doing so will pay off with better designs. Cooperation might also lead to related solutions in other fields (e.g., water, other materials, climate), since in cooperating you can get to know each other('s issues) better. Circularity by Design increases **social capital**. All actors have a role to play in connecting for circularity.

Become an owner yourself

High ambitions attract **frontrunners** like bees to honey. These 'challenge **owners'** who are not afraid to move forward, even when not all solutions are available yet—these people develop as they go. They do not use low Technology Readiness Levels (TRLs) as a delay tactic, but rather as an advantage. Challenge owners assume **ownership** and feel responsible for finding solutions. It might look hopeless from the outset—multi-problems, nightmarish legislation, unwilling parties—but it is important to find ways to engage more people, keeping thresholds low and easy for people to join in.

As an urban stakeholder, we invite each of you to also become a frontrunner, to **lead by example**, to become a launching customer and to be demanding of circular designs related to any biomass flows in your city. **Personal commitment** is important. If this commitment is a mask for (political) gains, it will lead to wavering support. In addition, we call out to avoid fragmented voices, i.e. we speak with one voice across departments.

We invite you to take the baton—to carry the torch—and to continue **using real-life challenges**. Will you join up with WUR to raise the bar on circular bio-economy ambitions for your city? Will you choose to benefit from the Amsterdam experience and kick into a higher gear for challenge owners in your municipality?

Safeguarding

By Bjorn Berendsen

Safety aspects are often only addressed after the production process is designed. We emphasise that, especially in a circular system, a safe-by-design strategy is a more efficient and sometimes more effective way than the current safety-as-an-afterthought approach. However, considering safety within a circular food production system becomes complicated very quickly. Valuable by-products (e.g., containing important nutrients) are reused or upgraded and reused, thus interconnecting animal production, plant production, aquaculture, processing and packaging and the human system. Because of this connectivity, chemical, (micro-) biological and physical hazards can also start moving between compartments (e.g., between soil, water and atmosphere). This connectivity can potentially cause unwanted effects for different endpoints, either before or after accumulation. Due to this complexity and interconnectedness, it becomes virtually impossible to study all hazards within the system as a whole, however much it is needed. To start understanding where safety issues can arise, we focus on specific compartments and hazards.

The importance of safety aspects to transition towards a circular bio-economy

Safety aspects can be primarily used to establish reference points to stick within planetary boundaries: soils should be regenerative; waters and the air should be clean; finally, animals should remain healthy. Safety research assesses new strategies to keep humans, animals and the ecosystem free from hazards and risks. Keeping safety in mind, innovative applications to close material loops in short cycles can be developed as preventive measures and mitigation strategies for a circular bio-economy.

The origins of risks and hazards

Hazards can be divided into three types: chemical, (micro-)biological and physical. Chemical hazards include all chemical compounds, such as plant protection products, medicines (for animals and humans), toxins (mycotoxins, plant toxins, marine toxins), environmental contaminants (dioxins, PCBs, PFAS) and process contaminants. Biological hazards include all bacteria and viruses. Physical hazards include, for instance, (micro) plastics, metal and bone fragments. These hazards originate from three different sources:

1 Hazards that are **deliberately introduced** into the system. These include medicines and plant protection products. If animals get sick, they need to be treated. Some of the same risks hold true for pests in crop production. Chemicals and sometimes biological hazards that have a positive effect on the production figures can become a hazard if they are transferred to other compartments or accumulate to levels exceeding a no-effect concentration.
2 Hazards that are **introduced unintentionally and usually unknowingly** through co-products. Co-products can contain all types of hazards that are, instead of incinerated, re-introduced into the system. An example is the use of animal by-products for fertilisation of agricultural land.
3 Legacy hazards. These are currently present in the ecosystem and are also emitted into the environment every day.

Assessing quality & safety aspects

A risk is defined as the exposure to a hazard and the severity of the effect after exposure. HACCP focuses on the definition of critical control points, taking into account these two aspects. As quality and safety aspects can be very complex, the following questions were drafted to aid with assessment:

1 What raw materials and rest streams are incorporated in the production and distribution process? Where do they come from? At what scale?
Here, the scale of the process should also be considered. Does the process consider a single farm, a region, a whole country or planet? Small-scale processes can lead to significantly amplified risks for a specific region.
2 What potential hazards can be present in these raw materials and rest streams? Is there legislation available? Can and will an input control monitoring strategy be applied?
Here, data is required by monitoring.
3 Do the hazards stay in the compartment into which they are introduced, or do they move among compartments? If so, to which compartments?
It is important to understand how hazards move among compartments from a mechanistic point of view to allow behaviour. The behaviour of a hazard depends on specific circumstances, including the environment in which the chemical is in. For instance, the transmission of chemicals from soil to water depends on soil composition.
4 Are the hazards degraded to no effect by the system (natural mitigation), or are they persistent?
In an ideal situation, a hazard is mitigated by the system itself, e.g., a substance is degraded in soil. The persistence of hazards should be known, as this is a main parameter in the definition of critical control points. Persistent hazards remain in the system and might accumulate. If these hazards currently show no negative effects, they will do so in time, whether that is five years from now of five hundred. Data must be obtained and should be made publicly available to allow risk assessment. Note that degradation of a hazard (e.g. chemical compound) can result in the transformation of the hazard, still (or even more so)

exerting a negative effect.

5 Do the hazards show a potential risk (one health perspective) in the compartments in which they can occur?
   Risk studies cannot be carried out for all hazards in all compartments for all possible endpoints. Therefore, it is important to understand which hazards can be present in which compartment. As such, risk studies should focus on specific hazards in specific compartments for specific endpoints. Note that some hazards can exert an acute risk (e.g. allergens in food products), and as such their degree of persistence is subordinate.
6 Are such potential risks permissible (from a policy and consumer perspective), and can such potential risk be actively mitigated, preferably at the source?

These questions are difficult to answer. In many cases, we might even lack the knowledge to do so. As such, we should carry out appropriate safety assessments based on critical control points using interdisciplinary expert panels. Furthermore, scientific research is required to gain the foundational knowledge for safety assessment from a circular point of view.

Next steps for quality and safety

For an effective and efficient transition, safety experts should be included in the design phase

New initiatives, processes and ways of applying co-products are being developed in the transition towards a more circular society. Safety is often only addressed after the production processes are designed. Safety research is sometimes considered to be a burden, as it might limit options for coproduct applications or indicate the requirement of additional (costly) processing steps. However, we must realise that safety research can prevent the occurrence of a safety incident or irreversible environmental changes (planetary boundaries). On the contrary, safety research could confidently open new pathways and facilitate innovative ways of applying or upgrading co-products.

Spatial and temporal effects must be considered

Safety assessment is complex. It considers multiple types of contaminations (chemical, biological and physical) and a **'One Health' perspective** is required to safeguard not only human health, but also the health of animals and the ecosystem (e.g. healthy, regenerative soils and clean water bodies). Also, we must realise that **contaminations are transferrable/transmissible** among compartments. Pathogens can, for instance, transmit among animals and humans. Chemicals can move between compartments (e.g. from soil to surface water). How the contaminations behave depends on the properties of the pathogens and chemicals and the type and composition of the compartment (e.g. soil composition or animal and crop species). In safety assessment, **open and closed systems are a completely different challenge**. Closed systems safety assessments are relatively simple, as the compartments are limited and controllable. Also, the focus is mainly on the inputs of the system, e.g., co-products, feed and fertilisers. In open systems, legacy effects are of importance. Contaminations are present in many compartments, and these potentially pose a risk in the circular transition.

Plant and animal production systems should be designed in such a way that pest and disease outbreaks are avoided as much as possible

In addition to the hazards arising from compartments or co-products, biological hazards can arise, and chemicals are commonly used in many production systems. However, such outbreaks cannot be fully averted, and to prevent food and economic losses and in the perspective of animal welfare, chemical treatments will be required. Currently, usually the most common, cheapest or most effective chemical is used. However, we emphasise that chemical use should be prioritised based on their potential risk. As only limited knowledge is available on all the potential risks that can occur, a good starting point is to introduce only chemicals into the system that can be bioremediated by the system itself. As such, **the first step is to ban the use of all avoidable persistent chemicals.** Persistent chemicals remain in the system for a long time and will ultimately result in unwanted effects. **For unavoidable persistent chemicals, active mitigation strategies need to be developed.**

Research is required to prioritise all relevant chemicals

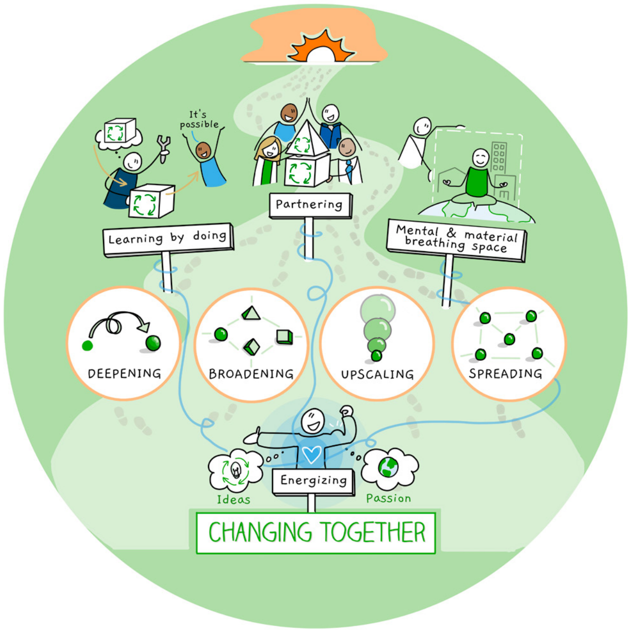
For all chemicals that are regularly used in agriculture, we need to understand their fate in the system. Most urgent is to study the fate of relevant pathogens and (many!) chemicals in organic fertilisers, soils, ground and surface waters and to understand the transfer of pathogens and chemicals from soil and water bodies to food and feed crops. Empirical studies and modelling are required. On the basis of such studies, chemicals can be categorised and **regulations need to be established**.

Finally, a social debate on risk tolerance is necessary

What risks are acceptable within the food production system? Is an increased risk acceptable for the benefit of a more sustainable system? How do we balance the probability and severity of a risk occurring and the economic investment to prevent one?

Changing together

By Tamara Metze



We need to change together because there is no single actor or group that is capable of creating the transformative change needed for moving towards a circular biobased economy by itself. For a circular bio-economy to succeed, we are **dependent on each other** and share responsibility. Furthermore, the objectives of a circular bio-economy, such as restoring biodiversity, addressing overconsumption of resources and mitigating greenhouse gas emissions, are beneficial for present and future societies—in short, they are in everyone's interest. Businesses, consumers, civil society organisations, governmental institutions and other stakeholders will have to cooperate to establish the radical changes necessary. Required steps include e.g. establishing new business models that incorporate the environmental external effects, changing and reducing consumer behaviour and safeguarding resources. These steps must be initiated within all layers of society. Reorganising linear production and consumption towards circularity requires different relationships among actors across the whole chain. This makes **partnerships** and **collaborations** key to establishing transformative change.

Scaling up initiatives is not enough

Upscaling implies expansion of successful initiatives to a larger scale. We prefer the term 'spreading' to complement upscaling, as spreading emphasises the expansion of the initiative but **not the linear growth** in economic or spatial scaling. Spreading innovative circular practices implies that others replicate it elsewhere. Establishing any 'right' scale of organising our production and consumption still encounters many uncertainties. Upscaling is not the only way to accelerate a system's change. Therefore, we want to emphasise the presence of other transformative pathways which are equally important.

Role of transformative pathways

Next to **spreading** and **upscaling**, we have identified **deepening** and **broadening** as transformative pathways. Within spreading and upscaling, the initiative itself does not have to change. For example, it can expand to other places or attract more 'members'. Deepening and broadening assume that initiatives will develop their selves into more in-depth versions or towards different directions. Deepening initiatives offer better and more in-depth solutions for the circular bio-economy. The initiative can be intensified and become more radical in addressing core issues of the linear fossil-based economy. This can be a transition from one principle, such as from recycling to prioritising. Through broadening, an initiative can integrate with other themes and agendas, such as combining circular ambitions with social ambitions. It also contains the integration of different sectors, which is necessary for developing a circular bio-economy. For example, connecting functions such as housing with nature inclusive agriculture and forestry, as is done within the Testlab Tiny House & Bos.

Mechanisms for transformative pathways

We have analysed how eight **mechanisms** contribute to deepening, broadening and spreading pathways for small wins initiatives in practice. **Learning by doing** is key within deepening, as it refers to the process of experimenting within and through initiatives and reflecting on current practices and beliefs. This experimentation is not only a vital part during the initial phase of circular initiatives but throughout their entire development, as it is one of the main drivers for deepening. **Partnering** is one of the main drivers for broadening, along with spreading and upscaling. Partnering describes the processes of sharing knowledge and resources and building (long-term) collaboration with partners who (preferably) share the same interests. Another important steering mechanism is **energising**, which refers to the trust and commitment in the initiative and the involved actors. Energising is key for initiatives to be able to continuously develop within these transformative pathways.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Next steps for changing together

When circular initiatives aim to deepen their circularity, this can best be done by learning by doing.
Experimentation and reflection on current circular practices can lead to developing a next step towards more circularity and adjusting the ambitions. *Partnering* with other actors, including academics, can assist in this, as it stimulates the sharing of knowledge and other resources. **Initiatives can focus on *partnering with like-minded* for upscaling and spreading**. For developing networks and creating a replicating effect it can be a strategy to partner with other actors who have a similar interest, ambitions, or those that encountered the same barriers. Partnering can strengthen the initiative. **For broadening, it is best to** partner with **other-minded people.** This is necessary for connecting with other domains and sectors that will provide different types of expertise, experience and networks.

Create mental and material *breathing space* within the energetic innovation process to maintain continuity of the initiative.
In order to accelerate through these pathways (spreading, broadening, deepening, and upscaling) it is important to also create mental and material space in the midst of all the energetic innovations and change. This stabilising aspect refers to having a stable flow of (human and financial) resources.

Emphasise the importance of organising and making these steps together, i.e. changing together.
Successful initiatives are and cannot do this alone. They form alliances across the value chain and with governmental actors. Therefore, our message is not only directed at circular business and societal initiatives – but also to the organisations and institutions that play a significant role in this transformation.

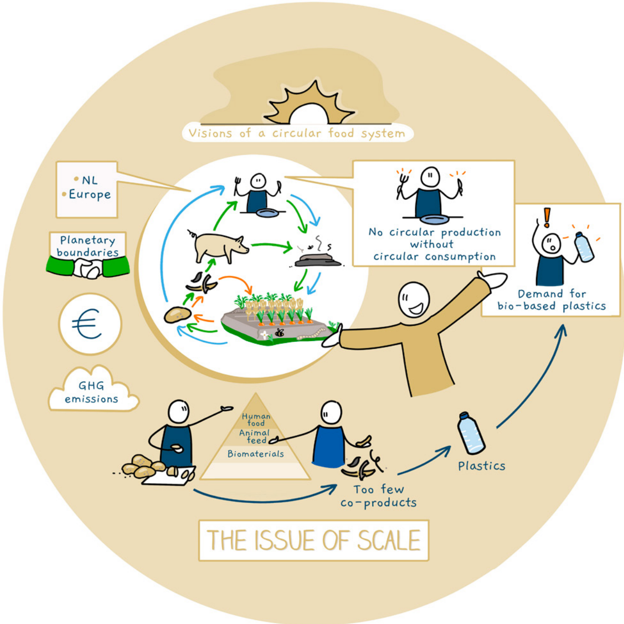
Governmental institutions can even better facilitate institutional learning based on ongoing circular innovations in practise.
In addition to experimental space, lessons for policies and rules and regulations need to be drawn together (as has been done with the Toekomsboeren/ Agro-ecological Federation).

In the processes of cocreation, the circular value chain can be designed.
In practise, this is already being done already by energetic innovators. For example, Oranjehoen is presenting and testing ideas to help HelloFresh to become more circular and to use their food residues to feed the chickens of Oranjehoen.

Financers can co-develop new indicators for providing loans or other incentives.
As a follow-up of our flagship projects, we hope to be involved in a project focused on loans or other incentives (in which Herenboeren and others are also involved). Last but not least, it is important to note that **academics can play a role in this and develop long-term relationships with energetic innovators in order to co-create alternatives**, not only technologies (e.g. within the initiative of Kwatrijnstal, different leftover streams were explored for alternative substrates) but also, for example, alternative evaluation schemes, new relationships and new models that better appreciate circular efforts.

The issue of scale

By Jan Broeze



Scaling for a circular bio-economy

The circular use of biomass materials prioritises applications that fulfil basic human needs. Circular use also requires that by-products are recycled back into the bio-based system, prioritising human and planetary well-being. Such optimal recycling, reduces demands for 'virgin' biomass (e.g., dedicated crops), by focusing on keeping nutrients from post-consumer and other waste streams within the bio-based system. This prioritisation principle can be realised through various practices, such as leaving crop residues in the field for the benefit of soil health, application of by-products from the food chain as animal feed and the application of manure and organic waste as fertiliser. In a circular food system, this valorisation approach can be further enhanced through an upgraded utilisation of residues: from feed to food, extracting nutrients from crop residues before ploughing, etc. The key for **determining the most optimal application is to take scale into account**: The choices will be different when looked at from company, national or global perspective. Although larger scales seem more attractive because of the wider set of options, larger distances also induce additional challenges with regard to transport, storage and processing requirements. Other complicating aspects include price-induced competing demands on bio-materials and preserving valuable nutrients throughout multiple cycles of reuse and recirculation.

Going for a 100% circular bio-economy in the EU

Running a number of scenario studies, we have seen that the nutritional demand for the European population can be fulfilled based on the production potential of the current European agricultural farmland. However, the idea to fulfil the EU demand for bio-based materials based solely on by-products from the agri-food chain, is not realistic without any changes in demand. For example, for calculations based on averaged macro-nutrient composition of residues from the primary sector and conversion efficiencies for biobased plastics, it was estimated that a maximum 7 Mton bioplastics could be produced annually. When valorising food waste (defined as fractions removed from the post-harvest food value chain), an additional 5 Mton could be produced. Compared with the current use of 'virgin' plastics in Europe (approximately 50 Mton per year), we can conclude from these estimations that there are not enough residues and by-products in the current agri-food system to meet the current biobased material demands, let alone the ambitions for bio-energy. This demonstrates the importance of mitigating those demands. Despite moderating these demands, it might still be necessary to produce dedicated crops with high conversion rates in order to meet these demands in the future.

Consequences for the agri-food system

A self-sufficient food production system for Europe is only possible in combination with dietary changes for both animals and humans. The current volumes of by-products are not sufficient to meet feed demands of the current livestock composition. Shifting towards more plant-based foods on the menu can help change the demand, but changes also need to be made in the types of animals in the system; chickens for example require nutrition that is difficult to derive from co-products. Pigs and cattle fit the picture better, where livestock is mainly fed those residues. Current material consumption patterns cannot be fulfilled from biobased sources; the dependence on virgin materials must be greatly reduced.

New opportunities

Research has revealed that significant progress is possible with respect to resource use efficiency, even with existing circular options. However, to reduce our environmental impact and simultaneously preserve a healthy production system, new, smart solutions are essential. We must explore how we can serve both goals. An example is the development of so-called multi-purpose crop rotations, that produce human food and utilise by-products as livestock feed and soil fertiliser (e.g., grasses or crop residues).

Methodological difficulties in modelling scale for circularity

Developing circular practices requires involvement of a large number of stakeholders, each with different interests. This is reflected in multi-disciplinary modelling challenges: material balance models, economic models, ecological models, etc. Each discipline uses different indicators and modelling perspectives. Integrating 'new' circular pathways into an existing model proved to be challenging due to the systemic complexity. Nevertheless, the different perspective angles have revealed effects of circular development on different scales. Furthermore, access to high quality data remains a huge challenge in the field of food systems modelling.

Next steps for scaling

Our research on biophysical resource flows in and economics of more circular systems has shown among others that circular solutions at food system level are more effective to stay within the planetary boundaries. Examples include the use of certain food waste streams for animal feed (possibly through insects as an in-between step) and the upgrading of streams that are currently used for feed to direct use for food. The research has, however, also made clear that at the scales of (for example) Europe and the Netherlands, even with maximised circular use of by-products, the current demand for biomaterials and bio-energy cannot be produced without substantial import.

Therefore, to **increase the circularity of the agri-food system**, **changes in production and consumption are essential.** To achieve circularity at scale, it is recommended to:

- **Stimulate dietary changes**: It is expected that by-products from food value chains will remain available for feed (and consequently livestock production remains relevant within a circular bio-economy), but the available volumes are insufficient to maintain current consumption levels of animal proteins.
- **Upgrade valorisation of by-products:** With increasing scarcity or resources, higher level valorisation of residues will gain increasing importance. Various by-products are suitable for upgrading (such as isolating food proteins from beet leaves and upgrading the spent brewers' grains to food products).
- **Reduce demand for virgin materials:** Preventing food waste and loss contributes to reducing resource demands. New demands for biobased economy (such as for bioplastics) cannot be fulfilled based on by-products alone; dedicated biomass production for such non-food purposes will be inevitable. This will further increase the pressure on the food system; dependency on virgin materials should be minimised, for example through maximising reuse and recycling.
- **Maintain soil health:** Higher-value application of by-products may result in lower availability of crop residues for soil improvement and fertilisation. Dedicated valorisation options that also include the returning of components that are most essential for soil health, and alternative sources of organic matter should be considered.

Research into issues of scale supports political debate and business opportunities as it **discloses the effects of different prioritisation options on the systemic demands** on biomaterials, and how these fit (or not) within the planetary boundaries. To improve scaling models, **higher quality data** are required, necessitating **more transparency on resource flows** in the bio-economy. At the moment, there is societal momentum for a transition to a more circular food system in the Netherlands and Europe. In addition to a societal debate, government measures are required to stimulate different diets and a redesign of the production system, including the livestock sector.

Learning from experiences together

- Together we are all deepening the scientific and practically relevant knowledge about **translating the dream of a circular bio-economy into practice**: What does circularity really mean for collaboration, for design, for scale and for safety?
- We have found **new patterns** that occur when people start working together on circularity and on what it means to create a safe operating space. It is unappealing for people from businesses and/or NGOs if the conversation is too highly (or over) aggregated, and not all actors are driven by a high circular ambition level. Trying to solve global problems on your own can sap your energy quite quickly.
- We have developed **several tools to support the transformative steps needed**. This process has just started, and there is still much more to be done. Science helps to capture complex problems, but we also need successful examples in practice that show how and that it can be done.
- We have noticed that most people from practice with whom we have collaborated are **eager to learn** and share insights on resources and needs, as well as safety aspects.

Circling forward

By Imke de Boer

Our key findings and experiences of connected circularity clearly demonstrate that, in order to produce and consume food and other biobased materials while respecting the planetary boundaries and our social fundament, we need to shake up the system. In other words, we need **transformative change**, i.e. fundamental, system-wide shifts in the way we produce and consume food and other bio-materials.

1 We need to **farm with nature**, not against it. This statement implies, for example, a need to grow different crops on the same field rather than sustaining monocropping systems.
2 We need to **change our consumption patterns,** especially in high-income countries. This implies, for example, that we need to move towards circular and healthy diets, rooted in the local context. Such diets consist mostly of local plant-based foods and include small amounts of animal-source food, produced by animals that are fed with by-products and grass resources only.
3 We need to **avoid food losses and waste and ensure safe recycling** of unavoidable losses and waste at their highest level of utility. This implies, for example, that we need to accept variability in sizes and colours of our foods rather than aiming for standardised food products.
4 We have the moral obligation that all humans and farm animals have a good quality of life. This implies, for example, that if we decide to keep farm animals, we need to adapt the housing system to the animal, not the other way around.
5 We need **technology that supports the implementation of circularity principles** and **acknowledges the social foundation** rather than enforces current lock-ins. This implies, for example, that we need to design technologies that support producing according to the five circularity principles (e.g., small-scale robots for sowing, weeding and harvesting rather than large-scale machinery that cause soil compaction).

6 We need to **go beyond using renewables and invest heavily in saving strategies**. This implies, for example, investing not only in electric cars but also in car sharing.
7 We need an **economy that goes beyond GDP and serves the planet and all its inhabitants**. This implies, for example, that farmers should be rewarded for the ecosystem services they provide and that we consumers pay a fair price for our products, including food. The latter of course also indicates that we need to close the income gap.
8 Etcetera.

Well … although such principles make scientific and social sense, the main challenge is how to fundamentally shift the trajectory we are all on.
I believe that we need to invest relatively more in social sciences than in natural sciences throughout the coming decades. Even more radically, I think we also need to fundamentally shift our approach to science. The core question is this: What is the role of science in sparking transformative change?

1 I think we should better acknowledge that there are **multiple ways of knowing things**. To enable fundamental transitions, scientists need to sit together with relevant stakeholders and acknowledge that we all bring our own knowledge and perspectives, and we need each other's qualities to move toward the desired future, as we can only build this future collectively.
2 To this end, we need to acknowledge that certain people are more powerful in a situation; we need to **challenge dominant power structures** and **ensure inclusion of marginalised voices, including those of non-humans.**
3 However, all of the above also has consequences for the type of research funding. I think we need to, at least partly, move away from competitive funding that builds on milestones and high-impact publication and also focus on **slow science**. We need inclusive seed-funding in order to build long-term collaborations with stakeholders in our (local) environments and contribute to decision-making in the search for a desired future. In addition, perhaps future PhDs can be evaluated based on their contribution to the societal transition instead of on their journal publications.
4 We need to **not only finance the working hours of scientists** in collaborative trajectories **but also those of farmers and others that are not automatically financially rewarded**.
5 In summary, we need to discuss what transformative research within WUR actually entails. Only then can we contribute to societal transformative change.

Circling back provides an overview of the results of the Wageningen University & Research Investment theme Connected Circularity flagship projects.
Running between 2019-2022, over 50 researchers from all WUR Science Groups have collaborated to generate new insights on important topics that relate to the transition to a circular bio-economy. The Flagships projects collaborate with all stakeholders, from small entrepreneurs at local level towards system partners at the global level to translate dreams of circularity into practice.

More info on the website
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