The Value of Transdisciplinary Perspectives During Transition to a Bio-based Economy: The Prospect for Converting Mixed Food Waste into Bio-based Chemicals

Birgit Brunklaus, Emma Rex, Johanna Berlin, Frida Røyne, Johanna Ulmanen and Graham Aid

Abstract Within the current political and industrial transition to a bio-based economy, food waste can be an alternative resource for biobased chemicals. This chapter describes a case study that evaluates the prospect for Swedish production of biobased chemicals such as succinic acid from food waste. The evaluation is addressed from multiple systems perspectives. From a technical and resource system perspective, the results of the case study show that production seems possible. However, from a social system perspective succinic acid production currently lacks institutional support and actor commitment and alignment for realizing development in Sweden. From an environmental and life cycle perspective, the scoping of the analysis is decisive for the results. The study shows that multiple perspectives complement each other when seeking a nuanced evaluation of technical innovation and give insights for the intended value chain.

1 Introduction

In line with current political and industrial ambitions for a transition into a bio-based economy, food waste can be an alternative to agro- and forest-based resources. The amount of food waste generated every year is about 1.3 billion tons globally [1]. This wasted food has caused problems related to climate change and resource depletion throughout their value chains, as well as increasing economic challenges related to waste disposal.

B. Brunklaus (✉) · E. Rex · J. Berlin · F. Røyne · J. Ulmanen
Energy and Circular Economy, RISE Research Institutes of Sweden, 41261 Gothenburg, Sweden
e-mail: birgit.brunklaus@ri.se

G. Aid
R&D Engineer and Group Strategy, Ragn Sells AB, Stockholm, Sweden

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E. Benetto et al. (eds.), Designing Sustainable Technologies, Products and Policies, https://doi.org/10.1007/978-3-319-66981-6_36
Some of these problems could be eased by converting food waste into valuable products like bio-based chemicals. Succinic acid (SA) is one such chemical with high market potential [2]. Today, it is produced from fossil sources but also partly from cultivated biomass on a commercial basis [3]. Several initiatives are now underway to examine the use of food waste as feedstock for SA production. Most of these initiatives are limited to homogenous industrial waste streams, but a research project in Sweden is looking at a more novel and complex feedstock—mixed food waste (MFW) [4].

The purpose of this project is to evaluate the prospect for realizing Swedish production of bio-based chemicals from MFW. In this chapter, we present the evaluation results of one possible production route, where microbial production of SA from MFW in Sweden is used as a case study.

The evaluation of SA from MFW is addressed from multiple perspectives: technical and social system structures are explored, in addition to resource and environmental implications. Several perspectives and methods are thus involved in the evaluations, such as the technical (laboratory cultivation and mechanical testing), the social (actor analysis, policy analysis, market analysis, and societal acceptance), the resource based (waste flow analysis and scenario analysis), and the environmental (life cycle assessment of current and future valorization techniques for MFW). The project thus uses a transdisciplinary approach and offers an arena where both research partners and industrial partners meet and discuss possible options for MFW-based SA production in Sweden.

2 Multiple Perspectives and Evaluation Methods for Converting Mixed Food Waste into Bio-based Chemicals

The case study chosen here involves microbial growth on mixed food waste derived from municipal solid waste to produce bio-based SA in Sweden. The mixed food waste was sourced from Ragn Sells AB’s full-scale waste management facility in the area of Stockholm, Sweden. In Sweden, the current value pathway for MFW involves anaerobic digestion to produce biogas [5]. The future production could involve the cultivation of *Escherichia coli* bacteria to produce succinic acid as a raw material for further polymerisation. The case study was chosen together with academic and industrial partners in a multidisciplinary research project on how mixed food waste can be used as a resource for the production of bio-based chemicals and higher value products than current biogas (FORMAS 211-2012-70). Research questions derived from different partners included different disciplines, such as molecular biology (natural science), biotechnology (bio-based engineering), as well as social systems perspectives (social science) and environmental systems science (resource and life cycle perspective). Multiple perspectives, scales and methods were thus involved in the different evaluations presented in Table 1, which lead to different results presented in the following sections.
2.1 Technical Evaluation Performed on Lab Scale

Several research questions and methods are involved in the technical evaluation e.g. laboratory cultivation and mechanical testing. By the use of *elementary analysis*, the composition of substances/molecules in mixed food waste was identified. The results show that mixed food waste contains required N and C for *E. coli* growth, although additional N would increase C use. *Enzymatic hydrolysis and carbohydrate analysis* was then used to show how the carbon sources included could be made more accessible for *E. coli* uptake [6]. Through *laboratory cultivating tests* it was assessed if *E. coli* could grow on mixed food waste. The results show that the liquid fraction of the waste supports growth and the solids can be used as carbon source. To determine if the water content of MFW was optimal for *E. coli* growth, *mechanical property tests* were made. The results show that the water content was too high for industrial production, described in Rex et al. [7].

### Table 1: Multiple perspectives, scale and methods involved in the evaluation

| Multiple perspectives | Scale of analysis | Multiple methods |
|-----------------------|-------------------|-----------------|
| Technical evaluation  | Lab scale         | Elementary analysis, Laboratory cultivation, Mechanical property |
| Social evaluation     | Innovation systems, National and EU scale | Policy analysis, Societal acceptance, Screening of market |
| Resource evaluation   | Plant and national scale | Material flow analysis, Scenario analysis |
| Environmental evaluation | Plant and life cycle scale | Life cycle assessment, Current and future system |

2.2 Social Evaluation Based on Innovation Systems

Several research questions and methods were also involved in the social system evaluation, e.g. policy analysis, analysis of societal acceptance, actor and market analyses. A policy analysis was performed to assess how existing rules and regulations influence the possibility to realize SA production from mixed food waste in Sweden. The main source of data for the analysis were documents on policy directives and instruments complemented with workshops and interviews with focus groups. A key result is that there are hardly any policy instruments supporting bio-based chemical development on national and EU level. So far there exists only declarations of intent in various policy documents and reports and limited R&D subsidies. Another key result is that subsidies and investments in the development of biofuels, in particular biogas, for the transport sector influence the access of
feedstock for the production of bio-based chemicals and might contribute to increased competition in the future.

Societal acceptance is essential for the legitimacy of an innovation and to assess how norms and values in society influence the prospects of producing SA from mixed food waste. The main source of data for the analysis were interviews and workshops complemented with analysis of discussions in related areas, such as GMO and food versus fuel (e.g. through newspaper articles, NGO webpages, and research reports). The results show that the perceptions of circularity of biomass and bio-based chemicals and related products are positive. However, public resistance towards genetically modified organisms has previously hampered the realization of a bio process production facility and may do so in the case of SA as well.

A screening of market data and scenarios was carried out to judge the future demand of increased SA production. The main source of data for the analysis were documents and literature on future market. The results indicate that there is a demand for bio-based SA and that it is expected to grow in the future considering bio-based SA can substitute a range of fossil chemical components, not only fossil SA. Also, there is an interest of producing and buying bio-based chemicals and related products in a more resource efficient manner, e.g. using waste instead of the currently used food crops.

Finally, a mapping of current and future actors was made to determine if the right type of actors can be mobilized to realize a SA value chain to enable the production facility. The results show that although technical competences exist and market demand is expected in the future, actors are not yet fully committed or aligned to develop bio-based chemicals production such as SA from food waste. Further details can be found in related work of Ulmanen et al. [8].

### 2.3 Resource Evaluation Based on Waste Flows

Several research questions and methods were involved in the resource evaluation e.g. material flow analysis and scenario analysis. The question of which capacity is needed for production of bio-based SA was approached using benchmark of existing and planned production sites for bio-based SA production. The results show that a capacity of at least 10,000 tons bio-based SA/year is likely to be needed for a commercial plant. Material flow analyses were used to determine if there is sufficient mixed food waste in Sweden for that production capacity. The results show that there is sufficient mixed food waste in Sweden as a whole, but not in individual facilities. Further, scenario analysis (including material flow analysis and policy analysis) was used to assess if there is sufficient mixed food waste in Sweden for the production capacity, also given political goals to minimize avoidable food waste. The results show that there are sufficient flows in Sweden, although distributed among sites in a large geographical area. Further details can be found in related work of Rex et al. [7].
2.4 Environmental Evaluation Based on the Life Cycle

In the environmental evaluation, a life cycle assessment of current and future systems was performed. Life cycle assessment with focus on valorisation options was used to analyse if the current biogas production or the future production of SA had the lowest environmental impacts as valorisation option for mixed food waste. The process description of biogas is based on an existing biogas facility in Heljestorp [9]. The process description used of food waste to succinic acid is based on lab-scale data with mixed food waste [10]. The results show that current biogas production has a better environmental performance on all main impacts categories used (global warming potential, energy use, acidification potential, eutrophication potential) than future production of SA with mixed food waste. In parallel, a life cycle assessment with focus on feedstocks was performed to address the question: Do mixed food waste have a better environmental performance than current feedstocks for SA production? The process description of Corn to succinic acid has been chosen based on Reverdia Direct Crystallization process described in Cok et al. [11] and Smidt et al. [12]. The results show that a future use of mixed food waste likely would have a better environmental performance than current corn-based feedstocks. Further details on the comparison and evaluation can be found in related work of Carlson [13] and Brunklaus et al. [14].

2.5 Multiple Evaluations Show Complementing Results

As seen from above, multiple perspectives and methods are involved in the different evaluations and show complementing results. The results of the case study show that, even though from a technical and resource system perspective, production seems possible, from a social system perspective SA production currently lacks institutional support and actor commitment and alignment for realizing development in Sweden. From an environmental and life cycle perspective, the scoping of the analysis is decisive for the results: SA production from mixed food waste is environmentally beneficial if compared with the SA production from corn, but from a pure waste handling perspective, it is environmentally better to produce biogas than SA from mixed food waste.

3 Potentials and Limitations of Combined Systems Approaches

Different systems approaches provide guidance about current and future industrial systems. Each of the method approaches are based on different questions and provide different answers. To take this further, one has to understand some general
3.1 Differences in Goal and Scope

Systems approaches are based on the goals and the scope of the study. To say something about how valid the different results of the multiple perspectives are in relation to each other, it is important to understand the object and the scope of analysis of each assessment, presented in Table 2.

In the technical evaluation, the object of analysis is the biotechnological possibilities and the scope of the study lies on the molecular scale and the laboratory scale. Results have to be seen per scale and technical indications can be made limited to the scale. The social evaluation was made as part of a technological innovation systems analysis on national and EU scale. Here the scope and boundaries of the study is based on so called structural components, that includes technology, actors, networks and institutions. Institutions refers to formal policy rules and regulations as well as informal norms and values related to societal acceptance. In the resource evaluation, material flows are in focus and the scope and boundaries the study is based on the production scale and geographical scale. In the environmental evaluation, the object of analysis is physical flows of material, resources, waste and energy, and the scope and boundaries of the study is based on processes that are part of the life cycle of handling food waste and producing SA, respectively. Results for resource and environmental evaluations have to be seen per scale and indication have to be seen as well in temporal scale of current and future value chains.

Systems approaches as used in the example above require significant time and efforts, as well as expertise in different scientific areas. These are essential for complex problem solving, and are thus system dependent as described in Flood and Calsson [15]. The potential in relation to systems perspectives lies in knowledge creation. Knowledge is built on like building blocks, which together forms the basis for decision-making and the next step in the innovation process.

Table 2  Multiple perspectives, object and scope of the analysis involved

| Multiple perspectives       | Object of the analysis          | Scope of the analysis              |
|-----------------------------|---------------------------------|-----------------------------------|
| Technical evaluation        | Biotech possibilities           | Molecular scale, lab scale        |
| Social evaluation           | Innovation systems              | National and EU scale             |
| Resource evaluation         | Material and waste flows        | Production scale                  |
| Environmental evaluation    | Current and future process      | Life cycle, temporal scale        |
3.2 Potentials in Relation to Life Cycle Management

Taken together, the studies differ in both the objects of analysis and the scope and boundaries in which the results are valid. Moreover, methods used derive from different research traditions and method approaches such as the analytical, the system and the social approaches described in Arbor and Bjerke [16] and Wolf [17]. Due to different research traditions and method approaches and their fundamental discrepancies, and the related amount of work and efforts made, it might be questionable to relate answers from these perspectives in the same assessment, as is the case in the example above. Yet we argue that for Life Cycle Management, assessing multiple perspectives and transdisciplinary approaches is a valuable way of working. Life Cycle Management is about decreasing the negative impact of physical flows in society, by approaching the acts and practices of actors in the system. In this respect, there is a need to understand the premises for success in everything from technological possibilities in lab scale to the amount of materials available in a region, and the norms, values and intentions of actors needed to develop the system. Thus, combined systems studies should, with careful respect to the differences in goal and scope, be seen as complementary studies to guide technology innovation. Insights form these multiple perspectives can be of value for any actor aiming to manage these systems for the advances of less environmental impact from a life cycle perspective. Further research on evaluating various actors might give some insights on of how useful the various systems studies were in the collaboration, and toward decision making. To this end, the above perspectives are seen as complementary, yet not exhaustive. An important perspective not included in the above is an assessment of the economic feasibility of SA from MFW. Also combining SA with other products in a bio-refinery has not been evaluated, to give some examples.

4 Conclusion

Combined-systems approaches and multiple methods contribute with a useful holistic perspective to evaluate and guide technology innovation from a life cycle perspective. Results from a case study on bio-based SA does not provide a unanimous answer on whether the prospects for transforming MFW into bio-based chemicals are favorable or not, but gives a nuanced evaluation that offers a more firm foundation for decision and further development than one perspective or method in isolation. The transdisciplinary approach can inform an arena of research and industrial partners with different perspectives to facilitate discussion and more well-informed decisions. Despite time and efforts, the case thus illustrates the benefits of applying a transdisciplinary approach with multiple perspectives when assessing and evaluating potential routes to a more bio-based economy, and when seeking to manage the progress of sustainable value chains.
Acknowledgements This research is financed by FORMAS and this paper builds on earlier studies including different perspectives: “systems perspective” [7], “technological innovation system” [8] and “life cycle assessment” [13, 14]. The authors gratefully acknowledge the Swedish Research Council Formas for financing this research (FORMAS project no 211-2013-70), as well as Ragn Sells AB for kindly providing the mixed food waste and production facility data.

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