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MULTISTEP CREATION OF A CRITERIA CATALOGUE FOR SOCIO-TECHNICAL TRANSITIONS IN AGRICULTURE

Contents

Abstract

To address today‘s grand challenges, socio-technical transitions need to be designed in different sectors (e.g., agriculture). Technology assessment (TA) is a valuable tool to identify interactions and consequences of transition processes, but it requires an appropriate assessment system to develop guidelines. This article addresses the question of how to assess technological transitions in agriculture from a stakeholder perspective and presents a multi-step TA procedure inspired by a multi-criteria decision analysis exemplified by one transition: electrical farming. The procedure contains three steps. First, assessment criteria for the transition are identified in the context of a classical TA using stakeholder interviews. On this basis, a multidimensional catalogue of 24 criteria was created. Finally, criteria are validated and weighted according to their relevance with a second sample. The results provide recommendations for communicating and evaluating transitions in rural areas and the agricultural sector.

Keywords

Agriculture – Technology Assessment – Participation – Energy Transition – MCDA – Transition Process

Mehrstufige Erstellung eines Kriterienkatalogs für soziotechnischen Wandel in der Landwirtschaft

Kurzfassung

Um den großen Herausforderungen unserer Zeit zu begegnen, müssen soziotechnische Übergänge in verschiedenen Sektoren (z. B. in der Landwirtschaft) gestaltet werden. Das Technology Assessment (TA) ist ein wertvolles Instrument, um die Wechselwirkungen und Folgen von Transitionsprozessen zu ermitteln, aber es erfordert ein geeignetes Bewertungssystem, um Leitlinien zu entwickeln. Dieser Artikel untersucht die Frage, wie technologischer Wandel in der Landwirtschaft aus der Perspektive von Steakholdern bewertet werden kann und stellt ein mehrstufiges TA-Verfahren vor, das sich an einer multikriteriellen Entscheidungsanalyse orientiert, die am Beispiel der elektrifizierten Landwirtschaft erläutert wird. Das Verfahren besteht aus drei Schritten. Zunächst werden im Rahmen einer klassischen TA mittels Stakeholder-Interviews Bewertungskriterien für die Transition identifiziert. Auf dieser Grundlage wird ein multidimensionaler Katalog von 24 Kriterien erstellt. Schließlich werden die Kriterien mit einer zweiten Stichprobe validiert und nach Relevanz gewichtet. Die Ergebnisse ergeben Empfehlungen für die Kommunikation und Bewertung von Wandelprozessen in ländlichen Räumen und im Agrarsektor.

Schlüsselwörter

Landwirtschaft – Technology Assessment – Partizipation – Energiewende – MCDA – Wandelprozesse

1 Introduction

Life on earth faces far-reaching challenges such as biodiversity loss, resource depletion, and climate change (Firbank et al. 2018: 2). Addressing these pressing challenges requires action from multiple sectors. The agricultural sector as a (sub-)system plays a special role in climate change in two ways. First, it is substantially responsible for greenhouse gas emissions. At the same time, it suffers from emerging negative consequences, such as extreme weather conditions, droughts, floods, and soil erosion (Arora 2019: 95). Therefore, there is a great need to foster the sustainability and resilience of the agricultural system.

Technological innovations are one way to shape the sustainability transition in agriculture. Despite all the opportunities, innovations can have unforeseen, sometimes negative consequences, and require careful management (de Boon/Sandström/Rose 2021: 408). One of the major challenges of emerging technological innovations is to anticipate future consequences and to account for the diversity of dimensions (social, ecological, and economic) that unfold in sustainability transition processes (Markard/Raven/Truffer 2012: 956). In particular, quantitative assessment of the socio-technical transitions altered by innovations is highly relevant to evaluate its potential contribution to a sustainability transition (Assefa/Frostell 2007: 65). One attempt to assess it prospectively is a technology assessment (TA), which has proven to be a powerful tool. Individual indicators (criteria) form the basis for the impact assessment and are essential for developing, testing, and evaluating technological innovations in the face of agricultural sustainability transitions (see de Boon/Sandström/Rose 2021: 415 et seq.). So far, criteria to determine the degree of sustainability exist for the status quo of the agricultural system (Talukder/Hipel/van Loon 2018: 781 et seq.) or parts of it, such as for dairy farms (Flint et al. 2016: 7). What is less clear is the process for determining these criteria to evaluate and compare new technologies and corresponding transitions that create change in the agricultural system or adjoining industries. Furthermore, the criteria have to be assessable, comprehensive, and relevant to the subsystems involved.

Therefore, criteria need to be developed that incorporate stakeholder and societal perspectives to reflect interests, ensure relevance, and also allow for adequate consideration of the social dimension of sustainability in agriculture.

Given the urgent need to provide a sound basis for decision-making on socio-technical transitions with a human-centered perspective, the main contribution of this article is to outline a methodological approach to identify relevant criteria for a technological transition pathway using electrical field cultivation (EFC) as an example. Moreover, the value of this methodology is also demonstrated for transitions at an early stage of development. Thus, this paper aims to answer the following research questions: 1) *How can we derive important criteria for deciding for or against socio-technical transitions in agriculture?* This leads to 2) *What are the relevant criteria for deciding, evaluating, and comparing different socio-technical transitions for the agricultural sector on multiple dimensions?*

Building on the multi-criteria decision procedure (Haase et al. 2021: 306 et seq.), this article outlines a three-step approach:

> identification of relevant criteria for an impact assessment of EFC

> validation of the identified criteria through a participative approach (here: workshop)

> weighting the relevance of each criterion on a trial basis

The first section of this article provides a brief theoretical introduction to TA and its application in agriculture. Then, the stepwise method procedures and results for the set of criteria for all three steps are listed. The final section addresses the value for practical application and the human-centered design of transition processes.

2 Prospective Technology Assessment to Inform Decision-Making

Historically, TA has been widely used in practice and academia in the past centuries (Tran/Daim 2008: 1402). In general, it represents a collective term for “systematic methods used to scientifically investigate the conditions for and the consequences of technology and technicizing and to denote their societal evaluation” (Grunwald 2009:

1104). In a narrower sense, it can be defined as a form of policy analysis tool that examines the short- and long-term consequences of technology application. Therefore, TA provides policymakers with information about alternatives, risks, and potential risk communication. It can also promote the legitimacy of certain decisions on technology (Grunwald 2009: 1104 et seq.). There are two crucial aspects to consider in TA and its application to new technologies. First, TA is regarded as particularly useful when technologies and associated transitions reach a certain development stage (Tran/Daim 2008: 1399), but shows potential for an initial assessment at an early stage (Rip/Kulve 2008: 50 et seq.). Second, it is a common misconception that the core of TA is the technology, rather than being about the vision, the idea, or the design behind the technology by people (Grunwald 2009: 1138). Thus, it is indeed about "people" and key stakeholders and society are relevant in TA procedures.

In the past, a variety of different types of TA have been established, characterized by varying degrees of stakeholder interaction. The spectrum ranges from classical *expert TA* based on stakeholder inputs, e.g. through interviews, to a more participative procedure (*participatory TA*). The latter involves stakeholders through sometimes resource-intensive methods (e.g. focus groups). In particular, participatory TA emphasizes the social nature of technology and technological transitions and their value for engaging society in the decision-making process. The most promising stream in TA for technologies at an early development stage is *constructive TA*. This methodology focuses on social issues by technologies still in development and aims at a co-creative process with society (Rip/Kulve 2008: 50 et seq.). According to Genus (2006: 14), public participation methods such as consensus conferences or scenario workshops allow for a co-creation process. Scenarios are particularly useful when it comes to forecasting future developments beyond the current state, i.e., they are based on technological options or promising technologies (Rip/Kulve 2008: 50 et seq.).

Altogether, TA is a fruitful tool to assess the unintended consequences of future technologies at an earlier stage but it also enables the involvement of different stakeholders.

For the agricultural sector, TA is seen as a promising approach to promote innovation and support sustainable and socially acceptable solutions (Vanclay/Russel/Kimber 2013: 406 et seq.). Such acceptance is particularly relevant as it ultimately results in social support and the adoption of technologies. This will determine the success of socio-technical transitions, which again highlights the need for a more participative approach within TA.

Especially in agriculture, criticism arose in recent years that the social dimension and social impacts have been neglected in new (technological) innovations and their assessment (Vanclay/Russel/Kimber 2013: 406 et seq.; Rose/Wheeler/Winter et al. 2021: 1). Instead, a strong focus on productivity and profit has been prevalent. Consideration of social impacts in technological transitions is as important as ecological and economic impacts. The sector has multiple societal functions that, optimally, bring social and cultural benefits e.g., in terms of food security, education, social cooperation, human-nature interactions, and community cohesion (Nowack/Schmid/Grethe 2021: 758 et seq.). In the wake of emerging technologies, it is indisputable that there are certain controversies, such as employment rate, fundamental changes in work, and data ownership in agriculture (Rose/Wheeler/Winter et al. 2021: 1). Even if certain developments cannot be fully prevented, there are possibilities to anticipate and work with undesirable changes. In particular, participatory TA is an established method in agriculture, which allows the various interests of different stakeholders (e.g., consumers, farmers, and residents) to be included. Tavella (2016: 120 et seq.) provides an overview of successful examples of participatory TA procedures, ranging from on-farm trials to develop and test seed priming techniques to workshops about genetically modified plants.

In summary, TA in the agricultural sector is a successfully applied method but has mainly focused on the simple identification of risks and benefits with few attempts to include stakeholders outside of politics and science. The question remains how to go beyond the identification of consequences to a transparent and comprehensive decision-making process of TA. Especially the selection of relevant criteria by various stakeholders (incl. society) forms the essential basis for this process.

3 Development of a Criteria Catalogue for Agricultural Transition

The present study seeks to demonstrate one procedure for determining multidimensional criteria that will allow future evaluation of emerging socio-technical transitions in agriculture. The intended output of this article is a criteria catalogue. The proceeding is oriented toward the application of the multi-criteria decision analysis (MCDA) according to Haase et al. (2021: 310 et seq.). We first provide an overview of MCDA within TA. Afterwards, the present case example for developing a criteria catalogue (here: EFC) is outlined step by step. Due to the methodological focus of this article, the applied methods are described in detail.

3.1 Study Context

With the expansion of renewable energies and political measures to combat climate change, alternative machine concepts and energy sources in agriculture are being considered. Therefore, EFC was selected to exemplarily investigate one emerging socio-technical transition in agriculture. It comprises electrically driven agricultural machinery (e.g. tractors, robots, or drones) as product innovations and new ways to maintain, harvest, and sow fields as process innovation. Overall, it can be classified as part of the energy transition (*Energiewende*[1]) and displays a high level of complexity due to its intertwining in political, social, and economic contexts (Sovacool/Hess/Cantoni 2021: 1) and intersections with other sectors. Therefore, it depicts a highly interesting case with consequences on multiple dimensions. Those consequences need to be critically assessed and incorporated into government strategy. Furthermore,

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[1] Energiewende is the German term for replacing fossil-based energy technologies with renewable energies. It can be defined as a socio-technical transition itself (see Dewald et al. 2020: 319 et seq.)

the classification of EFC in the energy transition is not only important for those associated with agriculture, but also for the public. Germany was chosen as the study context to closely examine one agricultural system and to elaborate specific criteria. On the one hand, Germany is under pressure as it is dependent on fossil fuels, but on the other hand, it is also very ambitious about contributing to the mitigation of climate change (Die Bundesregierung 2021).

3.2 Method

One method for addressing multi-objective problems is the MCDA, which has been chosen to create the criteria catalogue for agricultural transitions. MCDA can be understood as a collective term for methods and tools that provide a systematic procedure for creating a transparent decision-making process based on multiple criteria (Belton/Stewart 2002: 2). In general, the MCDA methodology consists of four steps that include structuring the decision problem, modelling preferences, selecting alternatives, and evaluating, with decision recommendations being derived as the end result (Guitouni/Martel 1997: 501). Due to its application to a broad range of different issues, there are many methods within the methodology. A well-known example is the multi-attribute utility theory (Keeney/Raiffa/Meyer 1976: 219 et seq.), in which each alternative is assigned a numerical value.

A particular feature of this process is the disclosure of normative ideals and values. This makes it possible to highlight conflicting goals and challenges within the targeted trade-offs, and even to uncover opportunities for reducing or resolving conflicting goals. For this reason, the main advantage of the MCDA methodology in the context of TA is that the different interests, information (quantitative and qualitative), and preferences of technological innovations are considered concurrently with their alternatives (Haase et al. 2021: 306 et seq.). The MCDA provides various tools to address complex issues (including socio-technical transitions) and allows multiple dimensions to be captured in a transparent formalization process (Haase et al. 2021: 308). It, therefore, facilitates complex decisions for or against a technological application and features a valuable addition to current TA procedures. On this basis, MCDA in TA is considered suitable for the complex investigation of sociotechnical systems and underlying criteria within agriculture.

Although there is no standardized MCDA, Haase et al. (2021) suggest a generic approach and its application within TA for any issue of a technological, political, or systemic nature. According to Haase et al. (2021: 307), TA can be divided into three phases: a) identification of alternatives, b) analysis, and c) evaluation. MCDA methods can be applied in the first and third phases of the decision-making process. In both phases, stakeholders should be involved iteratively to define criteria, weigh criteria, and thematize conflicting interests to reduce conflicting goals. In the first phase, MCDA enables the identification of criteria and alternatives through the transparent ranking and clustering of problems. In the third phase, MCDA tools such as the MAVT inform about the priorities of different stakeholders and facilitate weighting between criteria and alternatives. In the past, the application of MCDA within TA has been most prominent in the health TA (Marsh et al. 2018: 394) in various forms, such as expert panels and discrete choice experiments. In addition, there is a growing number of application examples for MCDA in sub-areas of agriculture (Cicciù/Schramm/Schramm 2022: 85 et seq.).

3.3 Procedure

The overall procedure to form a criteria catalogue is roughly based on the first and third phases of the MCDA by Haase et al. (2021: 310) (Figure 1). In this study, both qualitative and quantitative methods were combined to derive a criteria catalogue for assessing a socio-technical transition in agriculture. To begin with, a classical TA in the form of interviews was chosen as the basis for identifying important criteria for the transition (Phase 1). These criteria were validated in a small-group discussion with a second sample and quantitatively evaluated due to their importance on a trial basis (Phase 3). The following section provides information about the participants, the methodological procedure, and data analysis for each step.

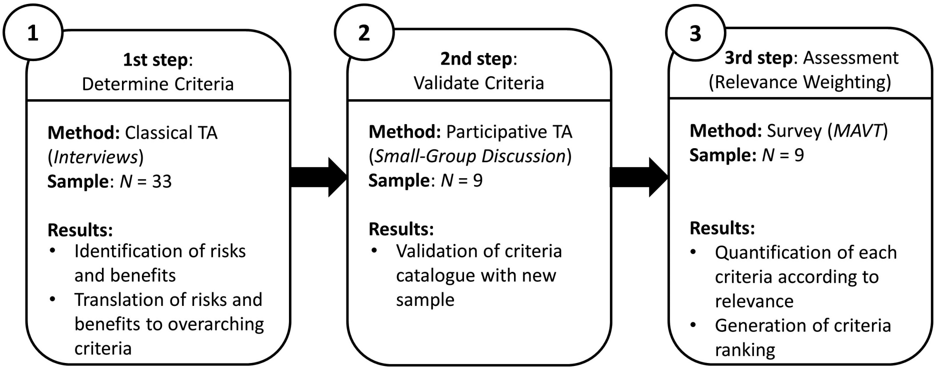

Figure 1: Multistep procedure application in present study according to generic MCDA approach by Haase et al. (2021) / Source: the author's graphic

With the aim to explore changes in the socio-technical system relevant to stakeholders, a classical TA was conducted in the form of semi-structured interviews that allowed for more flexibility. Interviews took place from June 2020 to December 2020 and were conducted mainly online due to pandemic circumstances. The scenario of interest (here: EFC) was introduced to the interviewees through a sketch showing a farm surrounded by grain fields and powered by electricity, supplemented by a short description (Figure 2).

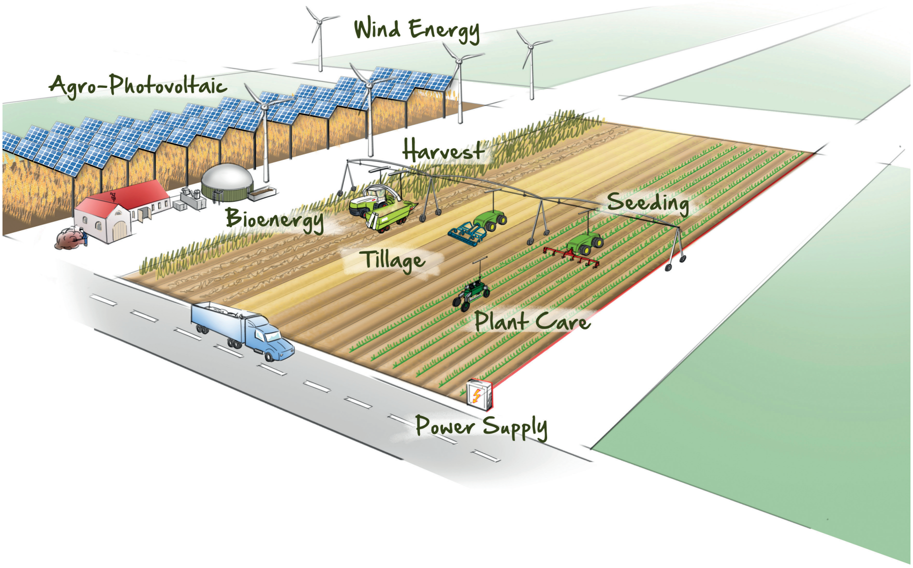

Figure 2: Scenario representation for interviews / Source: designed by Johanna Frerichs

Interviewees were openly asked what benefits and risks they expected from a potential implementation of EFC in 2050. To allow an assessment across multiple dimensions, interviewees were not limited by the number of consequences they expected. Afterwards, interviews were transcribed anonymously and analyzed in the qualitative data analysis program MAXQDA20 using a summarizing qualitative content analysis (QCA) by Mayring (2014: 65 et seq.). Mentioned risks and benefits were inductively identified and coded as general criteria without directed evaluation (e.g. quality of information instead of *high* information quality). Additionally, a brief definition was formulated for each criterion. Criteria were deductively classified within the main dimensions of TA. The main dimensions are based on the "triangle of sustainability", which has been applied since the 1990s (Kleine 2009: 5). This approach comprises ecological, economic, and social sustainability as necessary for comprehensive development. To ensure a more comprehensive assessment, two other dimensions were added in line with the VDI guideline no. 3780 (VDI guideline 3780 2000: 28 et seq.) and Blumberg/Kauffeld (2020: 15): technological[2] and work design dimensions. The technological dimension comprises technological characteristics and design, while the work dimension focuses on the design of work characteristics, work organization, and the workplace.

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[2] Contrary to expectations, the technological dimension has a rather human-centered focus. Consequences of technologies result in a combination of technical parameters and human behavior, for example, its intended application and design by humans (Grunwald 2020: 99).

Additionally, the frequency with which each dimension was mentioned was recorded across all interviews, providing a first impression of the perceived importance from the stakeholders' perspective. Overall, Mayring's recommendations for qualitative criteria within qualitative content analysis (2014: 17 et seq.) were applied (reproducibility, stability, and construct validity).

A classical TA is limited by the isolation of statements without any dialogue. In order to overcome this, step 2 was inspired by a participatory TA with a new sample. To stimulate a dialogue about the socio-technical scenario, data were retrieved in a participatory way through a digital workshop. In addition, the workshop allowed participants to become familiar with the EFC future scenario, which was particularly important for participants without a professional background. A survey was then conducted to weight the individual criteria according to their relevance.

The workshop began with an introduction to EFC as one future scenario for agriculture. The interactive TA was conducted in small groups of three. The dimensions used for the overall coding in the preceding interviews were presented to the participants in advance to make them aware of the variety of risks and benefits. Emerging discussions about the potential consequences of EFC were recorded on digital sticky notes. In the second phase of the workshop, the criteria catalogue derived from the interviews was compared with the previously discussed risks and benefits and presented to the participants. They were instructed to review the criteria catalogue and to (dis-) agree on its completeness.

The last step was conducted by employing a short survey according to the weighting procedure of Haase et al. (2021: 309 et seq.). Given the conflicting interests, it is necessary that certain criteria are prioritized. To determine the degree of relevance, workshop participants were invited to rate each criterion according to its degree of importance to enable a decision for or against the implementation of EFC. Participants were asked to answer the question to the best of their knowledge on a 7-point Likert scale from "very unimportant" to "very important". The average score and standard deviation were then calculated for each criterion to summarize the perceived importance of every single criterion. The ranking of each criterion allows for subsequent weighting of the impact assessment for individual criteria within the TA. Besides evaluating each criterion, all five dimensions were ranked using the MAVT method (see Section 3.2).

3.4 Participants

Key stakeholders were selected for the initial interview study. In addition to farmers, the sample also included various stakeholders from public administration, research, and industry PRI) to consider different interests and viewpoints and to reflect the diversity within the sector. Participants (*N* = 33) were recruited using the snowball principle with the local network as a starting point. Farmers (*n* = 18) worked primarily as farm managers on a full-time basis. The farmers' sample was mainly male (87,5%, *N* = 14). Farm types ranged from mixed farming (*n* = 8) to pure crop cultivation (*n* = 9) and just one livestock holder. A stakeholder from PRI worked in a variety of fields such as ministries, universities, and non-university research institutions. The interviewees' age ranged from 22 to 67 years (*M* = 39.77, *SD* = 13.92).

As with the first step, the aim was to reach a diverse group of stakeholders for criteria validation and relevance weighting (steps 2 & 3). It should be noted that previous interviewees were excluded from participation due to the need for independent validation. In addition to farmers and PRI representatives, two other interest groups were included: citizens and local politicians (*N* = 9). Citizens in their multiple roles as political agents, taxpayers, and residents, and politicians as representatives of the common interest and shapers of future transitions complemented the perspectives of the key stakeholders from the first step.

3.5 Results

Inductive coding of the interviewees' responses revealed 24 subfactors representing the subjectively perceived risks and benefits of a potential transition to EFC on all five dimensions (economic, ecological, social, technological, and work design). Generally, it can be noticed that the economic consequences (risks and benefits) were mentioned disproportionately more often than the other dimensions (see Figure 3). The least mentions appeared on the social dimension (*n* = 35).

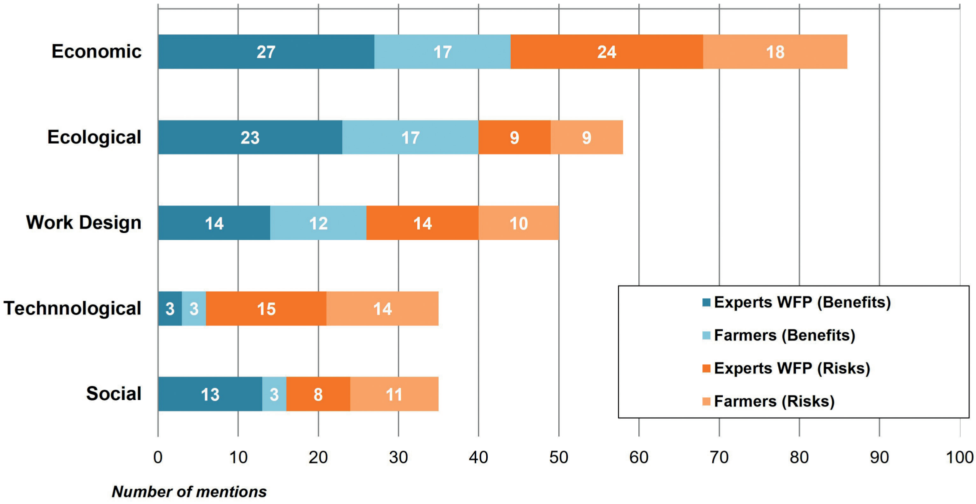

Figure 3: Frequency of consequences by the transition to EFC mentioned on each dimension / Source: the authors

As mentioned in Section 3.3, each risk or benefit was translated into a neutral criterion, which yields a criteria catalogue of 24 criteria (Table 1).

Dimension	**Criteria**	
Ecological	> Impact on biodiversity (1) > Influence on landscape structures (2) > Land demand (3)	> Soil pollution (4) > CO2-emissions (5) > Noise impact (6)
Economical	> (Acquisition-)costs (7) > Competitiveness of Germany (11) > Energy balance for employed technologies (8)	> Financing options (10) > Employment opportunity (9)
Social	> New (dependency) relations (12)	> Socio-political acceptability (13)
Technological	> Information quality (23) > Storage options (16) > Technology Compatibilities (21) > Degree of Technological Safety (17) > Availability of resources (e.g., electricity) (18)	> Suitability (e.g., across different regions and company sizes) (14) > Applicability (user-friendliness of the technology) (15) > Data Management (22)
Work Design	> Job characteristics of the work (e.g., physical stress) (24) > Qualification & training opportunities (20)	> Occupational identification (e.g. energy farmer vs. farmer) (19)

Table 1: Criteria catalogue derived from classical TA / Source: authors' illustration

Due to the high number of criteria, three of them are presented as examples with their definitions and underlying quotes from the interviews in Table 2.

Dimension	**Criterion**	**Definition**	**Underyling Quote**
Ecological	CO_2-emission	Degree of CO_2-emissions from EFC	*“EFC will save us a lot of CO_2 and might be climate neutral in the future.”* (PRI)
Economic	Financing Options	Overall costs for different stakeholders to implement technology (e.g. farms, regions, government)	*“The considerable high costs of the transition have to be seen and covered.”* (PRI)
Work Design	Qualification & training opportunities	Structure and opportunities for people affected to receive support in competence development for successful application of new technologies	*“The knowledge of employees must increase enormously. Many machines and modern techniques can no longer be operated by simple farm workers. Well-educated employees are needed.”* (Farmer)

Table 2: Exemplary extracts from criteria catalogue for evaluation / Source: the authors

Altogether, the large number of interviews enabled the identification of relevant criteria for TA in socio-technical transitions across multiple dimensions, taking into account the different interests of key stakeholders. Additionally, the number of mentions shows an initial tendency toward hope for ecological improvement through the case study of EFC and concern for technological realization. Nevertheless, it does not allow the relevance of individual criteria to be finally determined. For this reason, the subsequent workshop was conducted.

The above-displayed criteria catalogue was validated during the interactive dialogue with the second sample. The final criteria assessment with the second sample revealed substantial differences in the assigned importance between criteria (Figure 4). The overall average is m = 5.36 (SD = 0.97; range from 1-7), which reflects the relevance of each criterion respectively. Each criterion was rated as at least “neutral” (4) or “rather important” (5). On the one hand, the highest importance was assigned to mainly economic criteria such as criterion 16 (“Storage Options”, m = 6.4) or criterion 7 (“Acquisition Costs”; m = 6.4). On the other hand, the criteria with the least relevance involved technological-related criteria or work design criteria, for example, criterion 16 (“noise impact”; m = 3.4) or criterion 22 (data management; m = 4.3).

The ranking of the individual dimension from one to five with descending relevance according to the MAVT method supports these results. The ecological and technological dimensions were ranked highest, while work design ranked last. In summary, all criteria were considered relevant to some extent, although the highest relevance was assigned to the economic criteria.

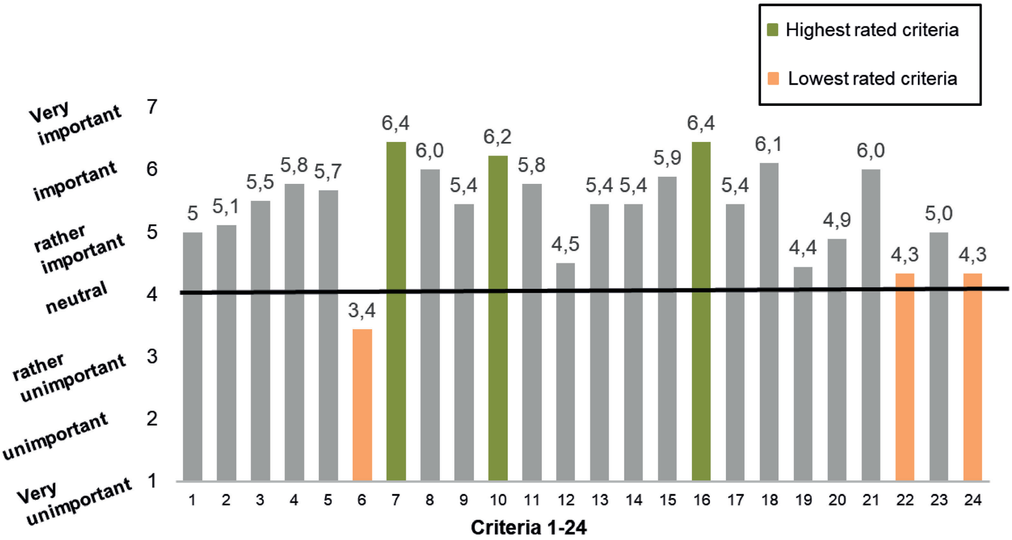

Figure 4: Relevance weighting for criteria / Source: the authors

4 Discussion

In the wake of wide varieties of potential technological transitions and the application of innovations, early TA with a human-centred perspective is vital to foster successful adaptation and resilience in agriculture. This article provides an overview of one methodological procedure to develop a set of criteria based on a stakeholder perspective to evaluate emerging socio-technical transitions in agriculture. EFC as one scenario was chosen as an appropriate object of investigation. The semi-structured interviews with farmers and experts from PRI yielded 24 criteria on five dimensions derived by a classical risk and benefit assessment. As a first step, classical TA opens the possibility of identifying areas of change within a certain transition. These areas can then be evaluated in terms of their potential for an overall contribution to greater sustainability.

The diversity of factors found for EFC as one potential technological transition to sustainability emphases the need to engage multiple stakeholders and use diverse methods (qualitative and quantitative) to assess technological, economic, and more manifold social indicators.

4.1 Implications

This article discloses vital methodological, theoretical, and practical implications. The multimethodological TA in combination with MCDA according to Haase et al. (2021: 306 et seq.) is very valuable for several reasons. First, the combination of classical and participatory TA promotes the identification of criteria that are relevant to stakeholders. Thus, it contributes to the legitimacy of technological advances and corresponding governmental strategies. It also enables early exploration of technologies and accompanying transitions with the goal of greater sustainability. The method can be universally applied to any socio-technical transition and system with possible adaptations to cultural and political backgrounds. This could be achieved by varying data generation methods and sequences within the process. Similar efforts to use MCDA approaches to assess agricultural sustainability are evident in current research (Cicciú/Schramm/Schramm 2022: 85 et seq.). Examples range from specific areas such as agricultural supply chain risk management (Yazdani/Gonzalez/Chatterjee 2021: 1801) to agricultural sustainability assessment in general (Talukder/Hipel/van Loon 2018: 781 et seq.).

In terms of content, the criteria catalogue forms a basis for EFC to compare alternative and competing technological transitions (here: hydrogen or biofuels). The risks and benefits identified in the first step of the catalogue creation enable an initial assessment of the different stakeholder opinions. This yields vital implications for the design and monitoring of the transition. The higher risk perception related to economic and technological issues underscores the need to actively address the existing concerns of all stakeholders and to work on concrete, noticeable technological solutions. Additionally, economic risks must be reduced through the creation of sustainable subsidy programs and financial advice for farm conversions. At this point, the resulting criteria catalogue provides a basis for further decision-making steps and the definition of indicators that can be recorded quantitatively and qualitatively.

Besides, the article offers noteworthy theoretical impulses, such as the use of MCDA to design decision-making processes for emerging socio-technical transitions in agriculture. Building on this, the agricultural transition with its accompanying technologies needs a human-centered perspective. A generic criteria catalogue for agricultural transition could be one approach to pave the way, with an addendum for specific regions and other characteristics. The catalogue should be expanded beyond the classic ecological, economic, and social criteria, such as technological, work design, or even individual dimensions (Blumberg/Kauffeld 2020: 15), to increase awareness for people within the system. Furthermore, the combination of different methods in this article allows the application of different underlying theories. Theories of participation, stakeholder integration, and decision-making could be fruitful additions to broaden theoretical understanding and refine the methodological approach (e.g., from social psychology or political science).

4.2 Limitations and Future Research

Nevertheless, certain limitations of this article must be reviewed when interpreting results. First, despite the diversity of stakeholders achieved, we are limited to a small sample for the second and third steps of the catalogue. The weighting of the relevance of the criteria certainly lacks a sufficient sample size for statistical analysis, which makes it a first trial. For future applications, we recommend the employment of criteria assessment with various stakeholders on a larger scale to achieve generalization for regions or countries. In addition, repeating multiple workshops with different groups would facilitate dialogue on possible transitions. Other possibilities include larger participatory formats such as policy labs. In general, the exploration and generation of important criteria would benefit from a variety of different foresight methods (see Karwehl/Kauffeld 2022: 5 et seq.).

Second, the specific example of EFC encompasses a range of possible machine concepts and processes. Therefore, it includes a mix of technologies that can influence the success or failure of the transition and make an assessment even fuzzier. To facilitate a precise assessment, it is advisable to create several scenarios with specific innovations that can be compared with each other as well as with alternatives.

Third, it should be noted that we do not claim that our catalogue of criteria is exhaustive. Even though we assume that all criteria have the potential to represent a crucial field of action for various socio-technical transitions in agriculture, the criteria may differ depending on the region and the technology area. As noted earlier, some criteria may be general in nature, while others may be more specific (e.g. storage options for the required electricity). The same applies to weighting, which may depend on various factors such as the region's dependence on the agricultural sector or the existing infrastructure. These factors could influence the final assignment of relative criteria relevance.

Overall, we propose the use of different TA methods to address new technologies and associated changes in agriculture at an early stage of development and, more importantly, to start a dialogue about scenarios that are not yet mature. Moreover, the steps outlined in this article are only the beginning of an assessment. The remaining steps involve identifying alternatives and defining specific indicators for each criterion to make it quantifiable and comparable (Haase et al. 2021: 312 et seq).

4.3 Conclusion

Taken overall, this article contributes by outlining one possible procedure for the early exploration and assessment of socio-technical transitions toward greater sustainability and resilience in agriculture. The multi-step creation of a set of criteria using different methods and the close involvement of different stakeholders beyond experts have resulted in a valuable process to address the unknown consequences of technological advances. Although TA is particularly useful when technologies have reached a certain stage of development, it initiates a first dialogue about future developments and possible consequences. It is hoped that this article will contribute to an early impact assessment with a stronger focus on people and their interests in agricultural transitions.

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